The key role of metrology laboratories in shaping the future

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Abstract. Europe aims to maintain its leading role as a sustainable, fair, and competitive advanced economy embracing a swift and inclusive transition towards environmentally sustainable lifestyles and economies. A Green and Digital transition is being envisaged to keep the planet liveable and seize economic opportunities, where digital technologies will play a crucial role in achieving climate neutrality and reducing pollution, by measuring and controlling inputs with increased automation. Also, increased connectivity and integration provided by the internet of things, smart systems and smart cities, requires strengthen the flexibility of systems and networks, and new products, services and businesses. Thus, the need to have measurement in the centre of the process of green and digital transition is obvious, to ensure safety and quality for products traceability, requiring standards and conformity assessment, enhancing the pillars of the quality infrastructure where metrology, testing and inspection laboratories are key. In Metrology, data acquisition and treatment will remain as core activities to ensure the quality and validity of results, but larger volumes of data have a potential that is not available using common software tools, so that Artificial Intelligence tools and calibration through machine-readable harmonized digital formats are critical to cope with the new metrology ecosystem.

1. Motivation and driving forces

In 2022 European Commission launched a major strategic document called "Towards a Green & Digital Future" [1] describing the political priorities of the European Commission that will shape long-term future, being reported the commitments to reduce greenhouse gas emissions by at least 55% by 2030, and to be climate neutral by 2050. In the forewords of the documents the main objective is mentioned as "The European Union aims to be sustainable, fair, and competitive. To keep the planet liveable and seize economic opportunities, the European Union is engaging in a swift and inclusive transition towards environmentally sustainable lifestyles and economies. The green transition aims to achieve sustainability, and combat climate change and environmental degradation".

The twin transition establishes key requirements for social, technological, environmental, economic, and political nature. The roadmap to the definition of priorities is given in the document "Communication from the Commission to the European Parliament and the Council 2022 Strategic Foresight Report" [2] which states that "*Digital technologies could play a key role in achieving climate* *neutrality, reducing pollution, and restoring biodiversity*" which can be achieved "*By measuring and controlling inputs, and with increased automation, technologies like robotics and the internet of things could improve resource efficiency and strengthen the flexibility of systems and networks*". It also mentioned that "*Digital product passports enable enhanced material, component and end-to-end traceability and make data more accessible, which is essential for viable circular business models*".

The framework decided by the European Commission makes clear the need to have *measurement* in the process of the green and digital transition and the need to provide safety and quality for products, based on traceability, standards and conformity assessment. This brings to the front line the need to strengthen the pillars of the quality infrastructure where metrology, testing and inspection have a key role.

2. The need for Artificial Intelligence tools

A metrology laboratory typically stores a sizeable amount of data resulting from the use of its measuring instruments, which builds-up over time. However, if one thinks nationwide in terms of all measuring instruments used in legal metrology, or in terms of data generated by satellites, or by any automatic system that records data continuously at a high rate, it is easy to conclude that very large quantities of data will be stored and will need to be processed somehow. It is in these cases that artificial intelligence (AI) tools will be extremely useful, if not mandatory, namely in areas such as behavior prediction, preventive maintenance, and useful life cycles both in instruments and in processes. Of the possible aims of using AI tools in a metrology laboratory [3], one could cite the awareness of patterns in big data, prediction of drift, definition of optimal calibration intervals, and definition of maximum permissible errors or acceptance criteria, among others.

As an example, the project MEDATA is a partnership between IPQ and Nova IMS University (Lisbon), with the objective to create a platform for store, interpret and collect information from data, in an autonomous way. The chosen platform was the Azure Data Lake, a cloud platform that supports big data analytics, provides unlimited storage for structured, semi-structured, or unstructured data, and stores any type of data of any size. This Data Lake and some digitalization tools, like, Azure Databricks among others, allow the storage and analysis of the speedmeter verification data over the last 15 years. The data stored was analyzed by Machine Learning (ML) algorithms and the information collected permitted some trends to be drawn, e.g., the algorithms were able to predict a speedmeter malfunction and the probability of failure of a certain parameter. The knowledge acquired in this project also allowed the application of an ML algorithm in the Time and Frequency field. The ARIMA algorithm, a statistical analysis model uses time series data to predict future trends and was implemented to the prediction of UTC(IPQ), the Portuguese reference time scale. The result can be seen in Figure 1 a). Figure 1 b) shows measures of the algorithm performance and accuracy. The results are in ns, e.g., the maximum absolute error for the 30 days forecast was 5,5 ns.

3. Digital calibration certificates

Besides the convenience and advantage in the exchange of calibration results, not just as a proof of metrological data traceability, accessibility, interoperability and reuse, the future development of a system for exchanging digital calibration certificates will enable customers to receive and analyze those certificates faster and more efficiently, reducing operation times and costs associated with the process of metrological acceptance, in addition to avoid human errors and their consequences. Taking advantages of the XML (Extensible Markup Language) format, all collected data, including calibration curves, can be directly and automatically transferred into all digitally supported processes and instruments, guaranteeing its integrity and the authenticity through cryptographic procedures [4].

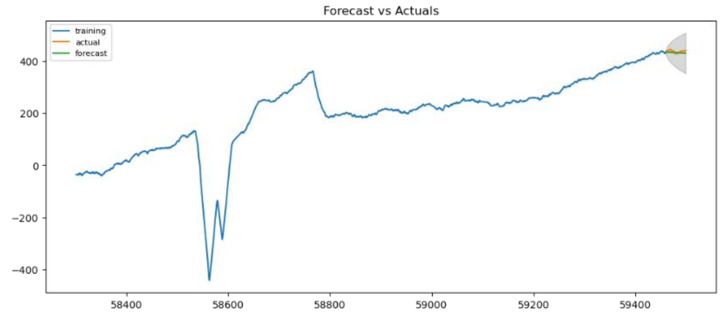

Figure 1a) 30 day*s* forecast from UTC(IPQ)

Metric:
{'mape': 0.01246034414764944,
'me': -4.462809784079803,
'mae': 5.459422909465709,
'mpe': -0.01012903574715258,
'rmse': 6.157520898717063,
'acf1': 0.8590489510133963,
'corr': 0.2359846750748443,
'minmax':

Figure 1b) evaluation of the model

In order to fulfill the European Commission strategy, published in 2020 “Shaping Europe's digital future”, EURAMET Technical Committee for the Interdisciplinary Metrology, created a working group for the Digital Transformation (WG M4D) with the mission to implement a strategic digital transformation that is aligned both with the aims of the European Commission, as well as the relevant needs of EURAMET members. For this purpose, WG M4D gathered expertise in the area and started project 1448, with the goal of enabling, via dissemination of training and practical guidance material, the use of Digital Calibration Certificates (DCCs) throughout major parts of the metrology community with particular and immediate focus on small and emerging NMIs/DIs within Europe, and also addressing the needs of the wider range of stakeholders with an interest in DCCs.

The project started in the beginning of 2023 and will carry out the following actions:

- define the minimum requirements for DCC regarding content and interfaces;
- develop and publication of case studies, guidelines and software;
- organize workshops to provide a forum for the presentation and discussion of novel approaches;
- organize training courses, both, web-based and in person;
- active collaboration with all EURAMET Technical Committees, and
- active collaboration with the CIPM and its Consultive Committees.

The participants in the project have already reached a consensus, so that the DCC shall be done in XML, e.g., Figure 2, and it will be generated based on the existing structure provided by PTB (Physicalisch-Technische Bundesanstalt), the German NMI, since it has already been working in this field for the last few years and have already made an “users survey” to understand their needs on DCC. Also, according to the participants expertise, it will be very difficult to reach a DCC structure that fulfills the requirements of all metrological areas.

Currently, in metrology there is the emission of a calibration certificate (CC) for every calibration that can only be read by the user, i.e., human readable. In the future, the CC should be machine readable, machine interpretable and should be based on a system of AI with cognitive capabilities, they should adapt to the current state of the art of technical and regulatory framework conditions.

```
<xs:element name="digitalCalibrationCertificate" type="dcc:digitalCalibrationCertificateType"/>

<xs:complexType name="digitalCalibrationCertificateType">
    <xs:annotation>
        <xs:documentation>
            The root element that contains the four rings of the DCC.
        </xs:documentation>
    </xs:annotation>
    <xs:sequence>
        <xs:element name="administrativeData" type="dcc:administrativeDataType"/>

        <xs:element name="measurementResults" type="dcc:measurementResultListType"/>

        <xs:element name="comment" minOccurs="0">
            <xs:complexType>
                <xs:sequence>
                    <xs:any namespace="##any" processContents="lax" minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
            </xs:complexType>
        </xs:element>
```

Figure 2: Example of XML code in a DCC.

To better understand the significance of the DCC, a scheme of what is intended is presented in Figure 3. There is a calibration with data that fills the CC and could only be readable by a human. In the future, NMIs with the data from a calibration, and following a certain standard, such as ISO 17025, VIM, GUM, shall generate a DCC that could be human readable and machine readable. This last part is the complex one, because what is intended for machine readable is that a machine talks to another machine and acquires the data from the calibration and autonomously adjust the equipment with the new values from the calibration. And this is the main goal of project EURAMET TC-IM #1448.

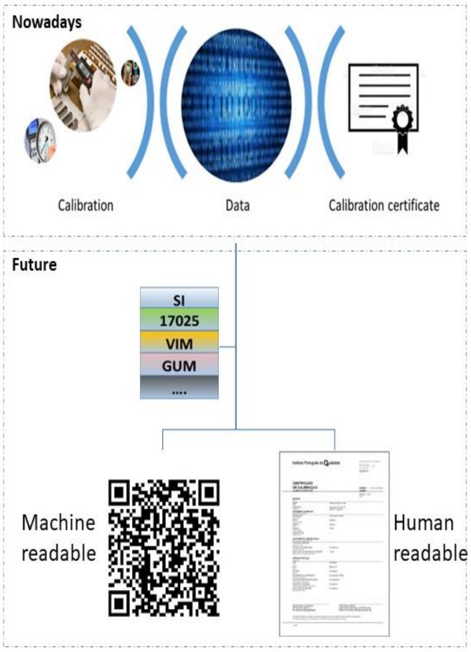

Figure 3: DCC scheme

One of the further advantages of this new scheme is the applicability to large network of sensors, which will be prevalent soon, allowing the automation of the calibration process, with effective and fast acceptance procedure and reduced stoppage times, plus the ability to deal with failures in individual sensors due to redundancy [5].

4. Laboratories and the future of conformity assessment

Laboratories are main providers for consumers and citizens regarding confidence and quality of products and services, making possible testing, inspection, and certification in a wide range of economic activities, being the backbone of conformity assessment.

New policies based on emergent technologies and innovative approaches are the support of new applications usually connected with what is called Industry 4.0, and the basis of smart systems, smart engineering and, in a more organized structure, smart cities. The relation between these levels of integration lead to the development of new business models, new production frameworks and new products and services. There is a direct interdependency of this levels (see Figure 4), driving to the final step to the market, where the conformity added value of TIC (Testing, Inspection and Certification) industry and its laboratories is critical.

At European level, the purpose of this digital transformation is to achieve the pillars of the digital single market (one of the European Commission top priorities): *Improving access to digital goods and services; an environment where digital networks and services can prosper;* and *digital as a driver for growth*.

The five main drivers for the laboratories in future are:
Sustainability - Sustainable management should make responsible use of finite resources.
Digitization and Laboratory 4.0 - information and communication technology is critical for networking of systems, persons, devices and sensors increasingly needed for smart products and services.
LIMS – Laboratory Information and Management Systems – modern laboratories rely on robust data management solutions.
Supply chain – new international trade conditions and geopolitical changes showed the impact os supply chains on the competitiveness and efficiency of laboratories.
Agility – Organizations strategies are developed to create new processes, seeking serendipity.

The future of compliance business implies new tools and strategies to be able to face the challenging new complexity, briefly presented in Figure 5, being expected to be increasingly "digital, automated, and connected".

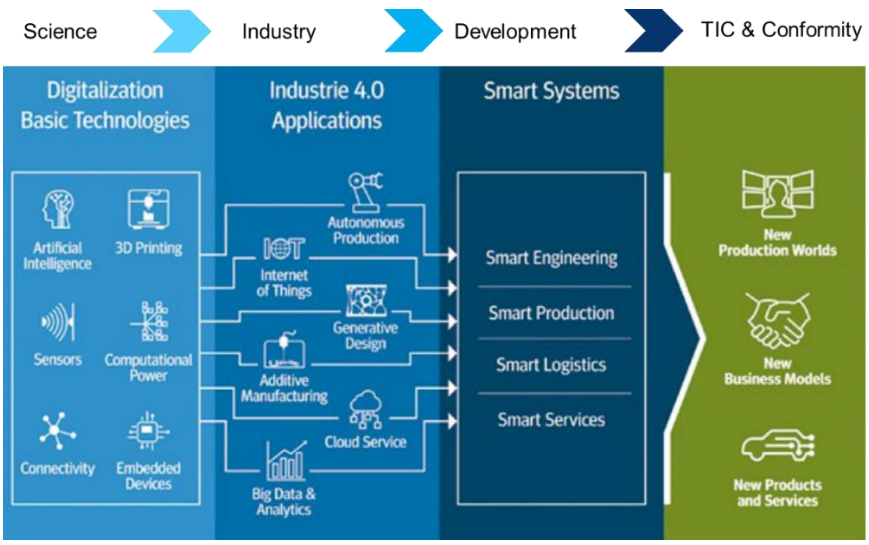

Figure 4 – From digital technologies to market conformity

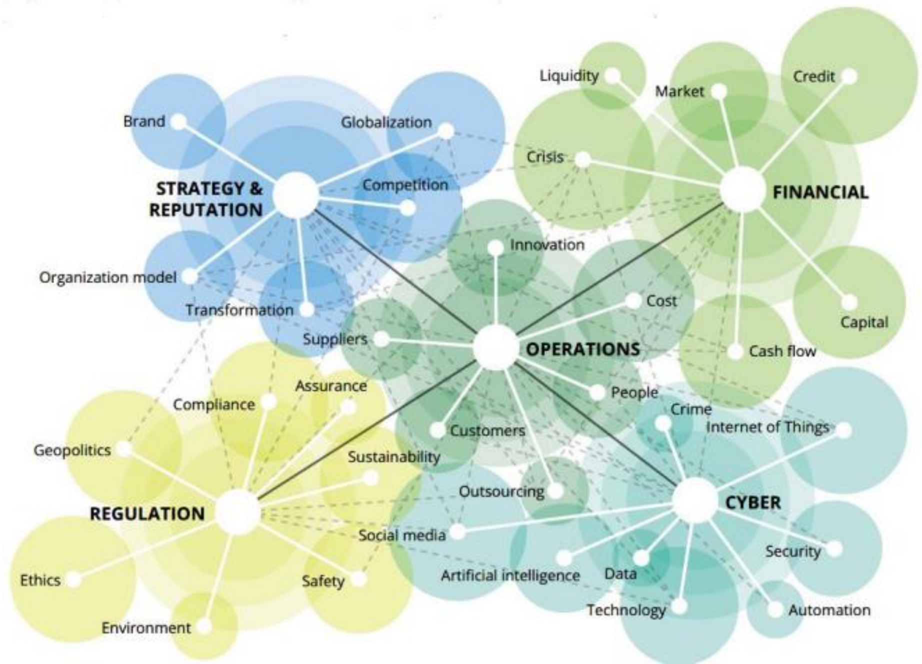

Figure 5 – Future of compliance complexity [6]

Each of the areas identified in Figure 5 have their own management challenges. In this paper a focus is made on three of these major areas, particularly relevant for the future of TIC industry: operations, regulation, and cybersecurity.

Operations have traditional business models that are having disruptions due to emerging technologies, such as, Artificial Intelligence, machine learning, IoT, big data analytics and others, using smart engineering, network communications between machines and smart devices able to respond and anticipate human needs. This change requires new regulatory frameworks intended to protect users, to assure fair markets and to enforce regulation as tool to safety and security.

There´s also a growing need to ensure that information provided by measurement is reliable, considering that measurement data supports inferences, being critical to some decision-making and key to many systems controls and management. For large-scale problems, data analysis must consider robust approaches for e.g., optimization, sampling, dynamic performance, connectivity, remote assessment, calibration, self-monitoring, cybersecurity. Data science and data analytics play a major role in the future of TIC industry, as in many other fields of economic activities.

The third major domain of growing interest and concern is cybersecurity, being defined as the procedures and techniques intended to protect a business's critical systems, to assure confidentiality of data against cyber threats (usually called cybercrime) and to reduce the vulnerability against cyber-attacks. Laboratories have growing concerns about protection and privacy of data, the main assets of most of TIC activities.

5. Final remarks and future work

Digitalization is a continuous process that is decisively and definitely influencing all areas of society. The focus is on digitalization programs for the organization itself, and for Metrology in particular, digitalization is seen in the context of supporting industry 4.0, i.e., production in an all-digital network, including digital calibration certificates, artificial intelligence and services to society. In research, the digitalization is reflected in new lines of research, multi-disciplinary cooperation programs and tools for the management of large quantities of data.

The National Metrology Institutes have an active role in several of the topics referred above due to the challenges and developments linked to its mission [7], which will be subsequently disseminated to the network of accredited laboratories, namely:

- In scientific metrology they are actively involved in multidisciplinary R&D projects, to be able to face the increasing demands for greater accuracy and tighter tolerances in measurement, as well as in matters related to simulations and virtual measuring instruments.
- In legal metrology, is actively concerned in fostering digitalization of processes and measuring instruments, through a structured process to support the national industry and the market surveillance authorities, in particular in topics such as smart meters and electrical mobility.
- In applied metrology, they target at and underpin the development of machine-readable digital calibration certificates, and the corresponding infrastructure for the recognition of authenticity.
- For data validation, algorithms are being developed and implemented by harmonized and validated methods using international peer comparisons supervised by BIPM (*Bureau International des Poids et Mesures*).

Several of these topics are included in subtopics of a quality infrastructure that, in the future, will be totally digitalized. In this system, the processes are fully digital, the objects are strongly entangled in networks, and algorithms are used intensively. This digital transition is ongoing already and will be accelerated by current technological developments. There are 5 main dimensions – European Metrology Cloud, Industry 4.0, Services to Society, Digital Calibration Certificates and Artificial Intelligence –, that will become common to most laboratories, of which this paper focused on the last three.
The digitalization is nowadays a crucial process for the development of any organization. Metrology laboratories are key to underpin the needs of industry and of key sectors such as health, energy, environment and, generally, most economic activities.

References

[1] Towards a green & Digital Future, JRC Science for Policy Report. EUR 31075EN. Joint Research Center. Luxembourg: Publications Office of the European Union. 2022.

[2] Communication from the Commission to the European Parliament and the Council. 2022 Strategic Foresight Report. European Commission. COM (2022) 289 final. Brussels.

[3] Carlos Pires, Fernanda Saraiva, Pedro Neves, João Alves e Sousa 2022 Transição digital nos domínios do tempo e comprimento do IPQ, *8.º Encontro Nacional da Sociedade Portuguesa de Metrologia*, 15 de novembro de 2022.

[4] Miguel Marques, João A. Sousa, Luís Ribeiro 2019 Calibration 4.0 – Information system for usage of digital calibration certificates, *Congrès International de Metrologie CIM2019*, 24-26 September, Paris, France.

[5] João A. Sousa, Luís Ribeiro, Jorge Antunes Isabel Godinho 2018 Digitalização, Investigação e Desenvolvimento da Metrologia no IPQ, *e-medida*, Revista Espanhola de Metrologia, (https://www.e-medida.es).

[6] The Future of Compliance 2017. Deloitte.
[7] João Alves e Sousa, Luís Ribeiro 2018 O Laboratório Nacional de Metrologia do IPQ e o seu posicionamento na sociedade − a definição de uma estratégia a médio prazo, *V Congresso Ibero-americano de Laboratórios* - *I Congresso de Avaliação da Conformidade - Presente e Futuro*, 17-19 de outubro de 2018, LNEC, Lisboa.

Acknowledgements

We are grateful to RELACRE (Association of Accredited Laboratories - www.relacre.pt) for their continued support to the national scientific community in activities related to R&DI including the participation in scientific events.