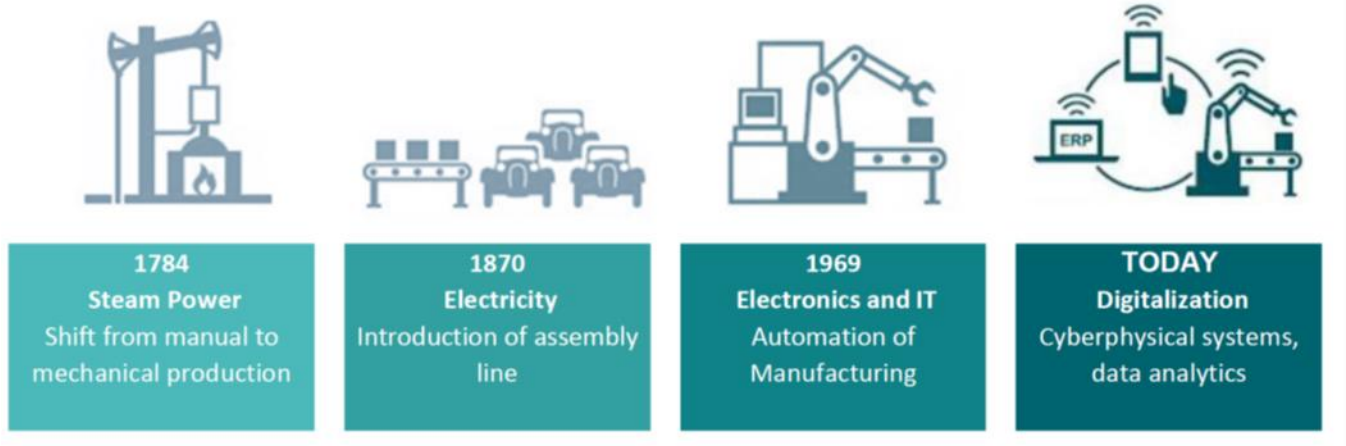

Challenges in Metrology for Advanced Manufacturing and the Fourth Industrial Revolution*

Challenges and Opportunities for National Measurement Institutes in the Americas

* The workshop, "Challenges in Metrology for Advanced Manufacturing and the 4th Industrial Revolution," was organized by Iris Mariela López (CENAM), Lisa R. Karam (NIST) and Georgette Macdonald (NRC); This white paper was prepared by Lisa R. Karam (NIST) and Iris Mariela López (CENAM).

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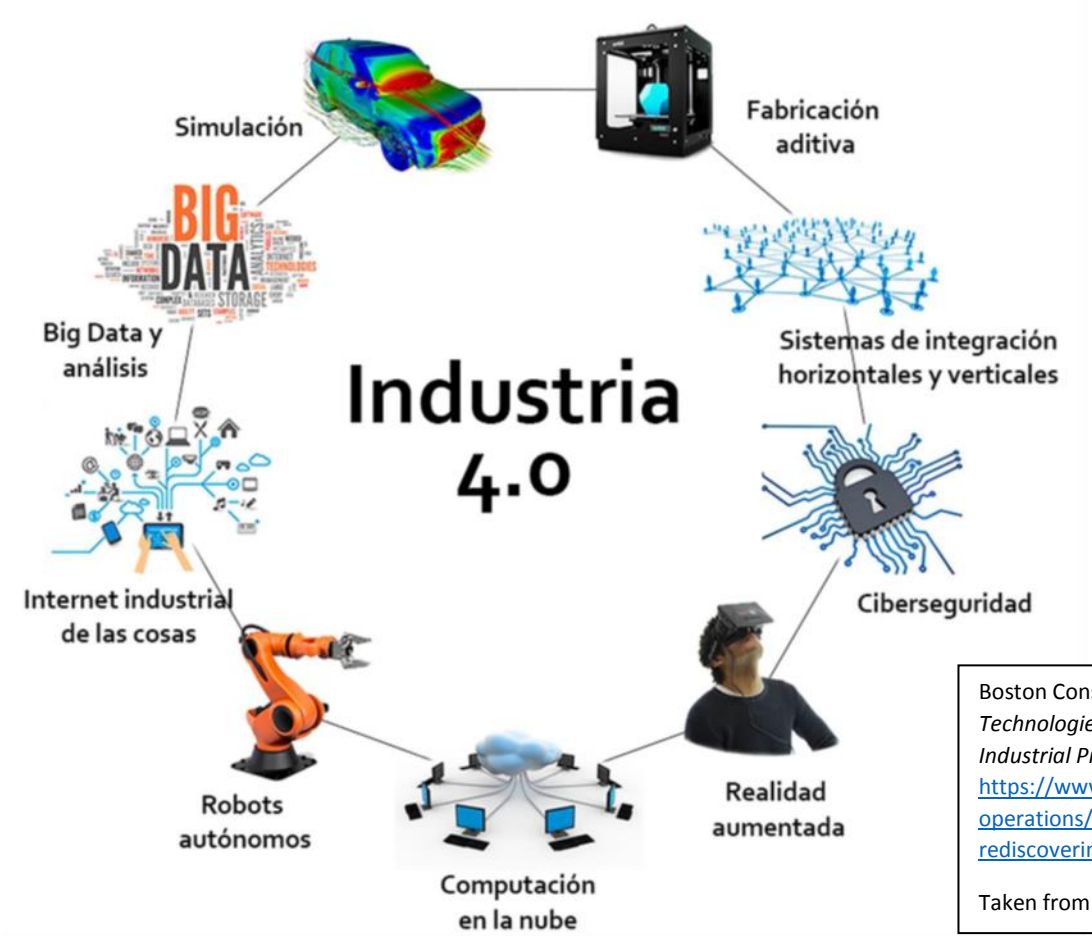


Boston Consulting Group, *Nine Technologies Transforming Industrial Production*, https://www.bcg.com/capabilities/operations/embracing-industry-4.0-rediscovering-growth.aspx

Taken from BLOP-A2G2, April 2019

INTRODUCTION

The "Fourth Industrial Revolution," a term coined by Professor Klaus Schwab of the World Economic Forum, represents the next logical step in technological evolution from biologically-based (human and animal powered) to mechanically-based (steam and oil) to digitally-based (computer and the internet) to, ultimately, a consolidation among these bases to revolutionize manufacturing and to support full implementation of key enabling technologies in society. To ensure the efficacious insertion of the fruits of the 4th industrial revolution, measurement science ("metrology") plays a critical role in not only verifying performance and improving technology, but also in assuring a seamless and safe integration of resulting technologies in consumers' daily lives.

The Sistema Interamericano de Metrología (SIM, the Interamerican Metrology System; https://sim-metrologia.org/) is the Regional Metrology Organization (RMO) for the Americas. SIM's mission includes cooperative development and research among its constituents National Measurement Institutes (NMIs) and associated Designated Institutes (DIs). NMIs and DIs develop, maintain, and disseminate measurements, standards and calibrations to industry and other users to assure quality, comparability, and regulatory or statutory compliance of goods and services (for an overview, refer to the *Springer Handbook of Metrology and Testing*, Czichos, Saito and Smith, eds., among other sources) as well as to enable advances in technological development. For those economies that are relatively early in developing manufacturing capabilities, the role of NMIs/DIs to provide crucial measurements and calibrations is paramount to enable implementation of advanced technologies with a level of confidence supportive of economic success.

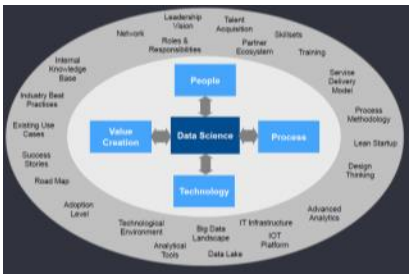
METHODOLOGY and INPUT

A workshop (https://www.gob.mx/cenam/articulos/taller-desafios-en-metrologia-para-manufactura-avanzada-y-la-4-revolucion-industrial?idiom=es) was held at the Centro Nacional de Metrología (CENAM) in June 2019 to discuss the role of metrology in advanced manufacturing and the challenges and opportunities for metrology to support transitioning the manufacturing base into the 4th industrial revolution. Participants from throughout the Americas met together at the CENAM's facilities in Querétaro, Mexico to listen to experts overview advances and near future plans is automation, mobility, sensory technologies, and transactive energy. Representatives of NMIs from the SIM community, particularly whose economies were developing and improving manufacturing capabilities were supported by funds from the Inter-American Development Bank (IADB) to participant in this 2-day public-private dialogue workshop that was co-organized and hosted by the CENAM, the NRC (Canada), and the NIST (USA), the metrological institutes of a subregion of SIM (NORAMET). The context included the revision of the International System of Unites (the SI; https://www.bipm.org/en/si-download-area/) from the metrology side, and the transformation in manufacturing (from automation to industry 4.0) and associated challenges from the industrial side.

The workshop was split into four focus areas: challenges in metrology for advanced manufacturing, challenges in different industrial fields, advances in metrological disciplines supporting manufacturing, and metrological applications for innovation in technology. Speakers from the NORAMET NMIs discussed metrological advances in nanoscale measurements, large-scale dimensional metrology, optical measurement methods, metrology "on a chip," dynamic quantities, additive (polymer) techniques, and various strategies supporting advanced manufacturing at metrology institutes. Experts from industry gave overviews of advances in the automotive and aeronautical sectors, electricity and energy generation and distribution (including photovoltaics and smart grid), artificial intelligence, distributed sensors, and autonomous mobility.

KEY FINDINGS: Bringing the 4th Industrial Revolution to the Americas

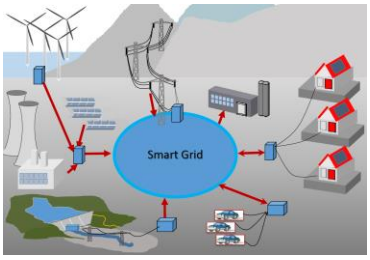
Quality Data is crucial (Erik Molino Minero Re, UNAM; Carla Quezada, GE)



> "In God we trust; all others, bring data."
>
> W. Edward Deming
>
> "What we have is a data glut."
>
> Vernor Vinge

Current artificial intelligence (AI) models and associated algorithms are very efficient in managing and analyzing large amounts of data, as well as using them for key decision making in manufacturing and remote/autonomous systems. The quality and confidence behind those decisions depends on the quality of the input data; only precision measurements (i.e., metrology) can provide the critical infrastructure to realize quality data and validate its accuracy while avoiding the clutter of uncurated data.

Energetic Resources will need to be made available and useable (René Carranza, CENAM; Antonio Sierra,CIDEC- CARSO; Héctor Castillo, CENAM)



> "Energy is liberated matter, matter is energy waiting to happen."
>
> Bill Bryson

The evolution of electrical networks to a better controlled distribution system ("Smart Grid") will address the ever-increasing needs for flexibility (including sources such as from wind, solar and nuclear as well as variability due to demand), accessibility (for everything from stationary needs in the factory to mobile vehicles and other devices), quality (to meet the requirements ranging from home use to transportation systems), reliability (including monitoring and resistance to environmental events), and market pressures (such as return of energy to the "grid" from generation at end-user sites) of energy resources. An optimized paradigm would consist of a network of integrated "microgrids" which are individually monitored and can self-repair. Key challenges will be monetizing availability during the daily variations in demand and assuring reliability in transmission. Potentially, automatic "meter reading" can enable near immediate response (both for and from consumers) for both pricing and for increase/decrease of availability. Metrology to support voltage, current, power, timing and energy quality measurements will provide crucial input for development of computation models and algorithms to support real-time demand-side response.

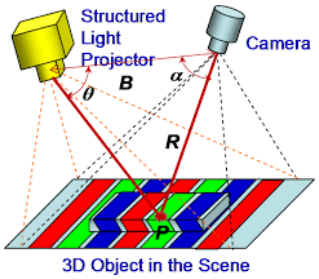
Sensor Technologies will enable future mobility (Manuel Wario, Continental Automotive; Mario Villalón, Eurotranciatura)

"To make a vehicle autonomous, you need to gather massive streams of data from loads of sensors and cameras and process that data on the fly so that the car can 'see' what's around it."

Daniel Lyons

Autonomous technologies will be dependent on precise and reliable sensory data for efficiency and safety. Biometric sensors will control access while sensory "feelers" (lidar, radar, etc.) will "see" other vehicles, objects, indicators, and pedestrians. Metrology such as in high-resolution flash lidar and V2X (e.g., 5G) communications is needed for current technologies and for those on the horizon to assure performance and reliability to enable implementation and provide a mechanism for validation of compliance to requirements. Infrastructure readiness (including standardization of road mapping and signs) will be critical to future success of these technologies.

Remote and Virtual testing and calibrations to assess current and new technologies efficiently and cost-effectively (Barbara Goldstein, NIST; Flavio Arssani, Siemens; Octavio Icasio, CENAM; Akobuije Chijioke, NIST)

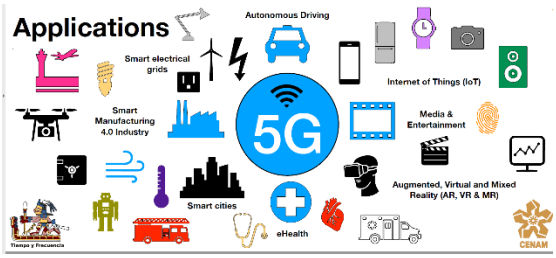


"The use optical dimensional measurement instruments (ODMI) is increasing more and more in the metal-mechanic industry."

Octavio Icasio

Although testing and calibrations will continue to be needed, especially to assess new technological solutions, the old paradigm of repetitive testing or testing at isolated sites becomes extremely inefficient and largely untenable. As the technologies in industrial processes and manufactured products advance at an accelerated rate, hands-off methods and calibrations at the site of manufacture [such as dynamic measurements and uncertainties, NIST-on-a-Chip (https://www.nist.gov/pml/productsservices/nist-chip-portal), and remote calibration services) will be at the forefront of providing key metrological infrastructure in situ. For example, measurement standards and metrological traceability will be needed for the renewable energy sector at the site of generation (e.g., photovoltaics for solar). Computational modeling and simulations (developed using well-validated quality data) will further optimize industrial processes.

New Applications will require novel approaches to leveraging technologies (Carlos Ortiz, CENAM; Richard Green, NRC; Brian Eves, NRC)



> "If you think that the internet has changed your life, think again. The Internet of Things is about to change it all over again!"
>
> Brendan O'Brien

The evolution of cellular network technology to address an ever-expanding field of applications (from analog communications to controlling autonomous automobiles) to finally reach in the fifth generation (5G) ubiquitous and pervasive presence in manufactured products during production and use (e.g., the internet of things) has presented challenges in accessing and controlling limited resources (such as synchronization in a very crowded spectrum). Metrology in frequency measurement will be key to realize the performance standards that industry develop as solutions to expanding technologies.

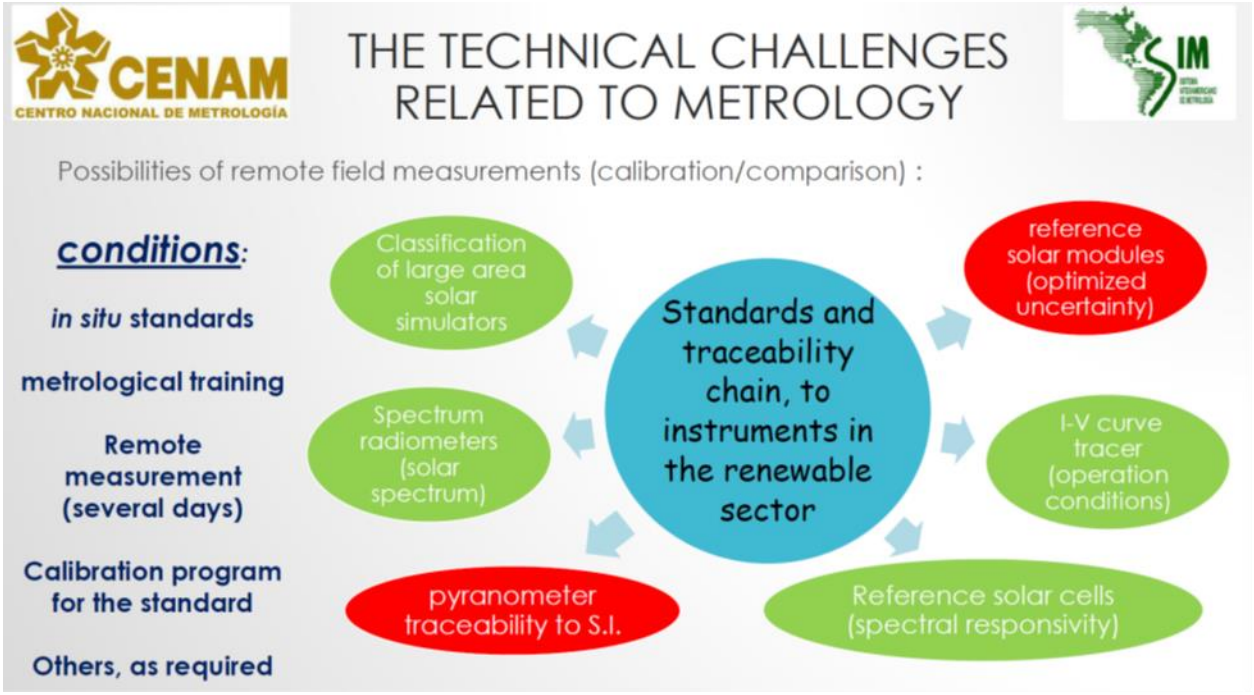
New Technologies will expand the scope of need in metrology education (Daniel Sawyer, NIST; Kalman Migler, NIST)


livescience

Baby's Life Saved with 3D Printing

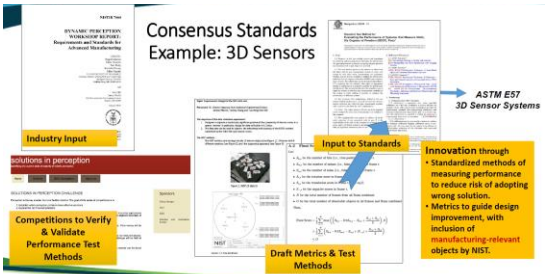
> "It is vital to nurture a workforce that is aware of and interested in industrial metrology."
>
> Industry Coalition, Coordinate Metrology Society, and UNC Charlotte

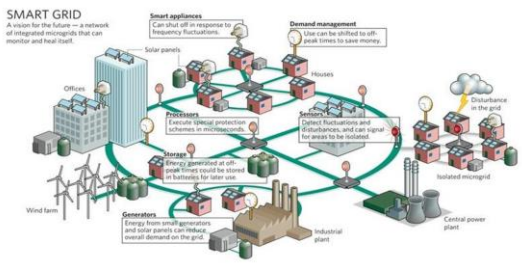
As the fruits of the 4th industrial revolution reach into the marketplace and the consumer environ, metrology will continue to play a vital role in assuring that new technologies operate efficiently, economically, and safely. While current expertise at metrology institutions is founded on historical measurement tools and techniques, innovation in industry will require a parallel innovation in measurement science. For example, new measurement systems with multiple positioning and technologies for large-scale dimensional metrology applications will require training on a multitude of techniques as diverse as microscopic evaluation of stress points to laser-based length measurements all on the same product nearly simultaneously. The Precision Path Technology Roadmap (http://precisionpathconsortium.com/) describes many of the challenges in achieving the high precision in manufacturing that will enable innovations into the future. As technologies evolve, as additive manufacturing has done from the simplest of prototypes to complex systems useable as replacement and functional body parts, the applications of metrology expand beyond many traditional areas, demanding a well-trained workforce learning through both traditional educational tracks and through on-the-job training, and developing interdisciplinary competencies.

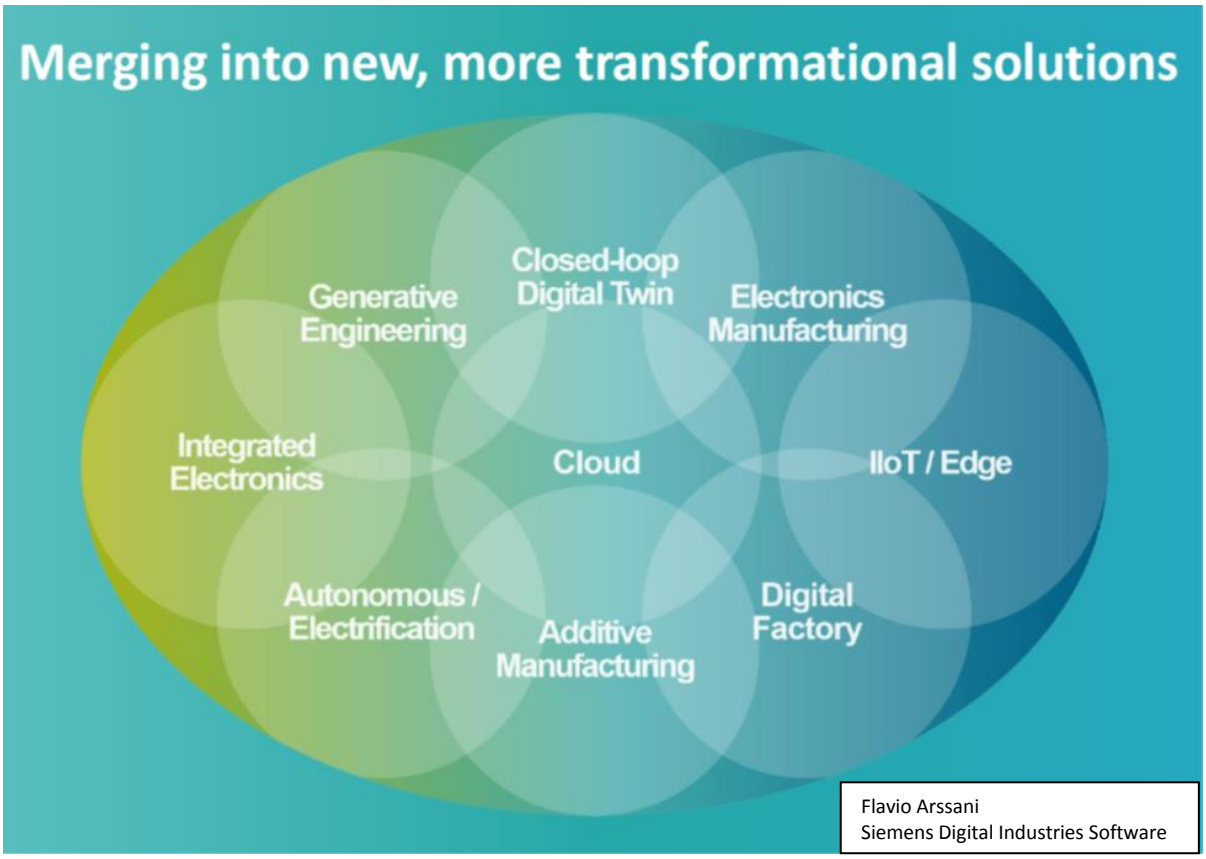


SEEING IS UNDERSTANDING

A key advantage for such a workshop is that it gives an opportunity for the participants to not only discuss points made during the presentations, but also a unique chance for reinforcing the message with visual cues, indelibly setting concepts in mind. For example, although the expression “4th industrial revolution” is well defined, seeing a depiction (particularly for non-native speakers of English) provides a critical resource for future consideration:







CONCLUSION

In closing the Workshop, topics discussed over the two days such as Challenges for Metrology 4.0, internet of things, Big Data, AI, and metrology for additive manufacturing were highlighted. Although not extensively covered, challenges in other sectors (such as food and health), technical specifications of sensor technologies, verification of validity of measurements in an interconnected world, and approaches of working with industry in countries at different stages in the evolution from Industry 1.0 to Industry 4.0., were recognized and may be addressed in future events. Follow-up comments stressed the challenge of the vast array of sensors being integrated in the manufacturing and consumer arenas, and the amount of data being generated.

The 4th industrial revolution presents an urgent opportunity for metrology institutions to provide precision measurements to enable innovation, implementation, and societal adoption of new technologies that leverage advances in science and engineering. Metrologists are best positioned to build on existing expertise and capabilities to derive and critically evaluate the physical data needed for modeling, performance evaluation, systems control, and advancing industrial capacity, but must continue to expand expertise as new technology becomes available and help "raise" the next generation of metrologists (possibly through SIM-sponsored projects, workshops, and cross-training among the NMIs/DIs). Integrating metrology in the manufacturing process (remotely, virtually, or through embedded resources) will further link the metrologist to the user community so dependent on the accuracy of measurements for quality, reliability and safety through measurement traceability.

Appendix 1: Workshop Talks and Speakers

Day 1 General Challenges for Metrology

Opening: SIM-IDB-NORAMET-Special Guests

Aidee Orozco, PhD- General Director of I+R&D of the Science and Tech Council of Mexico.

Víctor Lizardi, PhD – General Director of CENAM, and President of NORAMET

Claire Saundry, PhD- International affairs office NIST, and President of SIM

Zoltan Mester, PhD- R&D, Metrology, NRC

Block 1 General context of challenges in metrology for Advanced Manufacturing

Scientific Perspective: **The revised SI and future possibilities**

Richard Green, PhD, Team leader of Mass and Related Quantities Group, NRC, CA

NMI Perspective: **NIST Talk- Nanoscale measurements**

James Kushmerick, PhD, Dep. Director Physical Measurement Laboratory, NIST, USA

Industrial Perspectives: **Transformation in Manufacturing and challenges faced by industry**

Oscar Albín, Eng., National Autoparts Industry Executive President, MX

From Automation to Industry 4.0 Flávio Arssani, PhD, Siemens Digital Factory Division, BR - MX

NIST on a Chip Program Barbara Goldstein, PhD, NIST, USA

Block 2 Industrial sectors (*Challenges in different application fields)*

Automotive Industry Mario Villalón, PhD, Director of Innovation Eurotranciatura, IT-MX

Aeronautical Industry Carla Quezada, PhD, Data Science Team Leader of GEIQ Technology Center, QRO, MX

Electric-Electronic Antonio Sierra, PhD, Director of CIDEC Development and Research center, MX

Mechanical metrology tools to support improvements in additive manufacturing Richard Green, PhD, Team leader of Mass and Related Quantities Group, NRC, CA

NRC Dimensional Metrology strategies for supporting advanced manufacturing in Canada Brian Eves, PhD, Team leader for Dimensional Metrology, NRC, CA

Renewable Energy -Photovoltaics Héctor Alfonso Castillo, PhD, Scientific coordinator, CENAM, MX

Appendix 1: Workshop Talks and Speakers

Day 2 - Specific metrology disciplines and fields

Block 3 Specific metrological disciplines: measurement technologies with special relevance for advanced manufacturing.

Large Scale Dimensional Metrology Daniel Sawyer, PhD, NIST, USA

Optical measurement methods Octavio Icasio, PhD, Metrologist of CENAM, MX

Additive Manufacturing technologies (polymers) Kalman Migler, PhD, NIST, USA

Dynamic quantities Akobuije Chijioke, PhD, NIST, USA

Time & Frequency for 5G Telecommunication Carlos Ortiz, PhD, Scientific Coordinator

CENAM, MX

MESS group experience: into Industry 4.0 Óscar Morales, Eng., General Director of MESS Metrological Services

Block 4 Additional fields and disciplines: metrological applications in energy, IoT and Innovation Technology.

15:00-15:30

Artificial intelligence Erik Molino, PhD, Associate Researcher, IIMAS Mérida – UNAM

The future of mobility Manuel Wario, Eng., Systems and Technology Manager. Continental Automotive R&D, MX

Transactive Energy Rene Carranza, Director of Electric Metrology

MESURA 4.0 Salvador Echeverría, PhD, Director of Physics Metrology, CENAM, MX

Closing Remarks: Challenges for the SIM Region

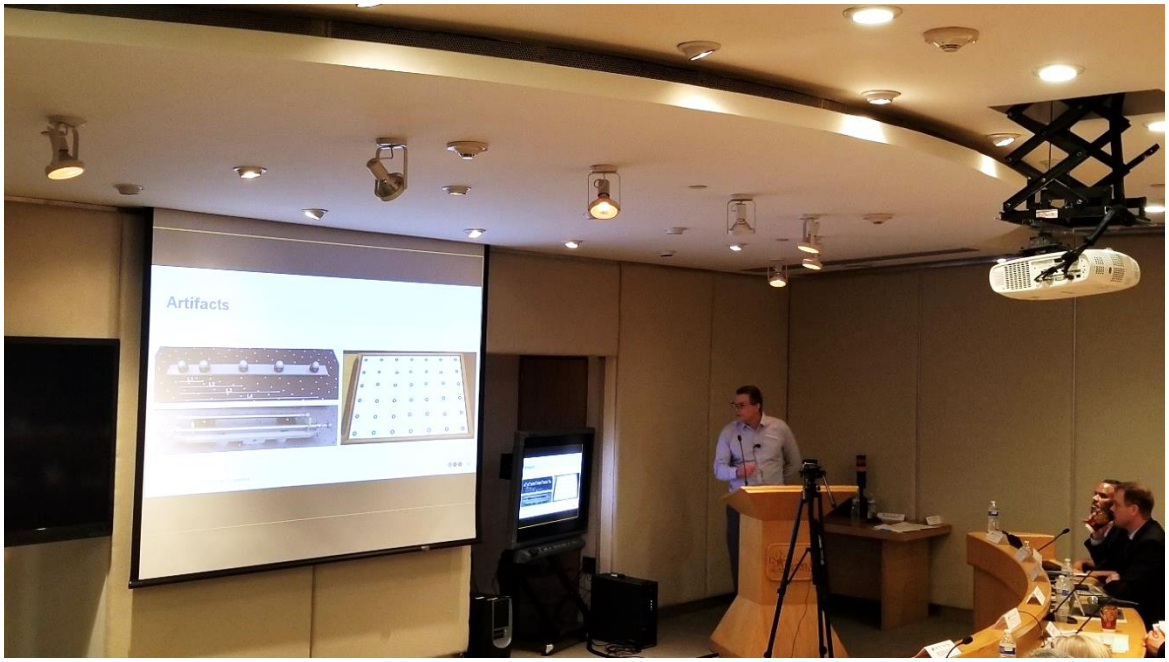
Víctor Lizardi, PhD - CENAM

Claire Saundry PhD - NIST

Zoltan Mester, PhD - NRC

Appendix 2: Presenters at the Workshop, A Photographic Memoire

Richard Green, *Team leader, Mass and Related Quantities Group, NRC Canada*



Brian Eves, *Team leader, Dimensional Metrology, NRC Canada*

Héctor Alfonso Castillo*, Scientific Coordinator, CENAM MX*

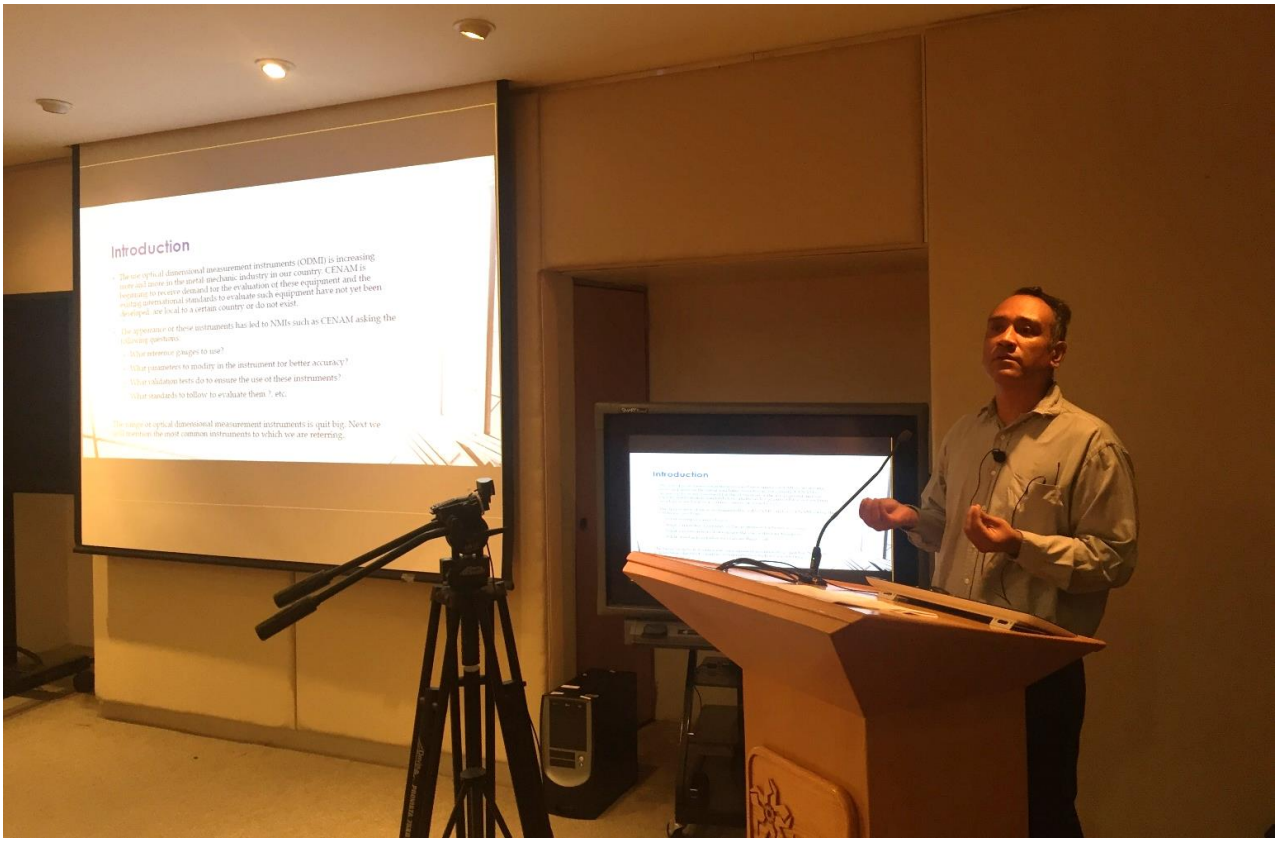
James Kushmerick, *Dep. Director Physical Measurement Laboratory, NIST USA*

Oscar Albín, *National Autoparts Industry Executive President, MX*

Carla Quezada, *Data Science Team Leader of GEIQ Technology Center, QRO, MX*

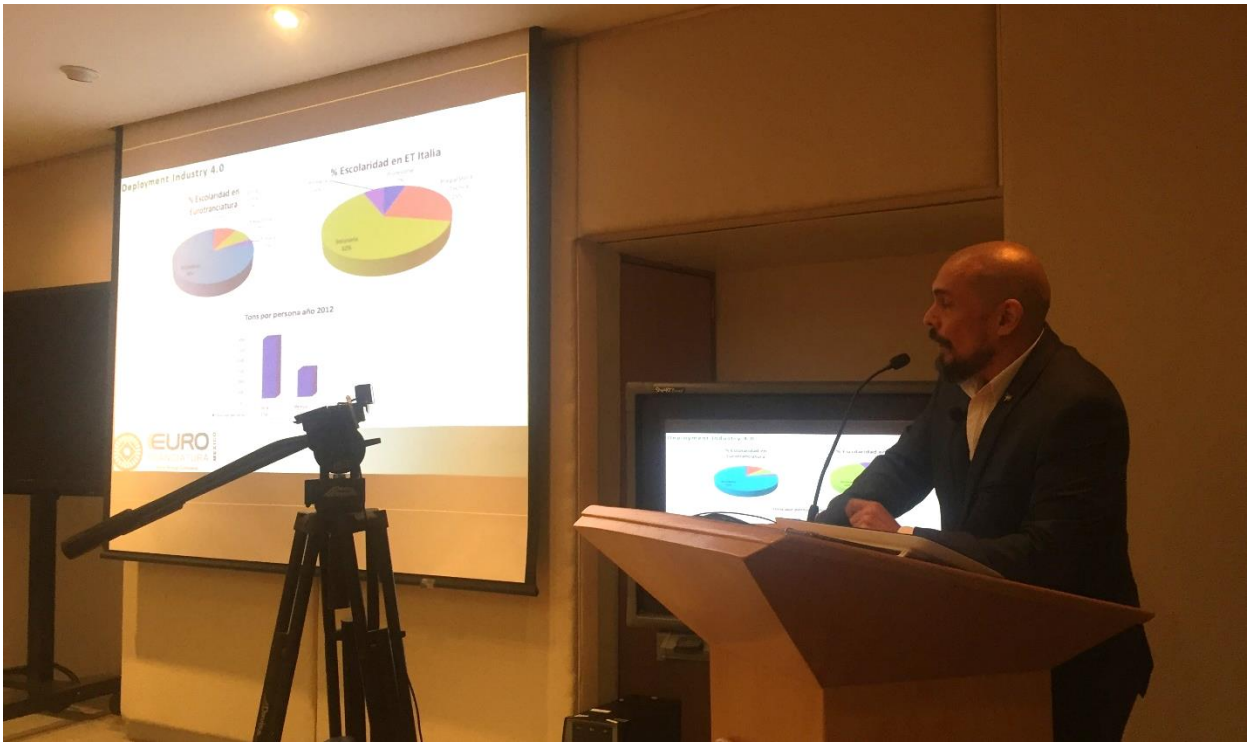
Antonio Sierra, *Director of CIDEC Development and Research center, MX*

Daniel Sawyer, *Large Scale Dimensional Metrology Laboratory, NIST USA*



Octavio Icasio, *Metrologist of CENAM, MX*

Óscar Morales, *General Director of MESS Group, MX*



Mario Villalón, *Director of Innovation Eurotranciatura, IT-MX*

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