17NRM05 EMUE

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

Overview

This project is providing a comprehensive set of worked examples illustrating how principles of measurement uncertainty evaluation can support documentary standards and guides. It is promoting uncertainty evaluation according to internationally recognized guides across broad disciplines of measurement. The project is delivering 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). The project is also providing examples to ten standardization bodies that are specifically related to standards they are developing.

Need

Measurement models describe the relationship between (input) quantities we measure or know something about to the (output) quantities of interest. In areas such as energy, environment and health care these models are frequently non-linear and the quantities measured may have substantial uncertainty. In almost all scientific areas, uncertainties associated with the output quantities must be calculated given the input uncertainties. The traditional approach to uncertainty propagation through a model uses the law of propagation of uncertainty (LPU) of the GUM, but the resulting uncertainty so produced may not always be fit for purpose.

Carefully elaborated examples are being prepared in the project that are practical and specific to many 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 being developed.

A specific instance is the continued use of illegal substances in sport, which is fuelled by individual, team or club ambitions, 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 given an athlete's sample, and the verification of these uncertainties. In health care, specifically in cancer treatment, where a stringent maximum dose is imposed for reasons of radiation safety, methods beyond traditional LPU may have to be applied so that the computed nano-volumes and micro-flows, and their associated uncertainties, ensure safe dose delivery, particularly for paedeatric care. The development of examples in these and many other topical and essential areas is well under way in the project.

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 recognized international practice, specifically the GUM suite of documents. Some examples concern the traditional metrology areas of calibration, testing, comparison and conformity assessment. Further examples relate to the thematic areas of environment, energy, quality of life, and industry and society. The examples are being offered to the JCGM and its member organisations for use in the examples document JCGM 110 it is developing to illustrate the application of the GUM suite of documents. They are also being provided to standards committees and other organisations that have expressed a need for them.

The focus is on supplementing state-of-the-art measurement and research with best practice in measurement uncertainty evaluation.

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, 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 having difficulty interpreting and applying measurement uncertainty principles as presented in the GUM suite of documents. They especially have difficulty in quantifying and accounting for correlation between quantities in a measurement model. To help overcome these problems, this project applies the “learn by example” principle to aid such practitioners.

Testing laboratories have activities related to testing, inspection and certification: these are critical in assuring safety of products and services and in market surveillance. Since conformity assessment according to the latest edition of ISO/IEC 17025:2017 will require uncertainty to be used in criteria for decision rules, this project is constructing examples illustrating how uncertainty can be taken into account in this area.

The examples in the GUM, now over a quarter of a century old, and related JCGM documents have been criticized as not relating sufficiently strongly to modern practice in measurement, and to calibration and testing laboratories in particular. The project is taking 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 straightforward mathematical or functional relationship and have only one output quantity.

The examples will be supplemented by generic tutorial material, particularly to assist practitioners in setting up their own uncertainty evaluations. These tutorials focus on reporting uncertainty, handling correlation, and Monte Carlo and Bayesian methods for uncertainty propagation.

Results

The following four examples are results from the project that contribute to Objective 1:

Two-point and multi-point interpolation of calibration data. A generic approach has been applied to laboratory data, revealing possible deficiencies in the ways calibration laboratories handle such data. Applications have been made to pH measurement and mass spectrometer leak detection.

Straight-line calibration. The reliability of conventional approaches for straight-line calibration has been compared with a generic treatment that takes account of stimulus and response uncertainties. Conditions have been derived for the applicability of these approaches. A relevant paper has been submitted for publication.

Conformity assessment. The application of guide JCGM 106, relating to a single quantity for which a conformance statement is required, can provide incorrect risks of making false decisions when applied to a multicomponent material. An approach for multicomponent materials has been produced and exemplified with influenza medication data. The results have been incorporated in an IUPAC/CITAC Guide. The guide has also been submitted for publication in a journal.

Fire tests. The Monte Carlo Method for uncertainty propagation was applied to data related to the “Single Burning Item” test, within the European normative framework of reaction to fire tests for building products, EN standard 13823:2010+A1. The study established the validity of the GUM approach for that data.

The following six examples contribute to Objective 2:

Airborne contaminants. Polycyclic Aromatic Hydrocarbons (PAHs) are toxic contaminants present in the environment. Among PaHs, benzo[a]pyrene is listed in European legislation (Directive 2004/107/EC) as a carcinogenic risk marker for all PAHs. The study showed circumstances in which a Monte Carlo evaluation of uncertainty gives more valid results than provided by the GUM.

Greenhouse gases. The Intergovernmental Panel on Climate Change (IPCC) is the United Nations' body for assessing the science related to climate change. In the context of greenhouse gas emissions, IPCC uncertainty guides consider LPU and MC for uncertainty propagation, stating that LPU is a useful quality control check on MC. That attitude is orthogonal to JCGM principles, which use MC as a "gold standard" to validate other methods. Following completion of an example in the area, IPCC will be approached for discussion of this point.

Thermal comfort is quantified in standard ISO 7730, Ergonomics of the thermal environment, by an index depending on metabolic rate, convective heat transfer, etc. For typical scenarios, the index was calculated and its uncertainty evaluated using GUM and MC. The probability distribution obtained from MC is not normal whereas the GUM assumes normality. The practical repercussions of these observations is being communicated to committee ISO/TC 159/SC 5, Ergonomics of the physical environment.

Fluid flow. Analysis of a database containing some 16 000 values was used to determine the orifice discharge-coefficient according to an industry-accepted (Reader-Harris/Gallagher) equation. The uncertainty in the use of that equation was deduced using LPU considering all uncertainty sources. This analysis substantiated previous results, increasing confidence in the use of standard ISO 5167 for measurement of fluid flow.

Water resource management. Clean water and sanitation are among the sustainable development goals of the United Nations' 2030 agenda. Growing demand increases the need to improve water management in society. Using data provided by regular measurements of volume, an example of how measurement uncertainty supports the analysis of performance and risk related to these utilities has been developed.

Mobile optical measurement systems (MOMS) are used in the automotive, motorsport, aerospace, and structural engineering industries. MOMS support static and dynamical dimensional measurement of objects with complex geometrical shapes, allowing in situ non-contact manual or automatic measurements of their position. Using actual measurement data, it was shown that the reference standards used for system calibration made the largest contribution to the calibration uncertainty.

Research mobility grant (17NRM05 RMG1)
Facilitated by a research mobility grant, an IMBiH researcher developed or upgraded three examples for measurement uncertainty evaluation in the fields of pressure and gas flow. Input was received from NPL, UKAS, VSL and Sarajevogas. A main goal was to discover how different approaches for evaluation of measurement uncertainty for the same measurement model affect the results. Measurement models for the three examples described

1. The calibration of a gas flow measuring instrument by the so-called "master meter" method,
2. The pressure drop due to gas leakage in a pressurised vessel, and
3. The preparation of calibration gas mixtures of ammonia (NH_3) in nitrogen (N_2) using permeation.

The Monte Carlo method was applied to two of the examples and validated the GUM approach. For example 3, current practice was improved by including a buoyancy effect on mass loss, and also other contributions including the calculation of mass flow from weighing data.

Impact

International conferences

Project activities have been presented at over ten international conferences, including standardisation of dynamic instrumented indentation, dynamic dilution for the calibration of chemiluminescence analysers, the

use of Bayesian methods in the production of gaseous reference materials, and an uncertainty budget for gas mixture preparation by dynamic dilution and subsequent use in the calibration of analytical instrumentation.

Training activities

Training activities undertaken have been “Data analysis for key comparisons and their linking”, with an extensive Q&A session (Lisbon, Sep 2018), “Introduction to evaluating measurement uncertainty according to the GUM – one day training course for members of the DKD and calibration authorities (Jan 2019), and “Electromagnetic dosimetry in MRI: computational and experimental methods” (PhD course with 21 hours dedicated to electrical properties tomography measurement, Mar 2019).

Website

A project website includes information on the scope and objectives of the project, as well as uploaded presentations and information on forthcoming events.

Impact on industrial and other user communities

An example of in-flight thrust (force generated by a turbofan engine) with partner Rolls-Royce has reached the stage where most of the work to present the defining equations and package the code has been completed.

An example on ephedrine administration in doping control with partner WADA has reached the stage where rounds 1 and 2 of a proficiency test have been completed and (the final) round 3 is under way.

Impact on the metrology and scientific communities

A compendium of examples is being assembled, the first edition of which will contain some ten examples and be offered to the JCGM in spring 2020 for the examples document JCGM 110, the conformity assessment document JCGM 106 and the interlaboratory comparison document JCGM 109.

Impact on relevant standards

The project consortium is configured to make input to 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 are made at its annual plenary meetings and its uncertainty Working Group SC 6/WG 7, and feedback invited.

Specific input made to standards bodies included planning for an example relating to ISO 6143 and ISO 6145-7 (ISO/TC 158 Gas analysis), an example for a new normative document (VDI/TC 1.21 Suitability of test processes), and an example included in an IUPAC/CITAC Guide, for evaluation of risks of conformity assessment of a multicomponent material or object due to measurement uncertainty.

Longer-term economic, social and environmental impacts

To support the documented examples on uncertainty evaluation in general, the project will in 2020 hold a workshop at LNE (Paris) and a training course at IMBiH (Sarajevo), which is open to all but particularly targeted at the 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 wider circle of end-users. There will be specific longer-term impact in many areas including greenhouse gas emission inventories, energy efficiency and thermal comfort in buildings, neonatology and cancer treatments, and doping tests.

List of publications

J.A Sousa, E. Batista, O Pellegrino, A S Ribeiro, L L Martins. Method selection to evaluate measurement uncertainty in microflow applications, Journal of Physics: Conf. Series, 1379 (2019), 012033 (doi: 10.1088/1742-6596/1379/9/012033).

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: http://empir.npl.co.uk/emue/		
Chief Stakeholder Organisation: Joint Committee for Guides in Metrology – Working Group 1 (GUM)	Chief Stakeholder Contact: Dr Walter Bich, w.bich@inrim.it	
Internal Funded 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	External Funded Partners: 12 ACCREDIA, Italy 13 LNEC, Portugal 14 UKAS, United Kingdom	Unfunded Partners: 15 AIST, Japan 16 RR, United Kingdom 17 WADA, Switzerland
17NRM05 - RMG1: Employing organisation: NPL, United Kingdom; Guest working organization: IMBiH, Bosnia and Herzegovina.		