INTERNATIONAL DEVELOPMENT IN PRACTICE

Brazil

QI Toolkit Case Studies

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Abbreviations

BIPM	International Bureau of Weights and Measures
CGCRE	General Coordination for Accreditation (Coordenação Geral de Acreditação do Inmetro)
CMC	calibration and measurement capabilities
CRM	certified reference materials
DM	deutsche mark (German mark)
GDP	gross domestic product
IAF	International Accreditation Forum
ILAC	International Laboratory Accreditation Cooperation
INMETRO	National Institute of Metrology, Quality and Technology (Instituto Nacional de Metrologia, Qualidade e Tecnologia)
INPM	National Institute for Weights and Measures (Instituto Nacional de Pesos e Medidas)
KCDB	Key Comparison Database (of BIPM)
NIST	National Institute for Standards and Technology (United States)
NMI	national metrology institute
PADCT	Program to Support Scientific and Technological Development (Programa de Apoio ao Desenvolvimento Científico e Tecnológico)
PTB	National Metrology Institute of Germany (Physikalisch-Technische Bundesanstalt)
QI	quality infrastructure
SI	International System of Units
SME	small and medium enterprise
UKAS	United Kingdom Accreditation Service
UNIDO	United Nations Industrial Development Organization
US$	U.S. dollar

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Abstract: Establishing a world-class quality infrastructure (QI) institution takes a long time and necessitates heavy investment in people, systems, and infrastructure. Brazil's National Institute of Metrology, Quality and Technology (INMETRO) developed from a small calibration laboratory to a leading national metrology institute at the international level, but it took three decades and the unstinting support of a development partner to do so.

EXECUTIVE SUMMARY

In the 1960s and 1970s, Brazilian exports increased dramatically, driven by an increase in manufactured goods. But Brazil was experiencing a high-technology deficit in its trade balance. High-technology goods had to be imported into Brazil, and this deficit—US$450 million in 1973—was projected to grow quickly to US$1 billion. The government therefore adopted a strategy to enhance the technological autonomy of the Brazilian economy. In addition, Brazil was embarking on the development of nuclear power, and the envisaged power plants needed local technological backup in terms of operation and safety. The cooperation agreement signed between the government and the National Metrology Institute of Germany (PTB) in 1967 provided for capacity enhancement of Brazil's National Institute of Metrology, Quality and Technology (INMETRO). This cooperation was strengthened in 1975 after the signing of the agreement between Germany and Brazil for the transfer of nuclear power technology.

The involvement of PTB in INMETRO and other players of Brazil's quality infrastructure (QI) can be described in three phases:

- *Phase 1 (1967–85):* INMETRO was extensively supported in establishing the national metrology laboratories.
- *Phase 2 (1985–95):* The scope was broadened to also include the calibration laboratories and the accreditation system, thereby enhancing the QI system as a whole.

- *Phase 3 (starting in 2002, with new agreements signed):* PTB and INMETRO established a more horizontal arrangement, operating as equal partners in metrological research and dissemination of knowledge.

This narrative describes the first two phases; the third phase is still operational and is not covered. Table 1 summarizes the overall results of QI reform in Brazil.

Phase 1: National metrology laboratories

PTB's involvement can be described as a matrix. On one level, it consisted of three modes—support in training, facilities, and equipment. These modes were implemented in a number of activities, namely scientific metrology, legal metrology, and accreditation. The amount and kind of support were continuously aligned with the needs as determined at the time.

Training. The Brazilian government took the first steps to strengthen metrology training by sponsoring the postgraduate training of 40 metrology students at the Federal University of Rio de Janeiro in 1975 and 1976. Many of these students joined INMETRO. Twenty of them were sent to PTB in Germany for about 18 months to be trained in high-technology metrology. On their return, they became the core around which INMETRO was developed. In the years following, PTB seconded a number of highly trained metrology experts to INMETRO, some of whom were involved for quite a few years, and others for shorter periods.

Facilities. The Brazilian government also took the first steps to establish its metrology facilities by providing funds for new INMETRO laboratories in 1971. Additional funds were made available from the Program to Support Scientific and Technological Development (PADCT), which was funded by the World Bank. Unfortunately, the completion of the buildings took many years because of bureaucratic idiosyncrasies and funds that were not forthcoming from subsequent governments. This procrastination had serious implications for the

TABLE 1 **Snapshot of quality infrastructure (QI) reform in Brazil**

BEFORE REFORM	AFTER REFORM
Brazil's National Institute of Metrology, Quality and Technology (INMETRO) is established in 1971, but its services relate mostly to legal metrology and a little bit of calibration.	INMETRO is the recognized national metrology institute (NMI) of Brazil; it has realized national primary measurement standards, and a vast number of independent calibration laboratories have been established.
INMETRO does not have any international recognition.	INMETRO has advanced to a globally well-respected NMI and is in the top 20 in calibration and measurement capabilities (CMCs) listed in the BIPM's Key Comparison Database.
Brazil does not have a national accreditation body, and the metrology division of INMETRO provides some recognition of calibration laboratories as a stopgap measure.	Brazil has a national accreditation body, the General Coordination for Accreditation (CGCRE), which is a signatory to the ILAC and IAF mutual recognition arrangements.
Brazilian manufacturers have to rely on accredited laboratories abroad to test their products for international markets. This is an expensive and time-consuming challenge.	Brazilian manufacturers enjoy the services of Brazilian conformity assessment service providers that have been accredited and whose measurements are traceable to international standards through INMETRO.

Note: BIPM = International Bureau of Weights and Measures. IAF = International Accreditation Forum. ILAC = International Laboratory Accreditation Cooperation.

development of INMETRO because new equipment could not be delivered and commissioned for months, sometimes years. By 1989, some of the buildings were still not completed, but fortunately that did not have a further impact on the PTB project.

Equipment. PTB's technical support started with the calibration of the metrology equipment already in use by INMETRO. This provided traceability to international standards that had been lacking up to that point, and results from calibrated instruments of the industry were accepted internationally for the first time. PTB provided some serious high-technology measuring equipment from 1971 until 1985, valued at DM 5.1 million.[1] This was necessary because the government had placed a ban on the importation of any electronic equipment and components until 1985. Thereafter PTB still provided equipment worth DM 0.7 million until 1995, even though INMETRO was able to source funding from the PADCT program.

Once the high-technology equipment was commissioned, INMETRO took the next step—realizing its own primary measurement standards. The international standards for the base units of the International System of Units (SI) are definitions in terms of natural constants, and each national metrology institute (NMI) has to build a piece of equipment to realize this definition in the real world. In this, INMETRO was initially supported by PTB expertise, but slowly INMETRO developed its own, ably supported by the workshop that had been established with PTB support in the meantime.

The next step for INMETRO was to gain international recognition of its prowess through the listing of its calibration and measurement capabilities (CMCs) on the Key Comparison Database (KCDB) managed by the International Bureau of Weights and Measures (BIPM). Such a listing is possible only after interlaboratory comparisons between INMETRO and other recognized NMIs, followed by a peer review of the results.

INMETRO listed its first CMC in 1994, after which progress was fairly rapid. Between 1994 and 2000, Brazil participated in 15 intercomparisons, of which 10 were in fields in which PTB provided support. By 2012, Brazil had participated in almost 150 comparisons, the 16th-highest number in the world. INMETRO had taken about three decades to advance from an insignificant calibration laboratory to a globally respected NMI with PTB support—a position that has since been further reinforced.

Phase 2: Calibration laboratories and accreditation system

During the second phase of PTB involvement, the focus shifted more to the independent calibration laboratories. No accreditation body had been established in Brazil; hence, the metrology division of INMETRO started "recognizing" calibration bodies after assessing their technical competency in accordance with INMETRO's own requirements.

Once ISO/IEC Guide 25 (the forerunner of ISO/IEC 17025, "General Requirements for the Competence of Testing and Calibration Laboratories") was published in 1990, the calibration laboratories needed to get properly accredited.[2] The accreditation activities were moved to an independent accreditation division in INMETRO, the General Coordination for Accreditation (CGCRE). This paved the way for the CGCRE's recognition by the International Laboratory Accreditation Cooperation (ILAC) and International Accreditation

Forum (IAF) in 2000 and 2008, respectively. The Brazilian calibration system has become an important part of the overall QI, and its international recognition through accreditation even more so.

COUNTRY CONTEXT

General background

Brazil is the largest country in South America. As the world's fifth-largest country by both area and population, it is the largest country to have Portuguese as an official language—and the only one in the Americas. Bounded by the Atlantic Ocean on the east, Brazil has a coastline of nearly 7,500 kilometers. It borders all other South American countries except Ecuador and Chile and covers 47.3 percent of the continent's land area.

Brazil's economy is the world's ninth-largest by nominal gross domestic product (GDP) and seventh-largest by GDP (purchasing power parity, PPP) as of 2015. A member of the BRICS group,[3] Brazil until 2010 had one of the world's fastest-growing major economies, with its economic reforms giving the country new international recognition and influence. But this was not always the case.

The economy in the 1970s and 1980s

In the late 1960s and early 1970s, growth of Brazilian exports exploded (for example, doubling from 1971 to 1973). Equally impressive was the increase in industrialized goods (for example, from 28 percent of total exports in 1971 to 40 percent in 1974). Hence, the quality of exported goods increasingly became an issue as economic operators needed to overcome the technical barriers to trade in Europe and the United States. Evidence of product conformity to standards and technical regulations frequently had to be provided by organizations outside Brazil and even South America because the national institutions lacked technology and international recognition. This was expensive and put Brazilian products increasingly at a disadvantage in these markets (Gonçalves 2013).

Furthermore, all through the 1970s, Brazil experienced what can be identified as a high-technology deficit concerning its trade balance. In 1972, for example, it was on the order of US$450 million, and it was projected to grow to US$1 billion as local companies were growing and demanding more and more high-technology equipment in support of their activities (Gonçalves 2013).

Hence, technological autonomy became a stated goal of the government. With funds from the World Bank and assistance from the United Nations Industrial Development Organization (UNIDO), the Program to Support Scientific and Technological Development (PADCT) was designed, with an emphasis on high-technology industries such as electronics, chemistry, and aeronautics. The PADCT had a 1973–74 budget of US$700 million (Gonçalves 2013).

In addition, in 1971, the Brazilian government decided to build a 750 megawatt nuclear power plant in Angra dos Reis (a city in the state of Rio de Janeiro) because improving the energy supply was an important aspect of Brazilian industrial development. The Companhia Brasileira de Tecnologia Nuclear, which was given the responsibility for planning and implementing the country's electro-nuclear energy program, was established at the same time. Brazil also signed an agreement with Germany in 1975 to transfer nuclear energy technology.

All of this required a high level of technology, and the nuclear energy industry was to benefit from the PADCT as well.

ISSUES TO BE ADDRESSED

One of the many issues that had to be addressed to close the obvious technology gap in the late 1960s and early 1970s was the lack of a sophisticated and internationally recognized metrology system. In 1961, the National Institute for Weights and Measures (INPM) was established. The INPM provided a very small set of services related to trade metrology, without any international recognition and without any department specifically dedicated to scientific metrology.

Then, in 1967, regulatory agencies for weights and measures were established at the state level to enforce trade metrology regulations in the 27 states making up the vast territory of Brazil. In the same year, a national metrology policy was promulgated with the force of law. This policy determined that Brazil would exclusively use the SI for measuring units and that the country should become involved in BIPM and International Organization of Legal Metrology (OIML) activities at the international level.

Even though the Brazilian government had started to establish the national metrology system in the early 1960s, its efforts were focused on developing Brazil from within, and it was not yet ready to accept support from outside. This stance changed somewhat in the early 1970s, as the government started to consider the importance of incorporating foreign technologies in national entities as a measure for faster economic growth. Insights of senior INPM management, gained during visits to PTB in the early 1970s, were key in developing a new strategy for the development of the Brazilian metrology system.

This new strategy allowed Brazil, from the mid-1970s until the late 1990s—a relatively short time for such endeavors—to establish a well-respected national institute, INMETRO. INMETRO is a key organization in the wider QI of Brazil that is overseen at the policy level by the National Metrology, Standardization and Industrial Quality Council (CONMETRO), chaired by the Minister of Development, Industry and Foreign Trade.[4]

During this period, sound investments were made by the Brazilian government in INMETRO, and technological capacity was enhanced with the assistance of international agencies and through cooperative agreements with other more-advanced national institutes, primarily PTB regarding metrology. Over and above its standing in the international metrology community, PTB's role as the major technology partner was strengthened by the 1975 agreement between Germany and Brazil regarding the transfer of nuclear energy technology. During PTB's long involvement with INMETRO, its position changed from a senior technology provider to an equal partner with INMETRO in pursuing specific metrology goals.

OBJECTIVES AND PROJECT COMPONENTS

The development of metrology in Brazil can be seen as following three distinct phases:

- *Phase 1 (1967–85)* was primarily concerned with the establishment of INMETRO and developing its capabilities.

- *Phase 2 (1985–95)* had a broader scope and considered the conformity assessment system as a whole, with the metrology component focusing more on a network of calibration laboratories and an accreditation body.
- *Phase 3 (starting in 2002)* envisaged a more horizontal cooperation in scientific and technology fields, with PTB and INMETRO as equal partners.

This narrative focuses largely on the development of INMETRO during 1967–95, the period in which INMETRO was established and reached international recognition. The developments after 2002 are not discussed in this publication.

Phase 1: Establishment of INMETRO

In 1967, a first agreement between the Brazilian government and PTB was signed. The objective of this agreement was to establish (a) a public institution in Brazil that would be responsible for the realization and dissemination of international measurement standards and methods within Brazil, and (b) an increased awareness of legal metrology. The components included a variety of measures focusing on scientific and industrial metrology, such as

- Consultancy on the establishment of the metrology laboratories of INMETRO;
- Supply of equipment for scientific and industrial metrology and their initial calibration;
- Training of Brazilian professionals through long- and short-term stays of PTB experts in INMETRO and similarly of INMETRO staff in PTB;
- Transfer of technical literature and documentation; and
- Seminars and consultations.

The signing of the nuclear agreement between Germany and Brazil in 1975 reinforced the agreement between the Brazilian government and PTB. Sophisticated technology in almost all metrology fields had to be established to support processes and safety measures for the production of nuclear energy. PTB had the necessary expertise, and the 1967 agreement was appreciably enhanced from 1976 to 1985.

In 1971, the government allocated funds to build the National Centre for Metrology, and in 1973 a new law was promulgated establishing the modern QI of Brazil.[5] The INPM's responsibilities were extended, and the INPM was henceforth known as INMETRO. But it would take some years before the new buildings were completed and the measurement equipment installed and commissioned. In the meantime, the training of INMETRO staff was intensified, and German experts were sent to Brazil for longer periods to support the establishment of INMETRO's metrology laboratories.

Phase 2: Extending the QI

The second phase of establishing the QI of Brazil lasted from about 1985 to 1995, after which time the agreement between the government of Brazil and PTB came to an end. During this second phase, the demand for quality management system certification of companies involved in international markets increased dramatically after the publication of ISO 9001 ("Quality Management Systems—Requirements") in 1987.[6] The requirements for quality management systems, such as ISO 9001, included calibration of companies' measuring equipment in production and testing.

Hence, the need for competent calibration laboratories rose dramatically in Brazil. Moreover, exporting companies had to have their products tested in accredited laboratories in order to gain acceptance in foreign markets.

This second phase of PTB support was therefore marked by the establishment of calibration laboratories and the parallel establishment of a national accreditation body. The Brazilian government designated INMETRO as the only national accreditation body it would recognize. Because INMETRO did not provide any conformity assessment services, this combination of metrology and accreditation, even though unusual, did not constitute a conflict of interest because calibration is not considered to be a conformity assessment service.

During the second phase, the new buildings of the National Centre for Metrology were completed with significant technical input from PTB experts seconded to INMETRO and from senior INMETRO staff who had spent many months at PTB laboratories in Braunschweig, Germany. An unforeseen key outcome was the establishment of workshops through PTB expertise that could maintain and repair INMETRO's extensive body of measuring equipment. PTB experts were also instrumental in supporting the nascent accreditation body in INMETRO, the CGCRE, in its first steps to ultimately gain international recognition through ILAC and the IAF in 2000 and 2009, respectively, under a United Kingdom Accreditation Service (UKAS) project.

Phase 3: Equal partners

INMETRO's status increased continuously during the latter part of the 1990s. Hence, the third phase of cooperation between INMETRO and PTB had a totally different character. Signed in 2002, the new agreement was no longer characterized by one organization supporting the other directly but by two organizations that would engage as equal partners in research and dissemination projects, reflecting the capacity built in the preceding years. The activities centered on scientific, industrial, and legal metrology as well as accreditation, and both parties included their priorities in the agreement regarding metrology in chemistry and other advanced fields of metrology.

INMETRO became a close partner of PTB for the dissemination of metrological knowledge in both Latin America and Africa, especially in countries that hardly had any metrology infrastructure established (for example, in Mozambique, where Portuguese is also the spoken language). In this sense, the capacity development of INMETRO through PTB allowed it to gradually become an equal partner, and ever since, the two organizations have engaged in cooperative projects in research and development.

German investment

Germany's investment in the project is demonstrated in three areas (PTB 1995): (a) project finances provided by the Federal Ministry for Economic Cooperation and Development (BMZ), (b) PTB personnel seconded to Brazil, and (c) the equipment provided.[7]

Project finances. The BMZ provided the following in direct project funding:

- *Funds earmarked in 1969:* DM 2.682 million
- *Funds added in 1977:* DM 3.500 million

- *Funds added in 1985:* DM 3.079 million
- *TOTAL:* DM 9.261 million.

PTB personnel. PTB seconded three long-term experts to INMETRO in Brazil. Those experts performed the following:

- *Establishment of mechanical workshop:* March 1981 to October 1995 (55 worker-months)
- *Scientific consultancy:* July 1983 to December 1987 (54 worker-months)
- *Establishment of electrical workshop:* September 1986 to December 1989 (39 worker-months).

In addition, PTB provided short-term experts to Brazil, as follows:

- *1981–87:* 5 short-term experts, approximately 5 person-months
- *1988–91:* 5 short-term experts, approximately 5 person-months
- *1992–93:* 11 short-term experts, approximately 5 person-months.

The costs for these and other PTB personnel involved in the project amounted to about DM 5.4 million from 1985 to the project's end in 1995. The earlier PTB personnel costs were not specifically identified.

Equipment. The value of equipment supplied by PTB to Brazil was as follows:

- *Until 1985:* DM 5.1 million
- *1986–95:* DM 0.7 million
- *TOTAL:* DM 5.8 million.

PROJECT DESIGN AND IMPLEMENTATION

The development of metrology in Brazil is probably best understood within a matrix of modes and fields of cooperation. The capacity building in INMETRO could be characterized as consisting of three main modes—training, equipment, and facilities—each of which received more or less attention depending on the situation at the time. These modes applied to various fields of cooperation, first in scientific and industrial metrology because this was identified as the major need for Brazil in the beginning. Second, some work was also done in legal metrology, although to a much lesser extent than scientific metrology. Finally, accreditation was targeted in the latter part of the INMETRO development, when accreditation rose to prominence globally in the 1990s.

Modes of cooperation

Training

Brazil started a process of training young researchers in the metrological field in 1975 and 1976 through a project called Criptônio, which had two phases. The first phase consisted of full-time postgraduate courses of a year for engineers, whereby 40 students were trained in the various fields of metrology. This took place at the Federal University of Rio de Janeiro, which was considered to be the biggest research and educational institute for engineering in Latin America. On completion of the postgraduate course, many joined INMETRO and teamed up initially with foreign experts through a UNIDO program to design and build the new INMETRO laboratories.

In the second phase, many of these postgraduate students went to Germany under the PTB cooperation agreement, to stay for roughly a year and a half. They spent the first five months learning German, and the rest of the time either at PTB in Braunschweig (those working in scientific and industrial metrology) or at the German Metrology Academy (DAM) in Munich (those working in legal metrology).[8] Between 1980 and 1982, about 20 INMETRO metrologists went to Germany for this intense training. These long stays were later augmented by a number of short courses and technical visits by INMETRO personnel to PTB over the years. During 1971–87, there were 20 such visits, which increased to 38 visits in 1988–94. The Brazilian government financed some of these; others were partially financed by PTB.

But this training arrangement also presented some serious challenges. As a result of the extreme technical requirements in the field of scientific metrology, the duration of stay in Germany for trainees had been set very high. Owing to the still-limited human resources in the scientific metrology field at INMETRO, not all the envisaged training could be initiated. Staff were sometimes simply indispensable for the daily business operations, and INMETRO could not take leave of them for 15–18 months, over and above the stress of being away from their families for such long periods. These training programs were therefore curtailed after 1981 and partly replaced by PTB experts seconded to INMETRO in Brazil for varying lengths of time to provide for the training locally.

Three of the PTB experts involved in general scientific support and the construction of the mechanical and electrical workshops were involved for many years, whereas those with more-focused missions came for single, short periods only. There were 5 visits of short-term experts in 1981–87, also 5 in 1988–91, and a final burst of 11 experts in 1992–93.

Equipment

Initially, INMETRO had a significant deficit in modern and accurate measuring equipment. It was therefore of vital importance that sound investments be made to overcome these deficiencies in order to build the required capacity in INMETRO. Not only was new equipment required, but the equipment already installed also needed maintenance and especially spare parts to get it fully operational again. Unfortunately, until 1988, there was an import ban on all electronic components and devices. Because much of the measuring equipment was not designed in Brazil with local components, this ban increased the difficulties of keeping the equipment operational. The bureaucracy associated with importing equipment for INMETRO further exacerbated the situation.

PTB played a significant role in alleviating this situation. First, it donated a massive amount of high-technology measurement equipment to various divisions of INMETRO. Up until 1985, the value of donated equipment reached DM 5.1 million. From then until the end of the project in 1994, equipment worth a further DM 0.7 million was provided, even though INMETRO received funds through the PADCT of the World Bank from 1985 onward. PTB-sponsored equipment included some large-scale measuring equipment:

- A Kösters comparator for length measurement with accessories
- A high-precision, three-coordinate measuring machine with computer-controlled evaluation and calibration
- Two heavy-duty precision weighing scales, of 500 kilograms and 5,000 kilograms, with calibration mass pieces

- A 1 kilogram, high-accuracy comparison scale with accessories and a 1 kilogram primary standard
- A geodetic base with measuring microscopes, scales, a 1 meter comparator, temperature measuring instruments, and auxiliary equipment
- A gear-measuring machine with evaluation electronics and accessories.

Second, PTB provided INMETRO with technical support to start building its own measuring equipment. This was as important as the donated equipment in overcoming the barriers to imports. It had the further benefit of improving the staff's equipment maintenance skills, because equipment brought in from the outside was frequently seen as a "black box" by the technicians, which they were reluctant to work on.

Third, PTB scientists visited universities all over Brazil to determine their capabilities regarding metrology. In many cases, they also brought their equipment to INMETRO, where it was well used, thereby limiting the negative impacts of the ban on imported electronic equipment.

Facilities

The facilities to house all the new measuring equipment had to be provided by the Brazilian government. Some funds were already approved in 1971 for the construction of the National Centre of Metrology. The buildings were designed by Brazilian architects, but further funds were required. These were eventually sourced from the World Bank's PADCT program. Because the PTB president had been on the PADCT advisory board for many years, he was able to successfully argue the importance of metrology for the technological development of Brazil, thereby facilitating the approval of the necessary funds to complement those of the Brazilian government for the construction of the metrology laboratories.

Some senior personnel of INMETRO also visited PTB in Braunschweig, where they gained firsthand knowledge of the requirements for specific metrology laboratories. This information was extremely valuable in guiding the design of the buildings by the Brazilian architects. German specialists stationed at INMETRO provided further input into the design. One such example dealt with the energy efficiency of the buildings. For high-precision work, laboratories require sophisticated temperature controls. If the buildings are too big (that is, contain vast amounts of unused space), these have to be temperature controlled as well, substantially increasing their running costs. The specialists were able to limit the size of laboratories to more practicable dimensions.

The completion of the buildings took a long time. This procrastination was a major stumbling block for the timely implementation of much of the cooperation agreements, especially the provision and commissioning of equipment, which had to be postponed sometimes for months, even years. INMETRO, as a government agency, as in many countries, had its limitations in expediting decisions within agreed-upon time frames. The political turmoil in Brazil—with governments coming and going and new governments rescinding decisions of previous ones—also contributed to this state of affairs, as did the overly bureaucratic systems ostensibly designed to curb the rampant corruption in state purchases.

From 1985 onward, expertise for large-scale facilities was no longer provided by PTB because INMETRO was able to source the necessary credits as a PADCT beneficiary for the procurement of laboratory facilities and equipment.

Fields of cooperation

Scientific and industrial metrology

The main areas for cooperation in scientific and industrial metrology encompassed mechanical, temperature, electrical, optical, acoustics, and vibration-related metrology. Industries such as aeronautics, automotive, naval, nuclear, and others needed calibration services that were traceable to international measurement standards. Until the 1980s, INMETRO could not provide such a service; hence, foreign NMIs had to be used. Once PTB got involved, it was able to provide the traceability for the INMETRO working standards at the beginning and to foster a more professional approach in service delivery. This slowly started to increase the confidence of industry in INMETRO, which in turn reduced costs for companies because they could now obtain calibration services in Brazil where previously they would have sent their instruments abroad.

The young Brazilian metrologists who spent considerable time in PTB laboratories in Braunschweig at the beginning of the 1980s came back to INMETRO with a wealth of knowledge. The dedication of some of these metrologists—in spite of the many challenges regarding funding, buildings, bureaucracy, political turmoil, and the like—was absolutely vital in getting the laboratories established and functioning properly. Many of them would go on to become the managers of the various laboratories within INMETRO. The long-term presence of selected German specialists in some of these laboratories also proved to be instrumental in enhancing their capabilities. Some examples of this progress are described below.

Mechanical metrology. Because mechanical metrology is fundamental to many industrial and regulatory fields, INMETRO pursued a wide range of activities, including mass, length, force, pressure, roughness, and fluids. In most of these, PTB played an important role, but INMETRO also had the support of Italy's National Metrological Research Institute (INRiM).

Many of these laboratories started life as pure calibration laboratories, but their working standards were not yet traceably calibrated to international standards. Some were still in the old buildings, waiting for the new buildings to be completed. Others had to wait for the new laboratories to be completed. Work started by calibrating the older working standards in PTB, and thereafter the older measurement standards were progressively replaced by more modern, more accurate ones. Major modern mechanical measuring equipment was donated by PTB (as listed earlier in the "Equipment" subsection).

Acoustics and vibration metrology. The development of acoustics and vibration metrology was considered vital for the automotive and aeronautics industries. In some respects, this metrology domain probably profited more from PTB cooperation than any other. Work started soon after the first group of metrologists came back from Germany in 1981, progressed slowly, and by 1996 INMETRO was able to establish its own primary standards. After 1999, it was no longer necessary to have the national standards calibrated by PTB, and INMETRO was able to do so by itself and to support major independent laboratories in Brazil in achieving their accreditation. INMETRO also became the source of acoustics and vibration measurement technology within the region, with Bolivia, Colombia, Peru, and the República Bolivariana de Venezuela being among the recipients.

Temperature metrology. Temperature is a core metrological issue, important to most measurements in other fields, and therefore it received ample support from PTB. This laboratory also profited from the long-term training periods of young metrologists in 1980 and 1981 in Germany. They came back with the necessary knowledge to establish a new temperature calibration laboratory; INMETRO did not have one at that stage. The need for accurate high-temperature measurements came primarily from the safety requirements in the nuclear power and petroleum industries. The technical prowess of the temperature laboratory has developed to such a level over the years that PTB and INMETRO ran combined research projects from 2002 until 2007 to develop thermocouples to measure high temperatures between 900 degrees Celsius and 1,500 degrees Celsius, for example.

Optical metrology. The optical metrology laboratories were a much later addition to INMETRO. These were established in the mid-1990s. One of their first achievements was enabling INMETRO to realize the national standard of the meter from its international definition and basic principles. An indirect consequence of this challenging achievement was that INMETRO metrologists went on to establish the fields of cryogenic radiometry and goniophotometry in Brazil. Later, a polarimeter and saccharimeter were also developed.

Electrical metrology. After mass, length, and volume (required in trade metrology), electrical metrology is usually one of the first fields to be established in a country because it is important for industry, and other metrological fields require their equipment to comply with electrical standards in order to get traceability for their own measurements. It is also relatively easy to establish in terms of technology and costs.

This is another area that benefited from the first group of young metrologists trained in Germany in 1980 and 1981. As soon as they returned home, the first electrical metrology laboratory was established with financial support from local financial institutions. In 1985, the laboratory was already providing calibration services to laboratories relating to voltage sources, instruments, and inductors. This division also had strong support from a PTB expert who stayed at INMETRO from 1983 until 1987. A major achievement was when it was able to provide calibration serves to the multinational company General Electric in the field of power meters.

Metrology in chemistry

Metrology in chemistry is a relatively recent field. The major NMIs—like PTB in Germany and the National Institute of Standards and Technology (NIST) in the United States—only created their metrology-in-chemistry divisions in the late 1990s. In 1997, this field received a significant boost with the publication of ISO Guide 32 ("Calibration in Analytical Chemistry and Use of Certified Reference Materials").[9]

INMETRO created its chemistry division in 2000 because this was a field subject to increasing demand from Brazilian industries. It was considered strategically important to realize a primary method for pH measurement, which would facilitate the production of certified reference materials (CRMs) by INMETRO, which nobody in Brazil had been able to do up to that point.

An INMETRO metrologist spent time in 2001 at the PTB laboratory in Braunschweig, where basic research in this field was being conducted.

On returning to Brazil, a laboratory was established with financial support from Brazilian institutions, with the INMETRO workshop instrumental in building the necessary equipment. The pH primary system was inaugurated in June 2003, but it still had significant levels of uncertainty. In 2004, PTB metrologists conducted the peer review of the INMETRO pH primary system to determine its CMC. This was an important step to improve the system and reduce uncertainty. By 2007, the uncertainty of the primary pH system was reduced to the same level as that of the best NMIs, and CRMs to calibrate other laboratories' pH meters were being produced. These were considerably more cost-effective than imported CRMs from NIST and elsewhere, thereby saving scarce foreign currency for their users.

Accreditation

As noted earlier, the second phase of the first cooperation agreement between the Brazilian government and PTB placed a stronger emphasis on broader QI development, not only on metrology. Hence, accreditation also became a focus of capacity development. The development of the accreditation system in Brazil cannot be understood without considering the Brazilian Calibration Network created in 1980. This network of calibration laboratories was established to offer calibration services to meet rising demand due to the industrialization process under way in Brazil.

These laboratories needed some form of recognition—that is, "accreditation"—and their reference standards had to be calibrated traceably to international standards. The calibration part was conducted by INMETRO, whose standards had been calibrated by PTB, thereby providing those standards with traceability to international standards. Because there was no independent body to conduct accreditation, the scientific and industrial metrology division of INMETRO started doing so in 1985 as a strategic activity. It was not called accreditation ("acreditação") at that stage because that terminology was not yet in use, but was instead called endorsement or authorization ("credenciamento").

A further significant development in the accreditation system in Brazil took place in 1992 after the publication of ISO/IEC Guide 25 (today, ISO/IEC 17025). This international standard, which Brazil adopted as a national standard, provided clear guidelines for laboratory accreditation. In 2000, a newly created division for quality assurance within INMETRO, DQual, took over accreditation activities, ultimately morphing into a fully independent division of INMETRO, the CGCRE. Although the design of the CGCRE was largely modeled on the U.K. accreditation body (UKAS), the involvement of experts from the PTB-aligned German Calibration Service (DKD) was also relevant for the development of the accreditation system in Brazil. Already in 2000, the CGCRE obtained international recognition through ILAC, making Brazil the first country in Latin America to do so and one of the original signatories to the ILAC Mutual Recognition Arrangement.

Workshops

It was soon apparent that equipment maintenance was a major challenge for INMETRO because no organizations in Brazil were capable of performing it. The situation was further exacerbated by the government's ban on the importation of any electronic equipment or components. Therefore, PTB provided long-term technical assistance to INMETRO to establish, first, a mechanical workshop and, later, an electrical workshop. The mechanical workshop was established in 1982, and PTB provided guidance on the list of equipment to be purchased for the repair workshop, the selection of human resources to work in the facility, and the training of personnel, including support for their participation at training events outside the institute. Some of the equipment was provided by PTB.

The workshop proved to be an important strategic decision; without it, INMETRO would have been hard-pressed to maintain its high-technology measuring equipment in a timely manner. Furthermore, the workshop played a decisive role in the development of new measuring equipment, especially in the design and manufacturing of high-technology primary measurement standards. Outsourced services of this kind (if outsourcing would have been possible in the first place) would have been much more expensive and time-consuming. The workshop served not only INMETRO laboratories but also some partner laboratories under specific cooperation initiatives.

STAKEHOLDERS AND THEIR ROLES

Many stakeholders in addition to PTB were involved in the development of INMETRO. Their involvement, however, was not always supportive but rather frequently created additional challenges that had to be overcome, as described below.

The government

The government's involvement was a checkered one. In the initial stages, it was a supportive partner in the development of INMETRO. The government was the main instigator of the cooperation agreement signed with PTB in 1967, which was strengthened in 1975 to support the nuclear energy cooperation agreement signed between the German and Brazilian governments. On the other hand, bureaucratic systems made it virtually impossible to obtain any sort of equipment or buildings within meaningful time frames. The provision of resources after this initial enthusiasm became difficult and subject to the whims and fancies of the government in power.

The years of delay in completing only some of the buildings was explained by fiscal problems that new governments inherited and by the lack of a binding contract for their completion. Some of the resources for personnel and operation of facilities, as well as for the trainee specialists, were eventually provided, albeit with much trouble and sometimes considerable time delays. The government did not allow INMETRO to appoint new personnel for many years, and the departures of highly trained technical staff (because of the much better salaries offered by private industry) left INMETRO without adequate numbers of skilled people to maintain service levels.

In the latter part of the project, it was not so much funds that were a problem but their timely utilization. In the wake of the corruption allegations against President Fernando Collor de Mello, administrative steps imposed also on INMETRO—such as the tendering process for even the smallest purchases—delayed for months the acquisition of replacement parts for the measuring equipment. After 1989, the situation normalized to some extent, and until the end of the project in 1995, the PTB project did not experience any further delays of significance, other than the uncompleted buildings and the selection and approval of trainees bound for Germany.

INMETRO

INMETRO, as the main beneficiary, did its utmost to respond to project requirements. The relationship with the donors was good, but it required immense patience from the donor side. The president of INMETRO changed quite a few times during the duration of the projects, and each new one had to be brought on board afresh. Development organizations such as UNIDO, as well as those from France and Japan, did not have the tenacity of the long-term PTB project, and their influence in INMETRO was soon no longer visible.

Universities

Before INMETRO was established, many of the universities had established metrology capacities in response to the expressed needs of industry. Some of these were quite capable; in fact, the first CMCs in Brazil were listed by these and not by INMETRO. PTB scientists were able to gain the universities' full support and cooperation, to the extent that some of their equipment was seconded to INMETRO. This helped a lot to circumvent the ban on the importation of electronic equipment by the government in the initial years. Some of the equipment remained at the universities, and PTB persuaded INMETRO to declare the relevant universities as designated metrology institutions under BIPM guidelines. This move enhanced the cooperation between the universities and INMETRO significantly and provided for a coordinated approach among several institutions regarding national measurement standards.

Industry

The major industrial entities such as the automotive industry had little trust in the capabilities of INMETRO and said so in many public forums. Hence, INMETRO's initial success was largely restricted to the small and medium enterprise (SME) sector, which lacked the access to resources that multinational companies had. Slowly, however, the multinationals also started to use INMETRO's services, especially after it was able to have some of its CMCs included in the KCDB of the BIPM. Many independent calibration laboratories were established and accredited during 1980–95, further enhancing the status of Brazil-based metrology services.

OUTCOMES

The establishment of INMETRO as a respected NMI in the international and especially in the regional metrology community was achieved through many incremental steps. All of these culminated in the listing of its CMCs in the international KCDB managed by the BIPM. Once INMETRO started to do so, it was able to increase the tempo of the CMC listings, with the result that it became one of the most prolific NMIs in the world in this regard. This was also the beginning of its recognition by Brazil's major industries, including automotive, aeronautic, and nuclear.

Calibration and measurement capabilities (CMCs)

International recognition of national metrology capabilities is founded on the realization of the international standard (which is a definition) for physical equipment called the primary measurement standard and determining its accuracy through interlaboratory comparisons between the NMIs of various countries. Once such comparisons have been verified in a peer review process, the NMI's CMC is listed in the KCDB managed by the BIPM, indicating the NMI's prowess in realizing the international standard. To get to this stage, however, is a long and technically challenging process.

The capacity to perform primary methods is one of the main challenges faced by any NMI. Realizing a measurement unit has various implications, primarily for the autonomy of the NMI to guarantee its traceability to international standards without requiring that its instruments be calibrated in foreign NMIs. Such a calibration process is not only more time-consuming but also implies higher costs for the NMI in the form of foreign exchange, which indirectly will be paid by the local industry and laboratory sectors.

On the other hand, bilateral comparisons with NMIs that have already participated in a key comparison are a faster way for a country to acquire calibration traceability to international standards. This was the situation for INMETRO by the end of the 1980s. The PTB cooperation agreement provided this opportunity to INMETRO in the beginning, which accelerated the expansion of its activities, namely regarding the calibration services provided to laboratories, giving them traceability to international standards. The financial side of this arrangement was adequately covered by PTB's agreement with the Brazilian government.

From that point on, it was a logical step for INMETRO to establish primary measurement standards of its own. Once this was achieved, it was no longer necessary for INMETRO to send its equipment to PTB for calibration, because establishing its own primary measurement standards allowed INMETRO to participate in interlaboratory comparisons within the context of the International Committee for Weights and Measures (CIPM) Mutual Recognition Arrangement (MRA). By 1995, Brazil had established primary measurement standards for the SI base units—length (meter), mass (kilogram), time (second), temperature (kelvin), electrical resistance (ohm), and luminous intensity (candela)—at basically the same level of accuracy as many industrialized countries. The measurement standards for derived units that are important for industry—such as force, viscosity, pressure, voltage, current, and so on—were also established, even though gaps remained.

Before 1994, Brazil had participated in only 13 key comparisons, none of them by INMETRO but by designated laboratories. Only in 1994 did INMETRO participate in its first key comparison. It was on direct current (DC) voltage (Josephson standards), which was a field in which PTB provided technical support. From 1994 onward, this situation started to change. Between 1994 and 2000, Brazil participated in 15 intercomparisons, 10 of which concerned metrological fields in which PTB had provided technical support. INMETRO's progress continued to evolve as, between 2000 and 2012, Brazil participated in 121 key comparisons and 29 supplementary comparisons, with a higher degree of diversification concerning the metrological fields. By 2012, Brazil had participated in almost 150 key comparisons, then the 16th-highest number in the world.

INMETRO's growth from the backwaters of calibration laboratories to a globally respected NMI had taken only three decades. This was an impressive performance by any measure, even more so considering the immense bureaucratic challenges that had to be managed and the political turmoil that had to be negotiated. This success was, to a large extent, possible only through the dedication of the metrologists involved and through the tenacity of PTB, which a few times had seriously considered withdrawing its support in the face of Brazil's ongoing political uncertainties.

Certified reference materials (CRMs)

In terms of the production of CRMs as the direct outcome of metrology in chemistry, INMETRO was able to increase the production thereof after the first one was successfully developed in cooperation with PTB by 2004 (as discussed earlier in the "Metrology in chemistry" subsection). In the same year, INMETRO produced another five CRMs, which increased to nearly 150 by 2011. This produced a major saving on foreign exchange for laboratories all over Brazil, because the necessary CRMs to validate their test procedures were now available in the country, whereas previously they had to be imported.

Accreditation

As a consequence of the capacity development of the QI as a whole, there were also developments in accreditation. The number of accredited laboratories in the Brazilian Calibration Network increased from 23 in 1991 to 51 in mid-1994, by which time another 26 were in the process of being accredited. By 2012, INMETRO had accredited more than 300 laboratories. In 2000, INMETRO became a signatory to the ILAC multilateral recognition agreement for ISO/IEC 17025, and, in 2013, for ISO/IEC 17020 ("Conformity Assessment—Requirements for the Operation of Various Types of Bodies Performing Inspection").[10] In 2009, it became a signatory to the IAF multilateral recognition arrangement for both ISO/IEC 17021 ("Conformity Assessment—Requirements for Bodies Providing Audit and Certification of Management Systems") and ISO/IEC 17065 ("Conformity Assessment—Requirements for Bodies Certifying Products, Processes and Services").[11]

The development of the accreditation system for laboratories in Brazil was important not only to industries but also to regulatory bodies of the Brazilian government like the National Health Surveillance Agency (Anvisa), National Telecommunications Agency (Anatel), and National Civil Aviation Agency (ANAC), which since 2005 required economic operators in their sectors to use the services only of accredited laboratories.

Finally, the development of accreditation was important for INMETRO because it allowed it to focus on metrological research and provide traceability to international measurement standards with the lowest level of uncertainty. The more basic industrial calibration activities could be left to accredited calibration laboratories, which otherwise would have been an impossible burden on INMETRO, especially given the size of the country. As the network of accredited calibration laboratories grew (from 3 in 1983 to 21 in 1995), the costs of metrological services also came down. For example, the cost of periodical verifications fell by almost 30 percent from 1982 to 1994, improving the competitiveness of local industry.

Financial sustainability of INMETRO

The establishment of an NMI and the expansion of its services requires significant investments in resources and time, especially in low- and middle-income economies that do not have the long history in this respect that technologically advanced countries do (such as Germany, the United Kingdom, and the United States). This financial burden is largely shouldered by the government. The benefits for the country only become apparent after years, and the financial sustainability of the NMI is continuously under pressure during this time. If the country faces political turmoil, this becomes even more problematic, as was the case in Brazil. Fortunately for INMETRO, it had another source of funds (that is, legal metrology), but even that eventually became problematic.

The primary sources for INMETRO metrology activities, other than government funds, are

- Calibration services and the sale of primary CRMs to the private sector;
- Income from legal metrology, namely fees or levies related to the implementation of technical regulations; and
- Services provided by the mechanical and electrical workshops, which give support to laboratories for maintenance and manufacturing of measurement instruments.

The revenue from legal metrology activities is a significant source for the INMETRO budget. In 1983, such revenues amounted to just over US$8.62 million, which was 51 percent of INMETRO's budget. By 1995, this increased to US$45.25 million (41 percent of the budget for that year)—five times more than in 1983 (Gonçalves 2013). However, legal metrology should not be conducted for the revenues it creates, and those that it does generate should be used for the development of the legal and scientific metrology. As scientific metrology develops, it should provide for more income, allowing INMETRO to reduce its dependency on the revenues from legal metrology.

But whether INMETRO will ever become self-sufficient is debatable. Almost all of the world's NMIs are dependent on government funds as an investment in the "public good" in some form. It can also be argued that if INMETRO is forced to become self-sufficient, there will inevitably be services it has to curtail. These services may not be financially viable on their own, but they may be strategically important for the country or they may be a basis for other organizations that do generate income. Losing them would therefore be detrimental to the country's technological development.

Impact on trade

The development of the QI was important for Brazil and its participation in international trade (Gonçalves 2013). Brazilian exports were US$51.1 billion in 1998, with a trade balance deficit of US$6.6 billion. In 2011, exports increased to US$256 billion, with a surplus of US$29.8 billion. An estimated 75–80 percent of these exports required demonstrable compliance with standards or technical regulations. This in turn requires accredited laboratories and certification bodies that are internationally recognized. For these to be internationally recognized means that the Brazilian metrology and accreditation system—in this case, INMETRO—must be internationally recognized.

If this were not so, then (a) Brazilian economic operators would have had to source laboratory and certification services from accredited laboratories abroad, or (b) the Brazilian laboratories would have had to gain accreditation from foreign-recognized accreditation organizations—both of which would have significantly increased the costs of Brazilian products, possibly rendering them uncompetitive. The situation would have been even more problematic considering that no other South American country had a QI that was internationally recognized at the time; in other words, the services would have had to be sourced from the United States and even farther afield.

A more direct measure of the impact of INMETRO's development can be gleaned from the business of the Brazilian instrument sector, which made significant improvements in terms of its exports (Gonçalves 2013). In 1997, instrument exports were only US$27 million, but these increased to US$121 million in 2011. This increase would not have been possible without INMETRO's provision of traceability to international standards with low uncertainties, as well as the system to transfer these measurements to the manufacturers' quality control systems. Even so, the instrument imports also grew seven times over the same period. This reflected the growing demands of industry for high-technology goods in the field of measurement and sustained concerns regarding the technological deficit. Nevertheless, INMETRO was certainly contributing to the growth of exports in this sector.

The scale and pressure gauge manufacturers are examples worth mentioning (Gonçalves 2013). In 1998, the trade deficit with respect to scales was US$3 million, which changed by 2004 into a surplus of US$3.4 million. Similarly, with the development of the force laboratory (which also received strong support from PTB), the Brazilian production of pressure gauges increased significantly, and the trade balance for pressure gauges evolved from a deficit to a surplus. In 1997–99, the average deficit was US$3.8 million per year. From 2004 until 2011, this changed into an average surplus of US$3.4 million per year. The exports of pressure gauges totaled only US$1.2 million in 1998, but increased to US$16.2 million in 2011.

PROBLEMS ENCOUNTERED: CHALLENGES AND ISSUES

A number of serious challenges had to be managed or negotiated. Many of them related to the political turmoil and instability Brazil experienced in the 1970s and 1980s.

Buildings

The Brazilian government was responsible for new laboratory buildings that were necessary to house high-precision metrology equipment. Although the Brazilian government allocated some funds already in 1971 at the beginning of the cooperation agreement, it took many years before some of the buildings were completed.

First, the Brazilian architects followed a then-common approach of designing the buildings to make a statement through size; they were much bigger than was required. Given the tight environmental controls (for example, temperature and humidity controls) that are required in such laboratories, the buildings' size would have resulted in a major drain on the electrical energy required to meet these requirements. Sound advice from PTB experts seconded to Brazil, as well as from senior INMETRO staff who visited Braunschweig (experiencing PTB laboratories firsthand), did help to deal with the issue to some extent, but it never went away completely.

Second, the funds allocated for the buildings were not adequate, and additional resources had to be found. Fortunately, some additional funds from the PADCT program funded by the World Bank could be accessed through the "good offices" of the PTB president, who was a member of the PADCT advisory board. His knowledge of the project helped to argue the case for the importance of metrology in the greater scheme of implementing the PADCT.

Third, the political turmoil in Brazil, with governments coming and going and new governments rescinding decisions of previous ones, contributed to this state of affairs, as did the overly bureaucratic systems ostensibly designed to curb the rampant corruption in state purchases. Successive governments pleaded a financial crisis inherited from previous ones and argued that there was no binding contract for the completion of the buildings anyway. Allocated funds were summarily scrapped. Within PTB, serious doubts were starting to surface as to whether the project would be successfully completed.

The completion of the buildings took years, and even by the end of the second phase of the cooperation activities between PTB and Brazil in 1995, some of the buildings had not been completed. This procrastination was a major stumbling block for the timely implementation of much of the cooperation agreement—especially for the provision and commissioning of equipment, which had to be postponed sometimes for months, even years. Fortunately, by 1989, most of the buildings required for the PTB project were available, and no further delays affected its implementation in this respect.

Materials and spare parts

The systematic procurement of materials and spare parts for the mechanical workshop was extremely difficult. The budget requested by PTB for repair and maintenance of high-precision instruments was finally approved after years of unsuccessful attempts. After a few more years, however, this budget was summarily canceled under a new Brazilian president. Furthermore, the Brazilian government had imposed a ban on the importation of electronic components and equipment until about 1988, making it difficult for PTB and other partners to source them outside Brazil. As a result, PTB had to include a specific paragraph to facilitate importation of electronic components in the agreement signed in 1985.

Staff and training

The initial group of Brazilian metrologists were sent to Germany for 15–18 months, of which the first few months were spent learning German. The allocated time for advanced training was considered necessary because of the technical complexity of establishing primary standards. The first batch of trainees had a major impact on the development of INMETRO, and many of them later became managers of various divisions.

After this first group, INMETRO did not wish to release further staff for such long periods, because they were now required to run the day-to-day business. The situation was exacerbated by the stress such a long training period put on the trainees being separated for months on end from their families. Unfortunately such training, as profitable as it was, could not be repeated.

Another major challenge was the general hold that the government had put on all state institutions regarding the appointment of additional staff—that is, no new staff under any circumstance. Because INMETRO was in a developmental phase, this hiring freeze put a tremendous strain on the staff contingent that was available to maintain service levels. This was further exacerbated by highly trained staff leaving INMETRO for better salaries in private industry. These individuals could also not be replaced. A minibreakthrough occurred only by the end of the second phase, when 20 metrologists were appointed in place of purely administrative personnel.

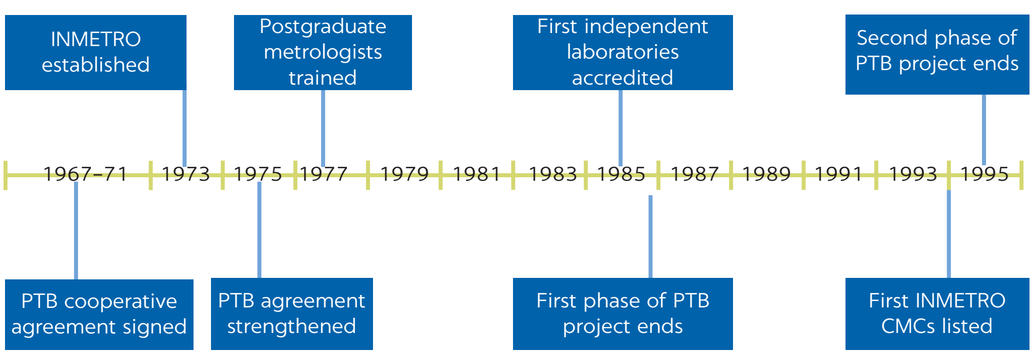
KEY SUCCESS FACTORS AND LESSONS LEARNED

It is not easy to isolate all the key success factors, because of the complexity of the whole project, especially through its first two phases (figure 1). But three factors stand out.

Gradual progression. The major lesson in the development of INMETRO through the unstinting support of the senior partner, PTB, is that it takes years to establish an NMI of note. It starts with small steps to calibrate existing measuring equipment and progresses through major steps such as the provision of appropriate laboratory buildings, in-depth training of metrologists, supply and commissioning of high-technology equipment, and ultimately the development of the requisite skills and technology to realize primary standards and establish the CMCs of these. Only when INMETRO had walked the whole journey—and internalized all the technical knowledge on offer from the world-renowned PTB—could it confirm its standing in the world of metrology. All of this took nearly three decades.

FIGURE 1

Timeline of INMETRO development and notable milestones, 1967–95



Note: CMCs = calibration and measurement capabilities. INMETRO = National Institute of Metrology, Quality and Technology. PTB = National Metrology Institute of Germany.

Long-term PTB support. Second, PTB's tenacity in staying with the project for nearly two decades was a major factor in INMETRO's eventual ability to develop into a globally respected NMI. PTB, in cooperation with INMETRO, had to negotiate many vagaries and procrastinations of the various governments in Brazil over the decades the project lasted, some of which PTB had to conduct on its own, as INMETRO also had its limitations.

Well-trained, dedicated metrologists. Third, the initial in-depth training of metrologists in Germany following their postgraduate training at the Federal University of Rio de Janeiro set the tone of technical excellence for the metrologists who worked during the beginning years at INMETRO. They were the ones who had the vision and the passion for new approaches that were so necessary for the future of the institution. They were the ones who took INMETRO forward over many years after becoming managers in its various divisions. Without these dedicated and well-equipped metrologists, INMETRO would have required a much longer period to develop into the well-respected NMI it had become by the end of the second phase of the project in 1995.

CONCLUSION

The long-lasting cooperation between INMETRO and PTB produced a multitude of impacts and benefits for both the NMIs and their respective countries. This was a comprehensive cooperation, covering a wide variety of fields and involving other countries.

For INMETRO as it was being established, the cooperation with the much more experienced PTB fostered the processes of capacity building because it was a way of getting sound technical input and reducing possible mistakes. Besides, the experienced PTB was able to provide INMETRO with credibility—namely through calibration certificates—once the latter was capable of meeting the necessary technical requirements. Combined with the development of a credible accreditation system, this helped Brazilian companies to gain access to foreign markets based on conformity assessment results that were internationally accepted.

Slowly, INMETRO was able to take the next step—realizing the first primary measurement standards, with PTB's support. Once these first primary standards were established and their CMCs determined, peer-reviewed, and listed on the KCDB of the BIPM, others followed. Thereafter, INMETRO was able to develop more CMCs on its own. It was now an equal partner of PTB and no longer the junior partner that had to be trained. From the experienced PTB and the German perspective, this meant getting a partner for future collaborations in research activities and helping to disseminate metrological knowledge, while it also facilitated the entry of German companies into the Brazilian market, because they share a similar measurement system, technical norms, and standards.

Metrology is a field that requires constant research and where the resources are never enough because it comprises activities that are complex, expensive, and require very specialized and qualified staff. Additionally, there is a wide variety of metrological fields—with new fields emerging in recent years, such as metrology in chemistry or materials metrology. Collaborating in such research activities would improve the results and reduce the costs incurred by each NMI. Furthermore, as the worth of metrological knowledge increases along with the number of economic actors using it, cooperative activities are likely to increase the number of users of the same metrological system, hence fostering the economic integration of countries and enlarging the networks through which companies can innovate.

NOTES

1. In this case study, German currency is expressed in deutsche marks (DM) in references to monetary value, costs, or expenditures up until 2002, when the euro was introduced.
2. ISO/IEC Guide 25:1990, "General Requirements for the Competence of Calibration and Testing Laboratories," was withdrawn when replaced by ISO/IEC 17025:1999 and has since been revised again as the current standard, ISO/IEC 17025:2017, "General Requirements for the Competence of Calibration and Testing Laboratories": https://www.iso.org/standard/66912.html.
3. "BRICS" refers collectively to five major emerging economies: Brazil, the Russian Federation, India, China, and South Africa.
4. Other key organizations in the QI of Brazil are the General Coordination for Accreditation of INMETRO (CGCRE), the Brazilian Association of Technical Standards (ABNT), and the Brazilian Association for Quality Control (ABCQ).
5. Law No. 5966 of December 11, 1973 (http://www.planalto.gov.br/CCivil_03/Leis/L5966.htm).
6. ISO 9001:1987, titled "Quality Systems—Model for Quality Assurance in Design /Development, Production, Installation and Servicing," has been revised five times. The current standard is ISO 9001:2015, "Quality Management Systems—Requirements": https://www.iso.org/standard/62085.html.
7. The DM (deutsche mark) was the German currency at the time. When the euro was introduced in 2002, DM 1.95583 (nearly 2 DM) was considered equal to €1.
8. The German Metrology Academy (DAM), based in Munich, was set up specifically for the training of metrologists in all fields of legal metrology. It is part of the Legal Metrology Department of Bavaria but is funded as a cooperative venture by all 16 German states.
9. ISO Guide 32:1997 has since been replaced by ISO Guide 33:2015, "Reference Materials—Good Practice in Using Reference Materials": https://www.iso.org/standard/46212.html.
10. For the current standard, see ISO/IEC 17025:2017, "General Requirements for the Competence of Calibration and Testing Laboratories": https://www.iso.org/standard/66912.html. Also see ISO/IEC 17020:2012, "Conformity Assessment—Requirements for the Operation of Various Types of Bodies Performing Inspection": https://www.iso.org/standard/52994.html.
11. For the current standard, see ISO/IEC 17021-1:2015, "Conformity Assessment—Requirements for Bodies Providing Audit and Certification of Management Systems—Part 1: Requirements": https://www.iso.org/standard/61651.html. Also see ISO/IEC 17065:2012, "Conformity Assessment—Requirements for Bodies Certifying Products, Processes and Services": https://www.iso.org/standard/46568.html.

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