Interoperability of DCCs for weights and weighing instruments through standardization

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Abstract **– This paper presents various efforts undertaken to standardize DCCs for weights and weighing instruments (balances) that aim to ensure interoperability between DCCs from different issuers. It is shown that, in addition to conventions regarding the structuring of information, "mini-taxonomies" and clear, unambiguous definitions for the identifiers of certain information are essential. Finally, it will be shown how "interoperability challenges" can be used to check the interoperability between DCCs from different issuers on the one hand and the unambiguity and clarity of the conventions on the other.**

I. INTRODUCTION

The digital transformation of calibration processes has necessitated the development of Digital Calibration Certificates (DCCs) to facilitate machine interpretability and interoperability of calibration data. The digitalization of calibration processes is not merely a technological advancement but a necessity driven by the need for efficiency, accuracy, and traceability. As calibration laboratories transition from traditional paper-based certificates to digital formats, the importance of standardization becomes evident. The Physikalisch-Technische Bundesanstalt (PTB) has spearheaded efforts to create a flexible DCC schema [1], which serves as a foundational framework for digital calibration documentation. The schema has been continuously developed for improvement and the current version 3.3.0 [2] is believed to be stable for a longer time except for minor improvements. However, the flexibility of this schema introduces potential problems concerning interoperability, as varied implementations may not seamlessly integrate across different laboratories.

The need for further harmonization with regard to the specific application of the schema for certain applications was therefore recognized and identified by the industry already at an early stage [3] - only through appropriate harmonization can it be ensured that no proprietary solutions are formed, i.e. that DCCs from different laboratories are interoperable in a way that importing software works regardless of who issued the DCC.

Fortunately, the "Deutscher Kalibrierdienst" (DKD, German calibration service) has taken on this task, so that various measures for the harmonization of DCCs were initiated in a committee consisting of a large number of accredited calibration laboratories from a wide range of branches under the leadership of PTB.

II. HARMONIZATION EFFORTS

To address the above-mentioned challenges, several harmonization approaches are currently undertaken in committees on different levels – an overview can be found in [4].

Within the DKD, several expert groups were formed – on the one hand, specific groups were formed by the several technical sections of the DKD to address specific harmonization topics for their specific community and additionally, a cross-sectional group was formed to address general harmonization topics.

The expert groups for "mass" and "weighing instruments" were two of the first respective groups formed and have undertaken several harmonization efforts that will be explained in detail in the next sections.

Most of these measures have been published in corresponding "DKD Expert Reports" and can be read in detail there [5-6].

A. Structural conventions

The first considerations concern structural conventions, i.e. how and for which results exactly the different elements available in the DCC schema should be used. This is essential for ensuring that DCCs are created in a consistent and standardized manner. The DKD expert reports provide detailed instructions on the use of the DCC schema.

For "mass", the following general structural conventions have been formulated for weights and weight sets [5]:
- Each weight of a set is identified in a respective dcc:item element.
- Identification properties of the whole set can be given in the parent dcc:items element.

- For each weight and each measurement, a separate dcc:measurementResult is used to represent the measurement results.
- Therein, dedicated dcc:result elements can be used to represent the measurands like volume, density or mass and conventional mass.

For "weighing instruments", similar structural conventions have been made as follows [6]:
- Each weighing instrument is identified in a respective dcc:item element of "first order" (see next point for explanation).
- Each range of a weighing instrument is identified in a respective dcc:item element of "second order", i.e. as a child element of a dcc:subitems element being a child element to the "first order" dcc:item element.
- The same applies for modular parts (e.g. indicator, platform) of a weighing instrument – if they are to be identified dedicatedly, this should also happen in a respective dcc:item element of "second order".
- For each range, a separate dcc:measurementResult is used to represent the measurement results.
- Therein, dedicated dcc:result elements should be used to represent different results of the individual measurements of repeatability, eccentricity and error of indication.

It should be noted that generally different ways of structuring the results would be possible (see [7] for descriptions of such different ways for weights), but these ways of structuring were chosen by the respective expert groups as the best mixture of high flexibility and low redundancy. By adhering to these structural conventions, calibration laboratories can ensure that their DCCs are compatible with other systems and platforms, facilitating seamless data exchange and integration.

B. Identifiers with clear definitions

Basically, specific information can be found via the known path to the corresponding element containing the information. However, at least if several elements of the same name exist at the same level and they then have the same path, it makes sense to explicitly label specific information. Examples are all those cases, where a "singular element" can be existing several times within a "plural element", e.g. dcc:result in dcc:results or dcc:identification in dcc:identifications. Such explicit labelling is done via refType attributes that can be assigned to an element, e.g.: <dcc:result refType="NAWI_repeatabilityMeasurement">, which is clearly distinguishable from: <dcc:result refType="NAWI_eccentricityMeasurement">. As can be seen from the example, these refType attributes comprise specific prefixes denoting, whether they are considered generally applicable for all types of DCCs (via the prefix basic_) or only for specific communities (e.g. via the prefix mass_ for weights/weight sets or NAWI_ for non-automatic weighing instruments). Although usually the "suffix" (e.g. repeatabilityMeasurement) is given a descriptive name, it is nevertheless essential that for each harmonized refType, a clear definition (and ideally a bibliographic reference and rules/guidance on the usage) is given to ensure that every user can look up somewhere, what exactly can be expected in an element carrying a particular refType attribute.

In both DKD expert reports, these harmonized names are given along with clear definitions for a certain number of refType attributes (namely 55 for "mass" and 25 for "weighing instruments). They are also available in a TemaTres database [8] so that it is possible to address them in respective software.

The importance of clear definitions and standardized identifiers cannot be overstated. These elements are essential for ensuring that the data within DCCs is interpretable and usable across different laboratories. By providing clear definitions and structured identifiers, the DKD aims to improve data management and retrieval, ensuring that DCCs are compatible and interoperable. This approach helps to prevent misunderstandings and misinterpretations, ensuring that specific data is findable and interoperable.

One example of a refType and its definition is given below for the refType basic_measuredValue that is intended to distinguish (and make identifiable) a dcc:quantity element that represents a measured value from other types of quantities, like for a example a reference value or a nominal value:

Table 1 Example of a refType description (from [8])

Name	basic_measuredValue
Definition	quantity value representing a measurement result
Bibliographic source	JCGM 200:2012 (VIM) 2.10
Example	```<dcc:result> <dcc:name> <dcc:content lang="en">Measuring result</dcc:content> </dcc:name> <dcc:data> <dcc:quantity refType="basic_measuredValue"> <dcc:name> <dcc:content lang="en">mass</dcc:content>```

	</dcc:name> <si:real> <si:value>0.999997191</si:value> <si:unit>\kilogram</si:unit> <si:measurementUncertaintyUnivariate> <si:expandedMU> <si:valueExpandedMU>0.00000053</si:valueExpandedMU> <si:coverageFactor>2</si:coverageFactor> <si:coverageProbability>0.95</si:coverageProbability> </si:expandedMU> </si:measurementUncertaintyUnivariate> </si:real> </dcc:quantity> </dcc:data> </dcc:result>
Element	dcc:quantity

C. Descriptions for particular use cases

The standardization efforts include detailed descriptions of particular use cases, providing guidance on the implementation and use of the DCC schema. These use cases serve as examples of how the DCC schema can be adapted to various calibration scenarios, highlighting the flexibility and versatility of the schema. By providing clear guidelines and best practices, the DKD aims to ensure that DCCs are compatible and interoperable across different laboratories.

The use cases described in the two expert reports comprise (among others)
- Interventions like adjustment, repair or exchange
- Decision rules and conformity statements
- Marking of results outside a laboratory's accreditation scope

D. "Mini-taxonomies"

Some elements of the DCC schema allow referencing entries of taxonomies or databases, e.g. the element dcc:equipmentClass with child elements dcc:reference (to denote a reference database or taxonomy), dcc:classID (to denote the entry ID within the database or taxonomy) and dcc:link (to provide a direct link to the entry, if available). A taxonomy generally holds information for a categorization whereas databases supply lists of entries.

However, not for all desired ways of categorizing there might exist appropriate databases or taxonomies yet. For example, it is common to categorize weighing instruments into "single range", "multiple range" and "multi-interval" instruments, but there is no well-known reference for this categorization. A harmonized categorization however is necessary in order to avoid that entries from different laboratories meant to be the same are interpreted as different by machines due to different spellings (e.g. "single-range", "single range", "singlerange") or languages. Therefore, in the DKD report for weighing instruments [6], it was simply decided to directly provide a "mini-taxonomy" with 3 entries to be used in the dcc:classID element:
- NAWI-SR: single range instrument, having one scale interval d and one maximum capacity Max
- NAWI-MR: multiple range instrument with $i = 2…n$ ranges, each extending from 0 to Max_i with a respective scale interval d_i
- NAWI-MI: multi-interval instrument with $i = 2…n$ partial ranges, each one extending from Max_{i-1} (or 0 in case of $i = 2$) to Max_i with a respective scale interval d_i

With such, "mini-taxonomies" it is possible to harmonize entries in those elements that allow referencing databases or taxonomies and it as well helps to ensure that DCCs are interpretable and usable across different laboratories.

E. Example DCCs

Perhaps most helpful for beginners in the topic of DCCs are the sample DCCs that are included as attachments in both expert reports. In principle, it is possible to take these examples and adapt them to your own case.

The provision of example DCCs is an important aspect of the standardization efforts. They serve as valuable resources for calibration laboratories, providing practical guidance on the creation and use of DCCs. However, it should be mentioned that examples alone are typically ambiguous - i.e. there should always be an additional description (e.g. in the form of an expert report) so that an example is not misinterpreted in ambiguous cases or regarded as the only solution.

In the two expert reports, the following example DCCs are given as Annexes:
Mass:
- DCC for a single weight
- DCC for a set consisting of two weights

- DCC of a mass standard

Weighing instruments:
- DCC for a single range balance with two measurements (before/after adjustment)
- DCC for a multiple range balance
- DCC for a multi-interval balance consisting of two identifiable parts (indicator and platform)

III.   TESTING INTEROPERABILITY

A. Background

It should be highlighted once again that interoperability must be a key focus concerning DCC: If users cannot rely on the fact that their import software, which works with DCCs from laboratory A, will also work with DCCs from laboratory B, any implementation of DCC usage would mean tying oneself to a specific laboratory - in the view of the authors, this would not only contradict the idea of the DCC, but would probably also prevent its widespread use.

The above-mentioned harmonization efforts and accordingly the respective expert reports are intended to ensure that such a scenario must not be feared by users. The intention clearly is that DCC users can reliably assume full interoperability of different laboratories as long as they all issue their DCCs in compliance with the expert reports.

In order to justify such an assumption, two questions have to be answered:
- Is the description in the expert reports complete, meaning that there are no cases where missing guidance or rules leads to different implementations concerning relevant information?
- Is the description in the expert reports sufficiently unambiguous so that different readers will not differently implement anything concerning relevant information?

B. Means for checking interoperability

In metrology the standard means of checking whether realizations fit together are comparison measurements. They basically ensure "interoperability" of measurement results. This is not transferable to the DCC, but the DCC is XML based. This enables some general means of validation:

Syntax of XML [9]: XML has syntax rules such as "All elements have to be opened and closed in the right order." Which can be checked in most XML tools.

Example: <dcc:items> <dcc:item> </dcc:item> </dcc:items>.

Validation against schema file: The XML schema file in XSD format (here dcc.xsd [2]) can be used to check for general rules [10]. The applied XSD file is given in each XML file. The rules include the structure but also cardinality and data types.

Example: <xs:element name="item" type= "dcc:itemType" maxOccurs="unbounded"/> means that the DCC must have at least one "dcc:item" which must be of the "itemType".

Validation against rules using Schematron: A Schematron file can be used to define rules as well as errors and warnings which are more flexible than the Schema file. This way, plausibility of inputs can be checked as well as additional structural rules that are not part of the XSD. Schematron is a standard XML means and has already been tested with the DCC [11].

Example: <sch:assert role="error" test="@id"> Id is missing </sch:assert> tests for an id e.g. at dcc:item which is expected if using the instructions from [5].

Using a combination of all these means ensures in general the highest level of interoperability (see Fig. 1).
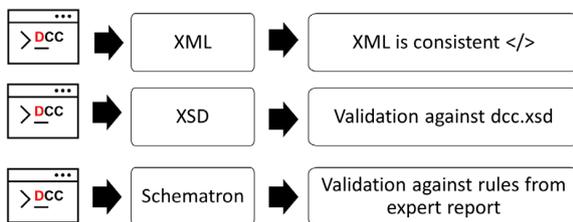

Fig. 1 Means for checking interoperability in XML in general and for the Interoperability Challenge in specific.

There is one other means which is less a formal checking tool but a means of showing information which can also be used:

Extraction and display of information using XSLT [12]: Using an XSLT file to ensure a harmonized human-readable

version can give a good idea about the overall interoperability for a human reader as missing information is easy to spot.

C. Interoperability Challenge

To test whether the expert report [4] actually leads to an interoperable DCC, a so-called interoperability challenge for mass DCCs was recently started, where a number of interested laboratories (comprising both NMIs and accredited calibration laboratories) formed three groups:
-   Group 1 will provide 3 calibration scenarios, i.e. a description of calibration items and their calibration results, along with some additional information, e.g. on influence conditions
-   Group 2 will create DCCs for these calibration scenarios and submit them
-   Group 3 will analyze the results to determine if all implementations are the same or if not, if this is due to unclear/missing information in the expert report. Fig. 1 gives an overview of the planned interoperability checks. Furthermore, XSLT will be used to create a human readable result and further analyze the content of the created DCCs.

This interoperability challenge is currently in progress and results are expected in autumn 2025. It is believed that such interoperability challenges (also for other types of calibration objects) in the future might become common as they not only help to identify possible "authors' white spots" concerning the harmonization conventions in expert reports, but a successful participation in such an interoperability challenge could also serve as some kind of "proof". Just like the validity of a laboratory's results can be controlled/proven via key comparisons, the interoperability of the DCCs issued by a laboratory could in the future be controlled/proven via such interoperability challenges.

IV. CONCLUSIONS

In conclusion, the digital transformation of calibration processes through the implementation of Digital Calibration Certificates (DCCs) marks a pivotal shift in the calibration industry, driven by the necessity for enhanced efficiency, accuracy, and traceability in data management. The transition from traditional paper-based certificates to digital formats is not merely a technological advancement but a fundamental requirement to meet the evolving demands of modern calibration laboratories. The efforts spearheaded by the Physikalisch-Technische Bundesanstalt (PTB) and the Deutscher Kalibrierdienst (DKD) have been instrumental in developing a robust and standardized framework that addresses the critical challenges of interoperability and harmonization across diverse laboratories.

The establishment of expert groups within the DKD has been a strategic move to tackle specific harmonization topics, ensuring that the DCC schema is applied consistently across various technical sections. The publication of DKD Expert Reports provides comprehensive guidelines and structural conventions, which are essential for creating DCCs in a standardized manner. These reports offer detailed instructions on the use of the DCC schema, ensuring that calibration laboratories can produce certificates that are compatible with other systems and platforms, thereby facilitating seamless data exchange and integration.

Moreover, the introduction of identifiers with clear definitions and structured naming conventions plays a crucial role in enhancing the interpretability and usability of DCCs. By providing explicit labels and harmonized refType attributes, the DKD aims to improve data management and retrieval, ensuring that DCCs are interoperable across different laboratories. This approach helps prevent misunderstandings and misinterpretations, making specific data findable and usable across various applications.

The standardization efforts also include detailed descriptions of particular use cases, offering practical guidance on the implementation and adaptation of the DCC schema to various calibration scenarios. These use cases highlight the flexibility and versatility of the schema, providing clear guidelines and best practices to ensure compatibility and interoperability across different laboratories. Additionally, the provision of example DCCs serves as valuable resources for calibration laboratories, offering practical insights into the creation and use of DCCs.

The concept of "mini-taxonomies" further contributes to the harmonization efforts by providing structured categorization for elements within the DCC schema. They help ensure that entries are interpretable and usable across different laboratories, avoiding discrepancies due to varied spellings or languages. By referencing these taxonomies, calibration laboratories can maintain consistency and reliability in their digital documentation. However, a more comprehensive taxonomy for measuring instruments and calibration terms is needed. One promising, yet not complete approach is the Measurement Information Infrastructure (MII) that has been set up and is still expanded by NCSLI [13].

Finally, the ongoing interoperability challenge underscores the importance of ensuring that DCCs from different laboratories can be reliably used across diverse applications. This challenge aims to identify potential gaps in the expert reports and ensure that the descriptions are complete and unambiguous, promoting widespread adoption and trust in digital calibration documentation. As industry continues to evolve, these harmonization efforts will play a crucial role in advancing the digitalization of calibration processes, paving the way for future innovations and improvements in the field. Through these collaborative efforts, the calibration industry is poised to embrace the full potential of digital

transformation, ensuring that DCCs become a cornerstone of modern calibration practices. Hopefully, it will also support the global effort in harmonizing DCCs.

V. OUTLOOK

It is important to point out that all of the harmonization efforts mentioned are voluntary – laboratories may or may not adhere to them. Nevertheless, it is of course hoped that as many laboratories as possible will adhere to one (or at least only a few) harmonization concepts in order to keep the variety of variants and thus the maintenance efforts small for both issuers and recipients of DCCs.

Perhaps in the future it will become an integral part of contract review for the customer and laboratory to agree on a certain harmonization before the calibration. Successful participation in an interoperability challenge could then serve as a proof of competence for a laboratory that it really does issue its DCCs according to this harmonization concept.

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