# Digitalizing metrology: the quality infrastructure services portal of IPEM-SP

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**Abstract.** The digital transformation of Quality Infrastructure is one of the main challenges in the context of Industry 4.0. Not letting control be an obstacle to innovation is leading organizations to modernize and incorporate new practices and solutions. In Brazil, the Institute of Weights and Measures of the State of São Paulo (IPEM-SP) implemented a Quality Infrastructure innovation laboratory at the Technological Innovation Hub in the City of São José dos Campos. With the aim of bringing Quality Infrastructure closer to companies that promote innovation, enhancing products and services, IPEM-SP developed a Quality Infrastructure Services Portal (PSIQ) project, based on Artificial Intelligence, to provide initial assistance to those interested in learning about and using Quality Infrastructure tools. This Paper presents the PSIQ case study, a pilot project still under development.

## 1 Introduction

Quality Infrastructure (QI) is a powerful instrument of competitiveness in an increasingly complex market. One of the reasons for this situation is the role that innovation plays in the context of Industry 4.0. Anchored in information technology and connectivity, the 4th Industrial Revolution (4IR) is transforming society in various aspects, such as the way companies produce goods and services. The main impacts of the 4th Industrial Revolution are economic growth, company productivity and pressure on jobs, with the main factors for these impacts being the speed, scope and systemic impact of new technologies [1].

The ability to seize trade opportunities, compete in global markets and participate in the international value chain is often hampered by the difficulty of demonstrating compliance with quality requirements and trade rules. Organizing a QI system is one of the most positive and practical steps a developing nation can take on the path to becoming an economy based on prosperity, health and well-being [2].

Thus, one of the challenges of IQ is to digitally transform the system itself, which was structured in the context of the 3rd Industrial Revolution, with the control of the production line as its paradigm. With digital transformation, IQ systems are challenged to keep pace with the speed of new technologies. The potential to innovate is no longer an option, it's rather a necessity not only in production, but also in IQ, particularly in accessing markets [3]. The main IQ tools, such as conformity assessment, measurement traceability, and standards, to name a few, were designed and consolidated in an environment of predominance of mechanization, automation and increasing use of computing. One of the central issues of today is the transition from the control paradigm to the innovation paradigm. The challenge is how to promote innovation without control being an obstacle. It is not about abandoning control, but going beyond it, using it as a support for innovation itself.

One example is regulation, which can contribute to innovation, but can also be an obstacle to creativity and to the development and implementation of innovation solutions [4].

Brazil is a country of continental dimensions, with great distances to be covered, a large population and an irregularly distributed GDP, which requires regionalized public policies, especially regarding economic development.

Among the Brazilian states, São Paulo occupies a prominent position. It is the state with the largest industrial base, the largest consumer market and a significant agricultural population. With 45 million inhabitants, a GDP of around R$350 billion ($80 billion) and 250 thousand square meters [5], it is comparable to a European country.

One of the consequences for Brazilian QI is that a single national metrology organization is not capable of providing support for the needs of the entire country. One solution was to organize a networked system, in which state organizations connect to the federal level in a metrology and quality system [6]. One such organization is the Institute of Weights and Measures of the State of São Paulo (IPEM- SP) [ 7].

Created in 1967, IPEM-SP played a relevant role in the development of legal metrology in Brazil and in market surveillance. In Brazil, the National Institute of Metrology, Quality and Technology (INMETRO) has the prerogative of regulating legal metrology and assessing conformity in areas where there is no primary regulator, covering a large part of product safety [8]. INMETRO delegates to the states, through the state metrology institutes, with different names, the power of administrative policing and the provision of legal metrology services, such as verification of measuring instruments.

In response to a modernizing agenda for the state of São Paulo, IPEM-SP developed a strategic plan for the period 2023-2026 with an emphasis on innovation, with the aim of promoting its digital transformation and developing industrial metrology [9]. To become more efficient, IPEM developed actions to approach the

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productive sector, seeking to develop solutions for the main problems encountered by the industry.

Innovation is an important topic for Brazil, especially for São Paulo. According to the Brazilian Innovation and Development Index (IBID), the state leads all 7 pillars of innovation. Still, it seeks to increase its efficiency in converting inputs into results [10]. In 2025, the Secretariat of Partnerships and Investments (SPI-SP) will have a budget of 8.5 billion reais (1.5 billion dollars), an increase of 129% compared to the previous year [11].

Seeking to bring IQ closer to companies, IPEM-SP created the Quality Infrastructure Laboratory (LIQ) [12], in the São José dos Campos Technological Innovation Park (PIT) [13]. This is an innovation laboratory dedicated to IQ, with the scope of promoting projects in partnership with companies to generate innovative technologies and businesses in the state of São Paulo.

**Fig. 1.** Panoramic view of the Technological Innovation Park (PIT)

This article will present the experience of IPEM-SP, highlighting the first LIQ project, a service portal for companies based on the use of Artificial Intelligence (AI). The portal seeks to digitalize metrological processes and other IQ components, promoting accessibility, transparency and innovation. Markets based on digital platforms are increasingly prevalent, which requires companies and organizations in general to move faster [14].


**Fig. 2.** Quality Infrastructure Services Portal (PSIQ)

The partial results achieved in the structuring of the Quality Infrastructure Services Portal (QIPS) were obtained through the combination of different scientific methods and applied research, integrating qualitative and quantitative approaches. Initially, a bibliographic review and a requirements survey were carried out to identify the needs of the productive sector and the most appropriate emerging technologies. Based on this data, the conceptual modelling of the platform followed the principles of Design Science Research (DSR), allowing the structuring of technological components, such as the Intelligent Virtual Assistant, Advanced Semantic Search, Big Data and Robotic Process Automation (RPA). The development and prototyping phase, corresponding to TRL 2 (Technological Formulation), used agile methodologies, enabling iterative adjustments and partial validations of the planned functionalities.

During the transition to TRL 3 (Experimental Validation), experimental methods were used, including usability testing, to ensure that the PSIQ components met the technical and regulatory requirements. The analysis of data collected during the tests was conducted using content analysis techniques, enabling evidence-based adjustments. Using this approach, it was possible to prove the efficiency of the virtual assistant in personalizing responses, the accuracy of the semantic search in retrieving technical information, and the optimization of automated processes via RPA. These results demonstrate that the integration of scientific methods with applied research has been essential to consolidate an efficient and interconnected digital ecosystem in the Quality Infrastructure, making PSIQ a reference model for the modernization of metrological and regulatory services.

## 2. IPEM-SP Innovation and Competitiveness Ecosystem

The state of São Paulo is Brazil's most important economic and industrial hub, home to a robust innovation ecosystem that drives the country's economic development. With a GDP larger than most countries, São Paulo has the largest industrial parks in the country and is a benchmark for sectors such as technology, healthcare, advanced manufacturing and agribusiness. This leadership role demands solid support for quality, trust and safety for products and services, making it essential to disseminate and strengthen IQ.

IQ is made up of 5 fundamental pillars – metrology, accreditation, standardization, conformity assessment and market surveillance – which guarantee competitiveness, safety and compliance for industrial production and the services provided, making it possible not only to drive innovation and efficiency, but also ensuring the integration of the state in the global value chain.

IPEM-SP, following its strategic planning, structured an innovation and technology center, published an innovation policy and transformed itself into an Institute of Science and Technology (ICT). ICTs, in the Brazilian legal system, aim to contribute to scientific and innovation production by promoting connections among government, academia and companies. This arrangement configures the triple helix of innovation, a concept presented in 1995 by Etzkowitz and Leydesdorff, who understood that economic development depends on this articulation [16]. Recently, the concept expanded to a quadruple helix by including society as another of its components, understanding that this component would be responsible for bringing innovation to the masses, civil society and the media [17]. Based on this concept, IPEM-SP sought strategic partnerships to form an innovation ecosystem focused on IQ. In January 2025, IPEM had already consolidated

its ecosystem formed by recognized institutions, as shown in the figure below.


**Fig. 3.** IPEM-SP Innovation and Competitiveness Ecosystem

Another strategic action was to seek closer ties with the production sector. The main objective was to understand the challenges that companies face in the context of Industry 4.0. A pilot project was designed based on a previous experience of one of the authors of this article who, as President of INMETRO, led an initial experiment to create an IQ laboratory in the city of Foz do Iguaçu in 2021[18]. Despite its initial success, the laboratory did not consolidate. One of the factors was the distance from INMETRO and the lack of its own human resources to conduct the laboratory's activities, resorting at the time to a partnership with a local university. Seeking to correct the flaws found, IPEM-SP established a new laboratory, LIQ, in a city close to its technology center, using its own personnel, in a location with a concentration of companies focused on innovation.

This location was the city of São José dos Campos, located 100 km from São Paulo, with a strong technological vocation, being home to the Aeronautics Technology Center (CTA) and Embraer, a Brazilian aviation company. The city has an innovation park, the PIT, which has more than 300 associated companies, 135 of which are residents, as shown in the table below. LIQ began its operations in January 2024.

| | |
|---|---|
| Total area of the PIT core | 188 thousand m2 |
| Special perimeter of the park | 15.8 million m2 |
| Related companies that are part of this universe | More than 300 |
| Resident companies | 135 |
| Business Centers | 4 |
| Technological development centers | 4 |
| Business incubators | 3 |
| Local productive arrangements | 2 |

**Fig. 4.** São José dos Campos Technological Innovation Park (PIT)

One of the first findings was that there is a huge pent-up demand for IQ. One of the factors is the lack of knowledge of IQ tools among companies themselves, especially companies focused on innovation. Every time LIQ introduced IQ to these companies, demand was generated, especially for information. The problem for LIQ became how to meet so many demands with limited human resources. The solution was to develop an IQ service portal, based on AI, to receive demands from companies, working on a funnel strategy to channel the most complex ones to the LIQ team.


**Fig.5.** IPEM-SP Quality Infrastructure Laboratory in São José dos Campos

## 3. Partial Results

The digital transformation of Quality Infrastructure (QI) has become a strategic factor for industrial development and global competitiveness. The Quality Infrastructure Services Portal (QISP) was designed to revolutionize access to metrology and conformity assessment services, promoting an efficient, integrated and accessible ecosystem. This advancement allows companies, regulatory bodies and society to use technical and regulatory information quickly, reliably and automatically, ensuring greater security and adherence to current standards.

The project is currently in the TRL 2 (Technological Formulation) phase, where the structural bases of the platform, its functionalities and technologies involved are defined. In the next six months, the transition to TRL 3 (Experimental Validation) will take place, in which the components and subsystems will be tested in controlled environments to ensure reliability, interoperability and operational efficiency. This validation will be essential to ensure that PSIQ accurately meets the needs of the production sector and the agencies responsible for regulating quality in Brazil.

One of the main differentiators of PSIQ is the implementation of an Intelligent Virtual Assistant, based on Artificial Intelligence (AI), which will provide personalized support to users. This technology will be able to interpret complex questions, suggest relevant standards and regulations, and offer specific guidance according to the user's profile. In this way, the aim is to eliminate barriers to accessing technical information and ensure that companies and professionals find quick and reliable answers on regulatory and metrological requirements.

The integration of Advanced Semantic Search will make access to information more intuitive and efficient. Unlike traditional search systems, this functionality will employ natural language processing to understand the user's intent and provide highly relevant and contextualized results. This will allow technical standards, ordinances and regulations to be located with greater precision, reducing ambiguities and optimizing the search for critical information for compliance and certification of products and processes.

The use of Big Data and Analytics will be essential to improve the management of Quality Infrastructure. By collecting and analyzing large volumes of data, PSIQ will be able to generate detailed insights into non-compliance patterns, regulatory trends, and opportunities for improvement in certification and metrology processes. This resource will provide a solid basis for evidence-based decision-making, benefiting both companies and regulatory bodies in building more effective policies and strategies.

Robotic Process Automation (RPA) will be one of the pillars of PSIQ's operational efficiency. By automating repetitive activities, such as document validation, certificate issuance and request processing, it will be possible to reduce response time, minimize errors and increase productivity. In addition, API integration will ensure that the platform can communicate with other institutional systems, promoting interoperability and connectivity between different components of the Quality Infrastructure.

The modernization promoted by PSIQ represents a significant advance for the Quality Infrastructure in Brazil, especially in a context where digitalization and connectivity are essential for sustainable development and global competitiveness. With the implementation of these technologies, IPEM-SP not only improves its internal processes, but also creates an innovative model for the digitalization of metrological and regulatory services, strengthening the productive sector and boosting the quality and safety of products in the national and international markets.

Furthermore, in its first year of operation, LIQ began a process of impacting the PIT ecosystem, highlighting the actions in the figure below.

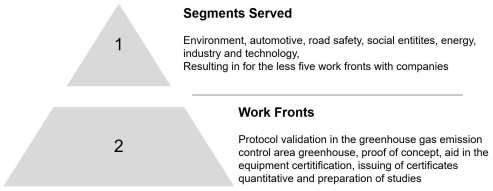


**Fig. 6.** LIQ Impact on the PIT Ecosystem

## 4. Conclusion

IPEM-SP has sought to put digital transformation concepts into practice at IQ, seeking to identify innovation projects to experiment with solutions that respond to the various challenges faced by the production sector. Industry 4.0 is having a strong impact on the market and IQ has challenges to overcome in all of its pillars. Examples include the development of remote calibration, smart standards, digital product passports, and others.

Understanding IQ as a system that provides services to the industry, with the aim of having reliable and safe products, in addition to contributing to competitiveness, the connection with companies is a critical factor for digitalization actions. Thus, the connection environment itself between institutions that directly or indirectly provide IQ services to companies must also occur in a virtual environment. With emerging digital technologies, these possibilities are greatly expanded.

LIQ and PSIQ are developments that aim to reduce this gap between IQ organizations and the productive sector, especially in Brazil, where the country's characteristics and dimensions often hinder integration and speed of solutions. With the validation of the portal, IPEM-SP will have a digital environment to meet various demands, especially in information, generating value for companies, particularly those dedicated to innovation.

This same principle can be applied to the same portal or to another one to be developed for different audiences, such as consumers, traders and governments. One of the recommendations in this article is that once the portal is validated, its scope should be expanded to other domains that can benefit from IQ.

The conclusion of this article is that organizations that work with IQ must seek innovative ways to modernize their services in order to be more efficient in the current context of 4IR, generating value for companies and trust for the market, thus being a factor in inducing Industry 4.0 itself.

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