

TC21 "Mathematical Tools for Measurements"**Officers**

Chairman: F. Pavese, INRIM^{*}, Italy

Scientific Secretary: A.B. Forbes, NPL, UK

Scope

To promote the harmonisation, the co-ordinated use and the development of new mathematical and statistical tools for measurements, and their implementation in guides, procedures and codes, acting as a portal on an international environment.

Aims

To help advancement

- ✍ in research, to bridge the gap between scientists working in the fields of measurement science, metrology, testing, applied mathematics, statistics, databases and IT, allowing better and more efficient tools to be developed for specific purposes. The activities should involve the synergy of specialists in all relevant fields;
- ✍ in production and services, by allowing a more efficient transfer of research results to the users in enterprises and a better knowledge of the needs of the enterprises on the relevant issues. The principal scope should be getting more value from the measurements, particularly for the benefit of measurement equipment manufacturers and users who use extensively computational tools;
- ✍ in supplementing other IMEKO TCs with a focused viewpoint and activities concerning the development of specific tools in the relevant fields of the scope.

^{*} National Institute of Research in Metrology. Until 2005, IMGC of the National Research Council of Italy.

Membership

Membership aims at continuing to group of Institutions having participated to the AMCTM Community (see Appendix B) and to the SofTools_MetroNet Network either as members (formally participating to the network) or as partners (“friends” in IMEKO terms”).

The subdivision of these Institutions into members and “friends” is not yet formally established. In addition, cross-membership of persons active in other IMEKO TCs is welcome and encouraged, from TCs with complementary activities.

The Technical Committee TC21 aims at organise its activities into Special Interest Groups (SIG) borning, in principle, from the Working Package structure used for the network, which can also be a method to increase the participation at the different levels.

The following persons and Institutions are presently involved in TC21 (in bold the established national members):

1	INRIM	Dr. F. Pavese	Istituto Nazionale di Ricerca Metrologica	Torino	Italy
2	NPL	Dr. A.B. Forbes	National Physical Laboratory	Teddington	England
3	AIST-NMIJ	Dr. I. Kishimoto	National Institute of Advanced Industrial Science and Technology, National Metrology Institute of Japan	Tsukuba	Japan
4	BAM	Dr. W. Bremser	Federal Institute for Materials Research and Testing (for VDI/VDE)	Berlin	Germany
5	BNM-LNE	Dr. M. Priel	Laboratoire National d’Essais et Métrologie (for CFM)	Paris	France
	UNIZG-FER	Dr. M. Jurcevic	University of Zagreb, Faculty of Electrical Engineering and Computing, Croatia	Zagreb	Croatia
6	CEM	Dr. D. Del Campo	Centro Espanol de Metrologia	Madrid	Spain
7	DFM	Dr. L.Nielsen	Danish Institute of Fundamental Metrology	Lyngby	Denmark #
8	DIMEC	Prof. G.B.Rossi	Università di Genova (for National Group of Mechanical and Thermal Measurement)	Genova	Italy
9	INMETRO	Dr. G. Kyriazis	INMETRO (for SBM)	Duque de Caxias - RJ	Brazil
10	INMETRO	Dr. H. Brandi	INMETRO (for SBM)	Duque de Caxias - RJ	Brazil
11	IPQ	Dr. E. Filipe	Instituto Portugues da Qualidade	Caparica	Portugal
12	IRL	Dr. R. Willinks, Dr. R.White	Industrial Research Limited	Lower Hutt	New Zealand #
13	IRMM	Dr. P. Taylor	JRC-IRMM (EU JRC organisation)	Geel	n.a. #
14	MIRS		Metrology Institute of the Republic of Slovenia	Ljubljiana	Slovenia
15	MSL	Dr. B. Hall, Dr. V. Bujanja	Measurement and Standards Laboratory	Lower Hutt	New Zealand #
16	NIST	Dr. A. Possolo and others	National Institute of Standards and Technology	Gaithersburg and Boulder	USA #
17	NRC	Dr. A. Steele	National Research Council	Ottawa	Canada
18	PoliMi	Prof. G. D’Antona	Politecnico di Milano (for National Group of Electrical and Electronic Measurement)	Milano	Italy
19	PTB	Dr. M. Baer and Dr. D. Richter	Physikalish-Technische Bundesanstalt	Berlin	Germany
20	SP	Dr. L. Pendrill	Swedish National Testing and Research Institute	Boraas	Sweden
21	UNIAix	Prof. J.M. Linares	Université de Aix-les-Bains (for CFM)	Aix-les-Bains	France
22	UNILodz	Prof. J. Korchinski	University of Lodz	Lodz	Poland
23	VNIIM	Dr. A. Chunovkina	VNIIM “Mendeleyev”	St.Petersburg	Russia
24	VSL-NMi	Dr. G. Rietveld	Netherlands Meetinstitut B.V.	Delft	Netherlands
25	BEV	Dr. R. Edelmaier	Bundesamt für Eich- und Vermessungswesen	Arltgasse	Austria
26	CNR-IAC	Dr. P. Ciarlini	CNR, Istituto per le Applicazioni del Calcolo “O.M.Picone”	Roma	Italy

27	IAE	M.L. Collucci da Costa Reis	CTA		Brasil
28	INTiBS	Dr. A. Szmyrka-Grzebyk	Instytut Niskich Temperatur I Badan Strukturalnych-PAN	Wroclaw	Poland
29	IST	Prof. S.D. Antunes	Istituto Superior Tecnico	Coimbra	Portugal
30	JV	Dr. H.A. Froystein	Justervesenet National Standards Dpt	Kjeller	Norway #
31	LNEC	Prof. A. S. Ribeiro	Laboratorio Nacional de Engenharia Civil	Lisboa	Portugal
32	MITUTOYO	Dr. A. Lazzari	Mitutoyo Italy	Milano	Italy
33	MIKES	Dr. A. Manninen	Mittatekniikan keskus Mätteknikcentralen Centre for Metrology and Accreditation	Helsinki	Finland
34	NAG	Dr. F. Brian	The Numerical Algorithm Group Ltd	Oxford	England
35	ROA	Dr. F.J. Galindo	Real Instituto y Observatorio de la Armada en San Fernando	San Fernando (Cadiz)	Spain
36	SMU	Dr. P. Nemecek	Slovak Institute of Metrology	Bratislava	Slovakia
37	UME		Ulus al Metrolojenstitüsü		Turkey
38	UNIFI	Prof. G. Pellegrini	University of Firenze	Firenze	Italy
39	UNIHUDD		University of Huddersfield	Huddersfield	UK

non-IMEKO countries

Internal organisation in the IMEKO frame, foreseen activities and their dissemination

When EuroConferences were the main activity, the AMCTM work was organised in Special Interest Groups (SIG) (see Appendix B). When the EU Thematic Network became active, the work has been organised by Working Packages (WP). The latter have presently generated “Co-Operative Projects” (COP), on the following issues (short list of the first-rank headings, see the Appendix B for a more detailed list and www.amctm.org link within www.imeko-tc21.org for full information):

Data-acquisition and virtual instruments

Good practice guidance for data-acquisition procedures (including virtual instruments)
Application of existing uncertainty best practice to measurement set-ups
Actual (informal) evaluations of data-acquisition procedures and software

Internet-enabled measurement

Good practice for implementation of internet-enabled measurement software
Specification for an application programming interface (API) to be used in Internet-enabled measurement
Applicability of Internet-enabled measurement

Best practice in uncertainty evaluation

Uncertainty evaluation in the context of testing
Methods for expressing and evaluating uncertainties
Methods for inter-laboratory (including key) comparison data evaluation
Methods for expressing and evaluating uncertainties for multivariate models, including spectral quantities

Discrete modelling, data fusion and data fitting

Review and evaluation of algorithms and software
Best practice guidance and guidance
Case studies on the use of the guidance, algorithms and/or software in metrology

Databases in metrology

Collection and review of existing solutions (data models, interfaces, application areas)
Exercises using selected solutions
Development of recommendations for using standard/non-standard databases

Validation framework for metrological software

Development of a common understanding of validation of metrological software
Evaluation of validations performed / further examples that will be performed
Classification of requirements / user needs
Development of criteria

In integrating these activities within IMEKO, the intention is to **retain an internal structure by Special Interest Groups (SIG)**, each SIG comprising a Leader and a number of participating members, working on an agreed and formalised set of Co-Operative Projects.

In addition, external partners may also be associated to each SIG, which can be either members of other IMEKO TCs or totally external.

Each of this group should develop and possibly finalise, for a definite period of time, some of the above issues, also in connection, co-operation and concertation with other IMEKO TCs that might be working on contiguous and complementary issues.

The **external dissemination** of TC21 activities are planned to be performed by:

- ✍ continuing the publication on the IMGCC server of the website www.imeko-tc21.org, mirrored by the IMEKO website www.imeko.org;
- ✍ other means which will come available through IMEKO, such as the MEASUREMENT Journal and the IMEKO website at PTB www.imeko.org;
- ✍ participation to World IMEKO Congresses;
- ✍ the AMCTM International Conferences, starting from AMCTM 2005 (7th in the series), to be organised each time in a different Country, in years not interfering with the World IMEKO Congress and other TC-related events;
- ✍ continuing to publish the Series of books AMCTM (World Scientific, Singapore www.worldscientific.com, seven until 2006) and other books on relevant subjects;
- ✍ helping preparing material useful to organisations for written standards, International like ISO and National.

TC21 and other IMEKO TCs are considering to organise joint events, selecting a topic of common interest and working together in a specific areas where scientific interest do converge. In this way IMEKO TC21 will create new synergies and interest in areas only peripherally covered at the present time.

Implementing the organisation and the TC 21 activities (2008)

With respect to co-ordination and harmonisation, researchers in the mathematical sciences are in a privileged situation compared to most researchers in measurement in that, through the dissemination of algorithms and software, it much easier to transfer research results from one group to another. As a corollary, the benefit of international co-ordination and collaboration, i.e., achieving more for the same resources, are easier to realise. A primary role of TC 21 is to enable these potential benefits to be realised, firstly by providing a focus for discussion and dissemination but also through a programme of co-ordinated research activities.

This programme is co-ordinated through a number of permanent Special Interest Groups (SIGs). Each SIG will have

- ? An appointed WG leader, responsible for overall co-ordination of the SIG activity.
- ? Participants from TC 21, other IMEKO TCs, and organisations external to IMEKO.
- ? A set of well-defined co-operative projects (COPs), each with objectives, time scales, etc, organised into themes, with each project participant providing its own resources.
- ? Dissemination routes for project outputs to IMEKO (IMEKO TC 21 events, other TC events, publication in the IMEKO journal *Measurement*, uploaded onto IMEKO TC 21 website etc.)

Established links

- ? **ENBIS** Network: formal link established in **2007** (www.enbis.org);
- ? **ISO TC 69**: formal link established in **2007** (www.iso.org);
- ? **Euromet** “Interdisciplinary Metrology” Focus Group “Software and Mathematical Tools for Metrology” (AT, DK, ES, FI, FR, GE, IT, NL, NO, PL, PT, SK, SE, UK), established since its constitution in 2006.

Appendix A***List of IMEKO TC21 activities (2008)*****SIG 1: Advanced Mathematical, Statistical and Computational Tools for instrumentation**

General topics: *Instruments and data acquisition: co-ordination of tests of firmware for intelligent instruments, self-calibration, net-based acquisition and diagnostic, comparisons for quality evaluation in automated measurements; validation of the new tools.*

Theme 1.1: Data acquisition

Good practice guidance for data-acquisition procedures; application of existing uncertainty best practice to measurement set-ups; actual (informal) evaluations of data-acquisition procedures and software. Calibration of the new instruments (measurement arm, laser tracker, multi sensor CMM...).

Theme 1.2: Virtual instruments

Application of existing uncertainty best practice to measurement set-ups based on virtual instruments, with actual (informal) evaluations of data-acquisition procedures and software.

Theme 1.3: Internet-enabled measurement

Good practice for implementation of internet-enabled measurement software; specification for an application programming interface (API) to be used in Internet-enabled measurement; applicability of Internet-enabled measurement.

SIG 2 – Advanced Tools for Mathematics and Statistics in measurement

General topics: *Collaboration and testing on new advanced mathematical tools, dissemination of their use, evaluation of methods for developing virtual instruments and simulation, data visualisation, evaluation of statistical tools for the MRA and the Qs; validation of the new tools.*

Theme 2.1: Best practice in uncertainty evaluation in static systems

Uncertainty evaluation in the context of metrology and of testing; methods for expressing and evaluating uncertainties; methods for inter-laboratory (including key) comparison data evaluation; methods for expressing and evaluating uncertainties for multivariate models, including spectral quantities. With particular emphasis on chemical metrology.

Theme 2.2: Best practice in uncertainty evaluation in dynamic systems - ..., SP (P.Hessling), ...

Estimation of dynamic measurement errors. Uncertainty evaluation in the context of metrology and of testing; methods for expressing and evaluating uncertainties; methods for inter-laboratory (including key) comparison data evaluation.

Theme 2.3: Best practice in uncertainty evaluation for complex variables

Uncertainty evaluation in the context of testing; methods for expressing and evaluating uncertainties; methods for inter-laboratory (including key) comparison data evaluation.

Theme 2.4: Discrete modelling, data fusion and data fitting

Review and evaluation of algorithms and software; best practice guidance and guidance; case studies on the use of the guidance, algorithms and/or software in metrology.

SIG 3 – Advanced Tools for Metrological databases, measurement software development and validation

General topics: *Harmonisation in the development of databases and data retrieval systems, general issues concerning identification and testing of advanced methods for software validation.*

Theme 3.1: Development of new measurement software codes

Promotion and dissemination of measurement software codes developed to implement procedures and algorithms solving problems concerning the activities of Working Groups 1 and 2. Development of a viewpoint for the type of license most suitable for this purpose, outside the commercial-type licences.

Theme 3.2: Validation framework for metrological software

Development of a common understanding of validation of metrological software; evaluation of validations performed / further examples that will be performed; classification of requirements / user needs; development of criteria.

Theme 3.3: Databases in metrology

Collection and review of existing solutions (data models, interfaces, application areas); exercises using selected solutions; development of recommendations for using standard/non-standard databases.

SIG 4 – Training, Dissemination and Education

General topics: *To maintain the information about training and education in the field; to organise and develop the e-learning tools that are shared on the website by the participants; to promote the localisation of the educational material; to organise dissemination concerning education from the master website.*

Completed activities

Theme 4.1: Maintenance of websites concerning TC21 activities (in addition to the relevant page on www.imeko.org, maintained by PTB): www.imeko-tc21.org (with internal link to www.amctm.org), maintained by INRIM; (www.eurometros.org (??, ...)).

Theme 4.2: VII International Conference “Advanced Mathematical and Computational Tools in Metrology”, June 2005, Lisbon.

Theme 4.3: Book “Advanced Mathematical and Computational Tools in Metrology VII”, vol. 72, World Scientific, Singapore, 2006, pp 363, 48 articles.

Theme 4.4: Special Issue on Journal MEASUREMENT for IMEKO TC21 “Mathematical Tools in Measurements” (INRIM (coord.), IAC-CNR, LNE, NPL, PTB, MIRS, SP, NRC, NIST): ten research papers for a total of about 100 pages, in publication in November 2006, n.9 2006.

Theme 4.5: Sessions of TC21 at the IMEKO World Congress, September 2006 (INRIM, BAM, BEV, CEM, CMI, IPQ, MIRS, NPL, NRC, and NIST, INMETRO, *et al.*): a total of 27 contributions, 14 of which oral and 3 extended (NPL, NIST, TC7). One Plenary Lecture on the behalf of TC21 (D.Richter, PTB), 2006, Conference CD-ROM.

Theme 4.6: Round Table, joint TC21 and TC7 at the IMEKO World Congress, September 2006. INRIM, NRC and 2 TC7 members proposed four themes to discussion: i) Classification of replicated and non-replicated measurements in metrology and testing; ii) Analysis of Measurement Comparisons; iii) On the measurand definition; iv) Rankings: are they useful for measurement practitioners? Are they in the scope of metrology and measurement science? 2006, Conference CD-ROM..

Theme 4.7: Contribution to the preparation of a proposal in the frame of European Commission FP7 Marie Curie Calls of a Training Network SOFTTOOLS-Train, co-ordinated by F. Pavese (INRIM) and of four Training Events (INRIM, LNE, NPL/ENBIS) on “Soft Tools” in the proposal ADMETRO, co-ordinated by L. Pendrill (SP), 2005-2006. Not funded.

Theme 4.8: ICIAM 2007 “Mini-symposium on Mathematical, Computational and Statistical Modelling in Metrology” (Chairmen: M.Bär (PTB), A.B.Forbes (NPL)), Zurich (Switzerland), 16-20 July 2007.

Theme 4.9: Contribution to the preparation of a proposal in the frame of European Commission FP7 iMERA-Plus Calls of a Joint Research Project “Mathematics and ICT underpinning a redefinition of SI”, N.13 in TP1 coordinated by L. Nielsen (DFM) (DFM, BEV, INRIM, IPQ, NPL, PTB), 2007. Not funded.

Planned activities

Theme 4.10: Multi-author book in the Series “Modeling and Simulation in Science, Engineering and Technology”, Birkhauser Publ., Boston: “Advances in data modeling for measurements in the metrology and

testing fields”, F. Pavese (INRIM) and A.B. Forbes (NPL) Editors. 14 chapters (INRIM, BAM, NPL, PTB, NRC, NIST, NRC, Metrel, Universities of Genova and Sannio (Italy) and Texas (USA), IST (Portugal)), to be published on Summer **2008**.

Theme 4.11: VIII International Conference “Advanced Mathematical and Computational Tools in Metrology and Testing”, Paris, France, 23-25 June **2008**. Sponsored by TC21, co-sponsored and organised by CFM, co-sponsored by IMEKO, TC7 and TC8.

Theme 4.12: Book “Advanced Mathematical and Computational Tools in Metrology VIII”, World Scientific, Singapore, **2008**.

Theme 4.13: TC21 co-sponsorship and participation into TC4 Symposium, Firenze, Italy, September **2008**.

Theme 4.14: TC21 co-sponsorship and participation into TC8 Workshop, Torino, Italy, October **2008**

Theme 4.15: Sessions of TC21 at the IMEKO World Congress, Lisbon, Portugal, August **2009**. *Planned*.

Theme 4.16: e-Learning. *Under construction*.

Theme 4.17: TC21 NewsLetter. *Planned*.

Appendix B

Detailed list of AMCTM Community activities

Data-acquisition and virtual instruments

Good practice guidance for data-acquisition procedures (including virtual instruments)

- Sharing existing guidance on development of data acquisition or virtual instrument procedures and software
- Sharing information on the procedures and software development environments used for data acquisition and virtual instruments
- Development of a guideline or good practice of setting-up and implementing data-acquisition procedures and software, building upon existing guidance where possible
- Case studies on the application of the guideline in some laboratory systems and instrument firmware / software.

Application of existing uncertainty best practice to measurement set-ups

- Outlier identification
- Uncertainty propagation in successive measurement steps
- Multivariate data capture and its impact on uncertainty evaluation
- Improving experimental design in order to reduce or make more reliable the estimation of Type B uncertainties
- Improving experimental design and sampling techniques in order to improve the reliability of Type A uncertainty evaluation, capturing sets of data with better statistical properties
- Investigation of uncertainty evaluations performed in SEVA (self-validating) instruments

Actual (informal) evaluations of data-acquisition procedures and software

Internet-enabled measurement

Good practice for implementation of internet-enabled measurement software

- Sharing and reviewing existing guidance material
- Security issues, including security policies, authentication, access control, data integrity, confidentiality and firewall issues
- Electronic calibration certificates
- Calibration history data tracking, including capture, storage, access and data mining
- Good practice for design and development of the control software, both at the client end and at the server end
- Software for online (web-based) services, such as software testing services, simulation and virtual testing services, expert system services, and measurement data processing services

Specification for an application programming interface (API) to be used in Internet-enabled measurement

- Identification and classification of interfaces used in existing and emerging instruments
- Clarification of requirements for a commonly agreed API
- Specification of the commonly agreed API
- Guidance on use of the commonly agreed API

Applicability of Internet-enabled measurement

- Sharing and reviewing existing information on applicability of internet-enabled measurement
- Clarification of new application areas of internet-enabled measurements
- Sharing of information on real applications and lessons learned. Indicate in the comment form the present area of application

Best practice in uncertainty evaluation

Uncertainty evaluation in the context of testing

- Understanding the requirements of testing laboratories, the consequences on the design of measurement procedures, and the relationship to uncertainty evaluation in the context of calibration.
- Relating the uncertainty associated with a measurements result to decision-making in testing.
- Case studies to promote appropriate statistical tools and methods, including investigating their use, benefits and limitations. Identifying the need for further tools and methods.
- Influencing input to and review of outputs from the EA Expert Group on uncertainties in testing.

Methods for expressing and evaluating uncertainties

- Promoting the probabilistic basis of uncertainty evaluation, and its relationship to the Guide to the Expression of Uncertainty in Measurement (GUM).
- Case studies to compare methods for uncertainty evaluation, including analytical methods, the GUM approach (based on the law of propagation of uncertainty), the propagation of distributions (and its implementation by Monte Carlo simulation), non-parametric and resampling methods (such as the bootstrap and jack-knife), robust estimators for Type A standard uncertainty component, convolution, use of moments, mixture distributions, and others.
- Influencing input to and review of outputs from JCGM Working Group 1 on measurement uncertainty.

Methods for inter-laboratory (including key) comparison data evaluation

- Input to the development of guidelines for the evaluation of interlaboratory comparison data. Cases to be considered include interlaboratory comparisons for which (a) a travelling standard does not possess good short-term stability, (b) several traveling standards are circulated, and (c) there are mutual dependencies among some or all of the laboratories' measurements.
- Relating the protocols and data evaluation methods used by NMIs for key comparisons and other organisations for interlaboratory comparisons.
- Case studies to promote the application of guidelines developed for interlaboratory comparison data evaluation.
- Influencing input to and review of outputs from BIPM Director's Advisory Group on uncertainties, and other organisations concerned with interlaboratory comparisons.

Methods for expressing and evaluating uncertainties for multivariate models, including spectral quantities

- Identifying applications for which the output measurand is multivariate and for coverage regions (the extension of coverage intervals for a univariate output measurand) are required.
- Investigating methods for uncertainty evaluation for multivariate output measurands, with input to guides and Standards.
- Application to key comparison data evaluation in the case that measurements are made at each of a number of stipulated values of a parameter, such as wavelength or frequency.
- Influencing input to and review of outputs from JCGM Working Group 1 on measurement uncertainty.

Discrete modelling, data fusion and data fittingReview and evaluation of algorithms and software

- Algorithms and software for established discrete modeling and data fitting (e.g. using polynomials or splines).
- Algorithms and software for newer univariate and multivariate empirical modelling and approximation, based on radial basis functions, wavelets, rational functions, etc.
- Best practice optimisation algorithms and software for use in total least squares (TLS) and other newer approximation methods.
- Algorithms and software for Gauss-Markov regression (correlation in uncertainty matrix), generalised distance regression (measurement uncertainty associated with response and explanatory variables) and generalised Gauss-Markov regression (correlation, measurement uncertainty associated with response and explanatory variables).
- Parameter estimation algorithms and software, such as generalised maximum likelihood estimation appropriate for the probabilistic models used in data fusion.
- Algorithms and software for feature detection in signal processing and data fusion.
- Best practice optimisation algorithms and software for use in maximum likelihood approximation and generalised regression.
- Automatic differentiation software tools.

Best practice guidance and guidance on

- established discrete modelling and data fitting (e.g. using polynomials or splines), reviewing current guidance material and proposing how to agree upon and then produce MetroNet approved guidance.
- newer univariate and multivariate empirical modelling and approximation, based on radial basis functions, wavelets, rational functions, etc.
- total least squares (TLS) and other newer approximation methods, and analysis of their behaviour.
- maximum likelihood approximation for more general distributions such as student t and other long-tailed distributions, and their relationship to TLS and robust estimation methods.
- incorporation of best practice optimisation algorithms into regression methods.
- probabilistic models for data fusion based on statistical models of sensor behaviour
- feature detection methods, for use in signal processing and data fusion.
- automatic differentiation methods.

Case studies on the use of the guidance, algorithms and/or software in metrology

- in established discrete modeling and data fitting.
- in newer univariate and multivariate empirical modeling and approximation.
- in total least squares (TLS) and other newer approximation methods.
- in maximum likelihood approximation.
- on regression methods (Gauss-Markov regression, generalised distance regression, generalised Gauss-Markov regression).
- on use of probabilistic models for data fusion.
- on applications of data fusion to metrology.
- on feature detection in signal processing and data fusion.
- on use of automatic differentiation methods.

Databases in metrology

Collection and review of existing solutions (data models, interfaces, application areas)

- requirements and solutions for the conceptual model (data model) of measurement databases or other metrological databases, i.e. the structure and the relations of the database tables or objects
- requirements and solutions for the implementation of interactive user interfaces with respect to different user roles such as data retrieval, data management or administration;
- requirements and solutions for the implementation of interfaces to measurement systems for automatic data input and output
- specification of desired data base support that could so far not or only partly realized (as, for example, systems for supporting an integrated management of calibration data including reference/standard devices used during calibration, calibrated devices and their calibration history and further data), analysis of the problems

Exercises using selected solutions

- exercises and evaluation of the kernel of a template database for registering different kinds of measurement, processing and evaluation; (e.g., the solution of PTB realized on the basis of the relational concept and implemented with the MS Access tool as the database 'db1' (file name: db1.mdb));
- exercises and evaluation of existing, remotely accessible measurement databases such as the PTB bio-signal database or the test environment of the PTB web enabled database for non invasive blood pressure measurements, further examples are highly welcome;

Development of recommendations for using standard/non-standard databases

- elaboration of recommendations as conclusions from the gathered examples, experiences and discussions
- recommendations supporting the initial design decisions concerning appropriate system architecture (stand alone or multi-tier systems), suitable DBMS (database management system), and selection of appropriate standard data bases or spreadsheet programs;
- recommendations supporting the selection of suitable data modelling activities;
- recommendations supporting suitable navigational means in user interfaces of metrological databases.

Validation framework for metrological software

Development of a common understanding of validation of metrological software

- Collecting and specifying the issues
- Classification of different types of validation to meet different requirements (e.g. model validation, validation of numerical stability and correctness, validation of correct implementation)

Evaluation of validations performed / further examples that will be performed

- Sharing information on cases studies already performed or that will be initiated by this COP, and on tools/methods used
- Evaluation of case studies including feedback for classification and development of criteria
- Identification of examples to be used as best practice recommendations
- Initiating new example tools using existing methodologies (e.g. developing new reference datasets for numerical correctness testing)

Classification of requirements / user needs

- Development of class definitions and limitations (e.g., for the above mentioned classes)
- Selection of classes so that validation procedures for practical applications can be provided, and/or validation is urgently required
- Commenting on how well existing guidance material and procedures meet these requirements and user needs, particularly identifying gaps that need to be filled

Development of criteria

- Classification of software
- Applicability of existing standards, guides, etc.; agreement on which guidance material can be recommended for use
- Application of further procedures and methods
- Acceptance criteria of validations performed
- Transferability of validations performed for similar but not identical software
- How to fill the identified gaps in existing guidance material and procedures in order to meet the full set of requirements and user needs.

Appendix C

**Prior IMEKO TC21:
The International Community
“Advanced Mathematical and Computational Tools in Metrology”**

Franco Pavese, INRIM, Torino, Italy

A short history 1993-2004

In October 1993, an International Workshop on “Advanced Mathematical Tools in Metrology” (AMTM) was organised in Torino by F. Pavese (International Programme Committee: A. Balsamo (IMGC), W. Bich (IMGC), P. Ciarlini (IAC), M.G. Cox (NPL), R. Monaco (Politecnico, Torino), F. Pavese (IMGC), F. Righini (IMGC), P. Tavella (IEN)), with great success and more than 100 participants. A book with peer-reviewed papers arising from the Workshop presentations was published by World Scientific under the Series on Advances in Mathematics for Applied Sciences.

The initiative was intended for bridging the gap between

“... people in universities, research centres and industries who are involved in measurements and need advanced mathematical tools to solve their problems, and to whoever is working in the development of these mathematical tools. Metrology aims at performing measurements at the highest possible precision level. Advances in metrology depend on many factors, related to improvements in scientific and technical knowledge, in instrumentation quality, in a better use of advanced mathematical tools and in the development of new ones. Only a few metrological institutions in the world have a tradition of close co-operation between metrologists and mathematicians, and include a division of applied mathematics. The Workshop aims to increase the extent of such a co-operation by calling scientists from both the mathematical and the metrological fields to meet and exchange experiences. Several industrial sectors, particularly those of instrumentation and software, are likely to benefit from this process, since metrology has a high impact on the overall quality of industrial products and applied mathematics is becoming more and more important in industrial processes.”

As a follow up, a proposal for a cycle of EuroConferences was proposed under FP4 to the EU and IMGC won the bid (Contract ERBCHCCT940254, F.Pavese co-ordinator), allowing two other AMTM Conferences to be held in Oxford (UK) in 1995 and Berlin (DE) in 1996. One multi-author book was published in the same series after each Conference (see references). It was followed by another proposal to the EU, where the words “and Computational” were added to the title, and another Contract to IMGC was obtained with F.Pavese as co-ordinator for two more Euro Conferences (ERBFMMACT970244), AMCTM, held in 1999 in Oxford (UK) again and in 2000 in Lisboa (Portugal), with two additional books published.

In 2001 it was decided to propose an upgraded tool, a thematic network under FP5, with the same title of the previous Conferences and the acronym SofTools_MetroNet. Again we won the bid and a new Contract (G6RT-CT-2001-05061) was assigned to IMGC with F.Pavese as co-ordinator for the period 2002-2005, later extended to June 2005. In addition to several other activities (see the website www.amctm.org), an annual conference was organized, and in particular the sixth AMCTM Conference in Torino in 2003, ten years after the first (with a new AMCTM book published). The seventh AMCTM is planned in Lisbon in 2005.

The original group of promoters and book editors composed of persons from IMGC (F. Pavese), CNR-IAC (P. Ciarlini), NPL (M.G. Cox, A.B. Forbes), PTB (D. Richter), IPQ (E. Filipe)) has been widened, especially thanks to the Network, to several other active partners (details in the indicated

website). Good relationships exist with other activities in the same field in Europe and abroad, namely with the SSfM programmes in UK (which may be considered initially as a spin-off of AMCTM.).

In the past 10 years, many activities and co-operations have been taking place in Europe in the field of the developments of “soft tools”, pioneered by the AMCTM group. These activities have now been recognized as an important area of future work in metrology (e.g., by Euromet in its MERA Project) – *and in measurements in general*. Some of the fields covered by the activities within this international group (the Networks extends also beyond the EU, covering up to 19 countries: IT, FR, DK, PT, NO, NL, UK, DE, SP, SE, SI, PL, TR, FI, GR, RU, CA, NZ; plus BIPM, CERN and JRC-IRMM) are the following, in both the fields of metrology, and more recently and with increasing accent, of testing:

Advanced statistical modelling – uncertainty evaluation, experimental design, optimisation, data analysis, applications, etc.;

Metrology software – engineering aspects, requirement specification, risk assessment; software development, software examination, software tools for data analysis, visualisation, experiment control; best practice; standards, etc.;

Numerical methods – numerical data analysis, numerical simulation, inverse problems, uncertainty evaluation of numerical algorithms, applications, etc.;

Data fusion techniques; Design and analysis of inter-laboratory comparisons, etc;

Databases and related issues;

Software validation, etc.

A more comprehensive list of activities can be found in the website www.imeko-tc21.org under the link www.amctm.org and heading COP “Co-Operative Projects”.

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Appendix D

**Prior IMEKO TC21:
*The UK National Programme
“Software Support for Metrology”***

Alistair B. Forbes, NPL, Teddington, UK

Appendix E

**Besides IMEKO TC21 in Europe:
The EURAMET Focus Group
“*Software and Mathematical Tools for Metrology*”**

Markus Bär and Dieter Richter, PTB, Berlin, Germany

Appendix F

**Besides IMEKO TC21 in the World:
The ENBIS Network
Ron Kenett, ENBIS**