Guide to formatting CMC entries (‘DimVIM Guide’) and to their inter-RMO review

Document history
draft1 This document was prepared for the WG-MRA meeting Oct 2014.
V1 First issue after comments from EP and Ala, issued August 2015.
V2 Comments from MM, RT, hint of coming flexible scopes and approved by WG-MRA 2015.

1 Rationale
This is a CCL/WG-MRA Guidance Document on Calibration and Measurement Capabilities (CMCs) in the field of length (and angle) metrology. The guidance has two aspects:

- supplementary (CCL-specific) formatting guidance (in addition to that provided by the JCRB) to be used when preparing CMCs for entry into Appendix C of the Key Comparison Database;
- guidance on the reviewing of CMCs.

This document replaces previous documents CCL/WGDM/00-51c, CCL/WGDM/00-52, CCL/WGDM/00-53c, and JCRL-02b, and should be read in association with the current CMC classification list (‘DimVIM’) (http://www.bipm.org/en/committees/cc/cl/dimvim.html).

The CCL sub working group on CMCs (sWG-CMC) has, as its first item in the Terms of Reference:

> to establish and maintain lists of service categories (DimVIM) and, where necessary, rules for the preparation of CMC entries (DimVIM Guide);

Both the DimVIM and the four documents referenced above were prepared in former times by the Working Group on Dimensional Metrology. Whilst the DimVIM has been maintained and brought within the control of the sWG-CMC, the DimVIM Guide has been missing. Additionally, requests for clarification on the reviewing of CMCs indicate that this current document, which is a combination of the abrogated DimVIM guides and the JCRL document ‘JCRL rules for reviewing Length CMCs’, is needed and should be maintained by sWG-CMC. Furthermore, in 2015 the WG-MRA recommended and CCL approved, the extension of CMCs to include so-called ‘flexible scope’ entries, starting with generic 1-D length CMCs, such as possible using CMMs. This document will be extended to cover this new format of CMCs when the relevant guidance is available.
2 Background

During the early years of the CIPM MRA, the CCL’s Working Group on Dimensional Metrology (WGDM) produced extensive guidance on how to prepare and format CMCs for the inter-RMO review process and eventual publication in the KCDB. This included two documents on formatting CMCs and an example document for use as a template for CMC preparation.

In the meantime, WGDM has ceased to exist and sWG-CMC has taken over responsibility for CMC matters within the CCL. Furthermore, the formatting guidance available from JCRB has been extended and the existing CMC files from the NMIs are now available for direct download from the JCRB website (via a password protected area, accessible to RMO TC chairpersons). Therefore the previous guidance from WGDM has been edited and reduced to the minimal supplementary guidance to be used in conjunction with that given in the JCRB document [CIPM MRA-D-04] and instead of using the WGDM template CMC file, current guidance from JCRB and KCDB office is to edit downloaded copies of existing NMI CMC tables.

With this in mind, the following section contains the currently applicable guidance on formatting issues specific to CCL, for the submission of CMCs.
3 Supplementary CMC formatting instructions

During the early years of the CIPM MRA, the CCL’s Working Group on Dimensional Metrology (WGDM) produced extensive guidance on how to prepare and format CMCs for the inter-RMO review process and eventual publication in the KCDB. This included two documents on formatting CMCs and an example document for use as a template for CMC preparation.

1 Scope

The purpose of this section of the document is to provide detailed guidance that is in addition to the JCRB instructions for completing submissions for the CIPM MRA Appendix C (herein referred to as AppC) listings of NMI services. There is some general instruction about language and units and also about the range and uncertainty entries, but most important is the harmonization of the naming of services. For this, a separate classification document “DimVIM” that provides the approved terminology has been created and is available in several languages from the CCL open access website (http://www.bipm.org/en/committees/cc/ccl/dimvim.html). The latest English version of the DimVIM is available from the Appendix C area of the KCDB.

2 Template for your NMI’s AppC List for Length Services

The best example CMC Excel files to be used are downloaded directly from the JCRB CMC website: 

http://www.bipm.org/JCRBCMCs/welcome.jsp

Details of Login name and Password are available from RMO TC-L chairpersons.

3 Language and Symbols

3.1 Language of AppC is English only. The DimVIM has been translated into other languages by expert volunteers from the CCL to guide others.

A common confusion is that the SI unit of length is “metre”, and a measuring device is a “meter”, so a micrometer is tool that may measure to a micrometre (µm) resolution.

3.2 Decimal point: use period (.), not comma (,). [95.37 okay, not 95,37]

3.3 Units for angle: use symbols °, ′, ″ or rad, but not: deg, min, sec, nor degree, minute, second, nor arc-second.

4 Criteria for Creating a Service Row-Item

4.1 The MRA AppC submission is an Excel spreadsheet where separate NMI services are listed in rows, and columns are used to organize the attributes of the services.

4.2 A separate service row-item shall be made in each case of a distinct artifact (instrument), a distinct measurand or a distinct calibration procedure.

Example: gauge block calibration by interferometry uses a significantly different procedure than that by mechanical comparison, even though both report the same central length of the block. Thus, these services are listed as separate row-items.
4.3 Use only one row per service except where there is more than one independent variable – use one row per variable. Compose text in each cell as a single text string, using spacing and punctuation (;) to separate items where necessary. Text in cells is pre-formatted to automatically word-wrap to make a multiline cell; the row height grows automatically to largest cell in the row.

5 The DimVIM – a CCL Length Services Classification for Appendix C

The Dim VIM is a classification scheme that provides NMIs with a uniform terminology in creating their AppC listings. It helps regional and CCL working groups to identify similar services, to determine where key and supplementary comparisons are needed to support mutual recognition.

5.1 The terminology is organized under six major headings, each with one or more groups (Classes) of instrument/artifact types and their measurands. For example:

2 Linear Dimensions ← Main Heading
2.3 Line Standards ← Class
2.3.1 precision line scale ← artifact (3-digit number is “CCL Service Category” code)

5.2 The Dim VIM lists most instruments/artifacts & measurands offered as a Length calibration service by NMIs participating in the CIPM MRA. Terms in the DimVIM have been chosen by experts from the CCL, and most NMIs will be able to express their AppC services using the current choices.

5.3 For instrument/artifact choices, optional terms are offered in (parentheses), such as “internal cylinder (ring)” – only use the term(s) that you wish for your listing (i.e., one, the other, or both as listed in DimVIM).

5.4 For measurand choices, optional terms are offered as a list – pick one per service row-item listing. In some cases, a list of similar phrases is condensed by listing the [options within square braces], such as “error in prescribed [translation; angular] motion” ← these different measurands must be listed as separate services, since their range and uncertainties have different units.

5.5 In the case that the DimVIM lacks a measurand term needed to express a particular service to be listed in AppC, continue anyway:

a) Enter the service in your AppC listing, using your (English) term for the measurand (column B, see §6.2).

b) Your regional Length chairman will contact the sWG-CMC to confirm an accepted term, which will appear in the next edition of the DimVIM.

5.6 In the rare case that the DimVIM lacks an instrument/artifact term needed to express a particular service to be listed in AppC, continue anyway:

a) Enter the service in your AppC listing, using your (English) term for the instrument/artifact (column B, see §6.2).

b) Enter “?n.n.n?” in column T (see §6.5), where nnn is a unique number you create, as the temporary CCL Service Category code for that service. The ‘?’ marks are part of the syntax, as in “?4.5.7?”.
c) Your regional Length chairman will contact the sWG-CMC to confirm an accepted term and assign a permanent 3-digit CCL Service Category code, both of which will appear in the next edition of the DimVIM. The translation of the new entry to other languages will follow later.

5.7 **Standard Reference Materials**, such as “line-width artifacts” and “microscopic spheres”, can be purchased from several NMIs. These services should be listed under Class 6.5 Special Reference Materials, and listed in AppC as a calibration service for that artifact & measurand.

**Note:** In the instructions that follow, “data to be entered in specific columns” refers to editing row-items (services) in your own AppC template file. Please do the following for each service to be listed:

### 6 Calibration or Measurement Service (Col. A, B, C) and CCL Service Category (Col. T)

6.1 Locate the appropriate instrument/artifact & measurand in the DimVIM; note the CCL Service Category code and also the Class name for that item (such as 2.3.1 for precision line scale, with Class name Line Standards).

6.2 **In column A**, insert the appropriate Class name (such as Line Standards).

6.3 **In column B**, insert the appropriate instrument/artifact and measurand choice as a single text string with the syntax “artifact: measurand” (note colon+space, no quotes). For example: gauge block: central length.

6.4 **In column C**, enter a short phrase that conveys the “Instrument Type or Method” used to make the measurement. The phrase should suggest (to an expert) the main scale, how the gauging features are probed, and any differential scale. These factors, combined with the identification of the reference standards used (Column L), tell an expert much about your procedure.

Examples:

<table>
<thead>
<tr>
<th>Artifact: Measurand</th>
<th>Instrument Type or Method</th>
<th>Reference Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>gauge blocks: central length</td>
<td>interferometry, exact fractions</td>
<td>stabilized lasers</td>
</tr>
<tr>
<td>stage micrometer: line spacing</td>
<td>video microscope &amp; 1-D comparator</td>
<td>length interferometer</td>
</tr>
<tr>
<td>index table: angle</td>
<td>index table &amp; one autocollimator</td>
<td>index table, autocollimator</td>
</tr>
</tbody>
</table>

6.5 **In column T**, insert the CCL Service Category code. (Refer to § 5.6 if needed).

### 7 Measurand Level or Range (Col. D, E, F)

7.1 In columns D, E, F, the range of the measurand has to be indicated, and not additional information such as size limitations (these are put in columns G, H, see below). Consider these examples:

<table>
<thead>
<tr>
<th>Artifact: Measurand</th>
<th>Range</th>
<th>Measurement Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>optical flat: flatness</td>
<td>0 mm to 1000 nm</td>
<td>maximum diameter: 300 mm</td>
</tr>
<tr>
<td>optical polygon: face angle</td>
<td>360°/n; n=3 to 24</td>
<td>number of faces, n = 3,4,5,6,8,9,10,12,15,18,20,24</td>
</tr>
<tr>
<td>ring: roundness</td>
<td>0.1 µm to 400 µm</td>
<td>cylinder size: 5 mm to 300 mm</td>
</tr>
</tbody>
</table>

7.2 Minimum value for range (column D): Always indicate a value (most often, this will not be zero). Do not use zero if it is significant that the measurand physically cannot be zero (resolving a line spacing, or wringing a gauge block).
8 Measurement Conditions/ Independent Variable (Col. G, H)

8.1 Cite any limitation or option restriction (not covered by measurand range) that is peculiar to your service, compared to what is typical from other NMIs. Examples would be those in §7.1 above, as well as: possible support restrictions of artifacts such as tapes (single-catenary, or on-flat), or possible illumination restrictions for line scales (reflection or transmission only), or possible orientation restrictions for device scales (horizontal/vertical axis of autocollimator only, or both). The purpose is not to further elaborate on ‘Instrument Type or Method’ in column C, but rather to alert the client to measurement conditions or limits that may be critical to his use of the artifact. For example, an NMI may only be able to calibrate a tape on-the-flat, whereas the client may need it measured in single-catenary suspension.

8.2 Do not cite laboratory ambient conditions, such as temperature & humidity if they are within normal ranges for a dimensional calibration lab. In particular, do not cite the reference temperature if it is near 20 °C, as this is the ISO Standard Reference Temperature for all dimensional measurements, and is implicit to all services unless stated otherwise. The Expanded Uncertainty for the service will include the NMI’s ability to maintain temperature (and other ambient parameters) and to compensate for measured offsets.

8.3 Do cite temperature where it purposely driven away from 20 °C, such as for thermal expansivity measurements.

8.4 Express multiple conditions for a given service in several Excel row-item for the service. It will be clear to an expert that there is a 1-to-1 correspondence between the parameter and specification terms. Do not use a separate row-item for each condition. As an example, some long line scales can only be viewed in reflection:

<table>
<thead>
<tr>
<th>Artifact: Measurand</th>
<th>Parameter</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>line scale: line spacing</td>
<td>artifact length</td>
<td>420 mm maximum</td>
</tr>
<tr>
<td></td>
<td>illumination</td>
<td>reflection only</td>
</tr>
</tbody>
</table>

9 Expanded Uncertainty (Col. I, J, K, L)

9.1 The CMC Uncertainty for AppC:

a) The Document CIPM MRA-D-04, version 4, dated October 2013 (based on the working document CIPM 2007-11, Calibration and Measurement Capabilities, a paper by the joint BIPM/ILAC working group, last updated on 2007-09-07) states:

A CMC is a calibration and measurement capability available to customers under normal conditions:

(a) as published in the BIPM key comparison database (KCDB) of the CIPM MRA; or

(b) as described in the laboratory’s scope of accreditation granted by a signatory to the ILAC Arrangement.

Also, Note N1 states: The meanings of the terms Calibration and Measurement Capability, CMC, (as used in the CIPM MRA), and Best Measurement Capability, BMC, (as used historically in connection with the uncertainties stated in the scope of an accredited laboratory) are identical. The terms BMC and CMC should be interpreted similarly and consistently in the current areas of application.
After that the unified notation CMC and no longer BMC has been preferred to refer to such capabilities. So, in the scope of ILAC accredited laboratories such capabilities are inserted under the heading CMC with the following indication: (*CMC: Calibration and Measurement Capability is the smallest uncertainty of measurement the laboratory can provide to its customers, expressed as the expanded uncertainty having a coverage probability of approximately 95 %. See also Document ILAC-G18:04/2010, Guideline for the Formulation of Scopes of Accreditation for Laboratories.

b) According to Document CIPM MRA-D-04, Note 2, under a CMC, the measurement or calibration should be:

- performed according to a documented procedure and have an established uncertainty budget under the management system of the NMI or the accredited laboratory;
- performed on a regular basis (including on demand or scheduled for convenience at specific times in the year); and
- available to all clients.

c) The CMC Uncertainty is the smallest that can be realised with real, available highest-quality artifacts. It is not the fictional uncertainty that would be possible with a perfect or ideal artifact.

9.2 In column I, enter the CMC uncertainty value: This may be a fixed value, valid over the entire measurand range. Or the uncertainty may be expressed as a formula, usually with a fixed term and a range-dependent (proportional) term.

9.3 In Column J, enter the units of the CMC uncertainty value, for relative uncertainties only (Column M: “Yes”) leave it blank.

9.4 In Column K, enter the coverage factor (usually 2).

9.5 In Column L, enter the Level of Confidence (usually 95 %).

9.6 Proportional Uncertainty: For range-dependent uncertainties, use the form \( bL \), where \( b \) is a proportionality factor and \( L \) is the measurand in units of the range (column F). \( b \) must be sized such that \( bL \) is in the units of the uncertainty (column J).

9.7 Measurand Symbols: Where a symbol other than \( L \) for length best describes the measurand (such as \( R \) for roundness or \( F \) for flatness), these symbols must be introduced in column C with the declaration of the measurand name.

9.8 Formula Uncertainty, by GUM: For uncertainties determined by an ISO GUM evaluation, the preferred method is to quadrature-sum the range-independent (constant, fixed, or end-effect) terms into a single end-effect value, and do likewise with the range-dependent (proportional) terms to form a single (proportional) term \( bL \). These two collective terms are then used to express the uncertainty as a quadrature-sum formula, so that the end-effects and proportional components are easily recognized (each has particular metrological significance for the expert). For uncertainties evaluated this way (by GUM), use the quadratic notation \( U = Q[a, bL] \), where \( a \) is the constant term. \( Q[a, bL] \) means the square root of the quadratic sum of the two arguments \( a \) and \( bL \).
9.9 **Formula Uncertainty, by sum:** Other means for evaluating the uncertainty may result in a simple linear sum of a constant ($c$) and proportional term ($dL$), resulting in $U = c + dL$.

9.10 **Do not Linearize a GUM Uncertainty:** The SWG-CMC has deemed it a poor and unacceptable practice to approximate a GUM quadrature uncertainty over a stated range of measurand by a linear sum. The coefficients of the sum no longer represent the end-effects and proportional component of the measurement process (but may be confused as such). Furthermore, for measurand ranges not starting at zero, the constant term of the sum may even be a negative value (which may be confused as a source of negative uncertainty). For these reasons, uncertainties evaluated by ISO GUM techniques must be expressed in quadrature, as per §9.7.

9.11 **Collapse Multi-Listings of Same Service:** Some NMIs are accredited to offer a service only at discrete measurand sizes, each with a specific uncertainty. An example would be a standard set of 8 long gauge blocks – only calibrations matching the sizes in the set would be possible by mechanical comparator. For the purpose of the AppC listings, the SWG-MRA requests that such a service be listed once (1 row-item), that the measurand range span the min/max values of the discrete sizes, that the actual sizes be listed under the Conditions (if deemed necessary to list them), and that a formula be used to convey the uncertainty over the range. (Usually, the uncertainty for each size has been calculated from an existing GUM-type formula anyway). If a separate service is available for a different range of measurands (probably with a different uncertainty), list it as a separate row entry.

9.12 **Zero Uncertainty not Permitted:** If zero is the minimum value for range, there must always be a fixed part in the uncertainty so that the uncertainty is never zero.

9.13 **Relative Uncertainties are not permitted for classes 2 and above.** In column M enter “No” and express as a proportional uncertainty (§9.5), by multiplying the value by the symbol of the measurand, e.g., $10^{-6}L_0$.

9.14 **For class 1 “Radiations of the Mise en Pratique” only one may enter in column M “Yes”, leave column J blank and enter the relative uncertainty, e.g. $10^{-6}$.

10 **Reference Standard used in Calibration (Col. N, O)**

10.1 In column N, enter the directly-used reference standard(s) used to make the next link in the traceability chain to the realization of the SI unit. In any measurement process, there may be several input quantities, and each has to be traceable to its own standards. More than one reference standard can be mentioned if appropriate.

   **Example:** Diameter measurement, using a length-measurement machine equipped with a laser interferometer, where the zero setting is done on a reference setting ring. The two reference standards are the laser interferometer and the setting ring. (Some NMIs use a gauge block instead of a setting ring).

10.2 **Perfect and Self-Calibrated Reference Standards:** Where appropriate, name the standard used to make the next link in the traceability chain to:

   a) to the realisation of a perfect form (such as a liquid surface for flatness, a master spindle for roundness, a master index table for circle division), or
b) to a self-calibration or error-separation techniques (such as a multi-step error separation technique for roundness, a reversal technique for straightness, or a cross-reference self-calibration technique with three independent circle divisions).

10.3 If more than one reference standard is cited, and the corresponding attributes listed in columns N and O must be distinguished, then use the notation a:[ref1]; b:[ref2].

**Example:** At NRC, Service #17 (optical flat: flatness) uses “a: liquid surface; b: 633-nm laser” as the reference standards. (Example continues in §11.3 b).

10.4 In column O, identify the lab that calibrated the reference standard(s).

**11 List of Comparisons Supporting this Measurement/Calibration Service (Col. P)**

11.1 In column P, enter the key comparison or supplementary comparison listed in the MRA Appendix B for this service, if you have participated in one. This entry of a comparison supersedes all other types of entries for column P as described in §11.3 below. The named comparison(s) must have directly tested this specific service (such as CCL-K3 directly supports an optical polygon service, since it required that an optical polygon be calibrated). Or the comparison must have been deemed by CCL or the region to have tested the principal techniques of this related service (such as CCL-K3 indirectly testing the principle techniques necessary for the calibration of an index table and an autocollimator.

11.2 If you have not participated in an AppB-approved comparison for this service, enter one of the following in column P:

a) [X]: Your own AppC-listed Service X is used to calibrate the reference standards, where ‘X’ is the NMI service identifier for that service (assigned in column S for each service), and is entered in column P in [square brackets].

b) [internal]: An internal service not listed in AppC, and does not link to one that is listed in AppC.

**Example:** At NRC, Service #4 (length interferometer: error of indicated displacement) uses “a: stabilized laser” and “b: length interferometer” as its reference standards (see §10.3). The former is calibrated by Service #2, but the latter is a “master interferometer system” that has been calibrated by a sequence of internal checks that are not listed as services in AppC. Thus for Service #4, enter “a: [2], b: [internal]” in column P.

**Example:** At NRC, Service #24 (optical flat: flatness) uses “a: liquid surface” as one of its reference standards. Since there is no key comparison for flatness, and NRC considers this reference standard to be an ideal realization of the form, then the traceability chain ends internally. For Service #17, enter “a: [internal]; b: [2]” in Column P, where the “b” term is referring to the 633-nm laser calibration in NMI Service #2.

c) **Blank.** This is a valid entry if there is an external source for the reference standard, or if the NMI is unsure about denoting the traceability. A blank cell alerts the regional chairman to a possible break in the traceability.

**12 CCL Services Administration (Col. S, T, U)**
12.1 **In column S**, number your services, such as 1, 2, 3... Note that these NMI Service Identifier numbers are referenced in column P, so be careful to keep the numbers linked with their use.

12.2 **In column T**, insert the CCL Service Category code. (Remember § 5.6).

12.3 **In column U**, enter comments, such as reference to written standards or remarks about comparisons, where appropriate.
4 Rules for reviewing length CMCs

The sWG-CMC deems that the following set of rules must be applied to the review of Length CMCs in order that their claims be judged as “fully reliable”.

4.1.1 After the Provisional Period of the MRA

Now that the provisional period of the MRA has ended, the rules to be followed are simply those given in the MRA. Document CIPM MRA-D-04 contains these rules. Section 3 of that document states the necessary requirements. They are reproduced here for expediency.

The JCRB requires that CMCs submitted for publication in Appendix C are accompanied by an RMO report indicating that the local Technical Committee/Working Group has approved the range and uncertainty of said CMCs and that each one of them is supported by a fully implemented Quality System reviewed and approved by the local RMO.

Furthermore, the JCRB requires that the range and uncertainty of the CMCs submitted be consistent with information from some or all of the following sources:

1. Results of key and supplementary comparisons
2. Documented results of past CC, RMO or other comparisons (including bilateral)
3. Knowledge of technical activities by other NMIIs, including publications
4. On-site peer-assessment reports
5. Active participation in RMO projects
6. Other available knowledge and experience

While the results of key and supplementary comparisons are the ideal supporting evidence, all other five sources listed above may be considered to underpin CMCs not directly related to the available comparison results and those for which comparison results are not yet available.

The NMIIs that issue the CMCs are primarily responsible for providing, through their local TC/WGs, the information that they believe is necessary to support their claims. TC/WGs from other RMOs may request additional information, if needed.

For item 6 in the above list, i.e. other knowledge and experience, the sWG-CMC interprets this to include the following:

- Range and uncertainty of the CMC agree with the scope of a third party accreditation.
- CMC is closely associated (uses similar techniques/ equipment) to an accepted high level service for which there are comparison results available.
- Critical aspects of the CMC have been demonstrated in other accepted CMCs (using the ‘Technique Approach to Reviewing Services’, as outlined in the CCL Strategy document section 3.1, & figure 2).
- An uncertainty budget and calibration procedure.
- Publications acceptable to the sWG-CMC.
4.1.2 CMC review process

The review process for CMCs follows the guidance in CIPM MRA-D-04.
5 References to available documents

5.1 CIPM/MRA documents

[1] Calibration and Measurement Capabilities in the context of the CIPM MRA [CIPM MRA-D-04]
http://www.bipm.org/utils/common/CIPM_MRA/CIPM_MRA-D-04.pdf

5.2 JCRB documents

[2] Monitoring the impact of key and supplementary comparison results on CMC claims [JCRB-11/7(a)]

5.3 CCL/WGDM documents

[3] DimVIM List of Services [DimVIM]

[4] CCL-WGDM Supplement to the JCRB Instructions for Appendix C [abrogated] [WGDM/00-51c]
No longer available from BIPM website – contact WG chairman.

[5] Example & Template for CMC [abrogated] [WGDM/00-52]


[7] JCRL rules for reviewing length CMCs [JCRL-02b]