Publishable Summary for 17NRM05 EMUE
Advancing measurement uncertainty – Comprehensive examples for key international standards

Overview

This project provides a comprehensive set of worked examples illustrating how the principles of measurement uncertainty evaluation can support and give added value to normative and related practices. It aims to promote the harmonised evaluation of measurement uncertainty according to internationally recognised standards and guides across broad disciplines of measurement. To achieve this objective the project will deliver new or improved adaptable examples of and templates for uncertainty evaluation to the Joint Committee for Guides in Metrology (JCGM) as publishers of the internationally acknowledged *Guide to the expression of uncertainty in measurement* (GUM). Further, the project will provide examples to some ten standardisation committees that are specifically related to the standards they are developing.

Need

In areas such as energy, environment and healthcare, the models used are frequently non-linear and, moreover, the contributing quantities (relating to, say, gas flow, air quality and radiation dose) often have substantial uncertainty. As such, the traditional approach to uncertainty propagation, using the law of propagation of uncertainty (LPU) in the GUM, may be invalid, with the consequence that the resulting uncertainty produced gives a misleading impression. Therefore, these areas require carefully elaborated examples that are practical and specific to these domains, capable of delivering reliable results, and as far as possible in a form that can be adapted to actual end-users' data and knowledge. Since many end-users "learn by example", a diverse set of practical examples, ranging in complexity from the simple (for example, linear interpolation of pH values) to the sophisticated (for example, impact of voxel size on perceived tumour mass), is required.

Approaches currently available for uncertainty evaluation cannot directly be applied when the measurand (the quantity intended to be measured) is not directly accessible and numerical simulation is required to relate measureable quantities to the measurand. There is a need for an extended approach that is applicable to problems such as the estimation of in-flight thrust given observations such as engine temperature at a limited number of locations. On societal issues, the continued use of illegal substances in sport is fuelled by individual, team/club and/or nationalistic desires to provide competitive performances. There is a consequential need in the area of doping control to determine the best approach for the evaluation of uncertainties based on laboratory validation data, and the verification of these uncertainties using inter-laboratory reproducibility data. Also on societal issues, specifically in cancer treatment, where a stringent maximum dose is imposed for reasons of radiation safety, methods beyond traditional LPU, such as Monte Carlo methods, may have to be applied so that the computed nano-volumes and micro-flows, and their associated uncertainties, ensure safe dose delivery.

Objectives

The overall objective is to provide a comprehensive set of new and improved examples to illustrate uncertainty evaluation methods that are in accordance with the GUM and related suite of documents. Some examples will concern the traditional metrology areas of calibration, testing, comparison and conformance evaluation. Selected examples will relate to the thematic areas of environment, energy, quality of life, and industry and society. The examples will be offered to the JCGM and its member organisations (BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP and OIML) for use in the developing examples document JCGM 110, which will illustrate the application of the GUM suite of documents. They will also be provided to standards committees and other organisations that have expressed a need for them.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

With some exceptions this project does not strongly focus on new research. Most examples will illustrate application of completed research targeted at users of standards and guides.

The specific objectives are:

1. To develop examples of measurement uncertainty evaluations capable of acting as template solutions that end users can use for related problems. Examples will include measurement model construction using JCGM 103 (expected publication in 2019), application of uncertainty evaluation principles for addressing industrial conformity assessments to support JCGM 106, and taking correlations into account as requested by ISO/REMCO, the ISO committee concerned with reference materials.
2. To derive worked examples of uncertainty analyses using the GUM and other methods to assist users to make informed choices on an appropriate uncertainty evaluation method to use. Examples will include an examination of the extent to which the GUM is appropriate for certain applications or whether the Monte Carlo methods of GUM Supplements 1 and 2, or Bayesian methods, have greater efficacy.
3. To collaborate with JCGM/WG1 (the chief stakeholder), and the standardisation, regulatory and accreditation communities (ISO/REMCO, IEC, CEN, OIML, and ILAC) to ensure that the outputs of the project are aligned with their needs, communicated quickly, and in a form that can readily be incorporated into the JCGM Guides and other documents.

Progress beyond the state of the art

Many practitioners, particularly in calibration and testing laboratories, admit difficulty with interpreting and applying the principles of measurement uncertainty as prescribed in the GUM suite of documents. They particularly have difficulty in quantifying correlation and taking it into account. To help overcome these problems, this project applies the “learn by example” principle to aid such practitioners.

Testing laboratories develop activities related to testing, inspection and certification: these are critical in assuring safety of products and services and in market surveillance. Uncertainty will have an even larger impact in the future, since conformity assessment will require uncertainty to be used in criteria for decision rules.

The examples in the GUM, now a quarter of a century old, and related JCGM documents have been criticised as not relating sufficiently strongly to modern practice in measurement, and to calibration and testing laboratories in particular. The project will take the readership of these documents beyond the scope of existing examples, which relate only to simple measurement models in calibration that can be expressed as a mathematical or functional relationship and have only one measurand.

Results

The project will extend current provisions by providing examples in areas that include:

1. Calibration where the response and stimulus variables both have uncertainties (quality of life, fluid flow, etc.),
2. Testing where repeated observations under the same conditions cannot readily be made because the process destroys the sample (destructive testing),
3. Interlaboratory comparisons where full account is to be taken of correlation effects (as arising, for instance, in repeated measured values from the same participating laboratory),
4. Tests of conformity to specification and regulation (air quality, doping control, etc.), with consideration of producer’s and consumer’ risks,
5. Comparison of candidate measurement models (environment),
6. Image quantification (in molecular radiotherapy and nanoparticle sizing, for example), and
7. Metering of utilities (water, electricity, etc.).

The examples in Work Package 1 (Examples related to metrological activities adaptable as template solutions) will use internationally recognised uncertainty evaluation methods, that is, those in the current documents within the GUM suite. The examples will be supported by introductory material and, in many instances, the manner in which metrological knowledge can be transformed into the information required for uncertainty evaluation. After applying appropriate uncertainty propagation principles, the results of the evaluation will be interpreted in the context of the application. Moreover, many of the examples will be expressed in a manner that enables them to be used as template solutions, and hence adapted to other domains. The latter aspect is an innovative feature in the presentation of examples of uncertainty evaluation.

The examples in Work Package 2 (Examples in major areas demonstrating choice of method) will give information on choice of method for uncertainty evaluation, in addition to directly supporting the GUM suite of documents. In the “New Perspective” being actively pursued by the JCGM, the structure of the JCGM documents on measurement uncertainty evaluation is redefined to articulate the co-existence of various methods for evaluating and propagating measurement uncertainty. Through an overarching introduction to the suite, the user will be guided to the appropriate document(s) and assisted in making best choice of method for his or her application. The examples document (JCGM 110), to which this project will make a major input, is a key component in the New Perspective in that it will support all other documents in the suite by exemplifying how the guidance is to be used in practice.

Many examples in WP1 and WP2 are provided in response to expressed needs from ISO/REMCO, ISO technical committees, and accreditation bodies such as UKAS or organisations like Eurachem. Some of the examples will provide a full Bayesian treatment since the JCGM intends that future documents in the suite will relate to such a treatment.

Impact

To achieve the objectives a broad consortium is required to formulate examples representing diverse disciplines where good examples are urgently required. Accordingly, this project brings together NMIs and DIs, accreditation bodies and other organisations with excellent access to end-users’ requirements. In addition, the expertise in measurement uncertainty evaluation within the consortium will be invaluable in providing coherent guidance. By its nature, this proposal has a large number of partners to give the multiplicity of examples required by the various standards and guides according to the objectives.

Impact on relevant standards

The JCGM and its member organisations will benefit from the work, which will particularly lead to enrichment of the examples document JCGM 110, the conformity document JCGM 106 and the interlaboratory comparison document JCGM 109. The project consortium is configured such that there will be specific influence on UKAS, Eurachem and ten ISO and CEN committees, which have made statements of need for improved examples. A number of partners are members of ISO/TC 69, to which presentations on project progress will be made at its plenary meetings and its uncertainty Working Group SC 6/WG 7, and feedback invited.

In relation to the further development of the GUM and related documents, the Secretariat of the ISO Technical Management Board (TMB) made a recommendation in September 2017 that a separate part in the series of JCGM uncertainty documents contain “detailed informative examples”.

All examples will apply uncertainty principles to specific application areas where practitioners would benefit directly in the near-term. Since many examples will be accompanied by information to facilitate transfer of the technology to other domains, an even larger set of practitioners will profit. International standards committees will implement examples in their standards in the near-term, with some supporting standards by uncertainty statements for the first time.

About a third of the examples are categorised metrologically as relating to calibration, testing and comparison, and conformity to regulation or specification. The remainder relate to the thematic areas of environment, energy, quality of life, and industry and society. Many examples apply to more than one area, for example, both environment and quality of life.

Impact on industrial and other user communities

Although this project will have greatest impact on relevant international standards and guides, attention is also paid to industrial and societal needs by involving a major European industrialist (RR) and an international regulator (WADA). Examples cover industrial application of the GUM using computer simulation and regulatory requirements in doping control. Through standards they also cover a range of industrial topics including hardness, air quality, fluid flow and coordinate measurement.

Impact on the metrology and scientific communities

A contribution on linking CIPM and RMO key comparisons would be made to JCGM document JCGM 109 and would be expected to be well received by CIPM Consultative Committees. The validation of CMCs (calibration and measurement capabilities) is carried out by the Working Groups of these Consultative Committees. Part of the project would be devoted to harmonisation of approach and a mathematical underpinning of the validation process.

Longer-term economic, social and environmental impacts

In the longer-term this project will bring about a wider appreciation of the application of uncertainty principles. Despite the primary uncertainty guide, the GUM, having been in existence since 1993, the uncertainty evaluation process remains daunting to many end-users. Together with the documented examples, this project will hold a workshop and also initiate a training course at IMBiH (Institute of Metrology of Bosnia and Herzegovina) for western Balkan countries. Further, it will assist in empowering existing training courses run by LNE, NPL, PTB and UKAS. All these activities will extend understanding to a much wider circle of end-users. There will be specific longer-term impact in many areas including for example that of greenhouse gas emission inventories, energy efficiency and thermal confort in buildings, neonatology and cancer treatments, and doping tests.

Project start date and duration:	1 July 2018; 3 years	
Coordinator: Dr Maurice Cox, National Physical Laboratory, Teddington TW11 0LW, UK Tel: 0044 20 8943 6096 E-mail: maurice.cox@npl.co.uk Project website address: Under development		
Chief Stakeholder: Dr Walter Bich, INRIM, Strada delle Cacce 91, 10135 Torino Italy, Tel: + 39 011 3919 945 E-mail: w.bich@inrim.it		
Internal Funded Partners:	External Funded Partners:	Unfunded Partners:
1 NPL, United Kingdom 2 BAM, Germany 3 IMBiH, Bosnia and Herzegovina 4 INRIM, Italy 5 IPQ, Portugal 6 LGC, United Kingdom 7 LNE, France 8 NEL, United Kingdom 9 PTB, Germany 10 SMD, Belgium 11 VSL, Netherlands	12 ACCREDIA, Italy 13 LNEC, Portugal 14 UKAS, United Kingdom	15 AIST, Japan 16 RR, United Kingdom 17 WADA, Switzerland