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Towards Seamless Digitalisation in TUBITAK UME Mass Laboratory

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***Abstract* – We present automatic generation of Digital Calibration Certificate for a set of weights calibrated using a Robotic Mass Comparator operating in the mass range from 1 mg to 10 g. The tool features a Graphical User Interface that streamlines the processing of Digital Calibration Certificate from the automatically extracted and organized data in the calibration reports and the most recent calibration certificates of the reference standards and test weights adhering to relevant international recommendations, standards and guidelines. This user-friendly and highly automated software application represents a substantial advancement in the mass subfield of modern metrology in terms of handling large volumes of calibration data with minimal intervention.**

I. INTRODUCTION

Mass metrology plays an indispensable role for accuracy and fairness in trade, consumer protection, regulatory compliance, safety and quality control, innovation and technical advancement and sustainable practices. Therefore having a framework for Findable, Accessible, Interoperable, and Reusable (FAIR) data in compliance with international standards and regulations is foundational in modern mass metrology. In this context, Digital Calibration Certificate (DCC) provides a sophisticated solution for the global exchange of metrological information in Extensible Markup Language (XML) format [1 - 3]. The GEMIMEG tool is designed as a free-access software application with a user-friendly interface enabling users to create and standardize Digital Calibration Certificates (DCC) without the need for in-depth knowledge on XML [4]. The advantages of using XML are clearly stated in [5]. Accordingly, a fully automated pilot study of an International Virtual Mass Comparison is performed as proof-of-concept where the exchange format of artificial data mimicking a real world comparison scenario is derived from DCC schema [6]. The implementation of DCC in mass metrology requires subject-related specifications since it is developed as a template for all measurands. Instructions on how to effectively generate DCC for weights and weight sets are provided in DKD Expert Report [7]. In this paper, we describe the seamless path in generating DCC for a test weight set calibrated in TÜBİTAK UME Mass Laboratory aligned with the DKD Expert Report, the Physikalisch-Technische Bundesanstalt (PTB) DCC Schema in version 3.2.1 and with the recommendations of the International Organization of Legal Metrology (OIML) [8]. The tool incorporates a Graphical User Interface (GUI) that simplifies the creation of DCC by automatically extracting and sorting the data from the calibration reports and the most recent certificates of the reference standards and test weights. The study is conducted to lay the foundation for the seamless exchange of globally interoperable data in the era of modern metrology.

II. INFRASTRUCTURE

TUBITAK UME Mass Laboratory is equipped with six different automatic weighing systems to provide certification services for mass calibration in the range from 1 mg to 500 kg and with standard weights and weight sets of various OIML accuracy classes. The calibration reports by these automatic weighing systems are exported in different file formats such as Tanned Database (TDB), Portable Document Format (PDF), Microsoft Word Document (DOCX), Microsoft Excel Spreadsheet (XLS). The calibration range between 1 mg to 10 g is performed by a Robotic Mass Comparator (See Fig. 1). In this paper we demonstrate the seamless generation of DCC by calibration of a weight set in the range of 1 mg – 10 g.

Fig. 1. Robotic mass comparator (1 mg – 10 g).

The calibration procedure of a weight set is programmed by the operator via the control terminal of the comparator. Calibration results by this robotic comparator are reported in TDB format in a structured and organized way. The content of the calibration report is divided into three parts as "Administrative Data", "Measurement Results" and "Summary Results" (See Figs. 2 to 4). The "Administrative Data" and the "Summary Results" are used for the automatic generation of DCC. Measurement results contains raw data which is useful for checking outliers in the data set. A separate calibration report in TDB format is generated for each individual weight in the weight set. The database under the main menu stores the information on operators, reference and test weights, calibration procedures and customers. The operator is responsible for creating the database. The stored information in the database is used for regular customers getting periodic calibration services from TUBITAK UME. The database is updated for the new customers.

```
-------------- Comparator --------------
Operator          OZLEM PEHLIVAN YILDIRIM
Name and Surname
Report number              C/13/02/24/08/43
Start date              2024.02.13 08:43:48
End date                2024.02.13 09:33:50
Test weight Set of Weights (10 mg - 2 g)
Order number                     2024.00168
Test weight number TestCompany_159351_2_g_0_TestManufacturer
Test weight class                        E1
Test weight position                     B1
Reference weight                  E0-02-2g
Real mass                               0 g
Reference weight class                   E0
Reference weight position               A23
```

Fig. 2. Administrative data in calibration report.

n	A	B	B	A	D
1	-0,0000012	0,0000081	0,0000077	-0,0000028	0.0000099
2	-0,0000051	0,0000062	0,0000051	-0,0000054	0.0000109
3	-0,0000063	0,0000041	0,0000034	-0,0000058	0.0000098
4	-0,0000064	0,0000034	0,0000040	-0,0000069	0.00001035
5	-0,0000063	0,0000028	0,0000034	-0,0000077	0.0000101
6	-0,0000068	0,0000044	0,0000049	-0,0000052	0.00001065

Fig. 3. Measurement results in calibration report.

```
Mean difference         0,000010283333 g
Standard deviation      0,000000432049 g
Cycles quantity                        6
Method                              ABBA
Min temperature                19.993 °C
Max temperature                20.124 °C
Min humidity                     41.26 %
Max humidity                     41.38 %
Min pressure                 986.066 hPa
Max pressure                 986.603 hPa
```

Fig. 4. Summary results in calibration report.

III. CALIBRATION PROCEDURE

In mass metrology, test weight calibration is typically carried out by substitution weighing utilizing reference standards of higher accuracy class than the test weights. The mass value is assigned by the mean difference in weighing of test weight and the reference standard. The most commonly used weighing cycle is Reference-Test-Test-Reference (often referred as ABBA-cycle where "A" represents weighing of the reference standard and "B" represents weighing of the test weight). The ABBA-cycle is repeated at least by the minimum number specified in the relevant international recommendations, standards and guidelines for the particular accuracy class of the test weight [8]. The weighing difference Δm_{w_i} of i^{th} cycle is determined by

$$\Delta m_{w_i} = \frac{B_{1_i} + B_{2_i}}{2} - \frac{A_{1_i} + A_{2_i}}{2}, \qquad (1)$$

where sub-index ≪ i ≫ represents the number of cycle and sub-indices ≪ 1 ≫ and ≪ 2 ≫ indicate the number of times the reference and test weights are measured within that particular cycle. The average of weighing differences between the test weight and the reference standard for n-cycle is given by (See first line in Fig. 4)

$$\overline{\Delta m}_w = \frac{1}{n} \sum_{i=1}^{n} \Delta m_{w_i}. \qquad (2)$$

The weighing equation for the mass of the test weight m_t is written as

$$m_t = m_r + \rho_a (V_t - V_r) + \overline{\Delta m}_w, \qquad (3)$$

where m_r is the mass of the reference standard, ρ_a is the mean value of the air density, V_t and V_r are the volumes of the test and reference weights at 20 °C. The volume expansion and the center of gravity correction terms are not included in this study. The second term in Eq. 3 is the air buoyancy correction on the test mass. It appears because apart from the gravitational force, the buoyant force from the displacement of the air acts on the weights. CIPM-2007 formula is used for determining the density of moist air [9] from the mean values of air pressure, air temperature and relative humidity (See the rows 5- 10 in Fig. 4). The parameters m_r and V_r are extracted from the most recent certificate of the reference standard and V_t is taken from the latest certificate of the test weight.

For practical reasons, a conventional mass value is assigned to a test weight by [7]

$$m_{ct} = m_{cr} + (\rho_a - \rho_0)(V_t - V_r) + \overline{\Delta m}_w \qquad (4)$$

where the sub-index c represents the conventional mass, $\rho_0 = 1.2$ kg m^{-3} is the reference air density. m_{cr} is extracted from the most recent certificate of the reference standard as well.

In mass metrology, for each weight, the expanded uncertainty U of the conventional mass, shall be less than or equal to one-third of the the Maximum Permissible Error, δm of the corresponding test weight (See Table 1 in [8]). The calibration uncertainty is calculated according to the general rules and principles in "Evaluation of measurement data – Guide to the expression of uncertainty in measurement" document [10]. The general practice in reporting calibration uncertainty U is to quote $\delta m/3$ of the corresponding test weight (in case the calibration uncertainty is lower than the quoted value). The calibration results of the test weights are examined whether they comply with the following rules.

Rule 1. The annual drift of the mass and conventional mass values should be less than the expanded uncertainty.

Rule 2. For each weight the conventional mass should satisfy

$$m_0 - (\delta m - U) \leq m_{ct} \leq m_0 + (\delta m - U). \qquad (5)$$

where m_0 is the nominal mass of the test weight.

IV. DIGITAL CALIBRATION CERTIFICATE

The infrastructure in TUBITAK UME Mass Laboratory allows automatic generation of DCC for a weight set from the calibration reports of automatic weighing systems. The content of this paper is confined to the generation of the DCC by using the calibration reports from Robotic Mass Comparator working in the range of 1 mg – 10 g. The GUI of the DCC generator is given in Fig. 5. It is designed for users with no expertise in XML.

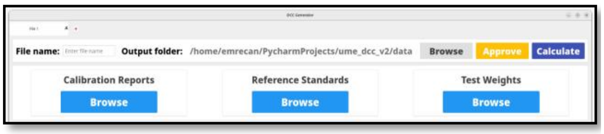

Fig. 5. GUI of automatic DCC generator.

Unified Modeling Language (UML) sequence diagram of the DCC generator is given in Fig. 6.

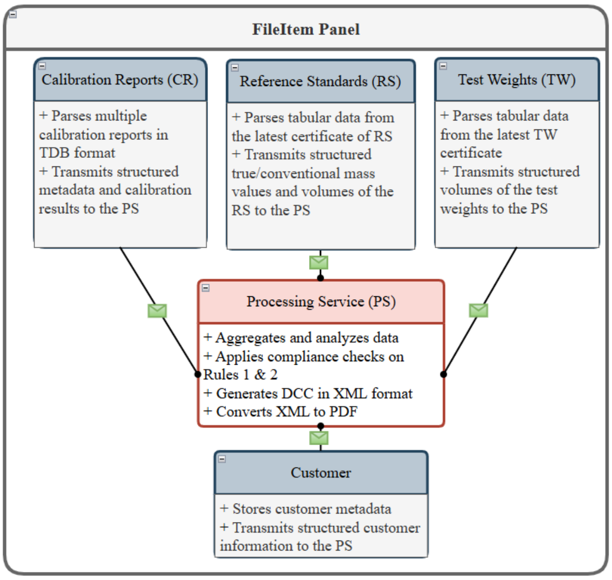

Fig. 6. UML sequence diagram.

FileItem Panel serves as the parent component for both uploads and services in the UML Sequence Diagram. The “Reference Standards” and “Test Weights” buttons are where the most recent calibration certificates of the reference standards and test weights are uploaded by the operator, typically in DOCX or XML formats. Currently, the calibration certificates issued by TUBITAK UME are in DOCX format and distributed to the customer as printed copies. Consequently, an archive of past certificates in DOCX format exists for our regular customers. If the previous certificate of the test weight set was not issued by TUBITAK UME Mass Laboratory, a PDF version of the certificate is provided by the customer; however, the format and the structure may vary significantly across different institutes. In such cases, the GEMIMEG tool is used for manually generating the DCC for the test weights as an intermediate solution [3]. As the DCC archive of certificates will be made available in the future, DCC generation tool currently allows both DOCX and XML formats as an interim solution during the transition phase. The “Calibration Reports” button is where the calibration reports of each individual test weight are uploaded by the operator. The sequence of file uploads is not critical. Notably, there is no communication between the top row buttons in the UML sequence diagram in Fig. 6. These buttons act as intermediaries between the operator and the “Processing Service”. Once all the files are uploaded, the corresponding file paths are communicated to the “Processing Service”. This service then automatically generates indexed dictionaries of the conventional mass, mass, volume/density data of the reference standards and test weights with their corresponding uncertainties, weighing difference, standard deviation and the environmental conditions. The "Calculate" button within the FileItem Panel triggers the routines in “Processing Service” that utilize these indexed dictionaries as input parameters for Eqs. 3 and 4 for each individual test weight. The calculated conventional mass value of each test weight is subsequently checked to ensure compliance with Rule 1 and Rule 2. Any test weights failing to meet these rules are displayed within the graphical user interface (GUI) as highlighted in red for the operator’s attention (See Fig. 7).

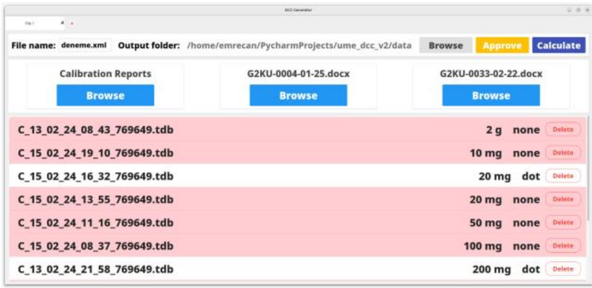

Fig. 7. Failing results summary in GUI.

The operator is then required to recalibrate the relevant test weights using an alternative reference standard and upload the updated files. The "Approve" button initiates the DCC generation routine for the test weight set. The generated DCC is in agreement with the version 3.2.1 of the DCC schema where five child elements dcc:administrativeData, dcc:measurementResults, dcc:comments, dcc:document and ds:Signature are under the main element dcc:digitalCalibrationCertificate [3], except dcc:document and ds:Signature which are presently under construction. The attributes such as *id*, *refType* and *refId* are attached to various elements as they are described in DKD Expert Report [7] for further interoperability of the data. Currently, the DCC is generated only in English. The dcc:measurementResults are partially displayed in Fig. 8, showing the mass value of 2 g with no marking. The number of digits in the quoted values are automatically adjusted to match the resolution of the robotic mass comparator. The calibration uncertainty is checked to ensure that it is less than $\delta m/3$ of the corresponding test weight. If this condition is met, it is reported as $\delta m/3$ of the corresponding test weight. The conventional mass, volume and density tables are formed in a similar fashion in line with the PTB DCC Schema in version 3.2.1 [3].


```xml
<dcc:measurementResult refId="weight_159351_E1_2_g_none" refType="basic_isInCMC">
 <dcc:name>
 ...
 </dcc:name>
 <dcc:usedMethods>
 ...
 </dcc:usedMethods>
 <dcc:influenceConditions>
 ...
 </dcc:influenceConditions>
 <dcc:results>
  <dcc:result>
   <dcc:name>
     <dcc:content lang="en">Mass</dcc:content>
   </dcc:name>
   <dcc:data>
    <dcc:quantity refType="basic_nominalValue">
     <dcc:name>
       <dcc:content lang="en">Nominal value</dcc:content>
     </dcc:name>
     <si:real>
       <si:value>2</si:value>
       <si:unit>\gram</si:unit>
     </si:real>
    </dcc:quantity>
    <dcc:quantity refType="basic_measuredValue">
     <si:real>
       <si:value>2.0000091</si:value>
       <si:unit>\gram</si:unit>
      <si:expandedUnc>
        <si:uncertainty>0.0000040</si:uncertainty>
        <si:coverageFactor>2</si:coverageFactor>
        <si:coverageProbability>0.95</si:coverageProbability>
      </si:expandedUnc>
     </si:real>
    </dcc:quantity>
    <dcc:quantity refType="basic_measurementError">
     <si:real>
       <si:value>0.0000091</si:value>
       <si:unit>\gram</si:unit>
      <si:expandedUnc>
        <si:uncertainty>0.0000040</si:uncertainty>
        <si:coverageFactor>2</si:coverageFactor>
        <si:coverageProbability>0.95</si:coverageProbability>
      </si:expandedUnc>
     </si:real>
    </dcc:quantity>
```


Fig.8. Partial measurement results in DCC.

The administrativeData is automatically generated from the information in the calibration reports (See Fig. 9). The Unique Identifier is generated initially as UME G2KU-0000 Month-Year with the date derived from the day the DCC is generated.


```xml
<dcc:administrativeData>
 <dcc:dccSoftware>
  <dcc:software>
   <dcc:name>
     <dcc:content>UME-DCC</dcc:content>
   </dcc:name>
   <dcc:release>v0.0.1</dcc:release>
  </dcc:software>
 </dcc:dccSoftware>
 <dcc:refTypeDefinitions>
 ...
 </dcc:refTypeDefinitions>
 <dcc:coreData>
  <dcc:countryCodeISO3166_1>TR</dcc:countryCodeISO3166_1>
  <dcc:usedLangCodeISO639_1>en</dcc:usedLangCodeISO639_1>
  <dcc:mandatoryLangCodeISO639_1>en</dcc:mandatoryLangCodeISO639_1>
  <dcc:uniqueIdentifier>UME G2KU-0000 02-24</dcc:uniqueIdentifier>
  <dcc:identifications>
   <dcc:identification refType="basic_orderNo">
     <dcc:issuer>calibrationLaboratory</dcc:issuer>
     <dcc:value>2024.00168</dcc:value>
    <dcc:name>
      <dcc:content lang="en">Order number</dcc:content>
    </dcc:name>
   </dcc:identification>
  </dcc:identifications>
  <dcc:beginPerformanceDate>2024-02-13</dcc:beginPerformanceDate>
  <dcc:endPerformanceDate>2024-02-15</dcc:endPerformanceDate>
  <dcc:performanceLocation>laboratory</dcc:performanceLocation>
  <dcc:issueDate>2024-02-22</dcc:issueDate>
 </dcc:coreData>
```


Fig. 9. The coreData in administrativeData in DCC.

After the approval of the DCC by the operator via the "Approve" button in the FileItem Panel, the four digit 0000 is replaced by the number of the issued certificate for that specific year. The count function for the number of issued certificate is linked with the approval of the operator. The beginPerformanceDate and endPerformanceDate are extracted from the calibration reports of the weight set, representing the earliest and latest calibration dates, respectively. The issueDate is set as the approval date of the DCC by the operator.

The items in the DCC are imported from the information supplied while programming the calibration procedure (See Fig. 10). The input data by the operator on "Test Weight" and "Test Weight Number" are provided systematically so that the information in DCC on devices under test is filled routinely.


```xml
<dcc:items>
 <dcc:name>
   <dcc:content lang="en">1 OIML set of weights from 10 mg to 2 g</dcc:content>
 </dcc:name>
 <dcc:equipmentClass>
   <dcc:reference>OIML R111-1:2004</dcc:reference>
   <dcc:classID>E1</dcc:classID>
 </dcc:equipmentClass>
 <dcc:identifications>
  <dcc:identification refType="basic_serialNo">
    <dcc:issuer>manufacturer</dcc:issuer>
    <dcc:value>159351</dcc:value>
   <dcc:name>
     <dcc:content lang="en">Serial No.</dcc:content>
   </dcc:name>
  </dcc:identification>
 </dcc:identifications>
 <dcc:item id="weight_159351_E1_10_mg_none">
  <dcc:name>
    <dcc:content lang="en">10 mg</dcc:content>
  </dcc:name>
  <dcc:identifications>
   <dcc:identification refType="mass_shape">
     <dcc:issuer>manufacturer</dcc:issuer>
     <dcc:value>Wire</dcc:value>
    <dcc:name>
      <dcc:content lang="en">Form</dcc:content>
    </dcc:name>
   </dcc:identification>
   <dcc:identification refType="basic_marking">
     <dcc:issuer>manufacturer</dcc:issuer>
     <dcc:value>-</dcc:value>
    <dcc:name>
      <dcc:content lang="en">Marking on weight</dcc:content>
    </dcc:name>
   </dcc:identification>
  </dcc:identifications>
  <dcc:itemQuantities>
   <dcc:itemQuantity refType="basic_nominalValue">
    <dcc:name>
      <dcc:content lang="en">Nominal mass</dcc:content>
    </dcc:name>
    <si:real>
      <si:value>10</si:value>
      <si:unit>\milli\gram</si:unit>
    </si:real>
   </dcc:itemQuantity>
  </dcc:itemQuantities>
 </dcc:item>
```


Fig. 10. The items in administrativeData in DCC.

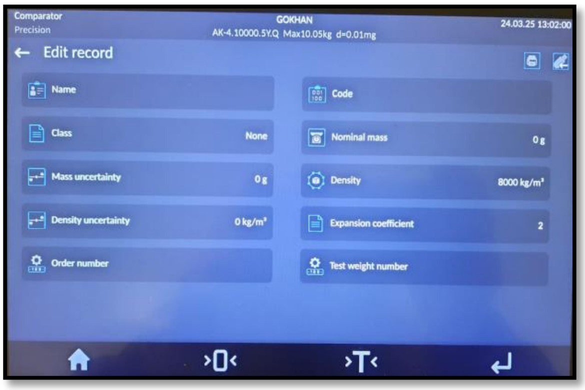

Fig. 11. Control terminal of robotic mass comparator.

The "test weight" is written as "1 OIML Set of Weights (from minimumNominalValue unit to maximumNominalValue unit)" and the test weight number as "Customer_SerialNumber_NominalValue_Unit_Mark_Manufacturer". The order number and class of the test weight, already specified in the calibration report, are entered during the calibration procedure programming. The customer's address is retrieved from a database within the FileItem Panel, matching the "Customer" listed in the "Test Weight Number" (See Fig. 11). The generated DCC is uploaded to GEMIMEG tool and it worked without errors in generating machine readable format in XML and human readable review in PDF [11]. The DCC generator developed by TUBITAK UME produces both XML and PDF files as machine readable and human readable formats, as well. The mass table generated in PDF is shown in Fig. 12.

Results: Mass

Nominal Mass	Marking	Measured Value	Unit	Uncertainty	Unit	Coverage Factor
10 mg	none	10.0042	mg	0.0010	mg	2.0
20 mg	dot	20.0077	mg	0.0010	mg	2.0
20 mg	none	20.0078	mg	0.0010	mg	2.0
50 mg	none	50.0052	mg	0.0013	mg	2.0
100 mg	none	100.0093	mg	0.0017	mg	2.0
200 mg	dot	200.0014	mg	0.0020	mg	2.0
200 mg	none	200.0099	mg	0.0020	mg	2.0
500 mg	none	500.0021	mg	0.0027	mg	2.0
1 g	none	0.9999936	g	0.0000033	g	2.0
2 g	dot	2.0000035	g	0.0000040	g	2.0
2 g	none	2.0000091	g	0.0000040	g	2.0

Fig. 12. The mass table generated in PDF.

V. CONCLUSION

The automatic generation DCC from the calibration reports of Robotic Mass Comparator working in the range of 1 mg – 10 g is demonstrated. The automatic generation of DCCs streamlines the calibration workflow by significantly reducing manual effort and the potential for human error in reporting the results. In order to adhere to the FAIR principles, version 3.2.1 of the PTB DCC schema is followed in generating DCC and the attributes are attached to various elements as they are described in DKD Expert Report. The use of standardized formats and automated tools ensures that each calibration certificate is consistent, accurate, and generated in real-time, without delays. This enhances the overall efficiency of the calibration workflow, allowing laboratories to handle large volumes of calibration data for various weight classes with minimal intervention.

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