

Title: Development of comparison analysis software

Abstract

Key comparisons are a core component of the Mutual Recognition Arrangement and 1178 have been carried out since 1999. All national metrology institutes participate in such comparisons, and most act as pilot for a comparison. However, the process of calculating a key comparison reference value and the degrees of equivalence for participants can be difficult, and while tools and guidelines exist for the most straightforward comparisons, many real comparisons have complexities that mean such tools cannot easily be used. Proposals addressing this SRT should contribute to the development of generalised tools to support comparison pilots, along with training material to help everyone in the metrology community understand the mathematics, and practicalities, of comparison analysis.

Keywords

Mutual Recognition Arrangement; key comparison; data analysis; technical committees; uncertainty analysis; covariance, Consultative Committees, software, comparison analysis,

Background to the Metrological Challenges

The Consultative Committees (CCs) of the International Committee for Weights and Measures (CIPM) organise key comparisons as part of the Mutual Recognition Arrangement (MRA) to provide evidence for metrology institutes to support their Calibration and Measurement Capability (CMC) claims. These are followed by key comparisons organised by Regional Metrology Organisations (RMOs) that must be linked to the CC comparisons. Each CC key comparison calculates a 'key comparison reference value' (KCRV) and a unilateral "degree of equivalence" that compare participants with the KCRV. While many guides and papers exist on how such KCRVs can be calculated these are either written around the most straightforward comparisons or for complex but specific cases. Further challenges arise when results are inconsistent, and decisions must be made about how to handle inconsistency. RMO comparisons must be linked in a robust way to the CC comparison KCRV through one or more "link laboratories" and supplementary comparisons also require a 'comparison reference value' (CRV).

There is a barrier to small NMIs/DIs piloting comparisons because the complexity of the analysis makes the process too expensive. This limits the pool of possible pilots, increasing piloting responsibilities and costs of others. This could be addressed by clear step-by-step guidance, software tools and training. For CC and CMC review it is difficult to check the analysis quality in a comparison when a new type of analysis is done for each comparison. Agreed processes and quality checking software would provide greater confidence in the results. CC groups working on comparison analysis with inconsistent data sets would benefit from software that provides options, written in a modular fashion. Despite long-term efforts, there has been no introduction of practical "key comparison reference curves" for spectral quantities. This also could be addressed by making the routine parts of comparison analysis easier and training more people in the concepts, creating space to think beyond existing methods.

The need for this proposal arose from CC for photometry and radiometry (CCPR) where most comparisons are spectral, carried out simultaneously at several wavelengths. Existing tools often consider a single value per artefact which are hard to bring into a comparison analysis of spectral quantities. Most CCPR comparisons are star-comparisons where a pilot laboratory measures many artefacts that are sent out to participants in small groups. Artefacts can be unstable so each participant measures three artefacts and covariance between artefacts/rounds must be considered. In addition, radiometric uncertainties are mostly considered as multiplicative effects and uncertainties are expressed as relative uncertainties, rather than absolute

uncertainties. This is particularly important to distinguish when different artefacts may have different absolute levels of the comparison quantity.

CCPR-G2 guidelines allow for a step-by-step analysis and a least squares analysis to obtain the KCRV. For a simple comparison design, these two methods are equivalent. With more complex star patterns there can be small differences between them. CCPR has considered approaches, such as Bayesian model averaging, to handle inconsistencies in the data sets. This considerable effort by the CCPR provides a strong baseline to develop a consistent approach and shows the need. At CCPR workshops in 2010, 2015 and 2023 consistent software was requested to allow different approaches to outlier handling, and comparison models to be rapidly and helpfully compared. The software should be based on a generalised least squares analysis as this is extremely flexible. Careful software design allows other modules to be developed for other approaches in the future, building on the same input data readers and data formats. The software should allow for different forms of KCRV calculation, and for different approaches to handling outliers and questionable data. To avoid confusion this should be presented clearly to help CCs and TCs decision making. The software should be fully flexible to allow future maintenance and extensions. Modern software development practices, and especially the use of object-oriented programming methods and test-driven software development, would support flexibility. The use of the EMN-Mathmet Quality Assurance Tools will support this design [1].

Other CCs also have unique aspects. In ionising radiation and chemistry, artefact ageing and/or the reference materials must be considered. For this reason, information about the practices, recently used tools and methods should be collected from all EURAMET TCs and then discussed to get a clear picture about the challenges. A subset of challenges/requirements should be prioritised for implementation that will have the largest benefit for those CCs with more complex comparison structures. The software developed should be written in a way that either answers the needs of other CCs or could be adapted easily to meet those needs. The software alone could risk becoming a “black box” used unthinkingly. Therefore, it must be supplemented by sufficient training and guidance, along with careful consideration on the theoretical basis on choices of analysis procedures.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The proposal shall focus on comparison analysis tools to support Consultative Committees and metrology institutes.

The specific objectives are:

1. To gather the needs across all EURAMET TCs who wish to contribute, and their corresponding CCs, for software for comparison analysis, along with requirements coming from other important stakeholders (BIPM, JCRB, JCGM, EMNs, other RMOs). To identify a subset of common requirements that will be implemented within this project and a list of those that are desired beyond the project.
2. To develop high-quality, readily available, object-oriented software that will calculate the KCRV and unilateral degrees of equivalence for comparisons. The software would be developed for an agreed subset of the requirements, but designed so that it can be readily extended in future to meet the broader needs.
3. To provide training materials for workshops, such as practical demonstrations, guides and videos, to support comparison pilots, participants, and comparison working groups in use of the software and to understand the theoretical basis of comparison analysis, and the scientific and practical implications of the selected comparison procedures (such as how to deal with inconsistencies).
4. To develop the scientific, mathematical/statistical and software skills of the participants of the project, through workshops, training materials and guides, extending the capability of the participating laboratories to engage in research activity/digitalisation efforts.
5. To facilitate the take up and long-term operation of the capabilities, technology and measurement infrastructure for comparison analysis developed in the project, by the measurement supply chain (NMIs/DIs), and end users (CIPM Consultative Committees and EURAMET TCs). The approach should be discussed within the consortium and with other EURAMET NMIs/DIs, e.g. via EMN Mathmet, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

Joint Research Proposals submitted against this SRT should identify

- the particular metrology needs of stakeholders in the region,
- the research capabilities that should be developed (as clear technical objectives),
- the area for which the capabilities will be built (Green Deal, Digital Transformation, Health, Integrated European Metrology, Industry, Normative or Fundamental Metrology) and in which future main call the developed research capabilities are planned to be employed,
- the impact the developed research capabilities will have on the industrial competitiveness and societal needs of the region,
- how the research capability will be sustained and further developed after the project ends.

Proposers should establish the current state of the art and explain how their proposed research goes beyond this.

The development of the research potential should be to a level that would enable participation in other TPs.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 0.7 M€ and has defined an upper limit of 0.9 M€ for this proposal.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 20 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the 'end user' community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the "end user" community (e.g. letters of support) is also encouraged.

You should detail how your proposal's results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Provide a lasting improvement in the European metrological capability and infrastructure beyond the lifetime of the project,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the metrology community and the CIPM Consultative Committees and EURAMET TCs.

You should detail other impacts of your proposed JRP as specified in the document "Guide 4: Writing Joint Research Projects (JRPs)"

You should also detail how your approach to realising the objectives will further the aim of the Metrology Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Timescale

The project should be of up to 3 years duration.

Additional information

The links provided in this section are only correct at the time of publication up until the end of the Call year.

The references below were provided by PRT submitters; proposers should therefore establish the relevance of any references.

- [1] *European Metrology Network for Mathematics and Statistics Strategic Research Agenda*
<https://www.euramet.org/european-metrology-networks/mathmet/strategy/strategic-research-agenda>