CAL LAB

THE INTERNATIONAL JOURNAL OF METROLOGY

A Unified Formula for Uncertainty Estimation in Interlaboratory Studies and Key Comparisons

Cost and Accessibility of Metrology, Calibration, Testing, and NDT Training

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THE INTERNATIONAL JOURNAL OF METROLOGY
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VOLUME 26, NUMBER 4

FEATURES

DEPARTMENTS

ON THE COVER: Nick and Ryan refining a Fluke MET/CAL procedure for a Fluke 5790B AC Measurement Standard at Essco Calibration Laboratory in Chelmsford, MA.

CALENDAR

UPCOMING CONFERENCES & MEETINGS

Feb 26-28, 2020 METROMEET. Bilbao, Spain. During the 16th International Conference on Industrial Dimensional Metrology (METROMEET), we provide information about the progress made in the sector and we constitute a forum for debate on metrology and its development in a fast changing industry. https://metromeet.org/

Mar 3-5, 2020 MSA 2020. Melbourne, VIC, Australia. The Conference of the Metrology Society of Australasia is held biennially. The three-day scientific conference will feature presentations and workshops on many aspects of metrology. https://www.metrology.asn.au/msaconnected/events-menu/msa2020-melbourne

Mar 24-27, 2020 MSC Training Symposium. Anaheim, CA. Since 1970, MSC has been an international leader in leader in promoting educational training in the measurement and metrology communities. https://msc-conf.com/

Apr 14-15, 2020 CAFMET. Casablanca, Morocco. CAFMET 2020 is the 8th Conférence Internationale de Métrologie en Afrique. Cet événement international constitue un carrefour d'échanges d'information, d'idées et d'expériences en Métrologie et en Management de la Qualité, autour de conférences, de tables rondes, d'ateliers techniques et de stands d'exposition. https://www.cafmet-conference.com/en/

Apr 20-22, 2020 CIRMS Annual Meeting. Rockville, MD. The Council on Ionizing Radiations Measurements and Standards (CIRMS) 28th Annual Meeting, "Building Synergy Among Standards Labs and End Users" http://cirms.org/news.html

Apr 26-29, 2020 A2LA Tech Forum. Chantilly, VA. The A2LA Tech Forum has grown to become one of the largest, multidiscipline events in the accreditation industry, attracting attendees from over 12 different industries, including automotive, environmental, pharmaceutical, calibration, and more. https://www.a2la.org/tech-forum

May 5-7, 2020 IMEKO TC3, TC5, TC16, TC22. Cavtat-Dubrovnik, Croatia. TC3 - 24th Conference on the Measurement of Force Mass and Torque, TC5 - 14th Conference on the Measurement of Hardness, TC16 - 6th Conference on Pressure and Vacuum Measurement, TC22 - 5th Conference on Vibration Measurement. http://conferences.imeko.org/index.php/tc3-5-16-22_2020/2020

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PUBLISHER
MICHAEL L. SCHWARTZ

EDITOR
SITA P. SCHWARTZ

CAL LAB
PO Box 111113
Aurora, CO 80042
TEL 303-317-6670 • FAX 303-317-5295
office@callabmag.com
www.callabmag.com

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EDITOR'S DESK

The Measurement Community

I recently updated the list of conferences for 2020 and found a few dual conferences happening this year and next. SENSOR+TEST is joined by SMSI and European Test and Telemetry Conference in Nuremburg, Germany, this June, while NCSLI Workshop & Symposium and CPEM are coming to the Denver Metro Area, Colorado, later this summer. Next year, the 10th International Temperature Symposium will run in conjunction with the MSC Training Symposim in Anaheim, California. IMEKO sponsored events often run concurrently each year as well. The advantages to organizers and the community are obvious (pooled resources, venue discounts, overlapping community involvement, etc.).

The fact they continue to draw an enthusiastic crowd each year is encouraging; conferences are still relevant and necessary in the age of virtual meetings and instant information. It is the face-to-face experience that draws attendees and brings them back each year. Our own Hannah Eilers and Michael Schwartz compiled feedback from within the community regarding the value of measurement conferences and published it here. So, if you need some convincing how and why measurement conferences and meetings are beneficial and worth your time and money, take a read from "Realized Value of Industry Events."

Dennis Destefan and William Hinton compiled an impressive amount of data to form their results about the value of different delivery methods for metrology instruction, in "Cost and Accessibility of Metrology, Calibration, Testing, and NDT Training." It would be interesting and of value to prospective technicians and lab managers, or anyone who has any concern about how the measurement community will replace a generation of calibration technicians and engineers.

But to begin a great lineup of papers this issue, we have another in-depth, technical paper from Hening Huang on "A Unified Formula for Uncertainty Estimation in Interlaboratory Studies and Key Comparisons."

A community shares ideas and informed results to a wider audience, so we are very grateful that Mr. Huang and our other authors choose *CAL LAB* to publish their findings. If you have something you would like to share for the benefit of the measurement community, consider submitting it to us at: office@callabmag.com.

Happy Measuring,

Sita Schwartz

Correction: The caption for the cover photo of the July-September 2019 issue should be "A technician is repairing a PCB at the 1A CAL GmbH facility in Kassel, Germany," not Nürnberg, as previously published.

CALENDAR

May 25-28, 2020 I2MTC. Dubrovnik, Croatia. The International Instrumentation and Measurement technology Conference – is the flagship conference of the IEEE Instrumentation and Measurement Society and is dedicated to advances in measurement methodologies, measurement systems, instrumentation and sensors in all areas of science and technology. https://i2mtc2020.ieee-ims.org/

Jun 1-3, 2020 MeMeA. Bari, Italy. The 15th Edition of IEEE International Symposium on Medical Measurements and Applications deals with all the aspects of interactions among the worlds of the instrumentation and measurement, bio-engineering, material science, chemical and biological measurements, and the medical field. https://memea2020.ieee-ims.org/

Jun 3-5, 2020 Metrology for Industry 4.0 & IoT. Rome Italy. MetroInd4.0&IoT aims to gather people who work in developing instrumentation and measurement methods for Industry 4.0 and IoT. Attention is paid, but not limited to, new technology for metrology-assisted production in Industry 4.0 and IoT, Industry 4.0 and IoT component measurement, sensors and associated signal conditioning for Industry 4.0 and IoT, and calibration methods for electronic test and measurement for Industry 4.0 and IoT. http://www.metroind40iot.org/

Jun 16-18, 2020 North American Custody Transfer Measurement Conference. Austin, TX. CEESI. The NACTMC 2020 will bring together meter manufacturers, end users, standards and testing representatives, and others to share hydrocarbon measurement knowledge on topics including metering technologies, flow measurement research, industry standards, government regulations, and diagnostic tools. https://ceesi.com/CustodyTransfer2020

Jun 19, 2020 95th ARFTG Microwave Measurement Conference. Los Angeles, CA. Measurement techniques, approaches and considerations for frequencies from RF through THz. Measurement-based modeling, uncertainties and related topics are also covered. https://www.arftg.org/

Jun 22-24, 2020 MetroAeroSpace. Pisa, Italy. Since the first edition, the IEEE International Workshop on Metrology for AeroSpace represents an international meeting place in the world of research in the field of metrology for aerospace involving national and international institutions and academia in a discussion on the state-of-the-art concerning issues that require a joint approach by experts of measurement instrumentation and industrial testing, typically professional engineers, and experts in innovation metrology, typically academics. http://www.metroaerospace.org/

CALENDAR

SEMINARS: Certification

Feb 27-Mar 5, 2020 Certified Calibration Technician (CCT) Review. Minneapolis, MN. QC Training. Advance your career and attain the credential of ASQ Certified Calibration Technician. This 24-hour course includes classroom instruction, group discussion, and computer-based training materials to prepare you for the ASQ exam. https://qctraininginc.com/

SEMINARS: Dimensional

Mar 2, 2020 Dimensional Measurement User. Telford, UK. Hexagon Metrology Ltd. In this three day training course, learners will be introduced to dimensional metrology and the importance of good measurement practice and the right measurement behaviors. https://www.npl.co.uk/training

Mar 3, 2020 Dimensional Measurement Tools – Basics. Milwaukee, WI. QC Training Services. This class is an introduction to some of the most common gages used on the shop floor. The purpose is to provide practical instruction on the different tools available and their proper use to build workers' skill and knowledge. https://qctraininginc.com/

Mar 3, 2020 Dimensional Measurement Tools – Basics. Chicago, IL. QC Training Services. This class is an introduction to some of the most common gages used on the shop floor. The purpose is to provide practical instruction on the different tools available and their proper use to build workers' skill and knowledge. https://qctraininginc.com/

Mar 3-5, 2020 Coordinate Measurement Machine (CMM) Basics. Minneapolis, MN. QC Training. This course will help to equip you for a rewarding and challenging position in the quality field. https://qctraininginc.com/

Mar 9, 2020 Dimensional Measurement Applier. Coventry University, UK. A four day training course for those who have a good basic understanding of measurement principles gained through the Dimensional Measurement User training course. https://www.npl.co.uk/training

Mar 10-13, 2020 Gage Calibration. Chicago, IL. Mitutoyo Institute of Metrology. Mitutoyo America's Gage Calibration course is a unique, active, educational experience designed specifically for those who plan and perform calibrations of dimensional measuring tools, gages, and instruments. https://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/

CALENDAR

Mar 10, 2020 Dimensional Measurement User. Huddersfield, UK. NPL. In this three day training course, learners will be introduced to dimensional metrology and the importance of good measurement practice and the right measurement behaviors. https://www.npl.co.uk/training

Mar 17, 2020 Dimensional Measurement Applier. Bristol, UK. INSPHERE Ltd. A four day training course for those who have a good basic understanding of measurement principles gained through the Dimensional Measurement User training course. https://www.npl.co.uk/training

Mar 24-25, 2020 Dimensional Measurement with Precision Measuring Equipment. Houston, TX. This 2-day classroom course is part of our dimensional metrology curriculum and is designed for individuals new to the manufacturing environment who need to use and care for basic precision measuring equipment. https://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/

Mar 26, 2020 Introduction to Dimensional Gage Calibration. Houston, TX. Mitutoyo Institute of Metrology. This 1-day classroom course is part of our dimensional metrology curriculum and is a blended learning opportunity to maximize the student's time in the classroom. https://www.mitutoyo.com/support/mitutoyo-institute-of-metrology/

Apr 1, 2020 Dimensional Measurement User. Telford, UK. Hexagon Metrology Ltd. In this three day training course, learners will be introduced to dimensional metrology and the importance of good measurement practice and the right measurement behaviors. https://www.npl.co.uk/training

Apr 6, 2020 Dimensional Measurement Applier. Telford, UK. Hexagon Metrology Ltd. A four day training course for those who have a good basic understanding of measurement principles gained through the Dimensional Measurement User training course. https://www.npl.co.uk/training

May 4, 2020 Dimensional Measurement User. Telford, UK. Hexagon Metrology Ltd. In this three day training course, learners will be introduced to dimensional metrology and the importance of good measurement practice and the right measurement behaviors. https://www.npl.co.uk/training

May 12, 2020 Dimensional Measurement User. Bristol, UK. INSPHERE Ltd. In this three day training course, learners will be introduced to dimensional metrology and the importance of good measurement practice and the right measurement behaviors. https://www.npl.co.uk/training

May 27-28, 2020 Dimensional Measurement. Port Melbourne, VIC, Australia. NMI. This two-day course (9 am to 5 pm) presents a comprehensive overview of the fundamental principles in dimensional metrology and geometric dimensioning and tolerancing. https://www.industry.gov.au/

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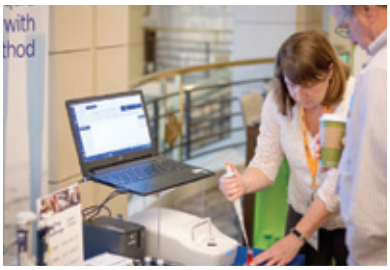


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Westfields Marriott Washington Dulles, Chantilly, VA
Sunday, April 26th through Wednesday, April 29th

Jun 1, 2020 Dimensional Measurement User. Telford, UK. Hexagon Metrology Ltd. In this three day training course, learners will be introduced to dimensional metrology and the importance of good measurement practice and the right measurement behaviors. https://www.npl.co.uk/training

Jun 23, 2020 Dimensional Measurement Applier. Telford, UK. Hexagon Metrology Ltd. A four day training course for those who have a good basic understanding of measurement principles gained through the Dimensional Measurement User training course. https://www.npl.co.uk/training

SEMINARS: Electrical

Mar 17, 2020 Traceable Electrical Energy Metering Workshop. Lower Hutt. Measurement Standards Laboratory of New Zealand. Offered on 17th and 18th March 2020. This course is focused on understanding the steps required to make traceable measurements, and will include training in the calculation of measurement uncertainties. https://measurement.govt.nz/training/

Apr 20-23, 2020 MET-301 Advanced Hands-On Metrology. Everett, WA. This course introduces the student to advanced measurement concepts and math used in standards laboratories. The student will learn how to make various types of measurements using different measurement methods. We will also teach techniques for making good high precision measurements using reference standards. https://us.flukecal.com/training

Jun 22-25, 2020 MET-101 Basic Hands-On Metrology. Everett, WA. Fluke Calibration. This course introduces the student to basic measurement concepts, basic electronics related to measurement instruments and math used in calibration. We will also teach various techniques used to make good measurements using calibration equipment. https://us.flukecal.com/training/

SEMINARS: Flow

Sep 29-30, 2020 Flow Measurement and Calibration (in English). Munich, Germany. TrigasFI GmbH. This seminar is designed to be an objective, independent review and evaluation of the current state of flow metering and calibration theory and technology for flowmeter users and metrologists. http://www.trigasdm.com/en/flowhow-2/seminars/

SEMINARS: Force

Jun 23-26, 2020 Force Fundamentals with SPC and Advanced Uncertainty Concepts. York, PA. Morehouse Instrument Company. https://www.mhforce.com/Training/TrainingCourses

CALENDAR

SEMINARS: General

Mar 5, 2020 Calibration and Measurement Fundamentals. Lindfield, NSW, Australia. NMI. This one-day fully interactive course covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. https://www.industry.gov.au/client-services/training-and-assessment

Apr 23, 2020 Calibration and Measurement Fundamentals. Edwardstown, SA, Australia. NMI. This one-day fully interactive course covers general metrological terms, definitions and explains practical concept applications involved in calibration and measurements. https://www.industry.gov.au/client-services/training-and-assessment

SEMINARS: Industry Standards

Mar 2-3, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Indianapolis, IN. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

Mar 4-5, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017. Indianapolis, IN. QC Training. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://qctraininginc.com/

Mar 9-10, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Frederick, MD. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

Mar 11-12, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017. Frederick, MD. QC Training. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://qctraininginc.com/

Mar 13, 2020 ISO/IEC 17025:2017 Bridging the Gap from 2005. Frederick, MD. A2LA WorkPlace Training. This course is a one-day overview of the changes made to ISO/IEC 17025 in its latest revision. In this course, the participant will become aware of the significant and subtle changes to existing ISO/IEC 17025 laboratory systems, as well as the necessary steps to ensure conformity to the new Standard. https://www.a2lawpt.org/events

Mar 17-18, 2020 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Chicago, IL. International Accreditation Service®. To learn about ISO/IEC 17025 from one of its original authors. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/testing-cal-labs/

Mar 23-24, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Dallas, TX. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

Mar 25-26, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017. Dallas, TX. QC Training. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://qctraininginc.com/

Mar 25-27, 2020 Internal Auditing to ISO/IEC 17025:2017. Memphis, TN. ANAB. Attendees of this 2.5-day training course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2017 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://anab.ansi.org/public-course-schedule

Mar 25-26, 2020 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Dammam, KSA. International Accreditation Service®. To learn about ISO/IEC 17025 from one of its original authors. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/testing-cal-labs/

Mar 31-Apr 1, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Livonia, MI. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

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Apr 14-15, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Cincinnati, OH. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

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Apr 16-17, 2020 Auditing Your Laboratory to ISO/IEC 17025:2017. Cincinnati, OH. QC Training. This course will introduce participants to ISO/IEC 19011, the guideline for auditing management systems as applied to ISO/IEC 17025:2017. The participant will learn about auditing principles and develop skills for performing higher-value internal audits. https://qctraininginc.com/

May 4-6, 2020 Internal Auditing to ISO/IEC 17025:2017. Washington, DC. ANAB. Attendees of this 2.5-day training course will learn how to coordinate a quality management system audit to ISO/IEC 17025:2017 and collect audit evidence and document observations, including techniques for effective questioning and listening. https://anab.ansi.org/public-course-schedule

May 11-12, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Chicago, IL. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

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May 13-14, 2020 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Delhi, India. International Accreditation Service®. To learn about ISO/IEC 17025 from one of its original authors. This 2-day Training Course examines structural components of the standard. Quality system and technical requirements are grouped in a manner that makes them clear and understandable. https://www.iasonline.org/training/testing-cal-labs/

May 14-15, 2020 Understanding ISO/IEC 17025 for Testing and Calibration Labs. Brea, CA. International Accreditation Service®. To learn about ISO/IEC 17025 from one of its original authors. This 2-day Training Course examines structural components of the standard. https://www.iasonline.org/training/testing-cal-labs/

May 18-19, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Houston, TX. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

CALENDAR

May 18-22, 2020 ISO/IEC 17025:2017 Lead Assessor Training. Salt Lake City, UT. ANAB. The 4.5-day ISO/IEC 17025:2017 Lead Assessor training course is designed to further develop your understanding of ISO/IEC 17025 and help you understand how to plan and lead an ISO/IEC 17025 assessment. https://anab.ansi.org/public-course-schedule

Jun 3, 2020 Documenting Your ISO/IEC 17025 Management System. Denver, CO. A2LA WorkPlace Training. During this course, the participant will gain an understanding of the basic concepts of management system documentation structure, content, and development. The participant will also practice developing processes, Standard Operation Procedures, and applying mechanisms needed to control, review, and update documents on an ongoing basis. https://www.a2lawpt.org/events

Jun 15, 2020 Documenting Your ISO/IEC 17025 Management System. Frederick, MD. A2LA WorkPlace Training. During this course, the participant will gain an understanding of the basic concepts of management system documentation structure, content, and development. The participant will also practice developing processes, Standard Operation Procedures, and applying mechanisms needed to control, review, and update documents on an ongoing basis. https://www.a2lawpt.org/events

Jun 15-17, 2020 Leading an Effective ISO/IEC 17025 Audit Team. Frederick, MD. A2LA WorkPlace Training. The participant will receive hands-on training as an internal auditor reviewing ISO/IEC 17025 conformant systems using scenarios common to testing and calibration laboratories. https://www.a2lawpt.org/events

Jun 22-23, 2020 Understanding ISO/IEC 17025:2017 for Testing & Calibration Laboratories. Dallas, TX. A2LA WorkPlace Training. This course is a comprehensive review of the philosophies and requirements of ISO/IEC 17025:2017. The participant will gain an understanding of conformity assessment using the risks and opportunities-based approach. https://www.a2lawpt.org/events

SEMINARS: Mass

Jun 1-11, 2020 5611: Advanced Mass Seminar. Gaithersburg, MD. NIST. This 9 day, hands-on mass calibration seminar focuses on the comprehension and application of the advanced mass dissemination procedures, the equations, and associated calculations. It includes the operation of the laboratory equipment, review of documentary references, reference standards, specifications, and tolerances relevant to the measurements. https://www.nist.gov/news-events/events/2020/06/5611-advanced-mass-seminar

SEMINARS: Measurement Uncertainty

Feb 27, 2020 Introduction to Estimating Measurement Uncertainty. Brisbane, QLD, Australia. NMI. This one-day course (9 am to 5 pm) will give you a clear step-by-step approach to uncertainty estimation with practical examples; you will learn techniques covering the whole process from identifying the sources of uncertainty in your measurements right through to completing the uncertainty budget. https://www.industry.gov.au/client-services/training-and-assessment

Mar 2-3, 2020 Measurement Uncertainty Budgets. Cincinnati, OH. QC Training. This workshop presents a combination of lecture and classroom exercises to demonstrate the principles of measurement uncertainty analysis. https://qctraininginc.com/

Mar 11-12, 2020 Measurement Uncertainty Budgets. Chicago, IL. QC Training. This workshop presents a combination of lecture and classroom exercises to demonstrate the principles of measurement uncertainty analysis. https://qctraininginc.com/

Mar 11-12, 2020 Measurement Uncertainty Budgets. Milwaukee, WI. QC Training. This workshop presents a combination of lecture and classroom exercises to demonstrate the principles of measurement uncertainty analysis. https://qctraininginc.com/

Mar 18-19, 2020 Measurement Uncertainty Budgets. Minneapolis, MN. QC Training. This workshop presents a combination of lecture and classroom exercises to demonstrate the principles of measurement uncertainty analysis. https://qctraininginc.com/

Mar 23-24, 2020 Fundamentals of Measurement Uncertainty. Memphis, TN. ANAB. Attendees of the two-day Fundamentals Measurement Uncertainty training course will learn a practical approach to measurement uncertainty applications, based on fundamental practices. https://anab.ansi.org/public-course-schedule

Apr 7, 2020 Introduction to Measurement Uncertainty. Frederick, MD. A2LA WorkPlace Training. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/events/

Apr 30-May 1, 2020 Uncertainty of Measurement for Labs. Washington, DC. International Accreditation Services®. Introduction to metrology principles, examples and practical exercises. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

May 7-8, 2020 Fundamentals of Measurement Uncertainty. Washington, DC. ANAB. Attendees of the two-day Fundamentals Measurement Uncertainty training course will learn a practical approach to measurement uncertainty applications, based on fundamental practices. https://anab.ansi.org/public-course-schedule

May 15-16, 2020 Uncertainty of Measurement for Labs. Delhi, India. International Accreditation Services®. Introduction to metrology principles, examples and practical exercises. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

May 18-19, 2020 Uncertainty of Measurement for Labs. Brea, CA. International Accreditation Services®. Introduction to metrology principles, examples and practical exercises. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

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Jun 2, 2020 Introduction to Measurement Uncertainty. Denver, CO. A2LA WorkPlace Training. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/events/

Jun 11, 2020 Introduction to Measurement Uncertainty. Livonia, MI. A2LA WorkPlace Training. This course is a suitable introduction for both calibration and testing laboratory participants, focusing on the concepts and mathematics of the measurement uncertainty evaluation process. https://www.a2lawpt.org/events/

Jun 23-24, 2020 Uncertainty of Measurement for Labs. Dammam, KSA. International Accreditation Services®. Introduction to metrology principles, examples and practical exercises. The training includes case studies and discussions, with application of statistical components in practical examples that are frequently encountered by testing laboratories. https://www.iasonline.org/training/uncertainty-of-measurement/

SEMINARS: Photometry & Radiometry

Apr 7-10, 2020 Spectroradiometry Short Course. Gaithersburg, MD. NIST. The NIST Spectroradiometry Short Course is offered every 2 years and covers radiometry fundamentals, radiometric properties of sources and detectors, spectroradiometric techniques, reflectance properties of materials, the handling and determination of measurement uncertainties, an overview of calibration services, and the implementation of the quality system at NIST. https://www.nist.gov/news-events/events/2020/04/nist-spectroradiometry-short-course

Aug 3, 2020 Spectrophotometer Calibration Workshop. Lower Hutt, New Zealand. MSL. This course covers the calibration of benchtop spectrophotometers including wavelength accuracy, photometric accuracy and stray light characterization. It is highly interactive and includes hands on sessions to develop practical skills. https://measurement.govt.nz/training/

SEMINARS: Pressure

Mar 9-13, 2020 Principles of Pressure Calibration. Phoenix, AZ. Fluke Calibration. A five-day training course on the principles and practices of pressure calibration using digital pressure calibrators and piston gauges (pressure balances).The class is designed to focus on the practical considerations of pressure calibrations. https://us.flukecal.com/training/

Apr 20-24, 2020 Advanced Piston Gauge Metrology. Phoenix, AZ. Fluke Calibration. Focus is on the theory, use and calibration of piston gauges and dead weight testers. https://us.flukecal.com/training/

Jun 17-18, 2020 Pressure Measurement. Malaga WA, Australia. NMI. This two-day course (9 am to 5 pm each day) covers essential knowledge of the calibration and use of a wide range of pressure measuring instruments, their principles of operation and potential sources of error — it incorporates extensive hands-on practical exercises. https://www.industry.gov.au/client-services/training-and-assessment

SEMINARS: Software

Mar 9-13, 2020 MC-206 Basic MET/CAL® Procedure Writing. Everett, WA. Fluke Calibration. In this five-day basic MET/CAL procedure writing course, you will learn to configure MET/CAL software to create, edit, and maintain calibration solutions, projects and procedures. http://us.flukecal.com/training

Apr 27-May 1, 2020 TWB 1051 MET/TEAM® Basic Web-Based Training. Fluke Calibration. This web-based course presents an overview of how to use MET/TEAM® Test Equipment and Asset Management Software in an Internet browser to develop your asset management system. You will learn a systematic approach to recording the information you need to manage your lab assets routinely, consistently and completely. http://us.flukecal.com/training

May 4-8, 2020 TWB 1031 MET/CAL® Procedure Development Web-Based Training. Fluke Calibration. Learn to create procedures with the latest version of MET/CAL, without leaving your office. This web seminar is offered to MET/CAL users who need assistance writing procedures but have a limited travel budget. https://us.flukecal.com/training

May 11-15, 2020 MC-207 Advanced MET/CAL® Procedure Writing. Everett, WA. Fluke Calibration. A five-day procedure writing course for advanced users of MET/CAL® calibrations software. https://us.flukecal.com/training/

Jun 8-12, 2020 MC-205 MET/TEAM® Asset Management. Everett, WA. Fluke Calibration. This five-day course presents a comprehensive overview of how to use MET/TEAM® Test Equipment and Asset Management Software in an Internet browser to develop your asset management system. https://us.flukecal.com/training/

Jun 9-11, 2020 VNA Tools Training Course. Beaverton, OR. Federal Institute of Metrology METAS. VNA Tools is free software developed by METAS for measurements with the Vector Network Analyzer (VNA). The software facilitates the tasks of evaluating measurement uncertainty in compliance with the ISO-GUM and vindicating metrological traceability. The software is available for download at www.metas.ch/vnatools. The three day course provides a practical and hands-on lesson with this superior and versatile software. https://www.metas.ch/metas/en/home/dl/kurse---seminare.html

SEMINARS: Volume

Apr 20-24, 2020 Volume Metrology Seminar. Gaithersburg, MD. NIST. The 5-day OWM volume metrology seminar is designed to enable metrologists to apply fundamental measurement concepts to volume calibrations. https://www.nist.gov/news-events/events/2020/04/5620-volume-metrology-seminar

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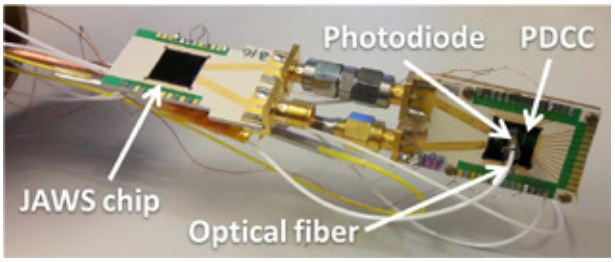
Josephson AC Voltage Standard with Optical Pulse Drive Successfully Implemented

PTB-News 3.2019 – At PTB, a pulse-driven Josephson standard for the generation of AC voltages has been realized where the voltage pulses are synthesized by means of optical components. This has advantages compared to the conventional operating procedure where the driving voltage pulses are conducted onto the superconducting chip via RF conductors.

Josephson Arbitrary Waveform Synthesizers (JAWS) allow quantized AC voltages to be synthesized with arbitrary and spectrally pure waveforms. They are based on series arrays of superconducting Josephson junctions of the kind manufactured in the Clean Room Center of PTB. Effective output voltages of more than 2 V have already been demonstrated at PTB. For this purpose, 16 JAWS arrays were operated in series with the driving voltage pulses being conducted onto the superconducting Josephson junctions, which were cooled in a liquid helium dewar, via an RF conductor per array.

As an alternative to the use of several RF conductors, a procedure was developed within the scope of the QuADC



Picture of the JAWS chip with 3000 integrated Josephson junctions and of the photodiode chip carrier (PDCC) connected to the optical waveguide. Credit: PTB

EMPIR metrology research program in which the driving voltage pulses are generated optically in the immediate vicinity of the JAWS chips. This simplifies the experimental setup, which, in turn, will make it easier to further increase the output voltages and to market the system. The new procedure is based on the use of fast photodiodes which are resistant to low temperatures and are coupled to optical supply fibers. The photodiodes are mounted on a custom-made silicon carrier chip by means of flip chip technology. The optical pulses generated with a pulsed laser outside

the helium bath are transmitted to the photodiodes via an optical fiber. At the photodiodes, they are converted into electric pulses and fed to the JAWS arrays over a short distance. In the first test conducted with an array consisting of 3000 Josephson junctions, effective sinusoidal output voltages of 6.6 mV (18.6 mV from peak to peak) and a frequency of 1875 Hz were generated.

Another advantage of this new procedure is the reduced noise background of the output signal generated. This considerably improves the signal-to-noise ratio of the waveforms generated, especially above 1 MHz.

The next step is to enhance the integration density of the photodiodes to enable several JAWS arrays to be operated at the same time and thus the output voltage to be increased.

Scientific publication

O. Kieler, B. Karlsen, P. A. Ohlckers, E. Bardalen, M. N. Akram, R. Behr, J. Ireland, J. Williams, H. Malmbekk, L. Palafox, R. Wendisch: Optical pulsedrive for the pulse-driven ac Josephson voltage standard. IEEE Trans. Appl. Supercond. 29, 1200205 (2019)

Source URL: *https://www.ptb.de/cms/en/presseaktuelles/journals-magazines/ptb-news/*

TÜV SÜD National Engineering Laboratory Launches £16million Advanced Multiphase Facility

TÜV SÜD National Engineering Laboratory, the flow measurement R&D specialist, today launches its £16million Advanced Multiphase Facility (AMF), which will help global oil and gas operators to ensure that production remains economically viable.

The AMF's test range (of operating pressures, temperatures, flowrates and metrology) is beyond the capability of any other laboratory in the world. Operating at pressures up to 140 bar, the AMF doubles previous test facility capabilities to meet industry's current and future measurement challenges. With a working envelope at least 20 times larger than any multiphase or wet gas facility in the world, the AMF also has the highest flow rate in the world (for both gas and liquid) within one multiphase facility.

Spanning 1,600 m2, the AMF contains a £1.45million, full production scale separator with an operating weight of 270 tonnes and is also the only facility in the world to offer an integrated subsea choke, as well as be capable of testing the complete range of flow meters. 2D, three-phase, x-ray tomography and sensors deliver high definition images of complex flows to expand industry's understanding of fluid behaviours and their impact on measurement.

Construction of the AMF began in September 2017 and it will be officially opened today by Derek Mackay, the Scottish Government's Cabinet Secretary for Finance. The AMF will focus predominantly on the £50-billion-per-annum global subsea sector and wet gas business, facilitating company-led industrial projects and product development, hands-on industry training and academic research. Creating at least 17 new jobs, the centre will futureproof the delivery of innovative technical services to the oil and gas production market for the next 25 years.

Dr Brian Millington, Managing Director of TÜV SÜD National Engineering Laboratory, said: "The AMF's world-leading research facilities will support the global oil & gas industry with both current and future measurement challenges, from well optimisation to fiscal accounting. While significant production opportunities exist in extreme environments, higher operating pressures and temperatures can impact the performance of multiphase flow measurement devices. The AMF will increase the viability of well exploitation by helping operators to more accurately measure multiphase flow and better understand the performance of production operations in these challenging but potentially profitable environments."

Scottish Enterprise has supported the development of the AMF with £4.9 million of research and development funding. Alongside the grant from Scottish Enterprise, TÜV SÜD National Engineering Laboratory's parent company, TÜV SÜD AG, also invested £11.1 million.

Professor Axel Stepken, Chairman of Board of Management of TÜV SÜD AG said: "Measurement of multiphase flows is a key factor in understanding the performance of production operations and production optimisation. Together, we have created the conditions necessary for ensuring that Scotland, and with it the TÜV SÜD National Engineering Laboratory, will continue to set the pace of progress in flow measurement in the future."

Derek Mackay, Cabinet Secretary for Finance, commented: "TÜV SÜD National Engineering Laboratory's £16m investment into this facility is great news for Scotland. The Scottish Government is working hard to establish stronger trading links between Scotland and Germany and this news is testament to Scotland's ability to attract inward investment in spite of the continuing uncertainty around Brexit."

David Smith, Director of National Opportunities for Scottish Enterprise, said: "It's fantastic to see the centre open and ready for business. Our £4.9m R&D grant was

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the catalyst for TÜV SÜD National Engineering Laboratory to secure over £11m of funding from its German parent company. Doing this means we can anchor the skills and expertise in the East Kilbride facility for the long term and create more economic opportunity for the families and communities in the area."

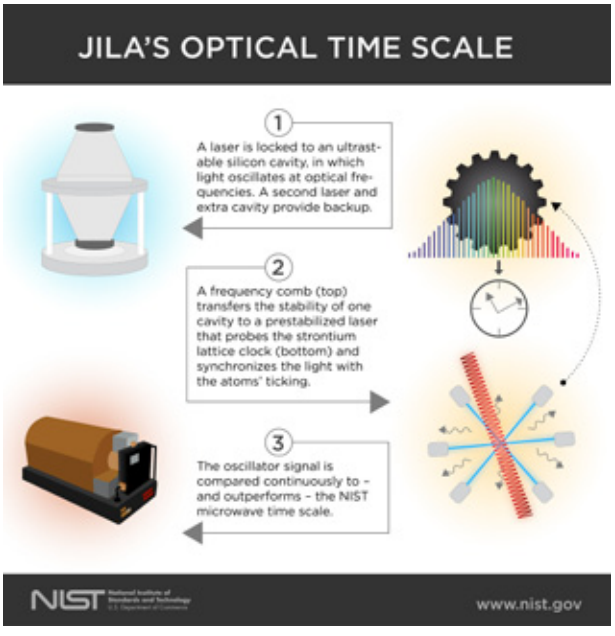
Source URL: *https://www.tuvsud.com/en-gb/press-and-media/2019/october/tuv-sud-launches-16-million-pound-facility*

JILA Team Demonstrates Model System for Distribution of More Accurate Time Signals

October 21, 2019 – JILA physicists and collaborators have demonstrated the first next-generation "time scale" — a system that incorporates data from multiple atomic clocks to produce a single highly accurate timekeeping signal for distribution. The JILA time scale outperforms the best existing hubs for disseminating official time worldwide and offers the possibility of providing more accurate time to millions of customers such as financial markets and computer and phone networks.

The novel time scale architecture combines a super-reliable, advanced atomic clock with an ultrastable device for storing time signals and is a "blueprint for the upgrade of time scales worldwide," as described in the journal Physical Review Letters.

JILA is jointly operated by the National Institute of Standards and Technology (NIST) and the University of Colorado Boulder.



JILA's "time scale" produces a highly accurate timekeeping signal at optical frequencies for possible future distribution. Credit: N. Hanacek/NIST

"I think this new time scale demonstration will be very important for the redefinition of time in the future," said Jun Ye, NIST/JILA fellow and project leader.

The recent redefinition of the International System of Units (SI) did not update the way time is measured. The standard unit of time, the second, has been based on properties of the cesium atom since 1967. In the coming years, the international scientific community is expected to redefine the second, selecting a new atom as the basis for standard atomic clocks and official timekeeping.

To prepare for this change, researchers need to upgrade systems for distributing time.

NIST operates the nation's civilian time scales, arrays of hydrogen masers — microwave versions of lasers — that provide reliable oscillating signals to maintain stable "ticking" for the official U.S. civilian time of day, which is linked to international time (coordinated universal time or UTC). Two atomic clocks based on the cesium standard, called NIST-F1 and NIST-F2, are used to calibrate and ensure the accuracy of the time scales.

Like next-generation atomic clocks, JILA's experimental time scale operates entirely at optical frequencies, which are much higher than the microwave frequencies of cesium time standards. Optical frequencies divide time into smaller units and thus can offer greater accuracy.

Efforts to incorporate the latest optical atomic clocks into older microwave time scales have run into limits on long-term stability, due to the inherent properties of masers and the fluctuations associated with linking them to experimental clocks that operate intermittently.

The JILA team solved these problems by optimizing a more stable type of oscillator and tightly controlling operating conditions such as temperature so their highly stable and precise strontium lattice clock can be operated regularly on demand.

The oscillator is formed by a laser beam aimed into a hollow cavity made of a single crystal of silicon, inside of which laser light of a specific color, or frequency, bounces back and forth regularly for a long time, like a metronome. These devices have been around for years, but a long-term JILA collaboration with Physikalisch-Technische Bundesanstalt (PTB), the German national metrology institute, came up with a new way of building them, greatly improving the stability of the light. Recently, the JILA team further boosted the long-term stability of their cavity, which is 21 centimeters long and operates at cryogenic temperatures of 124 K (minus 149.15 C), by using superpolished optics and improved heat control, among other tweaks.

In the JILA time scale, an optical frequency comb (a ruler for light) transfers the stable optical signal from this cavity to another, very stable laser that is shined on the clock's atoms and synchronizes the light's frequency with their ticking. Two additional lasers are stabilized to independent cavities. The multiple lasers and cavities provide redundancy in case anything malfunctions.

The stability of the oscillator was compared continuously

to that of the NIST microwave time scale by a preexisting underground fiber-optic link between JILA, on the university's campus, and NIST, a mile or so away. Over a month of measurements, the frequency stability of the optical oscillator consistently surpassed that of the masers in the microwave time scale.

The experimental results show that the JILA time scale architecture outperforms microwave time scales, even when the masers are calibrated by next-generation atomic clocks. The team's analysis indicates that by running the JILA optical clock 50% of the time, the all-optical time scale could reach a stability level about 10 times better than the standard microwave time scale, or 1 × 10−17, after a few months of averaging.

A further practical advantage is that the oscillator frequency can be predicted using conventional microwave analysis techniques, enabling the team to estimate a timing error of only 48 ± 94 picoseconds (trillionths of a second) after 34 days of operation.

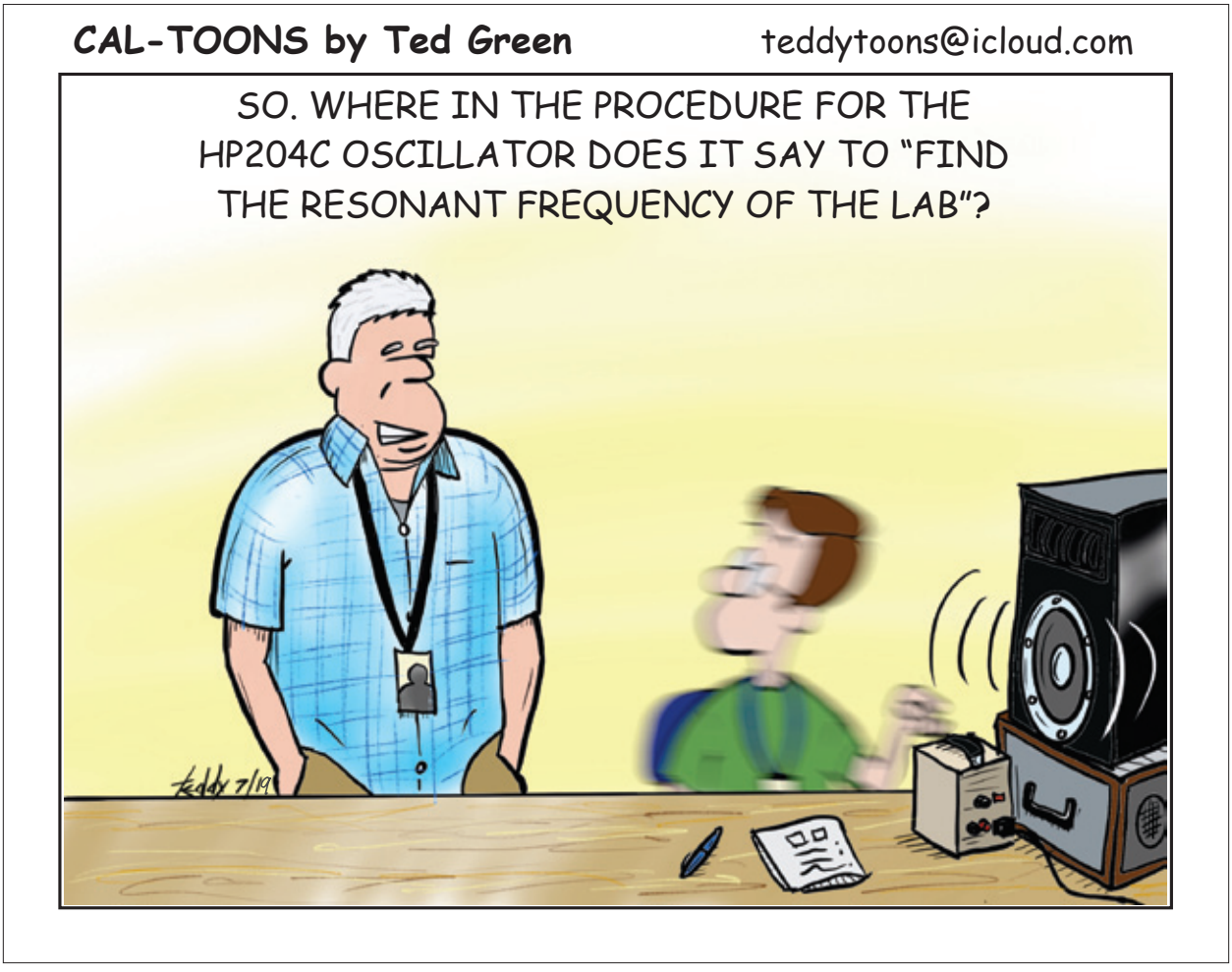
Additional technical upgrades are planned, including automation that should allow the clock to be operated more than 50% of the time. Researchers also plan to incorporate the optical time scale signal into the NIST time scale using the underground fiber network.

Co-authors of the paper include researchers from the NIST Time and Frequency Division as well as from PTB.

The work is supported by NIST, the Defense Advanced Research Projects Agency, the Air Force Office of Scientific Research, the National Science Foundation, PTB, and the Cluster of Excellence (Quantum Frontiers).

Paper: W.R. Milner, J.M. Robinson, C.J. Kennedy, T. Bothwell, D. Kedar, D.G. Matei, T. Legero, U. Sterr, F. Riehle, H. Leopardi, T.M. Fortier, J.A. Sherman, J. Levine, J. Yao, J. Ye and E. Oelker. Demonstration of a time scale based on a stable optical carrier. *Physical Review Letters.* Published online 21 October 2019. DOI: 10.1103/PhysRevLett.123.173201

Source URL: *https://www.nist.gov/news-events/news/2019/10/jila-team-demonstrates-model-system-distribution-more-accurate-time-signals*



A Unified Formula for Uncertainty Estimation in Interlaboratory Studies and Key Comparisons

Hening Huang
Teledyne RD Instruments

A variety of statistical methods are available for estimating consensus values in interlaboratory studies (including key comparisons). These methods, although developed based on different approaches and ranging from simple to complex, produce largely compatible estimates of consensus values. However, the formulas or methods for estimating the standard uncertainty (SU) associated with the consensus value estimators are different and may produce incompatible results. This causes confusion among practitioners about the performance of consensus value estimators. To resolve the incompatibility problem and to eliminate potential confusion, we propose using a unified formula for estimating the SU. The unified formula is an unconditional SU estimator that accounts for both within- and between-laboratory variances. It is applicable to all weighted-average (WA) type estimators. The unified formula makes it possible to evaluate the performance of WA-type consensus value estimators on the same methodological basis. A case study of estimating the Newtonian constant of gravitation is presented to demonstrate the effectiveness of the unified formula.

1. Introduction

The most important task in interlaboratory studies (including key comparisons) is to estimate a consensus value of the unknown true value and associated standard uncertainty (SU). The consensus value may be determined using the simplest approach such as the arithmetic mean, a complicated iterative procedure such as the maximum likelihood approach (a weighted-average), or a Bayesian approach. Koepke et al. [1] reviewed the DerSimonian–Laird method [2] (known as the DL estimator), a hierarchical Bayesian procedure, and the Linear Pool method. The author [3] presented a new method based on the criterion of zero-sum normalized residuals (ZSNR); it is referred to as the ZSNR estimator.

The author [3] recently observed some counterintuitive results in the estimation of the Newtonian constant of gravitation, G, based on a dataset that consists of the measurements from ten laboratories. The consensus value $\hat{G}$ and its SU were estimated with ten different methods: ZSNR estimator, inverse-σ^2 WA (weighted average), inverse-σ WA, PM estimator ([4, 5], also known as MP estimator), ML (maximum likelihood) estimator (e.g. [6]), REML (restricted ML) estimator (e.g. [6]), and four Bayesian methods of Dose [7]. The consensus values estimated with these ten methods are compatible. The relative difference with respect to the Dose [7] combined Bayesian estimate ranges from -0.00689% to 0.00165%. This suggests that, for this dataset, no one method is necessarily better or worse than the others. However, the estimated SUs are significantly incompatible, ranging from 0.00007 to 0.00043 (units: /10^{-11}m^3 kg^{-1} s^{-2}). The simple inverse-σ^2 WA has the lowest SU estimate 0.00007, while the much more complicated REML estimator has the largest SU estimate 0.00043. Because SU is a measure of the performance of estimators, it is difficult to infer, based on the SU estimates, that the REML estimator is worse than the inverse-σ^2 WA. This counterintuition motivated the author to explore insights on the existing methods and to look for a unified method (formula) for estimating the SU of consensus values.

In the following, section 2 reviews several existing SU formulas. Section 3 presents a unified formula. Section 4 discusses conditional SU estimators. Section 5 presents a case study: estimating the Newtonian constant of gravitation to demonstrate the effectiveness of the proposed unified formula. Section 6 presents conclusion.

2. Existing SU Formulas

Consider the following error model for a measurement made by a laboratory

$$y_i = \mu + \delta_i + \varepsilon_i \tag{1}$$

where i is the laboratory index (i = 1, 2, 3, … m, where m is the number of participating laboratories), y_i is the estimate of the measurand, μ is the unknown true value of the measurand, δ_i is the bias error (i.e. systematic error), ε_i is the random error (or sampling error). The bias error δ_i is assumed to be an unknown constant for a laboratory. However, δ_i varies between laboratories. Thus, δ_i reflects the between-laboratory variability; it is quantified by the heterogeneity variance τ^2. The random error ε_i varies

in repeated measurements made by a laboratory. It is quantified by the within-laboratory variance σ_i^2 that is assumed to be known. We assume that both ε_i and δ_i are independent random variables and each is normally distributed with zero mean. That is, $\varepsilon_i \sim N(0,\sigma_i)$ and $\delta_i \sim N(0,\tau)$. Accordingly, y_i is also normally distributed, $y_i \sim N(\mu,\omega_i)$, where $\omega_i^2 = \tau^2 + \sigma_i^2$. The expectation of y_i is the unknown true value μ, i.e. $\mathrm{E}(y_i) = \mu$.

Equation (1) is well known as the random-effects model in meta-analysis. It is often used in measurement science with the top-down approach for uncertainty quantification (e.g. [8]) or for interlaboratory studies or key comparisons [9].

According to the frequentist approach, the general form of equation for estimating the consensus value $\hat{\mu}$ is a weighted-average (WA)

$$\hat{\mu} = \frac{\sum_{i=1}^{m} w_i y_i}{\sum_{i=1}^{m} w_i} \qquad (2)$$

where w_i is the weight that depends on the estimation method or criterion used to derive $\hat{\mu}$. For example, the least-squares method gives the inverse-σ^2 weights [7]. Because $\mathrm{E}(y_i)=\mu$, $\hat{\mu}$ is an unbiased estimator of μ [10]. Since the estimator $\hat{\mu}$ will be unbiased regardless of the weights, we only need to consider the variance [10], or the SU of the WA.

It should be mentioned that, throughout this paper, we follow a convention in statistics to put a hat symbol ^ over a parameter to denote an *estimator* of it, unless otherwise stated.

Six analytical formulas for estimating the SU of consensus values in the form of WA, i.e. Eq. (2), are identified in the literature. They are referred to as formula A, B, C, D, E, and F in this paper and shown in Table 1. We consider analytical formulas only, which are all derived based on frequentist statistics. A Bayesian method usually does not give an analytical formula for either consensus values or SUs. Therefore, Bayesian methods are not considered in this study.

Formula	Weight	When σ_i^2 are different	When $\sigma_i^2 \equiv \sigma^2$
A (e.g. [3])	$w_i = \frac{1}{\sigma_i}$	$u(\mathrm{A}) = \sqrt{m}\left(\sum_{i=1}^{m}\frac{1}{\sigma_i}\right)^{-1}$	$u(\mathrm{A}) = \frac{1}{\sqrt{m}}\sigma$
B (e.g. [7, 11])	$w_i = \frac{1}{\sigma_i^2}$	$u(\mathrm{B}) = \left(\sum_{i=1}^{m}\frac{1}{\sigma_i^2}\right)^{-1/2}$	$u(\mathrm{B}) = \frac{1}{\sqrt{m}}\sigma$
C (e.g. [4, 12])	$w_i = \frac{1}{(\hat{\tau}^2 + \sigma_i^2)}$	$u(\mathrm{C}) = \left(\sum_{i=1}^{m}\frac{1}{(\hat{\tau}^2 + \sigma_i^2)}\right)^{-1/2}$	$u(\mathrm{C}) = \frac{1}{\sqrt{m}}\sqrt{\hat{\tau}^2 + \sigma^2}$
D [13]	$w_i = \frac{1}{(\hat{\tau}^2 + \sigma_i^2)}$	$u(\mathrm{D}) = \frac{\sqrt{\sum_{i=1}^{m}\frac{(y_i-\hat{\mu})^2}{(\hat{\tau}^2+\sigma_i^2)^2}}}{\sum_{i=1}^{m}\frac{1}{(\hat{\tau}^2+\sigma_i^2)}}$	$u(\mathrm{D}) = \frac{1}{\sqrt{m}}\sqrt{\frac{1}{m}\sum_{i=1}^{m}(y_i-\bar{y})^2}$ (also for $\hat{\tau}^2 \gg \sigma_i^2$ or $\sigma_i^2 = 0$)
E [14, 15]	$w_i = \frac{1}{(\hat{\tau}^2 + \sigma_i^2)}$	$u(\mathrm{E}) = \frac{1}{\sqrt{m-1}}\sqrt{\frac{\sum_{i=1}^{m}\frac{(y_i-\hat{\mu})^2}{(\hat{\tau}^2+\sigma_i^2)}}{\sum_{i=1}^{m}\frac{1}{(\hat{\tau}^2+\sigma_i^2)}}}$	$u(\mathrm{E}) = \frac{1}{\sqrt{m-1}}\sqrt{\frac{1}{m}\sum_{i=1}^{m}(y_i-\bar{y})^2}$ (also for $\hat{\tau}^2 \gg \sigma_i^2$ or $\sigma_i^2 = 0$)
F [3]	$w_i = \frac{1}{\sqrt{d_i^2 + \sigma_i^2}}$	$u(\mathrm{F}) = \frac{\sqrt{\sum_{i=1}^{m}\frac{1}{d_i^2+\sigma_i^2}\sigma_i^2}}{\sum_{i=1}^{m}\frac{1}{\sqrt{d_i^2+\sigma_i^2}}}$	$u(\mathrm{F}) = \frac{\sqrt{\sum_{i=1}^{m}\frac{1}{d_i^2+\sigma^2}}}{\sum_{i=1}^{m}\frac{1}{\sqrt{d_i^2+\sigma^2}}}\sigma$

Table 1. Existing formulas for estimating the SU of consensus values.

In Table 1, d_i is the sample residual: $d_i = y_i - \hat{\mu}$, $\bar{y}$ is the sample mean, and $\hat{\tau}^2$ is an estimate of the between-laboratory (or heterogeneity) variance τ^2. In the terminology of ISO 5725-1, heterogeneity means that there is a significant variance component attributable to lack of reproducibility in interlaboratory studies or key comparisons [1]. In meta-analysis, heterogeneity refers to the variation in study outcomes between studies.

It is important to note that each of these six SU formulas apply to certain consensus value estimators. Formula A applies to the inverse-σ WA. Formula B applies to the inverse-σ^2 WA. Formula C is the conventional formula that applies to the DL, PM, MPM (modified PM), ML, and REML estimators for consensus values. These consensus value estimators are all use the weight that is the inverse of the combined variance $\hat{\omega}_i^2 = \hat{\tau}^2 + \sigma_i^2$, but the procedures for estimating τ^2 are different. We refer these consensus value estimators to as the inverse-ω^2 WAs hereafter. Formulas A and B entirely depend on σ_i. Formulas C depends on $\hat{\tau}^2$ and σ_i^2. Note that if $\hat{\tau}^2 = 0$, formula C reduces to formula B. On the other hand, formula D and E depend on $\hat{\tau}^2$, σ_i^2, and the squared residual $(y_i - \hat{\mu})^2$. Formula F does not rely on $\hat{\tau}^2$; it is applicable to the ZSNR estimator only [3].

Notice that the heterogeneity variance $\hat{\tau}^2$ must be available when using formula C, D, or E. However, in the special case where all within-laboratory variances are the same, i.e. $\sigma_i^2 \equiv \sigma^2$, or in the limiting case where $\hat{\tau}^2 \gg \sigma_i^2$ (or $\sigma_i^2 = 0$), both $\hat{\tau}^2$ and σ_i^2 are dropped from formula D and E.

3. A Unified Formula

We have noticed from Table 1 that the six existing SU formulas are quite different in format and none of them is applicable to all four types of weights. We need a unified formula that can be applicable to all four types of weights.

Consider a 'robust' estimator of the variance of $\hat{\mu}$ given in [14]

$$\mathrm{Var}(\hat{\mu}) = \frac{\sum_{i=1}^{m} w_i (y_i - \hat{\mu})^2}{(m-1)\sum_{i=1}^{m} w_i} \tag{3}$$

This 'robust' variance estimator was originally developed for the inverse-ω^2 weight only, i.e. $w_i = 1/(\hat{\tau}^2 + \sigma_i^2)$[14]. Since $\hat{\mu}$ is not sensitive to the weight, we assume that this 'robust' variance estimator can be applicable to any set of weights w_i that meets the following criterion:

$$\sum_{i=1}^{m} \left(w_i / \sum_{j=1}^{m} w_j \right) = 1 \tag{4}$$

Also, the weights cannot be negative. Some weights may be zero, but not all of them (since the result of a division by zero is undefined). The weight $w_i = 1/\sigma_i$ in the inverse-σ WA, $w_i = 1/\sigma_i^2$ in the inverse-σ^2WA, $w_i = 1/(\hat{\tau}^2 + \sigma_i^2)$ in the inverse-ω^2 WA, and $w_i = 1/\sqrt{d_i^2 + \sigma_i^2}$ in the ZSNR estimator are all valid weights.

We could simply use the squared root of Var($\hat{\mu}$)as an estimate of the SU of $\hat{\mu}$. However, it is well known in statistics that the squared root of the sample variance underestimates the population standard deviation. We therefore suggest applying an approximate bias correction factor c_4 to the squared root of Var ($\hat{\mu}$). This leads to a unified formula for estimating the SU of $\hat{\mu}$

$$u = \frac{1}{c_4\sqrt{m-1}} \sqrt{\frac{\sum_{i=1}^{m} w_i (y_i - \hat{\mu})^2}{\sum_{i=1}^{m} w_i}} \tag{5}$$

where $c_4 = \sqrt{\frac{2}{m-1}}\Gamma\left(\frac{m}{2}\right) \Big/ \Gamma\left(\frac{m-1}{2}\right)$ and $\Gamma(.)$ stands for Gamma function (e.g. [16]). The factor c_4 depends on the sample size m. It is 0.7979 for m=2, 0.9400 for m=5, and 0.9727 for m=10. Therefore, the bias correction is only significant for small samples; it may be neglected when the sample size is greater than 10.

The proposed unified formula is applicable to all WA-type consensus value estimators. In the special case where $w \equiv 1/m$, Eq. (2) reduces to the sample (arithmetic) mean

$$\bar{y} = \frac{1}{m}\sum_{i=1}^{m} y_i \tag{6}$$

Equation (5) reduces to

$$u = \frac{1}{c_4\sqrt{m}} \sqrt{\frac{1}{m-1}\sum_{i=1}^{m} (y_i - \bar{y})^2} = \frac{\hat{\omega}}{c_4\sqrt{m}} \tag{7}$$

which is an unbiased estimate of the SU of the sample mean, where $\hat{\omega}$ is the sample standard deviation. This unbiased SU estimator is preferred for uncertainty-based measurement quality control [17]; it is also adopted in the Type A uncertainty estimation [18] and in the unified theory of measurement errors and uncertainties [19]. Roesslein et al. [20] also recommended using the unbiased SU estimator to avoid a significant underestimation of the measurement uncertainty when the sample size is very small. In practice, unbiasedness is always a desired property of estimators, although sometimes a slightly biased estimator may be used if it has much smaller mean squared error than an unbiased estimator.

Table 2 shows the specific expressions of SU when the unified formula applies to four WA-type consensus value estimators: inverse-σ WA, inverse-σ^2 WA, inverse-ω^2 WA, and the ZSNR estimator. In the special case where all within-laboratory variances are the same, i.e. $\sigma_i^2 \equiv \sigma^2$, the inverse-$\sigma$ WA, inverse-σ^2 WA, or inverse-ω^2 WA reduces

Estimator $\hat{\mu}$	Weight	When σ_i^2 are different	When $\sigma_i^2 \equiv \sigma^2$
Inverse-σ WA	$w_i = \frac{1}{\sigma_i}$	$u = \frac{1}{c_4\sqrt{m-1}}\sqrt{\frac{\sum_{i=1}^{m}\frac{(y_i-\hat{\mu})^2}{\sigma_i}}{\sum_{i=1}^{m}\frac{1}{\sigma_i}}}$	$u = \frac{\hat{\omega}}{c_4\sqrt{m}}$
Inverse-σ^2 WA	$w_i = \frac{1}{\sigma_i^2}$	$u = \frac{1}{c_4\sqrt{m-1}}\sqrt{\frac{\sum_{i=1}^{m}\frac{(y_i-\hat{\mu})^2}{\sigma_i^2}}{\sum_{i=1}^{m}\frac{1}{\sigma_i^2}}}$	$u = \frac{\hat{\omega}}{c_4\sqrt{m}}$
Inverse-ω^2 WA	$w_i = \frac{1}{(\hat{\tau}^2+\sigma_i^2)}$	$u = \frac{1}{c_4\sqrt{m-1}}\sqrt{\frac{\sum_{i=1}^{m}\frac{(y_i-\hat{\mu})^2}{(\hat{\tau}^2+\sigma_i^2)}}{\sum_{i=1}^{m}\frac{1}{(\hat{\tau}^2+\sigma_i^2)}}}$	$u = \frac{\hat{\omega}}{c_4\sqrt{m}}$ (also for $\hat{\tau}^2 \gg \sigma_i^2$ or $\sigma_i^2 = 0$)
The ZSNR estimator	$w_i = \frac{1}{\sqrt{d_i^2+\sigma_i^2}}$	$u = \frac{1}{c_4\sqrt{m-1}}\sqrt{\frac{\sum_{i=1}^{m}\frac{(y_i-\hat{\mu})^2}{\sqrt{d_i^2+\sigma_i^2}}}{\sum_{i=1}^{m}\frac{1}{\sqrt{d_i^2+\sigma_i^2}}}}$	$u = \frac{1}{c_4\sqrt{m-1}}\sqrt{\frac{\sum_{i=1}^{m}\frac{(y_i-\hat{\mu})^2}{\sqrt{d_i^2+\sigma^2}}}{\sum_{i=1}^{m}\frac{1}{\sqrt{d_i^2+\sigma^2}}}}$

Table 2. Specific expressions of SU when the unified formula applies to four WA-type consensus value estimators.

to the sample mean. Consequently, the unified formula reduces to $u = \hat{\omega}/(c_4\sqrt{m})$. This is a desired property of the unified formula.

4. Conditional SU Estimators

It is important to distinct the concepts of unconditional and conditional statistics in the estimation of the SU of consensus values. The SU of $\hat{\mu}$ should be an unconditional statistic attributed to both the within- and between-laboratory variances, or the total variance of observations. The unified formula accounts for the total variance, i.e. squared residuals $(y_i - \hat{\mu})^2$. Therefore, it is an unconditional SU estimator.

If we only consider the conditional variance of observations conditioned on each laboratory, i.e. $\mathrm{Var}(y_i|i) = \sigma_i^2$, a conditional SU estimator can be written as

$$u_{conditional} = \frac{\sqrt{\sum_{i=1}^{m} w_i^2\,\mathrm{Var}(y_i|\,i)}}{\sum_{i=1}^{m} w_i} = \frac{\sqrt{\sum_{i=1}^{m} w_i^2\,\sigma_i^2}}{\sum_{i=1}^{m} w_i} \qquad (8)$$

It is then readily recognized that formulas A, B, and F are conditional SU estimators. Thus, formula A, B, and F do not account for the between-laboratory variance; they account for the within-laboratory variances only. On the other hand, formulas C, D, and E are unconditional SU estimators. However, formulas C, D, and E are applicable to the inverse-ω^2 WAs only because they need the heterogeneity variance $\hat{\tau}^2$ in the calculation; they are not applicable to the inverse-σ WA, inverse-σ^2 WA, and the ZSNR estimator.

In addition, if let w_i=1/m in Eq. (8), it can be readily derived that the conditional SU of the sample mean $\bar{y}$ is $\frac{1}{m}\sqrt{\sum_{i=1}^{m}\sigma_i^2}$.

5. Case Study: Estimating the Newtonian Constant of Gravitation

Two datasets are available in the literature for estimating the Newtonian constant of gravitation, G. One can be found in [7] that consists of the measurements from ten laboratories. It is referred to as the old dataset hereafter. The other dataset can be found in [1] and [21] that consists of the measurements from 14 laboratories. It is referred

Statistics	Old dataset (m=10)	Updated dataset (m=14)
Range of G	6.67290 – 6.68730	6.67191 – 6.67559
Mean G	6.67497	6.67367
Standard deviation of G	0.00451	0.00117
Range of σ	0.000092 – 0.0094	0.000092 – 0.00099
Mean σ	0.00136	0.00042
Standard deviation of σ	0.00284	0.00033

Table 3. Summary of some statistics of the old and updated datasets.

to as the updated dataset hereafter. Table 3 summaries some statistics of these two datasets. The unit for G and σ is $/10^{-11}\mathrm{m^3kg^{-1}s^{-2}}$ that is omitted throughout this paper for simplicity.

In this study, we analyzed these two datasets to estimate the consensus value $\hat{G}$ using eight WA-type estimators: the sample mean, ZSNR estimator, inverse-σ^2 WA, inverse-σ WA, and PM, ML, REML, and DL estimators. We calculated the SU of $\hat{G}$ using formula C, D, and E, when applicable, the unified formula [Eq. (5)], and the conditional SU estimator [Eq. (8)]. Since formula C, D, and E require the estimates of the heterogeneity variance τ^2, we estimated τ^2 with the PM, ML, REML, and DL procedures accordingly.

5.1. The Old Dataset

Table 4 shows the estimated G and SU for the old dataset. Note that no SU results from formula C, D, or E are available for the sample mean, inverse-σ^2 WA, inverse-σ WA, and the ZSNR estimators because formula C, D, and E are not applicable to these consensus value estimators.

It can be seen from Table 4 that formulas C, D, E, and the unified formula give comparable SU estimates for the PM, ML, REML, and DL estimates of G. These formulas are all valid unconditional SU estimators. The SUs estimated with the unified formula are only slightly greater than those estimated with formula E. This is expected because the unified formula is a modification of formula E with the bias correction $1/c_4$=1.028 at m=10.

The SUs estimated with the unified formula range from 0.00022 to 0.00147. Among the eight consensus value estimators, the SU of the sample mean is the largest (0.00147) and the SU of the inverse-σ^2 WA is the smallest (0.00022). The SUs of the inverse-σ WA, and the PM, ML, REML, and DL estimates of G are consistent.

The estimated conditional SUs range from 0.00007 to 0.00095. The sample mean has the largest conditional SU estimate and the inverse-σ^2 WA has the smallest conditional SU estimate. Note that the estimated conditional SUs are significantly smaller than the unconditional SUs estimated with formula C, D, E, or the unified formula. This is expected because the conditional SUs do not account for the between-laboratory variance.

5.2. The Updated Dataset

Table 5 shows the estimated G and SU for the updated dataset. Again, no SU results from formula C, D, or E are available for the sample mean, inverse-σ^2 WA, inverse-σ WA, and the ZSNR estimators.

It can be seen from Table 5 that formulas C, D, E, and the unified formula give comparable SU estimates for the PM, ML, REML, and DL estimates of G. The SUs estimated with the unified formula are almost the same as those

Estimator	$\hat{G}$	u (C)	u (D)	u (E)	u (unified)	u (cond.)
Sample mean	6.67497	--	--	--	0.00147	0.00095
ZSNR	6.67400	--	--	--	0.00036	0.00013
Inverse-σ^2 WA	6.67419	--	--	--	0.00022	0.00007
Inverse-σ WA	6.67401	--	--	--	0.00043	0.00010
PM	6.67368	0.00047	0.00041	0.00047	0.00048	0.00016
ML	6.67369	0.00040	0.00040	0.00045	0.00046	0.00015
REML	6.67368	0.00043	0.00040	0.00046	0.00047	0.00015
DL	6.67373	0.00031	0.00039	0.00043	0.00044	0.00014

Table 4. Estimated G and SU for the old dataset.

Estimator	$\hat{G}$	u (C)	u (D)	u (E)	u (unified)	u (cond.)
Sample mean	6.67367	--	--	--	0.00032	0.00014
ZSNR	6.67385	--	--	--	0.00022	0.00010
Inverse-σ^2 WA	6.67408	--	--	--	0.00025	0.00005
Inverse-σ WA	6.67397	--	--	--	0.00029	0.00006
PM	6.67376	0.00035	0.00030	0.00031	0.00031	0.00011
ML	6.67378	0.00030	0.00030	0.00031	0.00031	0.00011
REML	6.67390	0.00040	0.00038	0.00040	0.00041	0.00013
DL	6.67378	0.00028	0.00030	0.00031	0.00031	0.00010

Table 5. Estimated *G* and SU for the updated dataset.

estimated with formula E. This is expected because the unified formula is a modification of formula E with the bias correction $1/c_4$=1.020 at m=14.

The SUs estimated with the unified formula range from 0.00022 to 0.00041. Among the eight consensus value estimators, the SU of the REML estimate of *G* is the largest (0.00041), and the SU of the ZSNR estimate of *G* is the smallest (0.00022). The SU of the sample mean is 0.00032, which is about the same as the SU (0.00031) of the PM, ML, and DL estimates of *G*.

The estimated conditional SUs range from 0.00005 to 0.00014. The inverse-σ^2 WA and inverse-σ WA have much smaller conditional SU estimates than the other estimators. Again, the estimated conditional SUs are significantly smaller than the unconditional SUs estimated with formula C, D, E, or the unified formula.

5.3. Discussion

The mean of $\hat{G}$ estimated with all eight consensus value estimators is 6.67399 for the old dataset and 6.67385 for the updated dataset. The relative difference is 0.00218%. If we exclude the sample means that are significantly different from the other WAs, the mean of $\hat{G}$ estimated with the seven estimators is 6.67385 for the old dataset and 6.67387 for the updated dataset. The relative difference is only 0.00029%. This suggests that these seven WA-type estimators produce compatible consensus values, but the sample mean does not.

Note that, among the eight consensus value estimators, the sample mean has the largest SU for the old dataset, about three times greater than the next largest SU. In addition, the sample mean does not utilize the within-laboratory variances σ_i^2, which is a waste of the available information. Therefore, the sample mean, though simplest in the calculation, should not be taken as a consensus value.

The proposed unified formula makes it possible to evaluate the performance of these eight consensus value estimators on the same methodological basis. According to Shahar [10], "The best estimator among the weighted averages can be obtained by choosing weights that minimize the variance of the weighted average." In the light of minimizing the variance of the WA, the inverse-σ^2 WA may be considered optimal. Among the eight estimators, the inverse-σ^2 WA has the lowest SU for the old dataset and the second to the lowest SU for the updated dataset. It has long been known that the ideal weight is the inverse of the variance, i.e. inverse-σ^2 [10]. In fact, the inverse-σ^2 WA is well known to every physicist and is regarded to as 'the physicist's pet tool' [7]. Shahar [10] provided three different proofs of the ideal weights. On the other hand, the ZSNR estimator may also be considered optimal. It has the lowest SU for the updated dataset and the second to the lowest SU for the old dataset.

In contrast, the most complicated REML estimator seems not optimal as far as the SU of $\hat{G}$ is concerned. Among the seven estimators excluding the sample mean, the REML estimator has the second to the largest SU for the old dataset. Among the eight estimators including the sample mean, it has the largest SU for the updated dataset. In addition, all inverse-ω^2 WAs, i.e. the PM, ML, REML, and DL estimators, have larger SUs than the inverse-σ^2 WA, inverse-σ WA, and the ZSNR estimator. However, the evaluation is based on and limited to these two datasets only.

In addition, the inverse-σ^2 WA gives $\hat{G}$ = 6.67408 with u = 0.00025 estimated with the unified formula. This estimated *G* coincides with the value of *G* = 6.67408 (with u = 0.00031) recommended by CODATA in the 2014 adjustment of the fundamental physical constants [21]. The CODATA 2014 recommended G was a weighted average based on the updated dataset but employing a different weighting strategy [1, 21]. Moreover, Merkatas et al. [22] recently recommended *G* = 6.67408 (with u = 0.00024) based on their proposed Bayesian mixture model with the updated dataset plus two new results reported by Li et al. [23]. It is a surprise that the simple inverse-σ^2 WA, 'the physicist's pet tool', produces the same *G* value as the complicated procedures do.

6. Conclusion

Among the six existing SU formulas examined in this study, three of them (formulas C, D, and E) are unconditional SU estimators and the other three (formulas A, B, and F) are conditional SU estimators. The conditional SU estimators significantly underestimate the SU of consensus values because they account for the within-laboratory variances only and do not account for the between-laboratory variance. This explains the incompatibility of the SU estimates observed in the previous study [3].

The proposed unified formula is an unconditional SU estimator that accounts for both within- and between-laboratory variances. Unlike the existing three unconditional SU estimators (i.e. formulas C, D, and E) that are applicable to the inverse-ω^2 WAs only, the unified formula is applicable to all WA-type consensus value estimators (including the sample mean). Therefore, the unified formula makes it possible to evaluate the performance of WA-type consensus value estimators on the same methodological basis. The case study of estimating the Newtonian constant of gravitation has demonstrated the effectiveness of the unified formula. It is a surprise that the simple inverse-σ^2 WA, 'the physicist's pet tool', produces the same G value as the complicated procedures do. In practice, therefore, the inverse-σ^2 WA should not be forgotten and should be always used along with other methods.

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Hening Huang (hhuang@teledyne.com), Teledyne RD Instruments, 14020 Stowe Drive, Poway, CA 92064, USA.

Cost and Accessibility of Metrology, Calibration, Testing, and NDT Training

Dennis Destefan
Advanced Measurement Science Consulting, LLC

William Hinton
Hinton Technical Services, LLC

It is well accepted in the metrology community that industry does not have a sustainable source of trained calibration professionals. We explore the availability of metrology-related training and its associated costs. Four types of training are considered: traditional college classes, short courses, specific equipment-based training, and employer provided programs. The discussion and conclusions apply to related testing fields including non-destructive testing (NDT). We conclude with some thoughts about whether the lack of trained professionals is an industry or STEM educational problem.

Introduction

There have been many excellent articles and presentations at NCSL International (NCSLI) annual conferences and other conferences on the topic of calibration and metrology training [1,2,3,4,5,6]. The authors have followed and/or participated in many discussions on this topic and how industry need is being or can be met.

Because of the close relationship of metrology, calibration, testing and NDT (Nondestructive Testing) we feel that the discussions below are applicable to all four fields. This is evidenced by the title of the most widely recognized ISO standard, ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories, with NDT being a common form of testing. These four disciplines will hereafter be referred to as "the field."

This article is written from the perspective of instructors and experienced metrologists. The authors entered the fields above not via formal training but through job necessity. It is recognized that the military metrology training programs are not providing a steady stream of metrology technicians as in past decades. A typical path into calibration and metrology is through formal engineering or engineering technology training and obtaining supplemental, discipline-specific training. A baccalaureate degree or higher in engineering or physics has typically led to a metrologist engineering position rather than a technician position.

One may have formal training as a machinist and later migrate into dimensional metrology. Other typical paths might be to obtain training as electronics, mechatronics[1] or control technician, then move into DC low frequency or physical calibration.

Some individuals are thrust into needing rapid understanding and knowledge acquisition related to their field due to changing employment circumstances. Testing performed for customers may require verification and validation of test uncertainty or laboratory equipment accuracy. Manufacturing process equipment may require a detailed understanding of equipment performance, calibration methods and standards used by the cognizant engineer or technician in order to resume production. It is the experience of one author that in industrial settings, metrology can provide the necessary tools to resolve disputes or determine if processes or equipment conclusively meet or fail to meet critical performance criteria in the above situations.

Calibration and metrology can have great financial impacts as well as legal ramifications when determining compliance to specifications or legal limits. Legal metrology can significantly impact a conviction outcome. More than 1,000 DUI (driving under the influence) cases filed in Washington State's King County were potentially impacted as a direct result of poor metrology practices in a state toxicology laboratory [7]. An excellent detailed discussion

1 Mechatronics is a multi-disciplinary field generally combining electrical and mechanical engineering with computer science. Mechatronic applications include control systems, motion control, automation and artificial intelligence.

on the impact of metrology and measurement uncertainty related to legal and forensic fields can be found in [8], especially regarding DUI cases.

The runway construction at the Denver International Airport provides an example of the importance and significant financial impact of test results provided by testing laboratories. Technicians incorrectly reporting test results created construction delays, an FBI investigation, a federal grand jury investigation, a Denver grand jury investigation, and numerous lawsuits and legal proceedings [9]. The concrete contract in dispute was for $193,000,000.

Aerospace company calibration and metrology programs can come under scrutiny during accident investigations [10]. National Transportation Safety Board (NTSB) accident investigators are trained to review aircraft instrumentation and control system calibration records, including procedures used, performance specifications, and traceability [11].

While the focus of this article and magazine is calibration and metrology, we should not neglect the field of testing. The main standard used in many industries is "ISO/IEC 17025 – General Requirements for the Competence of Testing and Calibration Laboratories." Note this standard is not limited to calibration laboratories. Testing laboratories have many of the same requirements to meet measurement traceability, understanding and applying measurement uncertainty, and other best practices. The NDT discipline also has requirements for adequately trained personnel, equipment calibration and measurement traceability.

Someone entering any one of these fields as a career will have substantially different education and training needs compared to someone needing only basic understanding of principles to support manufacturing processes. Different training requirements exist for specific training such as changes for the newly released 2017 version of ISO/IEC 17025 standard or training on new specialized test equipment. Therefore, we have two differing education needs: 1) those desiring education to enter the field as a career, and 2) those already in industry in related fields such as testing, calibration, auditing, quality, and manufacturing.

Somewhat unique to the field is the need for laboratory activities. An individual that needs rudimentary understanding and training in the basics of metrology, as applied to manufacturing, is quite different from someone that will be a calibration technician. A significant issue in providing laboratory training is the high cost of specialized test, measurement equipment and standards. Generally, as the measurement uncertainty decreases laboratory equipment costs increase dramatically as well as the cost of periodic recalibration. This situation combined with the small student base from which to generate revenue makes hands on training a difficult endeavor for any college or private training company.

State and federal funding can make a great difference in the viability of a training program. Such funding can allow maintaining programs for a smaller number of students compared to private programs requiring minimum profit margins. Local industry can drive which field areas are in demand and require training. Local industry support can also provide a pool of adjunct instructors and advisors to help training program development. In the Michigan and Ohio region the demand for dimensional metrologists may be higher than in Washington state where the demand for other disciplines such as NDT, physical, vision, electrical, and RF/EMI might be in greater demand. We must also look not just within the US borders but outside the US to learn why training programs are successful or not.

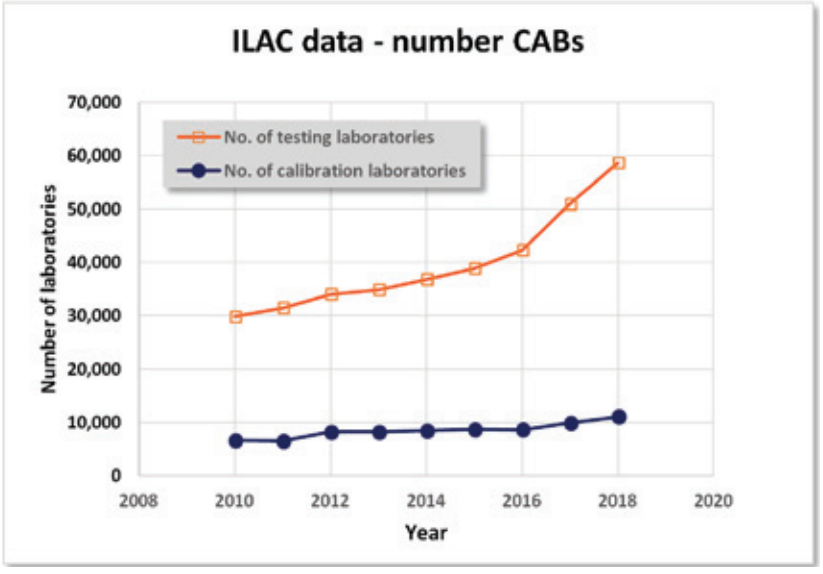

Figure 1. Number of accredited testing and calibration laboratories by year.

It is interesting to look at data on ISO/IEC 17025 accreditation to gain insight into demand projections for calibration and testing technicians and metrologists. ILAC published its annual summary at the end of 2018 showing accreditation growth in several areas [12]. The summary also listed the Total Number of Accreditation Conformity Assessment Bodies (CABs) from 2010 through 2018. The data included ISO/IEC 17025 calibration, ISO/IEC 17025 Testing, Accredited Medical Testing Laboratories (ISO 15189) and Accredited Inspection Bodies (ISO 17020). Only the ISO/IEC 17025-related (testing and calibration) data were used to create Figure 1.

Note that the number of testing laboratories in 2018 is approximately six times the number of calibration laboratories. The growth rate for

the number of accredited laboratories has dramatically increased in the last two years compared to 2010-2016. The accreditation growth rate has gone from 7% per year to 48% per year in testing laboratories while the rate went from 5% per year to 18% for calibration laboratories. This growth will drive demand for more training and qualified personnel. If the education community focuses on calibration alone, they are missing many potential students. This body of students could potentially find jobs and satisfy employer needs for entry level positions.

The authors have experience teaching college classes, leading workshops, seminars, and conducting outreach activities at varied grade and experience levels. The subject matter can range from basic measurement concepts to highly technical and specialized. Most of the participants in these varied training and outreach activities are highly engaged and interested in the subject matter.

When we discuss attracting new professionals to the field it does not appear to be a lack of interest by potential entrants. It is the experience of the authors that the opposite is true. Ninety percent of students exposed to the basics of calibration, metrology and NDT express a keen interest in the field! We will comment further on this later in the article.

The measurement community uses a vernacular, abstract concepts, and terminology that are very foreign to even many technical students. This can be a formidable hurdle for having anyone entering the field or becoming interested in studying in the field. Even individuals with training in related fields, such as quality or manufacturing, have difficulty relating to many concepts and activities required in the calibration and metrology fields.

Let's assume that there is interest by an individual or company in these fields, what training options are available?

Training and Education Options Available

Currently there are several instructional delivery methods available to those seeking training. We have identified four basic types of training available today. The identified categories are:

- College,
- Short Courses,
- Equipment related, typically from manufacturers, and
- Company training.

Each type of training has strengths and weaknesses which are discussed below. The costs of training in each of these categories will also be discussed in the following.

Colleges

A small number of colleges offer individual courses in metrology, testing, calibration or NDT compared to more widely offered topics like electronics technology. Even fewer colleges offer degrees in these areas. Many of these degrees are focused only in dimensional metrology which, it is assumed, is being driven by the local manufacturing companies when looking at their geographic locations.

Many college classes in related areas like instrumentation, control systems, or programmable logic controllers (PLCs), provide a few basic concepts of calibration such as linearity, accuracy, repeatability, and drift. These classes provide a minimal amount of information for students that may want to enter the field of metrology.

Some colleges offer basic courses in calibration or metrology such as "Introduction to Metrology" that cover basic topics in more depth. A typical text for this type of course might be the Certified Calibration Technician (CCT) Primer which is used in preparation for the American Society for Quality(ASQ) CCT certification exam.

The overall strengths and weaknesses for college training are shown in Figure 2.

Figure 2. Strengths and weaknesses for colleges.

NDT courses and degree programs are more prevalent compared to calibration and metrology. We can get an idea of the jobs demand by looking at society memberships. The ISA, International Society of Automation (previously the Instrument Society of America), has 40,000 members worldwide, the NDT society American Society for Nondestructive Testing (ASNT) has 16,000 members and ASTM International has over 30,000 members.

Cost comparison for the different training categories (colleges, short courses and manufacturer equipment training) is accomplished by converting semester or quarter system credits to equivalent number of contact hours. Training other than college classes were converted to contact hours by assuming there were 8 contact hours per training day. The contact hours are then divided into the approximate tuition costs. Some classes have laboratory fees, and some will have associated book fees while some now offer classes with free eBooks. Most colleges now disclose total degree costs which include many things like health insurance, athletic fees and housing. We have elected to only include tuition for a classroom-based course for comparison.

The colleges surveyed offered Bachelor of Science (BS) and Associates of Science (AS) level courses and/or degrees. There were colleges in three different states included in the data presented. Table 1 shows costs for typical 3 credit hour classes.

Residency	Quarter 3 credit class	Semester 3 credit class
In-state	$264	$360
Out of state	$350	$477

Table 1. Average costs for 3 credit hour college classes.

We assumed the duration for quarterly sessions was 11 weeks and a 3-credit class has 33 contact hours. Colleges on a semester system were assumed to have a 15-week duration and a 3-credit class would have 45 contact hours. Using the individual data from the colleges surveyed and the semester or quarter contact hours we calculated the per contact hour cost for in-state (resident) and out of state (non-resident) classes. Table 2 provides the costs for college classes when converted to a per contact hours basis. This per contact hour basis will be used to compare the relative costs of other types of training later in this paper.

Residency	Minimum $/ contact hour	Maximum $/ contact hour	Avg, $/ contact hour
In-state	6.4	9.8	8.0
Out of state	8.8	11.8	10.6

Table 2. Costs per contact hour for college classes.

Short Courses

A variety of short courses were selected for investigation. Two subcategories were considered: 1) online or web-based courses, and 2) instructor presented training in various cities or at corporate training headquarters.

Subcategory 1 had a format of on-demand prerecorded instruction or as a scheduled training with fixed presentation times. We do not comment on which style of presentation is more appropriate or a better learning format as that is student and topic dependent. We do acknowledge that in a classroom format there is more face-to-face interaction between students and between students and the instructor. Discussions with other working professionals in the field can have benefits beyond the presented topics. The strengths and weaknesses for short courses are shown in Figure 3.

Figure 3. Strengths and weaknesses for short courses.

Interestingly, the cost per contact hour was nearly the same for web-based and instructor-lead, classroom-based courses when compared on a per contact hour basis. We would have expected that the web-based training would be noticeably less expensive since there is less overhead associated with renting or providing training

rooms, providing refreshments and in many cases instructor travel expenses. There was a noticeable decrease in per contact hour cost with increasing length for both subcategories. Note that the short courses do not include any significant time with calibration equipment or laboratory activities. The data are from short courses provided by two accreditation bodies, one dedicated training company, one professional society with a training division, and one equipment manufacturer (only classroom training included).

The average cost per contact hour for these courses is $54 for one or two-day training (8 to 16 hours). The cost per contact hour drops to as low as $31 for five day or 40 contact hour training with an average of $38. The costs are shown in Figure 4. The relative cost per contact hour for a short course compared to college-provided training is roughly a factor of six.

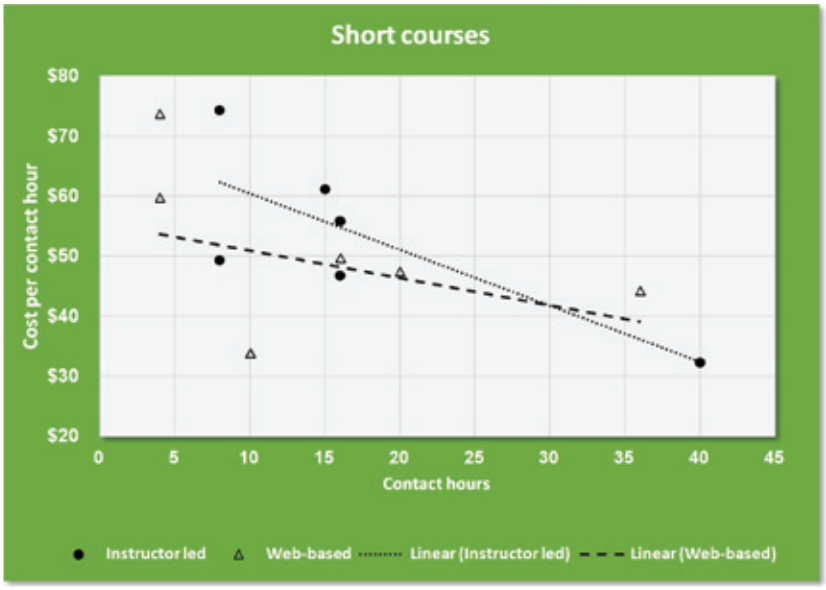

Figure 4. Costs per contact hour for short courses.

Manufacturer Training

The third training category is manufacturer training providing hands-on equipment exercises. Arguably this is the most expensive for several reasons including:

- Narrow and small audience,
- Access to costly equipment,
- Developed and vetted class exercises,
- Need for multiple instructors to support exercises when attendance is *large*, and
- Specialized facility requirements.

Classes may be presented less frequently compared to general interest short courses, such as Introduction to ISO/IEC 17025 or measurement uncertainty. Four manufacturers were surveyed for this category providing a total of 12 classes. The average cost of this type of training is $100 per contact hour and is nearly independent of the course length. There is considerable variability in the cost per contact hour as shown in the Figure 5. The strengths and weaknesses for this category of training is provided in Figure 6.

When we consider the cost per contact hour for manufacturer training compared to college classes, we see the manufacturer training costing 9.4 to 12.5 times more when compared to in-state and non-resident classifications, respectively. This is not to say anything about the relative effectiveness of the training, the relative benefits, or availability of the training. Figure 7 summarizes the costs for various types of courses discussed above.

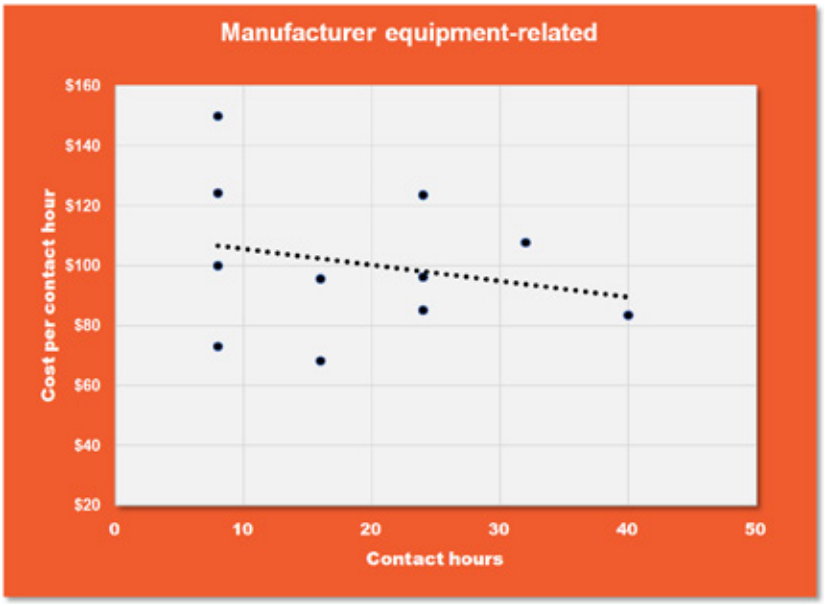

Figure 5. Typical cost per contact hour for manufacturer equipment-related training.

Figure 6. Strengths and weaknesses for manufacturer equipment-related training.

It is the authors experience that even in-state college tuition can be prohibitive for many students and it goes without saying then that all higher cost options would not be something that those students could consider. The short courses and manufacturer training do not qualify for most student loans and or grants. These classes are not transferable into any degree program. We must keep in mind that the main goal of those starting a career in the fields is to obtain adequate training to qualify for an entry level position.

Typical career progression consists of work experience and/or pursuit of additional training towards a certification or college degree. Each of the authors know of dozens if not hundreds of very successful individuals in the field that are non-degreed or only possess an associate's degree. In many cases, it is experience in these fields that provide employees with what is needed for a successful career. While a degree is desirable, most employers accept a combination of experience, education and training to be promoted within the company.

Demand for technicians and engineers in the field has been good. The employment market is the best it has been in decades and the demand for those skilled in these areas appears to have increased. The authors have recently seen many entry level postings for the fields on job sites requiring only basic technical skills through high school or an AS degree and the employer will provide specific training and education. Employers are also requesting some familiarity with ISO 17025. Anyone completing a basic introduction to calibration or metrology class would presumably have the requisite knowledge and skills to meet the employer's requirements. Many job postings also ask for skills in basic technology with some combination of skills that are equivalent to an Associates of Science (AS) degree. We interpret this to mean that basic electronics classes, college level or technical math, a basic physics class, an introductory metrology or calibration class, and possibly a couple of short courses in a related area would be accepted as equivalent to an AS degree. We have known of cases where students enter an NDT program and employers hire them after a few classes and provide tuition for the remainder of their training. This is an example of how much employers need people in the field.

Employer Provided Training

No discussion of training options would be complete without considering company developed or provided training options. Many companies are so in need of qualified testing and calibration personnel that they have developed their own training programs. The details of these programs are not as readily available as those that are publicly offered. The costs associated with these programs for the students are assumed to be very minimal if not without cost.

The training topics and laboratory experiences are assumed to be specific to each company. The authors know of no ability to transfer this type

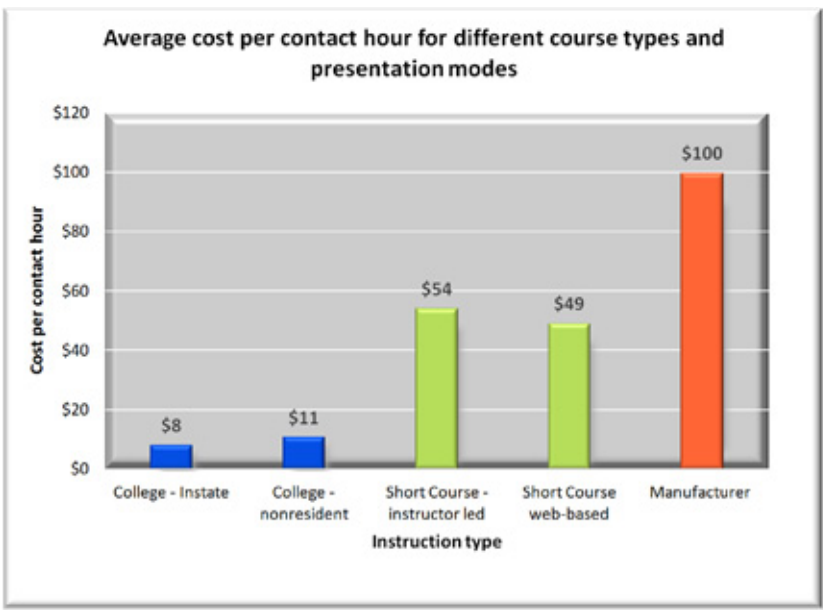

Figure 7. Comparison of per contact hour training of all categories.

Figure 8. Strengths and weaknesses for employer provided training programs.

training to other companies. This type of training makes employees more valuable to their employer. It would be only with a skills-based assessment that the training would be recognized and accepted by another employer.

The quality of these programs would be assumed to be high as the programs would have to be developed in coordination with human resources, a training department, the department needing the trained employees, and possibly a trades union.

The strengths and weaknesses of this training are shown in Figure 8. The authors encourage someone from a company with an employee in the field training program to write an article specific to their program. It would be of great benefit to all of us involved in training to understand the structure and inner workings of this type of program.

Recommendations

The authors believe that as an industry we do not have lack of interest once there is proper exposure to the topics and importance of the fields. It is a lack of awareness of these fields. Our experience has shown that students at all grade levels have a keen interest in the subject matter when we explain how significant these fields are in our everyday lives. Once presented with benefits of careers in the field, pay, paid vacation, demand, medical insurance and more, newcomers become even more interested. Demonstrations and an abundance of examples are needed to keep student's attention. Simple textbook-based courses are not adequate to maintain student interest, nor do they provide necessary learning or develop skills that employers desire.

We see the need to not only continue outreach programs, typically to high schools, but to expand them to middle school and possibly even earlier. In our colleges and universities, a single class covering some basic metrology, testing, calibration or NDT topics should be made available. We recognize that to fund a laboratory with metrology equipment can be prohibitive without state or industry support. Adding either a required or optional class in an already established technical program such as electronics or mechatronics would not be an insurmountable task. This would be especially true if the instructor could be provided from local industry. Laboratory exercises to demonstrate basic measurement principles do not require expensive equipment such as working standards found in calibration laboratories. Laboratory exercises developed at North Seattle College used measurement devices found online. A single instrument costing less than $50 was used for two different laboratory exercises and served two students working as laboratory partners. Most metrologists or test engineers can create laboratory exercises with very inexpensive measurement or demonstration items.

Metrology, test/evaluation and nondestructive testing employers are being impacted by the lack of training and education options and by the loss of highly skilled workers who retire. We believe that a highly skilled resource is becoming available to the education community. Retirees can assist local industry, local high schools and the community college system by passing their valuable skills to future workers in their related fields.

We, as an industry, need to get more creative in developing and inspiring interest in these fields. It will take industry and academia working together to draw more technicians and engineers into the field. The short course providers should consider providing discounts to students in college. Academia should be urged by metrology, testing, calibration or NDT professionals to discuss providing an appropriate single class for students, either as a required class or as a technical elective class. The class should be appropriate for industry in the area served by the college or university. College offerings typically serve geographical areas. Depending on the local industry, there may be more demand for metrology, testing, calibration or NDT related to the oil and gas sector, aerospace, or renewable energy, and finally some areas may have higher demand for machining and dimensional measurements. We should not think in terms of "one size fits all" when developing class offerings.

Conclusion

Reaching students as early as possible will establish the awareness and pique their interest in these fields. When we provide even introductory courses in colleges, we will have graduates or at least students that qualify for reasonably high paying jobs. Employers will then have potential entry level candidates that have basic knowledge so that they can be further trained on the expensive equipment only found in industry laboratories.

If we make some of the short courses available to students at reduced rates that are not 5 to 12 times more expensive, compared to college tuition, some students might be able to take classes like uncertainty analysis or understanding ISO/IEC 17025. If we could give college credit for these, a double benefit might result. We ask the question "could a deeper discount be provided to new entrants to the field in their first one or two years of working in the field as an incentive to rapidly gain specific knowledge in the field?" Offering the discount could potentially create more students for the course provider to help offset the discounts. It might also relieve financial burden off typically stretched corporate training budgets. Colleges that only have enough demand to infrequently offer an introductory class should consider working with local industry to allow non-degree students to attend the class. The increased demand could allow offering the class more often for degree students.

These are the thoughts of two experienced individuals involved in teaching metrology, testing, calibration and NDT. There must be more creative ideas from others in these fields to implement and provide training to the next round of metrology, calibration and testing technicians and engineers. Good luck to students, colleges, universities, training companies, and employers in solving this ongoing problem that we have discussed for so many years.

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Dennis E. Destefan (dennis.destefan@gmail.com) has worked as a researcher, educator, and consultant in the fields of instrumentation, data acquisition systems, calibration and metrology. He holds a BSEE and MS in Engineering Management degrees from the University of Colorado. Dennis is presently a principal consultant for Advanced Measurement Science Consulting, LLC. He has consulted for aerospace, automotive, nuclear companies and national metrology laboratories. He is presently an adjunct instructor at North Seattle College where he teaches introductory metrology and other courses in the electronics program.

William "Bill" Hinton (wdhinton@gmail.com) spent more than 45 years in the military and commercial nuclear power industries with the final 15-years focused on the Metrology (precision measurement) field before retiring in 2014. Bill earned a bachelor's degree in Business Administration from New Hampshire College. Bill has organized, participated, supported or sponsored outreach events for grades 1-14 over the past sixteen years and is now an adjunct instructor in NDT at Great Bay Community College – Advanced Technology and Academic Center in Rochester, NH.

Realized Value of Industry Events

Hannah M. Eilers
Cal Lab Solutions, Inc.

Where can you find the latest metrology news and information, introductory to NMI-level training, and valuable industry connections? All of this can be achieved at annual trade shows. And believe it or not, trade shows are not all fun and games. Plenty of work and information sharing gets done at these events all day, every day of the production. You'll see a schedule packed full of seminars, committee meetings, training sessions from experts around the world, and an exhibit hall constantly bustling with activity.

For those who want to sit in or get involved, there are committee meetings open to those who wish to participate. There is no better place for experts to meet, discuss, and define industry standards and best practices. Much of how and what lab auditors inspect today was at one time a committee meeting's agenda topic. Eventually, that agenda topic became an industry standard. Ever wonder who defined the operating temperature of a calibration lab?

Whether you plan to visit a tradeshow as an attendee or exhibitor, there is a deep pool of perks and benefits. This isn't just a free lunch; the entire day is jam-packed with valuable demonstrations, tutorials, technical papers, and more. The schedule will start early in the morning and continue well into the evening. There is plenty to see, do, and learn.

Metrology is lifelong learning, and continuing education requirements for both technicians and managers is a must. These training sessions are critical for keeping up to date and informed on the best techniques and practices in the industry. If you attend a course you will receive a certificate of attendance for classes you complete.

Networking, networking and more networking! Meeting colleagues and other experts in the field is always a great experience. Pick up the latest promotional materials on the newest products and get the most up-to-date information in your hands. If you're facing tough buying decisions, visit the booth for any manufacturer you are considering. There is nothing better than a face to face discussion followed up with a solid handshake. You can't do that over the phone or in a web meeting.

2019 Metrology Congress – Paris, France

At major shows, there is an enormous convention center and grounds to explore. For example, the MSC Training Symposium is held annually in Anaheim, CA at the Disneyland convention center, while NCSLI Workshop & Symposium is held in different US cities, such as Portland Oregon and Nashville, Tennessee.There is usually a mixer evening and typically an entertainment event as well. This is a perfect time to meet and greet in a less formal environment than on the exhibit floor or in the classroom.

Why is this important? The metrology industry has seen a drop in participation and attendance to these shows. We need to support the community and keep shows alive so we have easy access to the plethora of benefits and resources they offer each year.

Additionally, it is easy to approach show attendance with an ROI mentality. Return on Investment (ROI) tries to directly measure the amount of return on a particular investment, relative to the investment's cost. Where we typically go wrong in this mental calculation is adding up the value of the show; it is difficult to quantify. To evaluate the benefits of show attendance, we asked a wide range of professionals in the industry—from managers to techs to engineers—what value they gained from attending shows over the years. Here is how they responded.

Jeff Gust – Fluke

I think it is clear that we are all seeing a de-skilling of the workforce today. The people coming into the field nowadays generally did not have the opportunity for the excellent military training in metrology that many of the more seasoned metrology professionals had.

Another key opportunity for metrology education and training occurs at Metrology conferences such as the Measurement Science conference and the NCSL International workshops and Technical Exchange. The things that I learned at MSC and NCSLI are critical to the success that I have had in my career and the metrology knowledge that I possess today.

I understand that companies are looking for ways to reduce their operating expenses, but not investing in the development of their employees will cost them much more in the long run. A poorly trained calibration technician can cause both direct expenses to the company through incorrect calibrations, and through loss of customers by providing an impression of a lack of competency.

Jason Renn – Lockheed Martin

The value gained from trade show attendance is not always found in the Return on Investment from a capital asset purchase or the introduction of emerging technology. Over the past few years, my organization has benefitted just as much from attending training seminars and presentations at trade shows than any new technology deployed as a result of attending a tradeshow.

Trade shows offer my team the opportunity to be exposed to emerging technology, from various competitors in a setting that facilitates learning. These interactions help prepare team members for capital acquisition discussion which ensures that capital investment dollars are being invested in a manner that maximizes their ROI.

Howard Zion – Transcat

The first trade show I attended in my career was the 2000 NCSL International Workshop & Symposium in Toronto, CA. At that time I was a Calibration Engineer working for Philips electronics in Syracuse, NY. Shortly after that conference I changed jobs, accepting employment with Transcat based out of Rochester, NY. I've been with Transcat for 19 years now. I have attended 18 NCSLI conferences to date and about as many Measurement Science Conference events as well. I first attended with the purpose of expanding my network – not necessarily looking for a job (although my first post-military job at Martin Marietta in Orlando was made possible by the NCSL membership pamphlet), but to get a broader perspective on who's who in the Metrology industry and to develop relationships with suppliers. I found the paper presentations interesting but many of them were at higher levels of Metrology, not necessarily at the level in the traceability chain where instrumentation is being used to make pass/fail decisions on product. So I started writing and presenting papers in this targeted area. I love that the NCSLI conferences are in a different location each year. And I really enjoy seeing old friends and meeting new ones at these events. With my incredibly busy travel schedule, the conferences are a way for me to stay in touch with people I don't often get to see.

James Smith (Smitty) – Boeing

Often when planning to attend a Conference, Training Symposium or Trade Show the decision maker paying the bill will ask for justification or benefits to offset the cost & interruption to work. How do we concisely answer that question if the approver has not recently or ever participated in such specific events? How do we capture the qualitative and often intangible advantages one gains from proactively mixing with others in their industry? If you have been involved for years, you most likely have numerous examples of how relations were critical to meeting a schedule, acquiring technique or technology, providing a critical solution or saving significant money/labor due to the relationships and knowledge garnered from these events. But, if you are new to such attendance you may need to instead focus your rational on the acceleration of the knowledge you will gather and bring back to better the services you and your team provide.

Over the decades I have participated in various professional groups: in my late teens, the American Welding Society, to my late 20s & 30s with MSC, then ASQ, and now over 20+ years of involvement with NCSLI. I have learned that the significant ROI my Company & myself have received from these efforts is directly connected into the efforts which I, as an individual have participated. Problem solving and people skills need to be developed and honed, gathering experience, contacts and tools to make yourself, not just know the generic process but to allow one to be able to act efficiently and attain the desired results; these events, when committed to are THE dominant opportunity to develop those skill sets and future successes.

Jun Bautista – Global Pharmaceutical Technologies

Attendee, Exhibitor, Participation, I have done them all and the Return on Investment (ROI) in time, finances, and lost productivity in general is difficult to calculate. But the value is in the continued "partnership" between the conference/exhibition host and the prospective participants and attendees. It must be a "win-win" venture to make this a recurring and sustainable event. In the last 35 years I've witnessed the value that only comes from attending these shows.

Is there a real ROI? My answer

is "Yes!" It has been worthwhile and worth it for me. Once I began capitalizing and leveraging the denominators (Opportunity, Investment, Results & Risk), it has definitely been worth it for me as an attendee, participant, sponsor, and as a user/consumer. It enabled me to form alliances, enhanced my network, and net worth. This enabled me to form my Clustered Group of Cooperative Partner Companies, a sort of self-styled organization that seem to have made anything I venture into profitable and yes, it satisfies the ROI requirements.

Karl Haynes – ElectroRent

Why attend a test equipment industry trade show, or an accreditation body technical forum, or an MTS event?

For me its a balance between education, networking and keeping up with current events methods, standards and products. And many times it's a combination of these that adds real value.

We brought calibration of noise sensors in house because of an industry session at the NCSLI meeting in Nashville. We developed ways to test ECal kits in house between users because of an IEEE-MTS event in Atlanta. We learned how to guard-band for ANSI Z540.3 at another NCSLI meeting. All of these, tie to real dollars saved by our business.

Contacts in the metrology functions of suppliers and customers have developed into friendships and led to real time problem solving face to face or later with a direct contact. It helps to know a real human on the inside! Attendance at the accreditation technical forum can lead to different perspectives on a problem and result in a workable solution your lab can implement.

We were able to quickly develop a verification and validation process because of a poster session Tektronix shared at a recent NSCLI meeting. And finally, participating in committees, and keeping up with developments in the industry and sharing those ideas and trends with your boss and colleagues helps your career!

Jake Jacanin – Qualer

There are many reasons as to why attending conferences can benefit organizations and teams, as well as individual employees within a company. I've found that educational institutions and technical training did not always provide the specific detailed knowledge and expertise required for a specific industry and a professional role within a company.

I was trained in the Air Force in the field of Precision Measurement Electronic Laboratories (PMEL). The training and experience gained enabled me to obtain a civilian position as a calibration technician at a civilian commercial calibration company. Later, I obtained a position as a calibration engineer at a progressive Biotechnology company that was working on the cure for AIDS/HIV by developing Gene Therapies. I was expected to develop a calibration and maintenance program that complied to the code of federal regulations (CFR's), also known as the good manufacturing practices (GMP's). I tried to apply the military regulation for calibration standard system requirements, MIL-STD-45662A, in which I was already familiar. When I worked to apply this standard into a biotechnology setting, it helped establish general requirements, however, the regulation did not fully apply to the progressive company where I now worked.

By attending industry related conferences, I was able to learn about the life science industry, the relevant regulations, applicable calibration techniques and the field of biotechnology. I had the opportunity to participate with other industry colleagues on the refinement of an industry recommended practice for calibration programs within the life sciences industry. By attending conferences and getting to know others in the same situation, I learned that I was not alone on an island; there were others that were confused, curious and struggling to do the best for their companies.

Attending conferences allowed collaboration, sharing thoughts and the mutual development of industry practices. The conference and community gave me purpose. Without the collaboration, I may have not stayed in the field of metrology or contributed to improving practices and calibration techniques or have been part of companies that got lifesaving medicines and therapies to patients. "No man is an island entire of itself; every man is a piece of the continent, a part of the main." Individuals and companies need to collaborate as a community and conferences enable the coming together, expression of thoughts, sharing of ideas, mutual understanding and learning that benefits everyone.

Mike Schwartz – CLS

I like to be on the cutting edge of technology. Trade shows are the perfect place to see the latest and greatest in new hardware innovations. I know eventually we will have to write drivers to support the new hardware, but at the show I can find the contact I need to help with complex questions. I have noticed every new hardware introduction, the lead engineer is there somewhere at the show. Ask a good question and he or she is the only one that can answer it.

I have been a regular at both the MSC and NCSLI shows for the past 20 years and last year for the first time ever attended the Metrology Congress in Paris, France. I was amazed at the number of people I knew at that show as well. More impressive was the number of people I knew but have never met in person. I would have had to spend at least a month traveling around Europe establishing the personal connections made in just three days at the show.

Mike Suraci – Auditor

The resources that you establish with the Metrology community contacts that you make are INVALUABLE. You cannot place a price tag on these long standing relationships. It would be very difficult to replace the opportunity gained by Conference attendance with cold calls to industry experts.

Tim Mason – US Navy

Training and Symposium seminars are a valuable resource for management, technicians, administrative and engineering personnel. For each category within a level of employment, symposiums and seminars offer solution based opportunities for most issues related to the measurement area of every type of business. These homogeneous solutions/statements are possible since all organizations that work within the measurement fields all realize the same problems and issues.

The two large measurement seminars are the MSC Training Symposium held each year in March or April and the NSCLI International held late each summer. These two organizations are responsible for presenting training and to allow attendees to meet with many of the major test equipment manufacturers from around the world. This beneficial time to be spent with the manufacturers offer the attendee an opportunity to view new equipment, test new technology and ask questions that could assist with current processes at work.

Learning new innovations is important as future events and problems can be resolved quickly and efficiently with knowledge from these training events.

Recently, pharmaceutical B. Braun, USA (Irvine, Calif location) attended the MSC Training Symposium with specific areas to be trained and to find solutions to future expansion of the line of products that B Braun offers; specifically pressure calibrations within their cal lab. Lab Manager Jeff Sedor directed three of his specialists for training. One admin attended the Back to Basics course for further knowledge about the science of metrology from a basic level, and the remaining techs attended NIST seminars on Liquid flow and temperature measurement.

Mr. Sedor met with various pressure equipment manufacturers and concluded that he needed to procure calibration standards from Additel Inc.

These actions resulted in increased capability for his techs, greater working knowledge for the administrative personnel and to efficiently continue to calibrate pressure sensors on the expanding product line.

Ed Yankajtis – Test Equity

CONTACTS, CONTACTS, CONTACTS. You meet up with people you know from recent friendships to those of very old friendships. You also meet work related contacts that you may want to get advice for a particular problem. I received some free TME licenses because I had a conversation with a Keysight employee about a problem in TME.

Robb Thomas – Tool Testing Labs

Trade shows give us a chance to travel, network and learn. They offer great experiences that anyone working in a lab can benefit from. I enjoy the opportunity to get out of the lab for a few days and catch up with others in the metrology community.

Training offered at trade shows is quite valuable to me. Metrologists from national measurement institutes and many leaders of industry provide excellent training at MSC, NCSLI and other shows and exchanges. The variety of offerings during one week is great when you work for a third-party calibration lab that works in many different disciplines.

Another perk of shows is networking and brainstorming. I have met many colleagues that have helped shape my worldview of metrology. Many tips and tricks have been passed along while sharing a meal during a show. Each person comes to the table with a unique background which leads to interesting conversations.

Lastly, it is valuable to see your career with fresh eyes. During shows we learn more about our diverse metrology community. Spending a week surrounded by passionate experts is hard to put a price on. Recentering yourself is a great investment in my opinion.

It has been fun over the years to be a part of shows that bring us together. Many of my mentors have told me that relationships are the most valuable part of a career and there are so many great people that make it to the shows. I look forward to the next show where I can make more new friends!

In conclusion, past attendees continue attending because they have experienced the value these events bring to the table. Consider attending one show a year and give the overall value and experience a try. There will be opportunities for networking, prospecting new clients, training, the list goes on! Additionally, it isn't too late to register for MSC and NCSLI 2020; get registered and be there!

Visit
www.callabmag.com/calendar/
for Cal Lab Magazine's calendar of industry events!

ScalesNet-M Software for the Mass Laboratory

In mass metrology, one of the most important criteria is the careful collection of weighing data and associated parameters. Calibration of weights requires extensive calculations and additional information (such as environmental conditions, parameters of balances etc.) to correctly determine the conventional mass and true mass with all uncertainties.

Software solution for all tasks in the mass laboratory

ScalesNet-M (Modularity) was developed precisely for these mass laboratory requirements. All tasks, occurring in a mass laboratory, from order entry to calibration, including printout of a customer certificate, are performed step by step with all necessary parameters by the software. This makes it possible performing the work in the laboratory correctly and time-optimized.

From order entry all the way to customer certificate

Entering the order number and the serial number of the set to be calibrated is enough to activate the record from the archive. After selecting the test object and the reference weight, the calibration can be started.

After completion of the calibration, all calculated values are immediately displayed on the screen and can be printed and saved. Assessment criteria facilitate a quick statement about the quality of the test sample calibration. All physical effects are recorded and included in the calculations.

ScalesNet-M allows communication with all robots, load changers and manual comparators of all relevant manufacturers. This leads to a direct, error-free transmission of the balance values, without manual intervention.

Some software solutions allow the connection of only one climate station, but in most mass laboratories there are several and different data loggers for the detection of climate values. All climate stations or data loggers with RS232 or RJ45 interface can be integrated with ScalesNet-M, to be used for automatic data acquisition of the environmental parameters.

A summary of all the benefits of ScalesNet-M

- High flexibility to adapt to given laboratory conditions.
- Supports connection of robots (Sartorius, Mettler Toledo, Radwag), load changers and manual comparators of a wide variety of manufacturers.
- Error reduction through process-optimized processes.
- Automatic acquisition of climate data from a wide range of data loggers during measurement and long-term recording.
- Step-by-step instructions while calibrating weights.
- Automatic calculation of deviations and uncertainties in compliance with OIML and NIST regulations.
- Freely definable weighing schemes for dissemination.
- Inverse measurement method in dissemination to eliminate exchange errors.
- Averaging of several measuring cycles possible.
- Adjustable rework time, for the period of packaging and shipping.
- Freely definable certificates with Microsoft Word.
- Scanned signatures can be used when printing a PDAF / A.
- CMC table definitions for the smallest laboratory accredited uncertainties.
- Re-presentable history for all calibrations.
- On-site calibration with DB export and import of on-site data.

A live demonstration of ScalesNet-M via Teamviewer remote session can be scheduled. Please contact us for details via e-mail: info@scalesnet-m.com

C-SMART Analytics Launches GEN 3

C-SMART Analytics, a division of WESTERN ENERGY SUPPORT & TECHNOLOGY, prepares for a new year and a new chapter with the launch of the GEN 3 platform.

January 02, 2019, Houston, TX– C-SMART Analytics, a software provider focused on reducing measurement error, risk, and LAUF, announced today the launch of its newest software platform: GEN 3.

"Today marks the beginning of a new frontier for our company. The expanded capabilities and added features of GEN 3 will allow us to deliver greater value to our current customers while also enabling us to serve new markets. Every member of our team played a crucial role in the development of this new platform. It's exciting to see all the pieces come together and to launch this product into the market." stated Eric R. Calderon, President, C-SMART Analytics.

The GEN 3 platform introduces new levels of security, scalability, and agility to our analytics offering. Customers will experience a state-of-the-art user interface and wide selection of self-service tools which will add to their ability to effectively monitor and respond to operational needs. At its core, GEN 3 provides additional Augmented Intelligence, more accurate error detection, smarter messaging, and superior analyses.

About WEST

Western Energy Support & Technology, Inc., established in 1992, is a holding company for CEESI, Flow Systems, C- SMART Analytics, Graftel, and L-K Industries – all leading contributors to the fluid flow measurement industry. The WEST family of companies provides industry-leading expertise in calibration, sampling, consulting, communication, and manufacturing. More at WestEnergyTech.com.

Vitrek Releases Ultra-High Accuracy PA920 Series

Poway, CA—October 22, 2019—Vitrek, the leader in high-voltage test and measurement equipment, introduces the PA920 Series Ultra High Accuracy Power Analyzer. The PA920 sets the new standard for accuracy (0.024% of reading) in the graphical power analyzer market. It integrates an ultra-high accuracy, wideband waveform digitizer with advanced computational capability, a large high-resolution display and a full-color touch screen user interface. The multi-channel PA920 offers unprecedented 0.024% power measurement accuracy for all channels (1-4 channel cards available per unit), innovative VPA architecture, 100 full precision readings per second and measurement bandwidths sufficient to handle 5 MHz signals — all at a cost far lower than less capable, competitive models. The unit's intuitive touch screen operation — with built-in data history, scope mode and waveform zoom — allows users to explore many aspects of power measurement in greater detail than traditional power analyzers.

The PA920 delivers waveform visualization and measurement results necessary to validate the performance of power critical designs, such as LED lighting, solar power inverters, electric vehicles and aviation power distribution. Its Virtual Power Analyzer (VPA) functionality facilitates efficiency measurements, while its 0.024% basic accuracy and 5 MHz bandwidth provide world-class performance. The PA920 includes the capability of measuring and displaying up to the 500th harmonic (even at aircraft frequencies) and multi-unit linking for complex efficiency and synchronous measurement applications. Integrated routines facilitate compliance testing to a selection a performance standards including: EN60034-2-1:2014 (motor drives); EN50564:2011 (standby power); EN61000-3-2 and 3-12 and 4-7 (harmonics emissions); RTCA DO-160E/F/G (avionics); Boeing 787B3-0147; Airbus ABD0100.1.8 (A380) and ABD0100.1.8.1 (A350) and more.

"The ultra-high accuracy levels of the new Vitrek PA920 power analyzers allow our customers to reach the highest standards of testing accuracy at a price that fits their budget," said Chad Clark, Vitrek's VP Sales and Marketing. "One of the reasons Vitrek continues to lead the industry on innovative testing equipment is because we strive to provide the highest level of features while keeping the price-point within the customer's equipment budget. Other industry leading power analyzers offering comparable features can cost more than twice the price of the PA920."

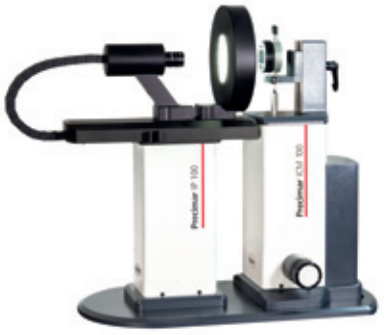
In addition to the PA920, Vitrek is also introducing the PA910 which offers accuracies of 0.045% power for applications where ultra-high accuracies are not required. Both the PA920 & PA910 are available as pre-configured or custom-configured units containing 1-4 channel cards.

Visit www.vitrek.com to learn more about Vitrek's PA920 or to request a free product demonstration.

Mahr Introduces New Vision Capabilities for Precimar® ICM 100

PROVIDENCE, RI – November 19, 2019 – Mahr Inc., a leading provider of dimensional metrology solutions, today announced the expansion of its proven Precimar® ICM 100 Dial and Digital Indicator Calibrator with image processing, designed for the automated testing of measuring equipment. Existing Precimar Optimar 100 devices can also be upgraded with the new vision capabilities.

The ICM 100 is a proven solution for testing dial and digital indicators, test indicators, and dial comparators. The new image processing upgrade now makes working with the measuring instrument safer and faster—a camera automatically records the indicated values of the test indicators and forwards them to a software for processing. The automated procedure saves time and eliminates error-prone readings by the operator. The user also benefits by eliminating eyestrain and muscle fatigue since no interaction is required once the automated calibration process begins.



The hardware and software add-on package provides a cost-efficient way to equip new or existing ICM 100 measuring stations for automated testing. The measuring system including image processing is also available as a complete package under the name Precimar ICM 100 IP.

The new vision capabilities incorporate the fast image processing of a USB 3.0 camera and stable daylight-independent LED illumination, along with secure digital identification and reading of digits. Mahr's Precimar Software for Gage Calibration controls the measuring device, evaluates the camera image of the scale or number display of the test object, compares the values with the high accuracy internal reference scale and automatically completes the process of calibrating the product under test. The software also makes it possible to create and store test certificates.

The easy operation of the ICM 100 with image processing speeds up and facilitates the monitoring of the indicators under test. With auto-recognition of the vison system, more test items and data points will be recorded faster than conventional manual methods. The completely automated inspection system enables the operator to be more productive, completing additional operations while the ICM 100 IP automatically completes the calibration process. This makes indicator inspection much more economical.

Precimar software is preloaded with many standard indicator calibration routines as defined by various national standards including American ASME/ANSI, British, German, French, Japanese and Russian. Simple choose the indicator type to be calibrated and the appropriate standard, and the system is ready to automatically perform a detailed calibration of the test piece. For more information, visit www.mahr.com

Let's Face it, Metrology Software is Complex!

Michael Schwartz
Cal Lab Solutions, Inc.

I have been writing custom metrology software for the last 20 years. And over the years, I have learned better, more efficient ways to write custom software. With every iteration, we discovered new ways to bridge the gap between custom and COTS (commercial off the shelf) software. What I have discovered is well written custom software is just COTS software with lots of options.

Relating this to metrology software and the traceability pyramid, most COTS software is typically the grey section at the bottom of Figure 1. With this kind of software, the engineer is usually tasked with writing software by utilizing a very specific set of standards to calibrate a set of units under test. This software is often written by the manufacturer with the goal of selling their hardware. If the manufacturer's software was designed to support their test equipment as the UUT, then the software is often written to support flexible standards. But if the manufacturer's goal is to sell lab standards, the application is usually written to support just their standards, qualifying the software as very turn-key.

However, there is a lot more to metrology software than the little grey area at the bottom of the pyramid—the area where it is easier to create turnkey solutions. By and large, metrology software as a whole is complex! And what we have discovered is that complexities change based on the level in the pyramid; at the top (NMI and primary lab calibrations), there is complexity in nuances of the calibration process, while at the bottom, there are complexities related to flexible equipment.

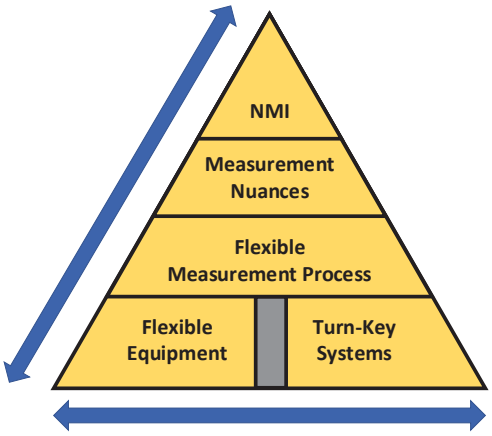


Figure 1. The Metrology Software Pyramid and the needs at each level

One would think NMI's have unlimited budgets and all the time in the world to write custom software. But I have worked with NMI's and that is not true. They have budgets and time constraints. What they do well is share ideas and often source code. They learn from each other the complexities and how to address them in their software—most of which is custom written.

Coming down one level to the primary lab, the complexities hardly change. But, still there is very little COTS software is used. Even though the hardware is usually the same, the metrology processes are extremely customized, taking into account drift, trending, cross checks, and check standards. Verifying the measurement results often takes as much time as the calibration itself, just like the NMIs.

Not until you get to the reference level calibration labs, you start to see COTS software creeping into the calibration lab, but only from instruments calibrated in high volume. Much of the non-automated calibrations are done manually with very sophisticated Excel sheets.

This creates unreal expectations for managers with it comes to automation. "Metrology is Complex!" And so too is the software used in metrology. In all my years, I have never seen two different labs that are 100% the same. Every lab has different equipment they support, different standards, different quality standards, and different management metrics.

We managers *"just want software that works!"* Write a check and the problems go away. The sales guy knows this, as well as how to hit all the bullet points to make the sale. In some cases, as long as you have the exact hardware required by the manufacturer and calculate your uncertainties the same way they do, these COTS solutions are great!

However, more often than not, the preverbal turnkey solution is not to turnkey, and some workaround or customization is needed. Labs are faced with the problem of "How can we make this turn-key COTS software work in our lab?" But this usually turns out to be the more expensive option.

I think we managers need to accept the fact that "Metrology is Complex!" Very little of our problems will have turnkey solutions. As an industry, we need to move to software that works up and down, as well as left to right in the pyramid. We need to do more of what the NMIs do with working together and sharing knowledge and source code. We all need to work to make better software for better metrology. ❧

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1364 West State Rd. Suite 101
Pleasant Grove, UT 84062, USA

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