Linking Results of International Comparisons of the National Standard and the National Inter-Laboratory Comparisons

O Velychko¹ and T Gordiyenko²
¹State Enterprise “Ukrmetrteststandard”, 4, Metrologichna Str., 03143, Kyiv, Ukraine
²Odesa State Academia of Technical Regulation and Quality, 15, Kowalska Str., 65020, Odesa, Ukraine

E-mail: velychko@ukrcsm.kiev.ua

Abstract. Inter-laboratory comparisons are widely used for a number of purposes and their use is increasing nationally and internationally. The equivalence of measurements of national metrological institute is established through key and supplementary comparisons of national measurement standards. The proposed procedure of linking results of international comparisons of the national measurement standards and inter-laboratory comparisons on national level is presented. The main purposes of this procedure are increase accurate identification of inter-laboratory differences and confidence level for statements of the equivalence of measurements of participant laboratories. The linking between the results of international key comparisons of the AC/DC voltage transfer standards of the regional metrological organization and inter-laboratory comparisons of AC/DC voltage transfer standards for calibration at the national level is shown with using the proposed procedure.

1. Introduction
The technical basis of the Mutual Recognition Arrangement (MRA) of International Committee for Weights and Measures (CIPM) is the set of results obtained through key comparisons (KC) carried out by the Consultative Committees (CCs) of the CIPM, the International Bureau for Weights and Measures (BIPM) and the Regional Metrology Organizations (RMOs). The RMOs organize corresponding RMO KCs with a number of common participants and with protocols allowing their results to be linked to those of the CC KC once these are treated in terms of equivalence: calculation of a KC reference value (RV) and of degrees of equivalence (DoE) [1].

The RMO KC must be linked to the corresponding CIPM KC by means of joint participants (linking National Metrology Institutes, NMIs). A supplementary comparison (SC) is a comparison, usually carried out by an RMO to meet specific needs not covered by KC. The outcomes of the CIPM MRA are the internationally recognized Calibration and Measurement Capabilities (CMCs) of the participating NMIs [2, 3].

Inter-laboratory comparisons (ILC) are widely used for a number of purposes and their use is increasing internationally. The need for ongoing confidence in laboratory performance is not only essential for laboratories and their customers but also for other interested parties, such as regulators, laboratory accreditation bodies and other organizations that specify requirements for laboratories [4].

The International Laboratory Accreditation Cooperation (ILAC) considers the elements for confirming metrological traceability to be an unbroken metrological traceability chain to an international measurement standard (BIPM) or a national measurement standard (NMIs), a
documented measurement uncertainty, a documented measurement procedure, accredited technical
competence, metrological traceability to the International System of Units (SI), and calibration
intervals [5, 6].

The ILAC MRA signatories then assess and accredit conformity assessment bodies according to
the relevant international standards including calibration and testing laboratories (using ISO/IEC
17025 [7]). Standard ISO/IEC 17025 can be used to demonstrate the competence of a proficiency
testing provider’s laboratory in accordance with international standard ISO/IEC 17043 [4, 7].

The proposed procedure of linking the results of international comparisons of the national
standards (KCs or SCs) and results of national ILCs is presented which main purposes are increase
aire accurate identification of inter-laboratory differences and confidence level for statements of the
equivalence of measurements of NMIs.

2. Evaluation results of international comparisons of the national standards
The general algorithm used for RMO KC/SC data evaluation is providing [8, 9]: determination of the
RV of RMO KC/SC with associated uncertainty; degree of equivalence with associated uncertainties
for RMO KC/SC NMI-participants; transformed data of RMO KC with associated uncertainties;
degree of equivalence with associated uncertainties for RMO KC NMI-participants except for linking
NMIs.

The degrees of equivalence of \( i \)-th NMI \( D_{NMI_i} \) and its combined standard uncertainty with respect
to the RV \( u(D_{NMI_i}) \) are estimated as

\[
D_{NMI_i} = x_{NMI_i} - x_{ref},
\]

\[
u(D_{NMI_i}) = \sqrt{u^2(x_{NMI_i}) + u^2(x_{ref})},
\]

where \( x_{NMI_i} \) is result for \( i \)-th NMI in KC/SC; \( u(x_{NMI_i}) \) is quoted standard uncertainty for \( i \)-th NMI;
\( x_{ref} \) is RV of KC/SC; \( u(x_{ref}) \) is standard uncertainty of RV of KC/SC.

3. Evaluation results of national inter-laboratory comparisons
The ILCs based on fundamental requirements: the repeatability and instability of the travelling
standard [10]. The main steps common to nearly all ILCs are [4]: determination of the assigned value
(AV); calculation of performance statistics; evaluation of performance; preliminary determination of
ILC item stability.

There are various procedures available for the establishment of AV. These procedures involve the
use of, in particular AVs – as determined by analysis, measurement or comparison of standard,
traceable to a national or international standard. Commonly used statistics for quantitative results are
listed below, in order of increasing degree of transformation of participants’ results.

The difference \( D_{labj} \) is calculated using equation

\[
D_{labj} = x_{labj} - X,
\]

where \( x_{labj} \) is the participant’s result; \( X \) is the AV.

The percent difference \( D_{\%labj} \) is calculated using equation

\[
D_{\%labj} = \frac{x_{labj} - X}{X} \times 100.
\]

\( E_u \) numbers are calculated using equation

\[
E_u = \frac{x_{labj} - X}{U^2_{\text{labj}} - U^2_X},
\]

where \( U_{\text{labj}} \) is the expanded uncertainty of a participant’s result; \( U_X \) is the expanded uncertainty of
the reference laboratory’s AV.
Criteria for performance evaluation should be established after taking into account whether the performance measure involves certain features which for performance evaluation are $E_n$ numbers: $|E_n| \leq 1.0$ indicates “satisfactory” performance and generates no signal; $|E_n| > 1.0$ indicates “unsatisfactory” performance and generates an action signal.

Obvious blunders, such as those with incorrect units, decimal point errors, and results for a different inter-laboratory comparison item should be removed from the data set and treated separately. These results will not be subject to outlier tests or robust statistical methods. If results are removed as outliers, they will be removed only for calculation of summary statistics. These results should still be evaluated within the ILC scheme and be given the appropriate performance evaluation.

4. The proposed linking procedure

The procedures used for RMO KC data evaluation are intended to provide linking to CIPM KC data with low uncertainty and they should correspond to those used for CIPM KC data evaluation [8]. The proposed procedure of linking results of international comparisons of national standards and ILCs on national level is based on the main stages of procedure RMO KC data evaluation.

The degrees of equivalence of the NMI participants of KC COOMET.EM-K6.a and its expanded uncertainties ($k = 2$) with respect to the KC RV at 1 kHz are presented in [11]. The degrees of equivalence of $j$-th Lab with combined standard uncertainty with respect to the AV with expanded uncertainty ($k = 2$) for national ILC are shown in Table 1.

**Table 1.** Degree of equivalence of the $j$-th Lab participant with respect to the AV and it expanded uncertainty for AC/DC voltage transfer standards for with linking to RMO KC at 1 kHz.

| Lab          | $x_{labj}$ | $D_{labj}$ | $U(D_{labj})$ | $D'_{labj}$ | $U(D'_{labj})$ | $E_n$ |
|--------------|------------|------------|---------------|-------------|----------------|-------|
| Lab 1 (NMI $i$) | -1.3       | 0.0        | 4.5           | 0.0         | 4.5            | -     |
| Lab 2        | -28.0      | -26.7      | 59.0          | -25.1       | 59.2           | -0.42 |
| Lab 3        | 4.9        | 6.2        | 6.1           | 7.8         | 7.4            | 1.05  |
| Lab 4        | 12.8       | 14.1       | 10.1          | 15.7        | 11.0           | 1.43  |
| Lab 5        | -50.0      | -48.7      | 260.0         | -47.1       | 260.0          | -0.18 |

The NMI $i$ result can be determined for linking (see Tables 1). The AV of ILC with it uncertainty are result of NMI $i$ with it uncertainty, and given in Table 1.

The results of the ILC are to be expressed in relation to the RMO KC/SC: $AV - RV = x_{NMIi} - x_{ref} = D_{NMAE}$. For this purpose the degrees of equivalence of the ILC (indicated $D_{labj}$), will be corrected by a correction $d$, which is determined from the results of the participant laboratory in both comparisons (NMI $i$ – Lab 1):

$$d = D_{NMAE} - D_{labi},$$

where $D_{NMAE}$ is degree of equivalence of NMI $i$ in RMO KC/SC; $D_{labi}$ is degree of equivalence of Lab 1 (NMI $i$) in ILC,

with the uncertainty

$$u(d) = \sqrt{\left(u^2(D_{NMAE}) + u^2(D_{labi})\right)/2}. \quad (7)$$

The corrected degrees of equivalence for $j$-th Lab participant in ILC with respect to linking to RMO KC/SC is estimated as

$$D'_{labj} = D_{labj} + d$$

with the uncertainty:

$$u'(D'_{labj}) = \sqrt{u^2(D_{labj}) + u^2(d)}. \quad (9)$$

Values of $E_n$ criterion was determinates

$$E_n = |D'_{labj}/u(D'_{labj})| \leq 1. \quad (10)$$
For Lab $j$ degrees of equivalence, its expanded uncertainties ($k = 2$) and values $E_n$ are shown in Table 1. The corrected degrees of equivalence Lab participants in national ILC ($D'_{lab}$) for AC/DC voltage transfer standards for with linking to RMO KC at 1 kHz are shown on Figure 1.

![Figure 1. Corrected degrees of equivalence for Lab participants of national ILC for AC/DC voltage transfer standards for with linking to RMO KC at 1 kHz.](image)

5. Conclusion

The proposed procedure links results from international comparisons of national standards and results from ILC. This procedure can be used for practical estimation of results specific ILCs on a national level in different countries by means of the results from the laboratories of National Metrology Institutes. This procedure will increase accurate identification of inter-laboratory differences and the confidence level for statements of the equivalence of measurements for participating laboratories as well as overcoming technical barriers between countries.

References

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