Knowledge Sharing Program

2017/18 Knowledge Sharing Program with Colombia (II):

Sharing Experience of National Quality Infrastructure of Korea for Promoting Industrial Development of Colombia

Ministry of Economy and Finance

KDI Korea Development Institute

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Project Title Sharing Experience of National Quality Infrastructure of Korea for Promoting Industrial Development of Colombia

Prepared by Korea Development Institute (KDI)

Supported by Ministry of Economy and Finance (MOEF), Republic of Korea

Prepared for The Government of the Republic of Colombia

In Cooperation with National Planning Department (DNP)
National Metrology Institute (INM)
Colombian Institute of Technical Standards and Certification (ICONTEC)
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English Editor Korea Institute of Culture and Arts Translation

Government Publications Registration Number 11-1051000-000832-01

ISBN 979-11-5932-318-8
979-11-5932-302-7 (set)

Knowledge Sharing Program

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11-1051000-000832-01

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Preface

Knowledge is a vital ingredient that determines a nation's economic growth and social development. Its true value was brought to light by the advent of the knowledge economy and a key question policymakers now face, especially in developing countries, is how an environment can be established that encourages and facilitates the creation and dissemination of knowledge across the nation. This need has led many countries to engage themselves in active policy dialogue to share their development experiences and benefit from mutual learning.

Korea's development has also depended heavily on knowledge. Its remarkable transition from a predominantly agrarian economy to an industrialized country was made possible by its well-rounded and extensive understanding of technology, management, public policy, and other diverse issues acquired from domestic and foreign sources and through trial and error. Building on these rich experiences, the Ministry of Economy and Finance of Korea (MOEF) launched the Knowledge Sharing Program (KSP) in 2004 to assist partner countries to improve their policymaking. KSP, as implemented by Korea Development Institute (KDI), focuses on providing solutions customized to each country's economic, social and administrative settings, building capacity for effective policymaking and strengthening global networks for development cooperation. In 2017/18, KSP policy consultations were organized with 31 partner countries, with Mekong River Commission joining the partnership for the first time.

The 2017/18 KSP with Colombia (II) was undertaken by the MOEF and the National Planning Department (DNP) with the aim of "Sharing Experience of National Quality Infrastructure of Korea for Promoting Industrial Development of Colombia."

To that end, the KDI research team and the Colombian counterpart made a range of collaborative efforts by exchanging development experiences, conducting joint studies and designing a policy action plan in line with the country's development targets.

With that, it is with great optimism for the future of Colombia that the results of the 2017/18 KSP are presented. I firmly believe that KSP will serve as a stepping stone to further elevate the mutual learning and economic cooperation between the two countries and hope it will contribute to Colombia's sustainable development in the future.

I wish to convey my sincere gratitude to Senior Advisor Dr. Kook Hwan Bae, Principal Investigator Dr. Gyung Ihm Rhyu as well as project consultants Dr. Jong Oh Choi and Mr. Sangwook Seo for their extensive contributions to the successful completion of the 2017/18 KSP with Colombia. I am also grateful to Executive Director and Project Manager Dr. Youngsun Koh, Project Officer Mr. Hoon Heo, Mr. Seung-Hyun Kim and all members of the Center for International Development for their hard work and dedication. Lastly, I extend my warmest thanks to the DNP, INM, ICONTEC, MinCIT and related Colombian agencies for their active cooperation and great support.

Jeong Pyo Choi
President
Korea Development Institute (KDI)

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Strategy for Infrastructure of Testing and Measurement in Colombia

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ACRM: Asian Collaboration on Certified Reference Materials
ADB: Asian Development Bank
APLAC: Asia Pacific Laboratory Accreditation Cooperation
APLMF: Asia-Pacific Legal Metrology Forum
BAM: Federal Institute for Materials Research and Testing
BIPM: International Bureau of Weights and Measures
CCQM: Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology
CGPM: General Conference on Weights and Measures
CIC/IQC: Inter-sectoral Quality Commission
CIPM: International Committee for Weights and Measures
CIPM-MRA CIPM Mutual Recognition Arrangement
CMC: Calibration and Measurement Capability
CMN/RCM: Colombian Metrology Network
CMS: Chemical Metrology System
COSD: Cooperative Organization for Standards Development
CRM: Certified Reference Material
DAC: Development Assistance Committee
DAkks: Deutsche Akkreditierungsstelle (German Accreditation Body)
DAM: Deutsche Akademie füer Metrologie (German Academy of Metrology)
DANE: Departamento Administrativo Nacional de Estadística, Colombia
DNP: National Planning Department, Colombia
ERM: European Reference Materials
FIC: Fine Instrumentation Center
GRI: Government-funded Research Institute
HRD: Human Resources Development
IAA: Industrial Advancement Administration, Korea
IAEA: International Atomic Energy Agency
IAF: International Accreditation Forum
IBRD: International Bank of Reconstruction and Development
ICA: Colombian Farming Institute
ICONTEC: Colombian Institute for Standardization and Certification
IDEAM: Institute of Hydrology, Meteorology and Environmental Studies
IEC: International Electrotechnical Commission

IFCC: International Federation of Clinical Chemistry and Laboratory Medicine
IGSM / B-IGSM: Braunschweig International Graduate School of Metrology, Germany
ILAC: International Laboratory Accreditation Cooperation
IMEKO: International Measurement Confederation
IMQP: Integral Management of Quality and Productivity
INVIMA: National Institute for Food and Drug Surveillance
INM: National Metrology Institute of Colombia
IRMM: Institute for Reference Materials and Measurements
ISO: International Organization for Standardization
ITM: Instituto Tecnológico Metropolitano
ITU: International Telecommunication Union
JCTLM: Joint Committee for Traceability in Laboratory Medicine
JICA: Japan International Cooperation Agency
KAB: Korea Accreditation Board
KAS: Korea Accreditation System
KASTO: Korea Association of Standards and Testing Organizations
KATS: Korean Agency for Technology and Standards
KATRI: Korea Apparel Testing & Research Institute
KC: Key Comparison
KCL: Korea Conformity Laboratory
KEMTI: Korea Environment Merchandise Testing Institute
KETI: Korea Electronics Technology Institute
KICM: Korea Institute of Construction Materials
KIET: Korea Institute for Industrial Economics and Trade
KILT: Korea Institute of Lighting Technology
KIST: Korea Institute of Science and Technology
KLRI: Korea Legislation Research Institute
KOLAS: Korea Laboratory Accreditation Scheme
KOSIS: Korean Statistical Information Service
KOTITI: Korea Textile Inspection & Testing Institute
KR: Korean Register
KRISS: Korea Research Institute of Standards and Science
KS: Korean Industrial Standards

Contents | List of Abbreviations

KSA: Korean Standards Association
KSRI: Korea Standards Research Institute
KTC: Korea Testing Certification
KTR: Korea Testing & Research Institute
LNE: French National Laboratory for Metrology and Testing
MAS: Metrology-Accreditation-Standardization
MiC: Metrology in Chemistry
MinCIT: Ministry of Commerce, Industry and Tourism, Colombia
MMA: Ministerial Metrology Authority
MOCI: Ministry of Commerce and Industry, Korea
MOEF: Ministry of Economy & Finance, Korea
MOTIE: Ministry of Trade, Industry and Energy, Korea
MPI: Meter & Petrochemical Testing & Research Institute, Korea
MRA, MLA: Mutual / Multilateral Recognition Arrangement
NBS: National Bureau of Standards, US
NIM: National Institute of Metrology, China
NIST: National Institute of Standards and Technology, US
NITL: National Industrial Testing Laboratory, Korea
NLP: National Laboratory Policy
NLMI: National Legal Metrology Institute
NMA: National Metrology Authority
NMI: National Metrology Institute
NMIA: National Measurement Institute Australia
NMIJ: National Metrology Institute of Japan
NMS: National Metrology System
NPL: National Physical Laboratory, UK
NQC: National Quality Committee or National Quality Council
NQI: National Quality Infrastructure
NRCC: National Research Council Canada
NSB: National Standards Body
NSC: National Standards Council
NTC: Technical Standard of Colombia
NTS: Sectoral Technical Standard

NVLAP: National Voluntary Laboratory Accreditation Program, US
ODA: Official Development Assistance
OECD: Organization for Economic Cooperation and Development
OECF: Overseas Economic Cooperation Fund
OIML: International Organization of Legal Metrology
ONAC: National Accreditation Body, Colombia
PISA: Program for International Student Assessment
PT: Proficiency Testing
PTB: Physikalisch-Technische Bundesanstalt, Germany
PTMP: Professional Technician in Metrological Processes
PTP: Proficiency Testing Provider
QI: Quality Infrastructure
QMS: Quality Management System
RM: Reference Materials
RML: Reference Measurement Laboratory
RMO: Regional Metrology Organization
RMP: Reference Material Producer
SI: International System of Units
SIC: Superintendence of Industry and Commerce, Colombia
SICAL / SNCA: National Quality Subsystem, Colombia
SIM: Inter-American Metrology System
SME: Small and Medium Enterprises
SNCCTI: National Administrative System of Competitiveness, Science, Technology and Innovation.
SNCeI: National Administrative System of Competitiveness and Innovation, Colombia
SSLG: Sector-specific Laboratory Group
STE: Science, Technology and Engineering
STI: Science, Technology and Innovation
STEM: Science, Technology, Engineering and Mathematics
TBT: Technical Barriers to Trade
TC: Technical Committee
TIM: Technologist in Industrial Metrology
TU: Technische Universität (Technical University)
UNIDO: United Nations Industrial Development Organization

UST: University of Science and Technology, Korea
VIM: International Vocabulary of Metrology
VNA: Vector Network Analyzer
WHO: World Health Organization
WMO: World Meteorological Organization
WTO: World Trade Organization

2017/18 KSP with Colombia (II)

Hoon Heo (Project Officer, Korea Development Institute)

Knowledge Sharing Program (KSP) aims to share Korea's development experiences with the partner countries to foster creation and dissemination of knowledge that can contribute to promotion of sustainable socio-economic development in partner country. Specifically, through policy research, consultation, and human and institutional capacity building, challenges and obstacles partner countries face are carefully analyzed to come up with practical policy measures based on similar cases and experiences Korea by integrating policy research, development consultation, human and institutional capacity building.

KSP with Colombia was initiated in 2012, and has continued for five consecutive years on an annual basis which have contributed in fostering sharing of policy know-hows and experience between Korea and Colombia under various thematic areas including science and technology, local economy, industry and trade, SMEs and other important areas upon the request by the Colombian Government.

2017/18 marked the sixth year of the KSP with Colombia. 2017/18 KSP II with Colombia was conducted under the main theme of "Sharing Experience of National Quality Infrastructure of Korea for Promoting Industrial Development of Colombia". The following table illustrates a brief overview of this year's project, including the project title and the sub-topics, and the KSP team comprised of senior advisor, project manager, principal investigator, and a team of researchers.

〈Table 1〉 2017/18 KSP Consultation Team and Topics

Project Title: Sharing Experience of National Quality Infrastructure of Korea for Promoting Industrial Development of Colombia
Senior Advisor: Kook Hwan Bae, Former 2nd Vice Minister of the Ministry of Economy and Finance (MOEF) of the Republic of Korea
Project Manager: Youngsun Koh, Executive Director, CID, Korea Development Institute
Principal Investigator: Gyung Ihm Rhyu, Research Advisor, Korea Testing Certification

Sub-topics	Researchers
Strategy for Enhancement of National Quality Infrastructure in Colombia: Focusing on Capacity Enhancement of Laboratories	– Gyung Ihm Rhyu (Korea Testing Certification) – Mario Andrés Pinzón Camargo (National Planning Department) – Carolina Angulo Fandiño (Colombian Institute of Technical Standards and Certification)
Strategy for Infrastructure of Testing and Measurement in Colombia	– Jong Oh Choi (Korea Research Institute of Standards and Science) – Luis Alfredo Chavarro Medina (National Metrology Institute)
Sharing Korea's Experience for the Promotion of HRD in Metrology of Colombia	– Sangwook Seo (Korea Research Institute of Standards and Science) – Alvaro Bermudez Coronel (National Metrology Institute) – Juan Sebastian Rodriguez Reyes (National Planning Department)

In the first stage of the 2017/18 KSP II with Colombia, the Korean delegation headed by Dr. Youngsun Koh conducted the Launching Seminar and High-level Meeting in Bogota, Republic of Colombia between September 7th and 15th, 2017. On September 11th, the Launching Seminar was held at DNP with the representatives of related ministries and organizations, where the current status of Colombia on the KSP topics and relevant Korean development experience was thoroughly introduced. Also, both countries' researchers discussed the objectives, future direction and expected outcomes of the KSP. For the High-level Meeting and Pilot Study, the Korean delegation visited the DNP, INM, ICONTEC, ONAC, and MinCIT to discuss not only the policy demands and priorities, but also to confirm high-level officials' support and cooperation throughout the project.

In the second stage of the KSP, the Korean delegation conducted the KSP Policy Seminar and Additional Pilot Study in Bogota, Republic of Colombia between October 26th and November 5th, 2017. On November 2nd, Local Reporting Seminar was held at DNP to share the progress of research, and to materialize the research contents through in-depth discussions with high-level officials, Local Consultants, and related experts. For Additional Pilot Study, the Korean researchers held several

meetings and conducted in-depth interviews at DNP, INM and INVIMA to gain in-depth understanding on the current situation of Colombia in the respective research topics and gathered data and information necessary for KSP research.

In the third stage, a total of three government officials and Local Consultants from Colombia visited Korea to participate in the Interim Reporting and Policy Practitioners' Workshop between January 15th and 19th, 2018. During the Interim Reporting Workshop held on January 17th, the Colombian Local Consultants introduced the current situation of Colombia and Korean experts presented the interim KSP results and policy recommendations. In connection with the Interim Reporting Workshop, Korean and Colombian experts had in-depth discussion on the interim results and policy recommendations to improve research contents and outcomes. For the Policy Practitioners' Workshop, the Colombian delegation visited relevant organizations in Korea including Korean Agency for Technology and Standards (KATS), Korea Research Institute of Standards and Science (KRISS), Samsung D'light, Korea Testing Certification (KTC), Korea Testing & Research Institute (KTR), as well as participating in the lectures provided by experts invited from Korea Association of Standards & Testing Organizations (KASTO) and Korean Standards Association (KSA) to enhance practical knowledge and skills in relevant fields.

In the final stage of the 2017/18 KSP II with Colombia, the Korean delegation headed by Dr. Youngsun Koh conducted the Final Reporting Seminar and Senior Policy Dialogue in Bogota, Colombia between April 23rd and 28th, 2018. On April 25th, Final Reporting Seminar was held at the Tequendama Hotel, Bogota, to share the final research findings and policy recommendations with roughly eighty participants comprising of high-level policymakers, policy practitioners, and other stakeholders. Also, High-level Policy Dialogue was held with high-level officials from DNP, INM, and MinCIT to share the final policy recommendations and request their continued support and cooperation to materialize the recommendations. In addition, end-of-project evaluation surveys and interviews were conducted to receive feedback on the year-long project were conducted to evaluate the project, and to explore avenues of follow-up cooperation.

Executive Summary

Gyung Ihm Rhyu (Korea Testing Certification)

The economic performance of Colombia has improved in the recent years, and it is forecasted that it would continue to rise at the rate of 3% in 2018–2019. Despite these recent achievements, the Colombian economy is experiencing some bottlenecks in sustaining its productive development and economic sophistication. As diagnosed by the draft report of National Policy of Laboratories (NLP) drawn up by the National Planning Department (DNP) of Colombia, the subject of National Quality Infrastructure (NQI) was chosen to be the core foundation that underpins productive development and economic sophistication of Colombia. The report has identified key challenges and main problems, which need to be addressed for strengthening the national measurement capacity as a tool for enhancing national export competitiveness, innovation and consumer protection.

The 2017/18 KSP with Colombia (II) was designed to address the laboratory policy challenge facing the Colombian government. Under the main theme of "Sharing experience of NQI of Korea for Promoting the Industrial Development of Colombia," research was divided into three sub-topics: "Strategy for Enhancement of National Quality Infrastructure in Colombia: Focusing on Capacity Enhancement of Laboratories," "Strategy for Infrastructure of Testing and Measurement in Colombia" and "Sharing Korea's Experience for the Promotion of HRD in Metrology of Colombia". The research aimed to review the draft NLP drawn up by the DNP and to make meaningful suggestions for possible improvements based on Korea's experience and international practices. The policy suggestions under each topic are provided as below.

1. Strategy for Enhancement of National Quality Infrastructure in Colombia: Focusing on Capacity Enhancement of Laboratories

The Colombian government has shown particular interest in learning Korea's experience and implications for promoting cooperation between government and private institutions, incentivizing the private sector to provide laboratory services, and financing public institutions involved in NQI, when available. In order to address the issues identified by the Colombian government, it is noted that the strategies for creating demand and supply of laboratory service should be established. As a possible approach to address these issues, the following policy recommendations are made.

(1) Introduction of the National Product Certification Mark of Colombia

To promote consumers' trust and awareness of certified products, the national product certification mark system should be introduced. The introduction of the National Product Certification Mark requires coordination between competent authorities and regulators as well as stakeholders, depending on the scope of the product sector that the mark would cover. National certification mark affixed to Colombian products will help domestic consumers to select quality products as well as increase confidence in Colombian products in the international / regional markets.

(2) Introduction of Certification Scheme to Colombia’s National Standards (NTCs)

In order to promote the use of standards and the participation of the private sector in the standardization process, it can be considered to introduce a voluntary certification scheme to NTCs (hereinafter, NTC Certification Scheme). The effective operation of the NTC Certification Scheme could expand demand for conformity assessment services, which in turn will encourage the Colombian laboratories to strengthen their capacity.

Under the NTC Certification Scheme, new development or revision of relevant standards will have a direct impact on creating a new demand for relevant test and measurement service as well as on product production and distribution. To ensure the effectiveness of the scheme, the government will need to intervene in market surveillance of certified products, as well. Thus, operation of the certification scheme will result in promoting cooperation among government, SNCA (National Quality Subsystem) institutes and industries

(3) Introduction of quality assurance in government/public procurement

In order to expand demand and supply of test and measurement services, an environment must be created in which products with proven quality are differentiated and their demand is secured. Government/public procurement is used as a classical and powerful policy tool to promote product quality improvement and related technology development. Colombian government should design a comprehensive strategy to introduce quality assurance in public procurements. For example, incentive measures such as preferential government procurement of certified products will help activate voluntary product certification scheme to national standards.

(4) Reshape of National Quality Award

The National Quality Award is the only policy tool the Colombian government currently has in order to improve the quality of Colombian products and to promote the dissemination of technical standards. It will be necessary to evaluate whether the National Quality Award are contributing effectively to achieving this policy objective. The operational procedures of the National Quality Award should be improved adequately on the basis of the evaluation results in order to ensure that it effectively contributes to improving the competitiveness and the credibility of Colombian products.

(5) On-going government support for public institutions

Government should promote financial support for the operation of public institutes that perform functions, not for profit activities, such as the development and dissemination of national measurement standards. Government should also consider supporting the public laboratories as a priority so that laboratory services can be quickly available in relevant sectors needed for industrial development and consumer protection.

(6) Strengthening NQI management capacity

The Ministry of Commerce, Industry and Tourism (MinCIT), which oversees the NQI in Colombia, should use the National Quality Committee (NQC) to oversee the operation of SNCA institutes and establish necessary policies. The authority of Intersectoral Quality Commission (CIC) should be strengthened to be able to take a roll as NQC successfully. That is, the decision of the CIC becomes the one that is implemented by relevant parties including SNCA institutes as an obligation rather than a recommendation. And MinCIT should also oversee the progress of its implementation through CIC.

2. Strategy for Infrastructure of Testing and Measurement in Colombia

Topic 2 deals with one of the key policy issues identified by the DNP, establishment of sound National Metrology System (NMS). The Colombian government has shown particular interest in developing its capacity of metrology in chemistry, and improving cooperation and networking among laboratories. After review of the draft NLP, and the analysis of experience in Korea and international good practices in establishing and operation of the NMS, the following policy suggestions and recommendations are made for NLP.

(1) Action Plans in the NLP with Consideration of NQI

In NLP, the action plans are categorized into two sections, which are the safety and the global competitiveness. Since the necessary activities to improve the technical capacity and quality of measurements are the same for both categories, the action plans should be regrouped according to the key steps in the process of establishment of the Chemical Metrology System (CMS). For effective execution of the action plans, it is emphasized that the National Metrology Authority (NMA), Ministerial Metrology Authority (MMA) and the National Metrology Institute (NMI) shall become the members of control tower for the NQI. They shall lead the cooperation among institutions in NQI in order to activate the Colombian Metrology Network.

(2) Operation of National Metrology System of Colombia

In the NMS of Colombia, the roles of NMA and MMA are not shown while the most responsibility of the operation of NQI, NMS and CMS belong to NMI. Therefore, it is recommended that the responsibilities of NMA and MMA are designated clearly so as to play their key roles in the operation of NMS. In addition, for the effective operation of CMS, the grouping of the field-specific laboratories such as health, environment, food etc. is recommended. Each sector-specific laboratory group (SSLG) will be led by the corresponding Reference Measurement Laboratory (RML) designated by MMA or NMI.

(3) Establishment of the CMS in Colombia

As for the Calibration and Metrology in Chemistry (MiC), it should be dealt at the national level so that the traceability in chemical measurements could be effectively confirmed by the CMS. The CMS is shown to be the NMS through Certified Reference Materials (CRMs).

Because there are so many different types of matrix RMs and diverse applications, NMI alone can't be responsible for all aspects of the CMS. A partnership model

between NMI and sector specific institutes to establish the CMS for Colombia is suggested. The roles and activities of NMI and partner institutes in the CMS are also described.

(4) Activity of Korea Research Institute of Standards and Science (KRISS)

For sharing the knowledge based on activity of KRISS, the mid- and long-term R&D plan for measurement standards and measurement technologies from 2015 to 2023 are described to provide as a motive for the innovation of NMI of Colombia (INM).

Considering the interests of Colombia on CMS and CRM production, the KRISS plans on CRM and its R&D from 2015 to 2023 are described accordingly. In the plan, KRISS has set up a mid- to long-term strategy by surveying the demand list of CRM expected for the next decade. For the short-term of the next three years, a detailed plan is established, which reflects the current demands. In addition, the KRISS strategy for CRM R&D and service promotions of CRM are also introduced.

3. Sharing Korea's Experience for the Promotion of HRD in Metrology of Colombia

This topic deals with human resources development (HRD) in metrology in Colombia. Colombia's practices of metrology education and training services are discussed to find facts, obstacles and future tasks to be tackled for further advancement.

Lack of metrology learning opportunities due to insufficient training providers, professional trainers and quality training programs remain as the root cause which is weakening the competence of the metrology community of Colombian. As the NMI of Colombia, INM is playing as the principal service provider of HRD in scientific and industrial metrology in Colombia. Besides, a couple of institutions are offering HRD in metrology services: the national learning service (SENA) of Colombia and the University of Cartagena. It should be noted that the training programs offered by all of them cover narrow horizon of very basic subjects of measurement. Advanced educational service in metrology is not available in Colombia which keeps it from fostering its young generation with advanced academic degrees in measurement science and technology. Low salary scale of employees in the metrology community of Colombia leads to high employee turnover rate across the NQI sector including even in the INM. It can hardly attract its young generation in this manner, for it to be willing to enter the metrology community and take up a career of experts in measurement science and technology. These factors are all putting significant

obstacles that should be overcome so as to achieve sustainable development of the NQI in Colombia.

Reviews, presentations and investigations regarding the current practices of Colombia in HRD in metrology, followed by the analysis of experience and good practices in Korea and other selected advanced countries have led to ten policy recommendations.

〈Table 2〉 Policy Recommendations for Promoting HRD in Metrology in Colombia

Categories	Recommendations
Service Provider	(1) Increasing Training Providers (institutions) (2) Creating Graduate School of Metrology (3) Improving Contents of Training Programs (4) Securing Competent Trainers
Customer & Regulation	(5) Expanding Potential Customers of Training Services (trainees) (6) Effective Use of Training Certificates for Accreditation (7) Expanding Proficiency Testing and Setting Mandatory Calibration Intervals
Strategic Support by Government	(8) Sophisticating Functions of INM, the NMI of Colombia (9) Cultivating Good Work Place across the Metrology Community in Colombia (10) Raising Investment in NQI by Government

A couple of recommendations (6 and 7) are suggested as complementing tools that should also have been taken into consideration while cultivating good practices in the sector of NQI in Colombia. They are to promote proficiency testing activities and to set calibration intervals for measuring equipment until good practices are settled down across the metrology community in Colombia.

It is advised that the DNP and the Colombian government should take actions to turn the policy recommendations into winning strategies for advancing the competence of the metrology community of Colombia enough to underpin its sustainable economic growth. When it comes to the priority of action programs and financial investments to bring them into existence, it is recommended that the priority be placed on INM, among others: in promoting the metrological capability of INM, as the competitiveness of the NQI definitely depends on the scientific and technological capability of the NMI among others.

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of Colombia

Chapter 1

Strategy for Enhancement of National Quality Infrastructure in Colombia: Focusing on Capacity Enhancement of Laboratories

Strategy for Enhancement of National Quality Infrastructure in Colombia: Focusing on Capacity Enhancement of Laboratories

Gyung Ihm Rhyu (Korea Testing Certification, Korea)
Mario Andrés Pinzón Camargo (National Planning Department, Colombia)
Carolina Angulo Fandiño (Colombian Institute of Technical Standards and Certification)

Summary

A well-established National Quality Infrastructure (NQI) can contribute to product competitiveness, trade facilitation, consumer protection and technological innovation by providing acceptable evidence of products and services meeting the specified requirements. In order to effectively support the government achieving its policy objectives of industrial development and trade facilitation, the NQI should be established in accordance with international practices. In particular, laboratory service for the proof of compliance should be easily accessible and accepted in target markets to effectively support industrial needs.

However, the indifference of Colombian consumers and manufacturers to quality results in poor demand and supply of measurement services, which impedes the development of measurement capacity in Colombia. The lack of national measurement capacity has become a major obstacle to Colombian companies' adoption of standards and, in particular, their own technology development and the entry of Colombian products into overseas markets due to the on-going high cost of relying on foreign institutions for testing and certification. As a result, the Colombian government has called for the establishment of National Laboratory Policy (NLP), including strategies for strengthening the national measurement capacity as a tool for enhancing national export competitiveness, innovation and consumer protection.

Keywords: National laboratory policy, National quality infrastructure, Laboratory capacity enhancement, Strategies for laboratory capacity enhancement, Quality promotion program, National standard certification scheme, Product certification mark.

This report shares Korea's experience in NQI policies that the Korean government has established to support Korea's industrial development, and proposes policy recommendations to support the Colombian government in establishing NLP to strengthen the capacity of Colombian laboratories. The Colombian government has shown particular interest in Korea's experience and implications for promoting cooperation between government and private institutions, incentivizing the private sector to provide laboratory services, and financing public institutions involved in NQI.

In order to address the issues identified by the Colombian government, it is noted that strategies for creating a demand and supply for the laboratory services should be established. To reduce burdens on companies, it is important to use an approach that utilizes voluntary measures while supporting incentives to promote its implementation, rather than mandatory measures. The policy suggestions are provided as below.

- Introduction of National Product Certification Mark of Colombia

To promote the consumers' trust and awareness of certified products, the national product certification mark system should be introduced. National certification mark affixed to Colombian products will help domestic consumers in selecting products as well as increase confidence in Colombian products in international and regional markets.

- Introduction of Certification Scheme to Colombia’s National Standards (NTCs)

For disseminating the use of standards and foster participation of the private sector in the standardization process, it can be considered to introduce certification scheme to NTCs (NTC Certification Scheme), which operates as a voluntary scheme. Operation of the NTCs Certification Scheme will create demands for conformity assessment services, which then encourage Colombian laboratories to strengthen their capacity.

If NTC Certification Scheme is introduced, development or revision of relevant standards will have a direct impact on the demand for relevant tests and measurement services as well as on the product production and distribution. In order to ensure the effectiveness of the scheme, the government will need to intervene in market surveillance of certified products as well. Thus, operation of the certification scheme will result in promoting cooperation among government, SNCA (National Quality Subsystem) institutes and industries.

- Introduction of Quality Assurance in Government and Public Procurement

In order to expand demand and supply of test and measurement services, an environment must be created in which products with proven quality are differentiated and their demand is secured. Government/public procurement is used as a classic and powerful policy tool to promote product quality improvement and related technology development. The Colombian government should design a complete strategy to introduce quality assurance in public procurements. For example, incentive measures such as preferential government procurement of certified products will help in activating voluntary product certification scheme to national standards.

- Reshaping of the National Quality Award

The National Quality Award is the only policy tool the Colombian government currently has in order to improve the quality of Colombian products and to promote the dissemination of technical standards. It will be necessary to evaluate whether the National Quality Awards are contributing effectively towards achieving this policy objective. The operational procedures of the National Quality Award should be improved adequately on the basis of the evaluation results in order to ensure that it effectively contributes to the improvement of competitiveness and the enhancement of the credibility of Colombian products.

- On-going Government Support for Public Institutions

Government should promote financial support for operation of public institutes that perform functions, not profit-making activities, such as development and dissemination of national measurement standards. Government should also consider supporting the public laboratories as a priority task so that laboratory services can be quickly available in relevant sectors needed for industrial development and consumer protection.

- Strengthening NQI's Management Capacity

The Ministry of Commerce, Industry and Tourism (MinCIT), which oversees the NQI in Colombia, should use the National Quality Committee (NQC) to oversee the operation of SNCA institutes and establish the necessary policies. The current Intersectoral Quality Commission (CIC) can take on the role of NQC after its authority is strengthened. That is, the decision of the CIC becomes the one that is implemented by relevant parties including SNCA institutes as an obligation rather than a recommendation. And MinCIT should also oversee the progress of its implementation through CIC.

1. Introduction

The NQI is the institutional basis for establishing and implementing standardization practices, including conformity assessment, metrology and accreditation. It is a tool that contributes to product competitiveness, trade promotion, consumer protection and technological innovation by providing acceptable evidence of products and services meeting specified requirements. In addition, the operation of NQI provides the basis for public policy decisions.

To effectively support the government achieving its policy objectives of industrial development or trade facilitation, NQI should be established efficiently and coherently in accordance with international practices. NQI supports demonstration of compliance with mandatory requirements set in the technical regulations being enforced for safety and health of people and environment protection. In order to effectively support the industrial needs, conformity assessment capacity must be secured in relevant technical fields and with a required level of accuracy to support technology innovation and quality promotion. For trade facilitation, conformity assessment services shall be accessible to demonstrate that the exporting goods comply with the technical regulations or standards of the importing country. Moreover, conformity assessment bodies must be accredited in accordance with internationally recognized procedures to gain confidence in domestic and international markets for their conformity assessment results. Accordingly, governments are making efforts to establish NQI in accordance with international practices and secure reliable testing capacity that can be accepted internationally.

The Colombian government installed the National Metrology Institute (INM), the National Standards Body (ICONTEC) and the National Accreditation Body (ONAC), which are the core organizations of NQI, and expected that they would serve as a support infrastructure for industrial development. However, weak quality culture in both the Colombian consumers and manufacturers has caused low demand and supply conditions for measurement services, which has impeded the development of measurement capabilities. Moreover, lack of national measurement capacity has become a major obstacle for the Colombian companies to adopt national standards, and in particular, their own technology development. These have hindered entry of Colombian products into overseas markets due to the on-going high cost arising from reliance on foreign institutions for testing and certification.

As a result, the Colombian government has called for the establishment of National Laboratory Policy (NLP), including strategies for strengthening national measurement capabilities as a tool for enhancing national export competitiveness, innovation and consumer protection in the National Development Plan (2014–

2018). The objectives of NLP are first, to improve and expand the supply of testing and calibration services needed to effectively promote consumer protection and environmental protection, and second, to establish the appropriate incentive measures to ensure the demand and supply of laboratory services for strengthening the competitiveness of Colombian products and promoting technological innovation.

On the other hand, Korea is the only country in the world's poorest economy that has grown into a member of the OECD Development Assistance Committee (DAC) in 50 years. The government regarded national standards and measurement in the field science and technology as the key foundations for successful industrialization and promoted related development policies in line with industrial development policies. Therefore, sharing Korea's experience in NQI policies that the Korean government has established to support Korea's industrial development would provide useful implications for the establishment of NLP by the government of Colombia.

As the title of 2017/18 KSP II with Colombia implies, the purpose of the study is to review NLP being developed by the Colombian government and provide policy suggestions for possible improvements based on Korea's experience. Accordingly, this chapter analyzes the limitations of measurement capacity in Colombian laboratories, and draw policy implications through comparative analysis with both international practices and practices conducted in Korea, which supported industrial development. In pursuit of drawing policy recommendations to strengthen the capacity of laboratories in Colombia, this year's project is divided into three sub-topics (chapters); topic 1 considers possible policy measures for the capacity enhancement of laboratories; topic 2 deals with improving technical measurement capabilities in Colombia; and topic 3 deals with human resource development in metrology.

In relation to the topic 1 covered in this Chapter, the Colombian government has shown particular interest in learning Korea's experience and implications for promoting cooperation between the government and private institutions, incentivizing the private sector to provide laboratory services, and financing public institutions involved in NQI, when available. As a possible approach to address these issues identified by the Colombian government, strategies for creating a demand and supply for laboratory service are considered among others.

2. Status of National Quality Infrastructure in Colombia

2.1. Overview of NQI: Structure and Performance

2.1.1. Objectives of Colombia's NQI

NQI in Colombia is organized and regulated by Decree 1595 of 2015. According to this Decree, NQI in Colombia is denominated by the name National Quality Subsystem (SNCA), and it is a part of the National Administrative System of Competitiveness, Science, Technology and Innovation (SNCCTI) (Decree 1595, 2015, Art. 2.2.1.7.1.3).

The general purpose of SNCA is to support and incentivize the entrepreneurship productivity and innovation, and to guarantee the consumer's trust. Decree 1595 mentions the following six specific objectives of SNCA (Decree 1595, 2015, Art. 2.2.1.7.1.7):

- Promote market safety, quality, trust, innovation, productivity and competitiveness from productivity sectors and product importers.
- Protect consumers' interest.
- Facilitate market access and international exchanges.
- Support system users to protect the health and life of people and animals, and to preserve the plant life.
- Protect the environment and national security.
- Prevent practices that can mislead the consumer.

2.1.2. Institutional Arrangement and Main Entities of NQI in Colombia

One of the basic components to guarantee coordination of SNCA corresponds to the Inter-sectoral Quality Commission (CIC). It was created through Decree 3257 of 2008, headed by the Regulatory Directorate of MinCIT, and the meetings are held at least four times a year.

SNCA is composed of public, private and nonprofit entities, which have different responsibilities. <Table 1-1> shows the main entities in the SNCA and their performance fields.

〈Table 1-1〉 SNCA's Main Entities

Standardization	Technical Regulation	Conformity Assessment Bodies	Inspection, Oversight and Control
Colombian Institute for Standardization and Certification	Ministries, Regulatory Commissions	National Institute of Metrology	Colombian Farming Institute
		National Accreditation Body of Colombia	Institute of Hydrology, Meteorology and Environmental Studies
		Public and private laboratories, accredited or not.	National Institute for Food and Drug Surveillance
		Certification bodies, accredited or not.	Superintendence of Industry and Commerce.

Source: Authors, based on Decree 1595 of 2015.

ICONTEC, the Colombian National Standards Body (NSB), is a non-profit private entity established in 1963 by a group of private representatives. ICONTEC has been recognized as the NSB by the Colombian government since 1984 and represents Colombia in various international and regional standards organizations.

As of April 30, 2017, ICONTEC has published 6,446 Colombian technical standards. ICONTEC's main revenue source is membership fees from 2,596 Affiliate Companies and sales revenue from standards. In addition to standardization, activities of ICONTEC include product and management system certifications (ISO 9001, 14001, 22000, OHSAS 18001), training of standardization and quality system, and operating calibration laboratories (ICONTEC, 2017).

INM, the National Metrology Institute (NMI) of Colombia, is a public agency responsible for industrial and scientific metrology. For legal metrology, Superintendence of Industry and Commerce (SIC) has the responsibility. SIC is an inspection, surveillance and control body belonging to MinCIT. INM has 100 staff members comprised of 59 laboratory staffs and 41 administrative staffs, as well as 40 external contractors. INM is leading the Colombian Metrology Network (CMN). INM is in the process of enhancing its measurement capabilities to ensure the traceability of chemical measurements. INM's annual budget for 2017 is 6.50 million USD (INM 2017a).

ONAC, the national accreditation body in Colombia, is a nonprofit organization. ONAC provides accreditation services to testing laboratories, calibration laboratories, inspection bodies, medical laboratories, personnel certification bodies, product certification bodies, as well as certification bodies for management systems and proficiency testing providers. ONAC joined the ILAC MRA in 2014 for testing and calibration, and the IAF MLA in 2015 for product and management system certification (ONAC, 2017).

2.1.3. Development Stages of NQI in Colombia

The SNCA development began with Law 155 of 1959. Since then, it has been possible to identify two milestones that have fostered the SNCA, and that have also allowed to divide the SNCA's performance in three stages since 1959.

The first milestone is the issuance of CONPES 3446 document of 2006, Guidelines for a National Quality Policy, which is the first explicit quality policy for Colombia. This document seeks to develop and complement the technical gaps in the SNCA's legal framework. To this end, the document defines strategies to create an accreditation body and an industrial and scientific metrology institute. In addition, it provides the guidelines to guide the SNCA towards consumer protection friendly measures, access to international markets, and support enhancing competitiveness of the country.

A recent milestone is the issuance of Decree 1595 of 2015. This decree is developed in compliance with the guidelines defined in CONPES 3446 document of 2006. The importance of this decree lies in the roles and competencies definition of the entities that are a part of the quality infrastructure in Colombia. Additionally, it incorporates clear rules for the process of issuing technical regulations, which puts the country at the forefront for the implementation of the best regulatory practices.

In addition to the issuance of Decree 1595 of 2015, the active role of the Regulatory Directorate of MinCIT is highlighted on three fronts: i) strengthening the cooperation and coordination among the different entities that make up NQI; ii)

dissemination of Decree 1595 among other regulators and thereby addressing their concerns to increase the quality of technical regulations; iii) positioning of the quality infrastructure in Colombia as a tool for entrepreneurs, citizens and public authorities to increase the country's competitiveness, access markets, and guarantee consumer rights.

As part of the strategy for positioning quality infrastructure in Colombia, the Regulatory Directorate advanced with a communications strategy that involved other players of the SNCA and led to the definition of a corporate image for the SNCA. The main result was a SNCA marketing strategy. It included a new brand for the SNCA, which was "SICAL," and a new slogan, "SICAL, dile Sí a la calidad!"[1)] This strategy was accompanied by the design of a website and the development of videos explaining the importance and usefulness of the quality infrastructure. The videos have been disseminated through social networks and explain in a very easy but precise manner regarding the function of each of the SICAL institutions (SICAL, 2017).

2.2. Quality Dissemination Policies (Quality Assurance Programs and Quality Promotion Programs)

2.2.1. Mark CO

[Figure 1-1] Mark CO

Mark Colombia is an initiative that was born in order to position the positive image of the country abroad. To achieve this goal, a new campaign was launched in Colombia in August 2005 known as "Colombia is Passion" - a strategy financed by Pro-export and private sector companies. This campaign had two great challenges. First is to generate a sense of belonging for the Colombian nationals with the brand, and second is to promote it globally to attract investment, expand exports and increase tourism.

1) SICAL, say Yes to quality!

One of the positive results of the "Colombia is Passion" campaign is that the Colombia Country Brand was positioned within the world standards and thus has achieved national and international recognition.

In 2011 after reaping many successes, the "Colombia is Passion" campaign came to an end and was replaced in 2012 by an initiative that can take advantage of the momentum the country is going through, and distributing the good news daily confirming to nationals and foreigners why Colombia is the answer.

This new campaign is very aligned with the new trend since it offers a progressive image of Colombia in which mega diversity, innovation, sustainability and natural wealth, as well as the environment, its people and their culture are more than just a part of the Country Brand; they became the flag and reason of pride of the Colombians.

Country Mark, as part of Procolombia, supports three key axes for the development of the country: export, investment and tourism. The campaigns in which the Colombians are children that transmit their own messages, make Colombians feel proud of their country.

The private companies are another main supporters of the Brand that have become allies of it that use its logo and support different events that are carried out in favor of the objectives of the Mark CO.

2.2.2. Environmental Colombian Label (Eco label)

It is a voluntary differentiation system that allows identifying non-food products available in the market that meet environmental specifications, which have been previously determined according to the category to which they belong.

The design and implementation of this scheme is presented as an awareness tool aimed at allowing national consumers to identify and guide their purchasing preferences towards environmental-friendly products; likewise, it is an instrument to promote national supply, which producers can use to create or access new market niches and thus place their products inside and outside the country.

[Figure 1-2] Eco Label of Colombia

The Colombian Environmental Seal constitutes one of the first eco-labeling schemes in Latin America seeking to respond to the worldwide trends of similar programs for the identification of environmental goods and services such as the Ecological Label of the European Union, the White Swan of the Nordic Countries, the United States Green Seal or the Blue Angel of Germany. These schemes are based on the growing awareness of consumers and governments about the environmental impacts generated by the countries' traditional economic and productive development and their unsustainable consumption patterns, triggering an increase in the demand for goods and services with environment-friendly characteristics.

With the establishment of the Colombian Environmental Seal, they look for:

- Creating an informative and commercial tool to differentiate the products that comparatively present a better environmental performance
- Encouraging the growth of the national market for this type of products
- Promoting a shift towards environmentally friendly products in consumer's buying preferences
- Facilitating access to the market and improving the image of products with a better environmental performance
- Promoting the use and development of clean or sustainable processes, techniques and technologies

The environmental criteria are issued through the Colombian Technical Standard (NTC) or Sectoral Technical Standard (NTS) through voluntary standardization processes. The environmental criteria for the products are set according to each category that is selected and grouped taking into account the goods that fulfill similar functions and are equivalent with respect to their use and the consumer's perception.

2.2.3. Certification to Sectoral Standards of Tourism

[Figure 1-3] Tourism Quality Mark

In the case of certification for the sectoral standards of tourism, certification is based on sectoral standards defined by MinCIT and allows companies to use the "ECO" brand. The certification is accompanied by actions taken by MinCIT with which it is sought to make it visible or differentiate the certified companies from those that are not.

According to MinCIT, the objective is to ensure that "Colombian and foreign tourists will be able to distinguish, as the name implies, the quality of care they will receive from both the establishments and the people who make up the country's tourism sector." Sectors that have NTSs include Gastronomic Establishments, Adventure Tourism, Accommodation and Lodging, Sustainable Tourism, Tour Guides, and Travel Agencies.

2.2.4. National Quality Award

The following is a description developed by the Regulatory Directorate of MinCIT in 2015 on the development of 'National Quality Award':

Through the Decree 1653 of 1975, the government created the National Quality Award, which aimed to recognize the efforts of public and private companies to implement a comprehensive approach that allows them to achieve higher levels of competitiveness and reliability in their products or services. To do this, and staying in line with the Application Guide for 2014, the award was aimed at meeting four objectives:

– Promote the adoption of the approach and practices of Integral Management, as foundations for the competitiveness of the organizations in the country

– Being the basis for the dissemination of experiences and successful management strategies and benefits derived from their implementation by the winning organizations of the Prize

– Encourage the use of Award criteria as a platform to achieve excellence

– Promote the use of the Prize to make organizations socially healthy and economically successful

In 2015, it was considered necessary to advance in a process of reorganization of the recognition granted by the Prize, with the purpose of generating market signals from MinCIT that would guide the national companies in increasing their quality standards, measured through the fulfillment of voluntary requirements defined in technical standards (MinCIT 2015).

Thanks to document CONPES 3866 of 2016, the National Quality Award was modified to support certification processes and, thereby, increases exports. The new structure of the award consists of a call seeking to co-finance the cost of the certification process for companies "(...) that are advancing the export processes and those that are in the process of enlisting to export from the sectors of fashion, cosmetics, automotive, shipyard and aeronautical and construction industries" (PTP, 2017).

The resources allocated to this call amount to 1,971,848,784 COP. The percentage of resources to be co-financed will be up to 70% of the cost of the certification process and in no case, may exceed 200 million COP.

In addition to the quality label, there are some isolated efforts made to try to promote the consumption of quality products such as below.

– The advertising campaign in December 2016, "Colombia buys Colombian", included some messages about the importance of buying products with quality standards, and the importance of quality for consumer protection

– Training and dissemination agreements between MinCIT and ICONTEC

– Programs to support the process of enlisting export products. Among the topics covered in this program, listed is the support to the fulfillment of quality requirements to access markets. This activity is developed by Procolombia

2.3. Role of INM and Activities

2.3.1. General Aspects about INM

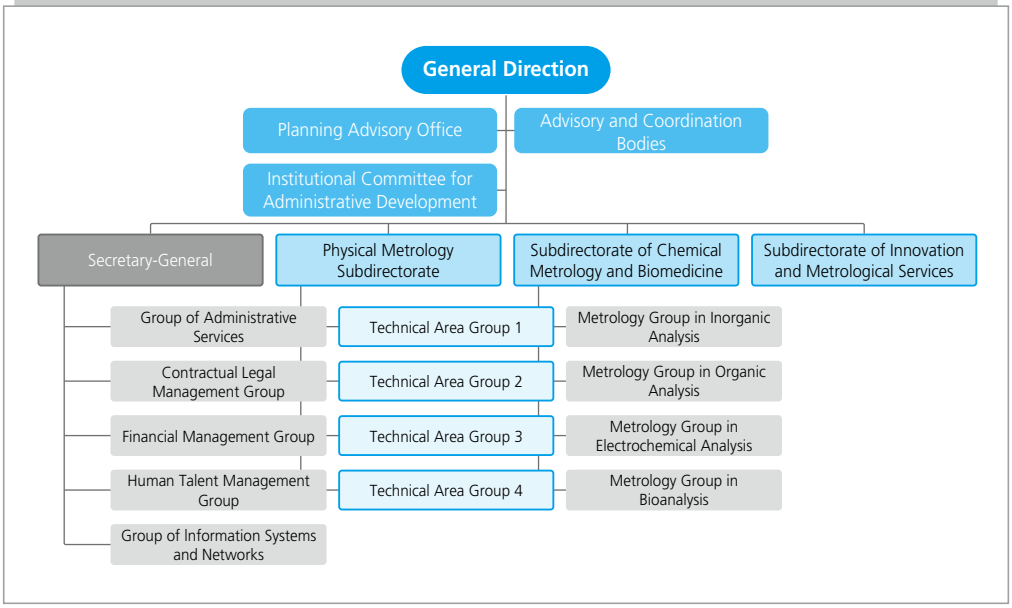
Legal, scientific, and industrial metrology in Colombia was headed by the SIC. However, the CONPES 3446 document of 2006 recommended to split out scientific and industrial metrology from the SIC, leaving legal metrology as the head of this entity. This advice was also part of the National Development Plan 2010–2014, Prosperity for all, which gave the guidelines to encourage the SNCA and establish the INM (DNP, 2011).

In 2011, Decree 4175 of 2011 split out scientific and industrial metrology from the SIC, and created the INM as an entity with administrative and budget-wise independence, that belongs to the Commerce, Industry, and Tourism sector. The main INM objective is the "national coordination of scientific and industrial metrology, and developing activities that allow innovation and support economic, scientific, and technological development of the country through researching, providing metrology services, supporting of activities related to metrology, control, and disseminating measures in line with SI" (Decree 4175, 2011).

2.3.2. Organizational Structure

[Figure 1-4] shows the general organizational structure of INM. The INM has 4 Technical Area Groups in the Sub Directorate of Physical Metrology and has 4 analytical areas in the Sub Directorate of Chemical Metrology and Biomedicine. The technical areas of the physical laboratories include: DC and AC current Density; Force; Temperature and Humidity; Mass and Scales; Dimensional Metrology; Torsional Torque; Power and Electric Power; Pressure; Time and Frequency; Volume and Flow. As for chemical laboratories, the calibration services are provided for UV-Vis spectrophotometry; Filter certification in calculating the percentage of transmittance; and Certification of filters in the wavelength scale (INM, 2015).

[Figure 1-4] INM Organizational Structure

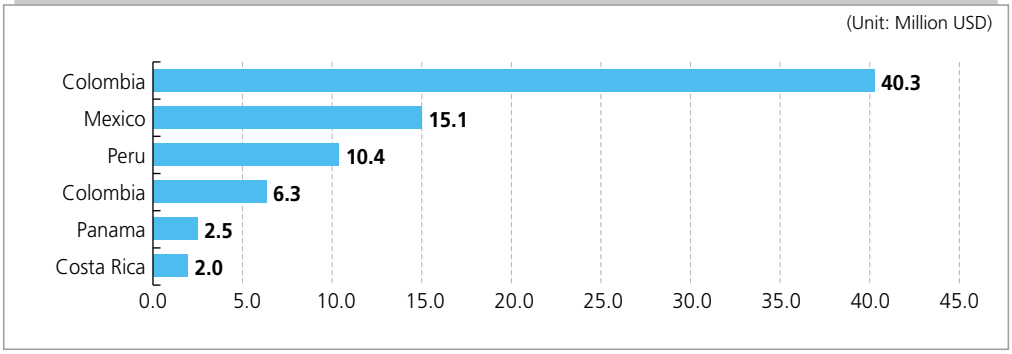


Source: Authors, based on INM (2017b).

2.3.3. Financial Budget

[Figure 1-5] shows INM budget in contrast with the resources that similar entities have in the Latin-American region showing that Colombia has the third lowest budget among its peer countries.

[Figure 1-5] Budget Comparison between Some Regional NMIs, 2017



Note: 1) Brazil allocated for the year 2017 a total of 349.1 million USD; includes accreditation activities.
2) Budget includes accreditation activities.
Source: Authors, elaborated based on INM data (INM, 2017c).

<Table 1-2> shows INM's budget share. Government resources represent an average of 91% of the total over the past four years. INM's investment budget share decreased from 56.4% in 2014 to 41.2% in 2017 while total budgets and government resources have increased slightly over the same period. Besides, [Figure 1-6] shows that INM's investment budget dropped by 22.5% in 2015 and had remained lower than in 2014 while budgets for others had also steadily increased over the past four years.

〈Table 1-2〉 Budget of INM

(Unit: Million COP)

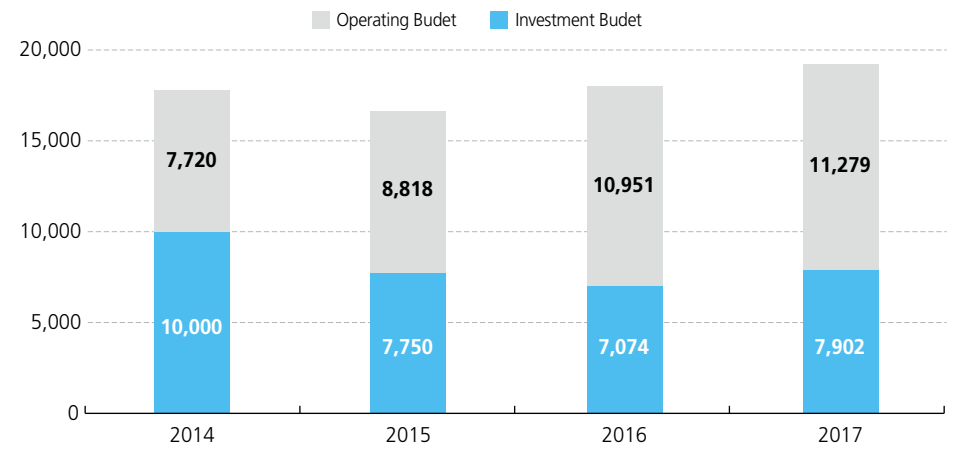
Budget of INM	Fiscal Year			
	2014	2015	2016	2017
Total Budget	17,720	16,568	18,025	19,181
Government Resources	16,720	14,839	15,921	17,558
Own Revenue	1,000	1,728	2,104	1,623
Investment Budget	10,000	7,750	7,074	7,902
Investment Ratio	56.4%	46.8%	39.2%	41.2%

Note: 1) Budgets are calculated using exchange rates per one USD of 2000 COP (2014); 2743 COP (2015); 3050 COP (2016); 2951 COP (2017).
2) Investment Ratio (%) = (Investment Budget/Total Budget) x 100

Source: Authors based on data of INM (2017a and 2017d).

[Figure 1-6] INM Budget Analysis, 2014–2017

(Unit: Million COP)

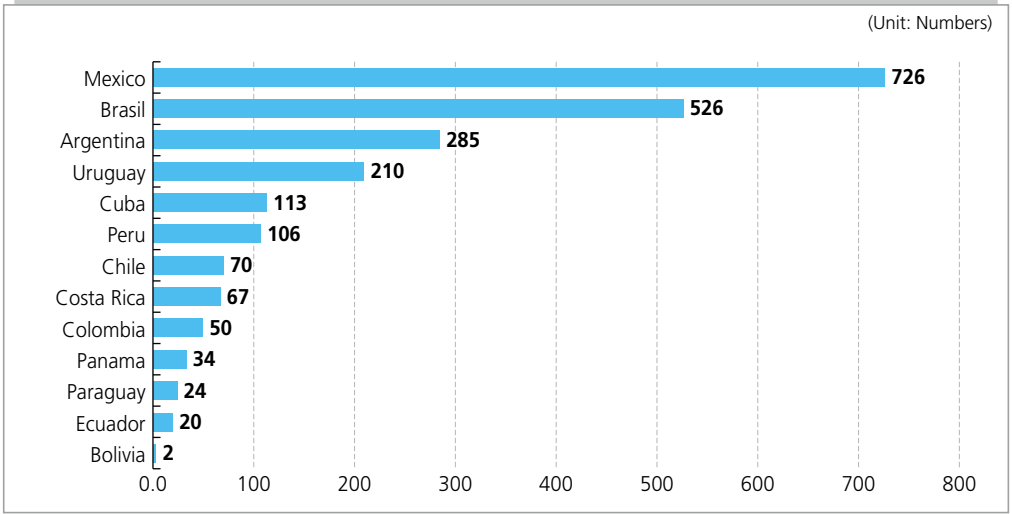


Source: Authors based on data of INM (2017a and 2017d).

2.3.4. Capabilities and Main Services

The INM's technical development has been slow; this could be explained by the budgetary lag seen in section 2.3.3. According to [Figure 1-7], the INM reached the ninth position among thirteen countries in the region with 50 Calibration and Measurement Capabilities (CMC)[2] published by the BIPM, it means that its number of CMC is only above countries such as Bolivia, Ecuador, Paraguay and Panama.

[Figure 1-7] CMC of Regional NMIs Published by the BIPM



Source: DNP (2017).

Despite the budget and technical lags, INM has tried to develop a services portfolio to meet stakeholder requests. This portfolio offers services to public and private laboratories as well as private companies that have their own laboratories. Services currently provided by INM are shown in <Table 1-3>.

〈Table 1-3〉 Current Services of the INM

Service	Description
Calibration and Measurement	Calibration service of the highest quality in the country using national standards, guarded by the INM under quality systems in compliance with the international regulations. This service includes physical and chemical metrology.

2) The INM has reached the international recognition of 50 CMCs since its entry into operation in 2012. 37 of these CMCs correspond to the magnitude of thermometry and 13 to time and frequency (BIPM, 2017).

〈Table 1-3〉Continued

Service	Description
Metrology Training	The INM has a team of experts in different areas of measurement, who have designed a series of courses in different sizes for those participants who need to know and apply internationally recognized measurement methods. This training covers physical and chemical metrology.
Technical Assistance	Services are provided to companies in general, including calibration and testing laboratories, for the improvement of their measurement systems and the implementation of metrological assurance programs in their production processes. Technical assistance includes metrological advisory services and capacity assessment, capacity and technical competence assessment[3], and specific training courses.[4]
Inter-laboratory Comparison and Aptitude Tests	The quality standards currently required by consumers of products and services must necessarily be backed by production systems that have reliable metrological assurance processes protected by calibration laboratories that can demonstrate reliability in the measurements obtained. The aptitude tests evaluate the performance of the participants with respect to previously established criterion through inter-laboratory comparisons.
Production, Certification and Marketing of Reference Materials	In order to contribute to the quality assurance and provide traceability to the measurements, calibrations and tests carried out in the chemical area of the country, the INM makes available the following certified reference materials, produced with the highest standards of quality and complying with all international requirements. Reference materials for the electrolytic conductivity and pH magnitudes are also provided.

Source: Authors, based on INM (2015).

Besides the services mentioned above, INM has a close relationship with the SIC to provide support to the legal metrology department.[5] INM has two main responsibilities in the field of legal metrology. The first one is to strengthen the metrological control activities carried out by the competent authorities to ensure the reliability of the measurements, and the second is to perform calibrations of standards for legal metrology and tests for approval of model or prototype of measuring instruments in accordance with the current standards (Decree 4175, 2011).

3) This service is provided in coordination with ONAC or other accrediting bodies authorized according to the quality management system of the requesting body for the purpose of evaluating the capabilities and technical competencies of the calibration laboratories.

4) Based on information, identification and diagnosis provided by the user, the design and implementation of specific training courses in the various areas of scientific and industrial metrology is considered.

5) INM has provided technical assistance to the accreditation of SIC's laboratories in the ISO/IEC 17025 standard. The laboratories of the SIC are in the INM building and correspond to the magnitudes of mass and volume. These two laboratories are accredited by ONAC.

Finally, it is important to note that INM has also been working with Universities and Technology Development Centers to develop goods and services to go ahead in metrology R&D projects. As an example, INM assigned COP $153,000,000 to this sort of activities in 2017.

2.4. Obstacles and Future Tasks

The overview of the development stages of NQI and its current performance allows one to identify some challenges that are now pointed out below.

The market of laboratory services must be fostered. This is a nascent market which has a coordination market failure, which means that customers do not demand services because they do not find them, and laboratories do not supply services because customers do not demand them. According to the DNP, this situation produces a suboptimal provision and hinders the development of technical capabilities, services, and infrastructure in the country (DNP, 2016 and 2017). Adequate incentive measures should also be considered as a tool to consolidate the demand and supply of laboratory services.

SNCA needs a strong coordination. According to Castro *et al.* (2013), the role of the CIC has not had the expected impact in its coordination role. Furthermore, there are problems associated with the weakness of the level of compliance with the agreements reached within the Commission. This happens because the Commission does not have the capacity to make binding the commitments that are already reached. It is also important that SNCA works closer to industry.

Also, it is noted that with limited use of resources (taking into account that Colombia has public laboratories to provide very limited industrial services), laboratories often do not know how to rely on the entire quality infrastructure. That is, they know that their direct interlocutor in this entity would be the ONAC for accreditation issues, but they do not know in what more way they can find useful either the ICONTEC or the INM, which is also part of the NQI. In addition to the above, there is not a sufficiently strong communication link between the SNCA entities, which makes it even more difficult for laboratories to know how they can benefit from NQI.

The Colombian national government has to understand the value and importance of SNCA to the SNCCTI. According to Gallego & Gutiérrez (2016), despite the fact that SNCA belongs to the SNCCTI, the coordination between the system and subsystem only works in theory. The relationship between both systems has not been evident in policies, sectoral strategies or public projects with resources assigned.

Accreditation procedures need to be coordinated among the accreditation authorities. In Colombia, ONAC is assigned to be the national accreditation body, however, there are other regulatory entities authorized for the accreditation process. As a result, some private laboratories have to face the burden of seeking multiple accreditations, one from ONAC for international recognition of their test reports and another from a competent authority to participate in domestic conformity assessment procedures.

3. Status of Korea's National Quality Infrastructure

3.1. National Quality Infrastructure Overview

3.1.1. Laws and Regulations Related to Korea's NQI

Article 127 (2) (1980.2) of Korea's Constitution stipulates that "the State shall establish a national standard system." The Framework Act on National Standards (1992. 2), which was established on the basis of this provision, provides legal basis for establishing the NQI in Korea. As a subordinate act for the implementation of the Framework Act on the National Standards, there is the Enforcement Decree of the Framework Act on National Standards (1999.7).

The Industrial Standardization Act (1961) is the basic law on document standards. The standards developed and adopted in accordance with the Industrial Standardization Act became Korean Industrial Standards (KS), which is the Korean national standard. This law stipulates various matters related to industrial standards such as the establishment of the Council for Industrial Standardization, the KS development procedures, and KS mark certification scheme. Meanwhile, the Korean standards in the telecommunication sector are developed and maintained according to the Framework Act on Telecommunications (1991) which also constitutes as a part of the KS standards.

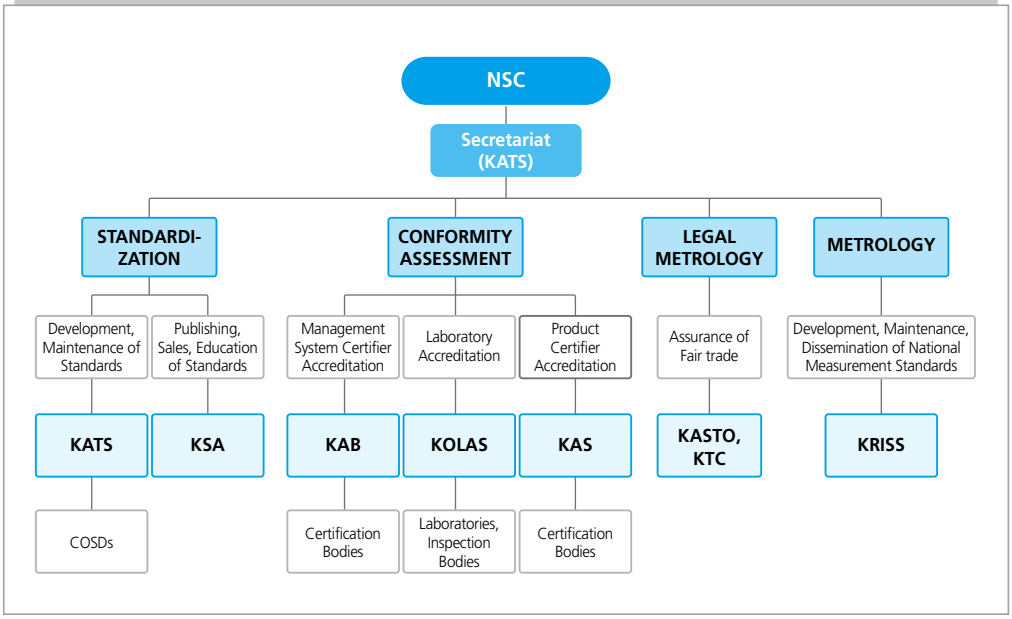
The rules concerning legal metrology are stipulated by the Law on Metrology. In addition, ministries and government agencies operate according to the technical regulations aimed at health and safety, environmental protection and national security.

The Korean government has established a five-year national standard plan that covers the entire contents of national standardization activities since 2000 in accordance with the Framework Act on National Standards. This plan shall be settled

and confirmed by the National Standards Council (NSC), which is chaired by the Minister of Trade, Industry and Energy (MOTIE) and is represented by the competent ministries. The Administrator of Korean Agency for Technology and Standards (KATS), a governmental body under the MOTIE, shall be the secretary of the National Standards Council.

The NSC shall have a working committee, chaired by the Administrator of KATS, for technical research, prior-review and coordination of matters to be included in the agenda of the Council meeting, and conducting of delegated tasks by the Council. The relevant ministries and agencies shall establish and implement the "National Standards Implementation Plan" annually for the implementation of the national standard five-year plan. The implementation plan for the following year and results of the implementation plan for the preceding year shall be submitted to the National Standards Council for deliberation.

[Figure 1-8] The Scheme of NQI in Korea



Source: Authors.

KATS operates and implements laws related to NQI such as the Framework Act on National Standards, the Industrial Standardization Act, and the Law on Metrology. The role of KATS includes the management and operation of national standard policies, along with establishment and maintenance of KS, operation of accreditation schemes for laboratories and product certification bodies, management of Korea Certification (KC) mark system, representing Korea in international standardization activities, and management of National Quality Management Convention.

The scheme of NQI in Korea is shown in [Figure 1-8]. The current status and performance for each of the three pillars (standardization, conformity assessment and metrology) of NQI in Korea are described below.

3.1.2. Standardization

Korea's NSB is KATS. The total number of KS standards is about 20,598 with 2,706 compulsory standards that are used in various technical regulations. As of August 31, 2017, the harmonization rate of KS with relevant international standards is 60.3%, which corresponds to more than 98% of the KS standards for which relevant international standards exist (KATS, 2017a). The publication and dissemination of KS is carried out by the Korean Standards Association (KSA).

The government-led standardization in Korea has been a cornerstone for industrial development in the last 50 years, including technological development and quality improvement. Now, when the private standardization capacity is strengthened, KATS has adopted the Cooperative Organization for Standards Development (COSD) program to encourage development and management of standards as a private initiative. A number of business associations, academic societies and professional organizations have been designated as COSD in their specialized fields. The roles of COSD are to respond quickly to industrial needs for standardization purposes in the designated fields, to develop national standards by collecting opinions from relevant stakeholders, and to review existing standards for any need regarding revision, abolition, and maintenance of them. The proposed national standards developed by COSD are adopted as the national standards after approval of the Council for Industrial Standardization operated by KATS.

In order to strengthen the market dominance of technologies and products developed in Korea, it is necessary to promote international standardization of developed technologies. To this end, the Korean government supports the expansion of standardization R&D. At the same time, Korea is expanding its standardization influence in the international standards setting organizations by proposing new work items for standardization in the field of new growth industries, proposing establishment of new working groups, and taking positions to serve as a council member, a management board member, chairs and secretaries of technical committees, etc.

3.1.3. Conformity Assessment

In Korea, three government-designated accreditation bodies are being operated in accordance with the ISO/IEC 17011. The Korea Accreditation System (KAS) and the Korea Laboratory Accreditation Scheme (KOLAS) are operated by KATS. KOLAS

provides accreditation services in testing (including medical testing), calibration, inspection, standard material production and provision of proficiency testing. Meanwhile, KATS accredits product certification bodies. Accreditation services for management systems are provided by the Korea Accreditation Board (KAB), a private organization.

KOLAS joined the International Laboratory Accreditation Cooperation (ILAC) and Multilateral Recognition Arrangement (MRA) for testing (including medical testing) and calibration. KAS joined International Accreditation Forum (IAF) and Multilateral Recognition Arrangement (MLA) for product certification, and KAB joined IAF and MLA for quality management system and environmental management system certification.

KOLAS makes consistent effort to promote the regulatory agencies that utilize the conformity assessment bodies accredited by KOLAS in the conformity assessment procedures. While some regulators use KOLAS-accredited testing laboratories for demonstrating compliance to technical regulations, other regulators use separately designated conformity assessment bodies in accordance with the relevant conformity assessment procedures. And regulators in the field of information and communications, and the environment operate their own accreditation program.

3.1.4. Metrology

Korea's NMI is the Korean Research Institute of Standards and Science (KRISS). KRISS was established in December 1975. KRISS, as an NMI, establishes, maintains, improves, and disseminates national measurement standards and conducts R&D of measurement science and technology. KRISS is actively participating in the International Committee on Weights and Measures (CIPM), Asia-Pacific Metrology Program (APMP) and International Measurement Confederation (IMEKO). KRISS is a full member of all the 10 Consultative Committees (CCs) of CIPM.

KRISS participated in Key Comparisons for 428 items by December 31, 2017 and registered 1100 CMCs (calibration measurement capabilities) in the international organization's database, KCDB (BIPM, 2017). KRISS has developed 767 items of certified reference materials (CRMs), including 648 items currently available for service (35 for engineering properties, 187 for physical properties, 426 for chemical composition). KRISS provides precise measurement related education and training for 420 local customers in 32 courses; 208 in 10 group courses; 185 in 20 individual courses; and 21 science teachers in 2 seminars, respectively (KRISS, 2018a). The measurement results of KOLAS-accredited testing laboratories maintain traceability to the SI units through KRISS.

NMIs, from all over the world, actively participate in R&D activities. R&D results are a valuable source of knowledge that can be applied in the industry and can be confirmed by the number of patent registrations and technology transfers for commercialization. KRISS reported 1,259 cases of patent registration as of December 2017, along with 214 technology transfers over the past six years, from 2012–2017.

The background of how KRISS acquired current measurement capabilities and became one of the leading NMIs globally will be discussed in detail in section 3.4.

The matters related to legal metrology are managed by KATS in accordance with the Law on Metrology. Twelve types of measuring devices including water meter, watt hour meter and gas dispenser are subject to type approval in order to be used for commerce or certification. For these legal measuring devices, either the validation period of verification is fixed, or regular inspection is mandatory. Korea Testing Certification (KTC) was designated as the regular inspection agency for legal measuring devices.

The Law on Metrology stipulates that the International System of Units (SI) determined by the General Conference on Weights and Measures (CGPM) are legal units, and that other non-legal units shall not be used for commerce, certification or advertising. The Korean government is using various methods such as imposition of penalties for habitual users of non-legal units, monitoring of media and sending corrective messages to reporters using non-legal units, and promoting the use of legal units for the public in order to settle the international system as the default.

Any person who manufactures, imports, processes, or sells pre-packaged goods under the control of the Law on Metrology (27 kinds of daily necessities) shall carry out voluntary quantitative management from the production and packaging stage of the product and conduct self-verification. The pre-packaged goods are needed to be verified by the conformity verification body, so as to be allowed to use the "k" mark on the container or packaging of the product. The Korea Association of Standards and Testing Organization (KASTO) is designated as the conformity verification body by the Law on Metrology. The main tasks of KASTO includes fostering technical personnel in the measurement industry, and, developing as well as disseminating of technical specifications of measuring devices.

3.2. Quality Dissemination Policy (Quality Assurance Programs and Quality Promotion Programs)

3.2.1. Korea's Industrial Development and Standardization

3.2.1.1. KS Certification Scheme

In Korea, the Industrial Standardization Act was enacted in September 1961 and thus a full-scale standardization work began. In 1963, the KS certification scheme was introduced to promote the dissemination of national standards, and to encourage companies to adopt internal standardization and quality management systems aiming at quality improvement of Korean products. The certification process consists of factory audits and product testing. A company that acquired the certification (hereinafter referred to as a KS certified company) may display the KS mark (㉾) on its product, packaging or delivery note.

The items subject to KS certification scheme are designated by the Council of Industrial Standardization through request of administrator of KATS when it is deemed necessary in view of consumer protection and achieving national policy objectives. <Table 1-4> shows operational status of KS certification scheme.

In order to encourage companies to participate in the certification scheme, the Korean government has introduced incentive measures for KS certified companies such as preferential government procurement of products certified to KS, exemption of various tests for regulation and preferential treatment in government-funded technology innovation projects. The government also made various efforts to promote the use of the KS certified products, for example, exhibiting KS certified products, promoting the KS mark through mass media, and restricting distribution of defective products.

〈Table 1-4〉 Operational Status of KS Certification Scheme

(Unit: Numbers)

Year	1965	1970	1980	1990	2000	2010	2017
No. of Item	41	145	395	951	1,013	841	701
No. of Factory Certified	59	269	665	2,951	5,498	6,607	6,954
No. of Certificate Issued	148	457	1,851	7,888	12,687	10,826	11,628

Source: Authors, data from KATS (2017a).

The certification of products to KS had been carried out by the government - KATS until KSA was designated as the certification body for KS certification scheme in July 1998. The Industrial Standardization Law was revised in 2015 so that any competent certification bodies can participate in the conformity assessment procedure for more effective implementation of the scheme.

3.2.1.2. Activities and Functions of Laboratories

Korea's export inspection system started with specific agricultural products: fishery products and livestock products. Export inspection of industrial products was carried out in earnest after the enactment of the Export Inspection Act (1962) following the enactment of the Trade Act (1957).

In order to ensure the reliability of inspection results conducted by private bodies, government-led efforts had been made to abolish and integrate existing inspection bodies and establish new facilities. As a result, nine private inspection bodies remained to conduct export inspection of industrial products. The average number of employees of the resulting private inspection bodies was about 40, including management personnel. Most of these private inspection bodies were non-profit entities established under the Civil Law and designated as the export inspection bodies under the Export Inspection Act by the competent overseeing Ministry of Commerce and Industry (MOCI) and the Industrial Advancement Administration (IAA) (MOCI & IAA, 1974).

The private inspection bodies were established with contributions from companies of relevant industrial sector. These companies received a partial exemption from inspection fees. The government indirectly provided important support by creating demand for export inspection and other quality inspection of products, rather than directly funding the operation of private inspection bodies.

The government established eight local (provincial) public industrial research institutes in consideration of the fact that export inspection bodies are concentrated in the Capital city, Seoul. The function of the local industrial test institute is to carry out export inspection in accordance with export inspection law, testing to support the KS certification scheme, inspection of measuring devices, etc. Recently, as the capacity of private laboratories has been enhanced, these local laboratories were abolished.

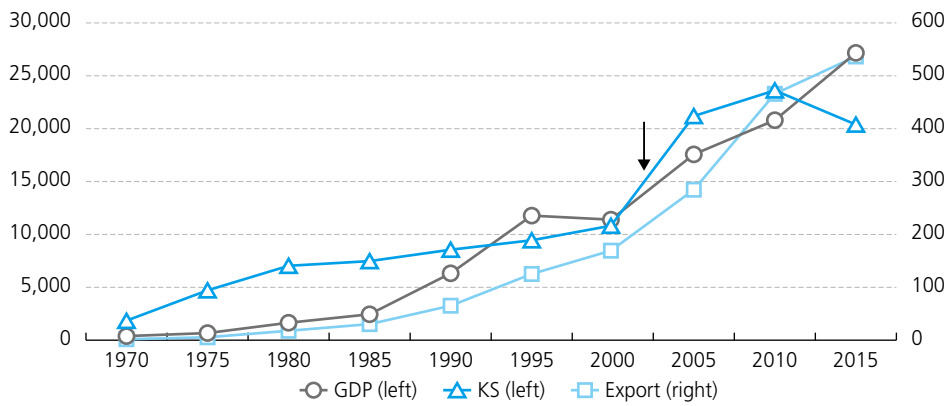
The competent authorities also operated governmental inspection bodies. Most of the export inspection of industrial products, however, was conducted through local or private inspection bodies. The National Industrial Testing Laboratory (NITL) is a government agency responsible for various tasks relevant to industrial standards

such as 'assistance for industrial scientific research and analysis of industrial materials and quality inspection of industrial products.' As for export inspection, the NITL provided inspection services only for items that cannot be inspected by private bodies, for example, due to lack of inspection facilities needed (MOCI & IAA, 1974).

〈Table 1-5〉 Korea's Economic Growth and KS

(Unit: USD, Billion USD, Numbers)

Year	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015
GNI(USD)	87	255	607	1,660	2,355	6,304	11,735	11,292	17,531	20,759	27,170
Export (Bil. USD)	0.5	1	5	18	30	65	125	172	284	466	537
No.KS	300	1,846	4,698	7,029	7,475	8,552	9,368	10,845	21,251	23,622	20,392



Source: Authors, elaborated on the basis of data from KOSIS and KATS (2017a).

In the 1990s, the Korean government made great efforts towards supporting industrial technology to further strengthen the international competitiveness of Korean companies. Moreover, in order to improve the national competitiveness and facilitate exports, the goal of the industry standardization policy has shifted from developing national standardization to promoting the technical level of national standards and international standardization. As a result of the introduction of international standards and the advancement of national standards, the number of national standards increased sharply, and the harmonization rate of KS with relevant international standards, which was only 14% in 1999, reached about 80% in 2005 (KATS, 2011).

However, while the majority of non-profit test laboratories had a statutory test facility, they did not have adequate test equipment and facilities to conduct the tests

according to many of international standards adopted. The Korean government recognized the necessity of the testing laboratories for raising their testing capacity to an international level so as to promote the acceptance of their test results in the international market in order to effectively support exports. The Korean government established a comprehensive plan for enhancing national testing capabilities in March 2002, in which a support project for equipment purchases at major testing institutes was included.

〈Table 1-6〉 Establishment of Selected Inspection and Testing Institutes in Korea

Institute	Year	Remarks	Equipment Support
Korea Textile Inspection & Testing Institute (KOTITI) 1)	1961	1990 KOTITI	
Korea Fabric Testing & Inspection Institute 1), 2)	1965	1994 FITI Testing and Research Institute (FITI)	Phase 1, 3
Korea Knit Testing & Inspection Institute 1), 2)	1963	1994 KATRI (Korea Apparel Testing & Research Institute)	Phase 1, 3
Korea Chemical product Testing & Inspection Institute 1), 2)	1969	1994 Korea Testing & Research Institute (KTR) 2010 KTR (merged with ERI)	Phase 1, 2, 3
Korea Mining Testing & Inspection Institute 1), 2)	1969	1980 incorporated to Korea Chemical Product Testing & Inspection Institute (KTR)	
EMI Research Institute (ERI) 2)	1997	2003 Korea Electromagnetic Engineering Institute 2010 (merged with KTR)	
Korea Petrochemical Testing Foundation 2)	1969	1991 Meter & Petrochemical Testing & Research Institute (MPI) 2010 Korea Testing Certification (KTC) (merged with KETI)	Phase 1, 2, 3
Korea Electric Testing & Inspection Institute 1), 2)	1970	1994 Korea Electric Testing & Research Institute (KETI) 2010 KTC (merger with MPI)	Phase 1
Korea Inspection Institute of Exporting Merchandise 1), 2)	1971	1983 Korea Merchandise Inspection and Testing Institute Korea Environment Merchandise Testing Institute (KEMTI) 2010 Korea Conformity Laboratory (KCL) (merged with KICM)	Phase 1, 2, 3
Korea Institute of Construction Materials 2)	1994	2010 KCL (merged with KEMTI)	Phase 1

〈Table 1-6〉 Continued

Institute	Year	Remarks	Equipment Support
Korea Export Packaging Testing & Inspection Institute 1), 2)	1969	1970 Korea Design Packaging Center 1997 Industrial Design Promotion Institute 2001 Korea Institute of Design Promotion	
Korean Register of Shipping Association 1)	1960	1987 Korean Register (KR) Export Inspection (1971.10–1987.2)	
Korea Institute of Lighting Technology 2)	1999	2010 Korea Institute of Lighting Technology (KILT)	Phase 3
Fine Instrument Center (FIC) 2)	1966	1966 FIC (sponsored by UNESCO-Korean government) 1972 FIC (government-funded institute) 2006 Korea Testing Laboratory (KTL)	Phase 3

Note: 1) Export inspection body designated according to the Export Inspection Act;.
2) Non-profit private or government-funded institute.

Source: Authors, elaborated based on information from Seo *et al* (2013) and KATS as cited in KIET (2015); website of KOTITI, FITI, KATRI, KTR, KTC, KCL, KIDP, KR, KILT, KTL.

The total amount of government support by KATS regarding equipment purchases for testing institutes started from 4.9 billion KRW in 2003 and gradually increased to 12.3 billion KRW in 2015. The support project for equipment purchase can be characterized into three different phases. In the first phase of the project (2001~2007), the government supported the equipment needed to ensure that the seven non-profit testing institutes overseen by KATS secured the test capacity against international standards needed to support export (KIET, 2015).

However, due to the size of the private laboratories and the limitations of the available test coverage, it was difficult for the laboratories to gain international competitiveness and companies were unable to receive comprehensive services they needed from just one laboratory. To solve this problem, the integration of nonprofit laboratories was encouraged. Thereby, in the second phase of the project, equipment purchases were supported intensively for the laboratories involved in the integration (indicated as 'Phase 2' in the fourth column of Table 1-6). Six laboratories were merged into three laboratories, namely, KTR, KTC and KCL.

In the third phase, the government support was concentrated on securing the testing capacity to support promising industries towards their future growth. For this, supporting technology fields and supporting testing institutes were expanded so as to acquire the testing capacity not only for international standards but also for de facto standards in the rapidly developing technology and industrial sectors,

as necessary, by considering the proposals of non-profit laboratories. The supported equipment and facilities in this phase includes those for testing of the high-performance insulation material used in construction of smart eco-buildings, large-capacity energy storage system, wearable smart devices, semiconductor lightening, etc. This equipment support project will be seeing a sunset in 2018.

The laboratories supported for each phase are indicated on the fourth column of <Table 1-6>. Thanks to the equipment support program, 80 new MOUs were signed between 2012 and 2014 for mutual recognition of test reports between the supported laboratories and overseas laboratories while only nine such cases were signed in 2003. The number of test reports issued in foreign language per year increased from 12,314 in 2003 to 74,052 in 2014 (KIET, 2015).

The non-profit export inspection bodies established in the early days of industrialization period in Korea have grown to become leading testing and research institutes, with an average sale of more than 69 billion KRW and more than 380 employees as of 2013 (MOTIE, 2014). In addition to testing and certification services, these institutes actively participates in standard development as COSD and government-funded R&D projects, and are also entering the overseas markets for testing services.

3.2.2. Quality Assurance System

Korea operates 166 legal certification schemes, including 69 mandatory certification schemes and 97 voluntary certification schemes. The legal compulsory certification system is aimed at protecting people's safety, health and the environment. The legal voluntary certification scheme is used for quality certification, promotion of recycling, certification of traditional products, etc. Of the legal compulsory certification schemes, 34 certification schemes require the use of product certification mark (KATS, 2017c).

In 2009, the Korean government introduced the national certification mark, KC mark system. Before the introduction of the KC mark system, each of 34 certification schemes utilized different mark, resulting in confusion among consumers as well as firms constraining the product design to equip multiple marks on small products.

[Figure 1-9] KC Mark

The Korean government is urging the use of international standards as the basis of national standards and use of national standards as the basis of technical regulations. Although many technical regulations use KS as the basis, some regulators prefer to develop their own mandatory standards.

Qualification requirements for conformity assessment body to participate in conformity assessment procedures for the enforcement of technical regulations vary according to technical regulations. In the case of most legal mandatory certifications, certification is conducted by a government agency or by a government-designated agency. In the case of testing, however, in many cases the participation is open to any laboratories that meet the qualification criterion set for the relevant conformity assessment procedure.

The qualification requirements for the testing laboratory to participate in the conformity assessment procedure may be fully open to the laboratories accredited by KOLAS. However, some regulators, including those in the fields of environment and electromagnetic compatibility, do not recognize KOLAS and operate their own accreditation programs. These government accreditation schemes are participating as associate members in the regional laboratory accreditation cooperation (APLAC). Besides, as for food and environmental sectors, testing laboratories are required to demonstrate their testing capabilities by participating in proficiency testing provided by the relevant regulators.

In case that the regulator does not recognize KOLAS, when the importing country requires a test report from a laboratory accredited by the ILAC MRA signatory, then the exporter must utilize a laboratory recognized by the competent regulator for domestic use and a laboratory accredited by KOLAS for export. The laboratories also have a burden of obtaining multiple accreditations, one from KOLAS and the other from the regulator according to the conformity assessment procedure. The Korean government has been trying to coordinate the related ministries for many years to solve the issue of multiple accreditations.

3.2.3. Quality Promotion System[6)]

In addition to mandatory systems for quality assurance, the government can implement appropriate promotion policies to spread quality culture in the industry. The quality promotion programs include operating the national quality awards to encourage companies to voluntarily conduct quality management, as well as education and promotion, and technical assistance for SMEs on product quality and quality management. The Korean government enacted the Industrial Product Quality Control Act in 1967 to improve the international competitiveness of industrial products and protect consumers. While quality control was mainly driven by quality inspections in the 1960s, quality control activities at production sites was introduced in the mid-1970s. And since the introduction of the ISO 9000 certification program, quality management has spread to companies.

In Korea, the National Quality Award was issued in 1975 as a group prize. The National Quality Award is aimed at spreading quality management activities across the country by awarding outstanding companies that have contributed greatly to national industrial competitiveness and national economic development by creating excellent management performance through quality management innovation activities.

In addition, the Excellent Quality Circle Award was established in 1975. The award recognizes outstanding quality circles, which have achieved remarkable achievements in quality improvement, cost reduction, and productivity improvement by promoting quality circle activities in an exemplary manner. Quality circle refers to a sub-group in which employees voluntarily conduct meetings to find problems related to activities in the workplace, and to find solutions and implement them.

In addition, there is a program that appoints the workers who become the models of the field workers as Master of Quality Award (established in 1991) by devoting their craftsmanship as a workplace worker and devoted to quality management activities for quality improvement.

Since the first Convention in 1975, the National Quality Management Convention has been held annually. Quality Awards are awarded at the National Quality Management Convention. The National Quality Management Convention provides a floor to share the success stories of quality management of awardees with other companies or entrepreneurs.

The Quality Award winner companies were used to be supported for marketing their products. As the quality awarding history has been getting longer, the level of

6) Written based on MOCI & IAA (1987) and KATS (2017b).

quality management of the awarded companies has improved and other business capacities have also strengthened. As a result, such support is no longer needed. In order to revitalize quality management in Korea, the award-recipient companies should disclose the case and site for three years after the award, when requested by the quality management promotion headquarters (KSA).

In order to spread the quality management movement, the government appointed KSA as a quality management training institute. In addition, the government also institutionalized the adoption of a quality control system as semi-mandatory for companies receiving various licenses from the government or receiving funding from the government and better utilized the tax support systems such as investment tax credit or research tax facility tax deduction.

Technical assistance includes training and holding seminars on various quality control techniques and implementation performance. A little more aggressively, a technology assistance program may be conducted to solve the difficulties faced by SMEs in order to improve the quality competitiveness of their products.

3.3. Role of NMI and Development Path of KRISS

3.3.1. Role of NMI

The role of NMI includes: ① establishing a national measurement system; ② developing, maintaining and disseminating national measurement standards appropriate to the needs of the country; and ③ developing new measurement techniques and disseminating them to users. A national measurement standard underpins activities such as calibration, commercial measurement, conformity testing, and accreditation, both in the regulatory and voluntary sectors. Here, national measurement standards appropriate to the needs of the country include aspects of the level of accuracy required. The NMI is generally a government agency or a semi-government agency.

NMI disseminates measurement standards by providing calibration services to independent regulatory agencies and other regulatory and standards-related bodies. When the industry measurements are traceable to NMI, the accuracy of equipment used for calibration, process control and quality control is ensured. To this end, the NMI implements the CIPM-MRA on national measurement standards, and measurement and calibration reports to maintain traceability of national measurement standards to the international measurement standards and SI units through participating in Key Comparisons. The NMI should then be able to provide the appropriate range of measurement standards that correspond to the technical needs of the testing laboratories, industry users and other calibration service customers. The NMI provides

technical experts for accreditation assessment and often provides measurement artifacts and reference values for measurement and calibration-based proficiency tests.

KRISS establishes and maintains national measurement standards, conducts R&D of measurement science and technology, and cooperates with overseas measurement science and technology institutions in accordance with the Framework Act on National Standards. Accordingly, KRISS performs functions as shown in <Table 1-7>.

〈Table 1-7〉 Missions and Functions of KRISS

Missions	Functions
Establishment of national measurement standards	• To perform R&D on maintenance, development, and improvement of national measurement standards of the seven SI base units and derived units • To perform R&D on establishment of traceability of national measurement standards to ensure the international equivalence
Research and development of measurement technologies	• To carry out R&D on new and better technology for measurement standards • To perform R&D on cutting-edge measurement technology for emerging industries
Dissemination of national measurement standards	• To provide calibration and testing services • To develop and supply certified reference materials • To offer training and education services of measurement science and technology • To promote technology transfer for commercialization

Source: KRISS (2018a).

3.3.2. Development Path of KRISS[7)]

3.3.2.1. Emergence of Government-Funded Research Institutes

From 1962 to 1981, the Korean government continuously established the five-year economic development plan and implemented it steadily. The Korean government has also established a science and technology development plan in line with the five-year economic development plan to support achieving the latter goal effectively. According to each science and technology development plan, government-funded research institutes (GRIs)[8)] for relevant fields of science and technology have been established as necessary. Prior to the establishment of GRIs, most research institutes

7) This section is mainly prepared based on the content in Seo, *et al.* (2013) with updated data.
8) There are currently 26 GRIs in Korea.

that existed in Korea (around 80) were public research institute, and only a few universities and private companies had research laboratories. However, due to poor research environment such as low wages, insufficient research funds, lack of research equipment and facilities, and inadequacy of various literature information bases, the demand for technological support for economic development at that time could not be satisfied. Technology development in this era relied on technical assistance from foreign countries, and the system for supporting national technology development started to be established only after the establishment of Korea Institute of Science and Technology (KIST) in 1966 and the Ministry of Science and Technology in 1967.

In order to establish the foundation for establishing the national science and technology capacity and secure the international competitiveness, the Korean government continuously provided financial support and steadily introduced loans from overseas to support securing the facilities, research equipment and human resources of the GRIs. As for human resources, in order to recruit renowned Korean scientists staying in foreign countries, Korean government offered unprecedented conditions such as high salaries and housing provision for researchers who came back to Korea. In addition, a GRI was established as an independent corporation rather than as a government agency, providing an autonomous and creative research environment. The government has provided funding for the operation of GRIs in the form of contributions.

In December 1973, "Specific Research Institutes Support Act" was enacted to establish a legal basis for establishment and support of GRIs. The GRIs have been given the benefit of tax incentives such as exemption from corporate tax and local taxation, exemption of tariffs on goods for research, as well as preferential participation in government sponsored R&D projects. In addition, a support system such as exemption from mandatory military service was provided to secure young researchers.

3.3.2.2. Development Path of KRISS

In the industrial development process according to the Korean government's economic development plan, the industrial field required measurement service of higher precision and the demand for quality assurance for Korean products in the export market increased. The Korean government, recognizing the importance of securing national measurement standards that could be recognized internationally, introduced foreign loans and used them to establish the Korea Standards Research Institute (KSRI), the predecessor to KRISS, on December 5, 1975.

In addition to sustained financial support, the government has invested more than 35 million USD in foreign loans and over 10 million USD in public development

assistance funds to strengthen the facilities, equipment and manpower of KRISS. For manpower, efforts have been made to attract Korean scientists from overseas. Prior to returning to Korea, the scientists were given a six-month to one-year orientation training program at the National Bureau of Standards (NBS), the NMI of the United States, to gain a basic knowledge of the measurement standards. Since the commencement of calibration services in 1979, KRISS has focused on improving its research capabilities to the international level in the mid-1980s. KRISS promoted collaborative research with advanced NMIs. The OECF Loan, which was introduced in 1986, and its subsequent funds were used for the purchase of advanced measurement equipment and training of research personnel to expand the research capacity of the Institute.

〈Table 1-8〉 Summary of Loan and ODA Projects Offered to KRISS

(Unit: USD)

Resources	Amount (USD)	Main Project Activities Invested
USAID (1975–1980)	5,000,000	Construction, Equipment Orientation of researchers
ADB (1979–1981)	8,000,000	Equipment
OECF (1986–1987)	6,000,000	Equipment, Training
IBRD (1990–1991)	6,000,000	Equipment
IBRD (1994–1995)	10,000,000	Equipment
PTB (1979–1996)1)	1,952,000	Equipment, Training, Technical advice
JICA (1991–1996)1)	8,401,000	Equipment, Training, Technical advice

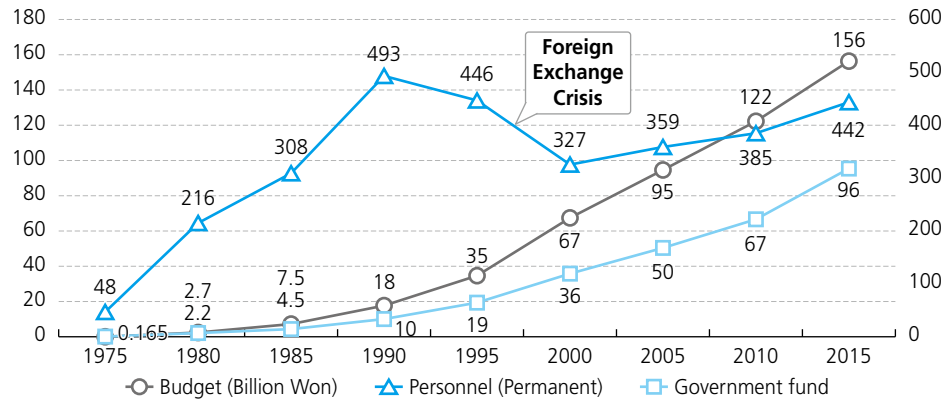
Note: Technical Cooperation Projects between Governments (ODA by Germany and Japan).
Source: Seo, *et al.* (2013).

For KRISS, which is a GRI, the government funded the entire operations cost at the beginning of the institute. The amount of government subsidies has been steadily increasing, but with the increase in other income derived from the operation of KRISS, the government subsidy has accounted for about 60% of the total budget of the institute recently. What is remarkable is that the Korean government has recognized the importance of measurement technology for economic development and has continued to support KRISS without reducing the support budget even in difficult financial situations such as the foreign exchange crisis. On the other hand, between 1990 and 2000, the number of full-time employees at KRISS decreased for several reasons. One of the reasons is that during the financial crisis, the number of full-time employees had been reduced by turning staff in charge of facilities management into outsourcing personnel.

〈Table 1-9〉 Personnel and Budget of KRISS (1975–2017)

(Unit: Million KRW)

Year	1975	1980	1985	1990	1995	2000	2005	2010	2015	2017
Total Budget	165	2,653	7,512	17,944	34,747	67,174	94,984	122,293	156,374	158,715
Govt. Fund	165	2,152	4,515	9,990	19,460	36,045	50,390	67,418	95,782	95,883
No. Personnel	48	216	308	493	446	327	359	385	442	462

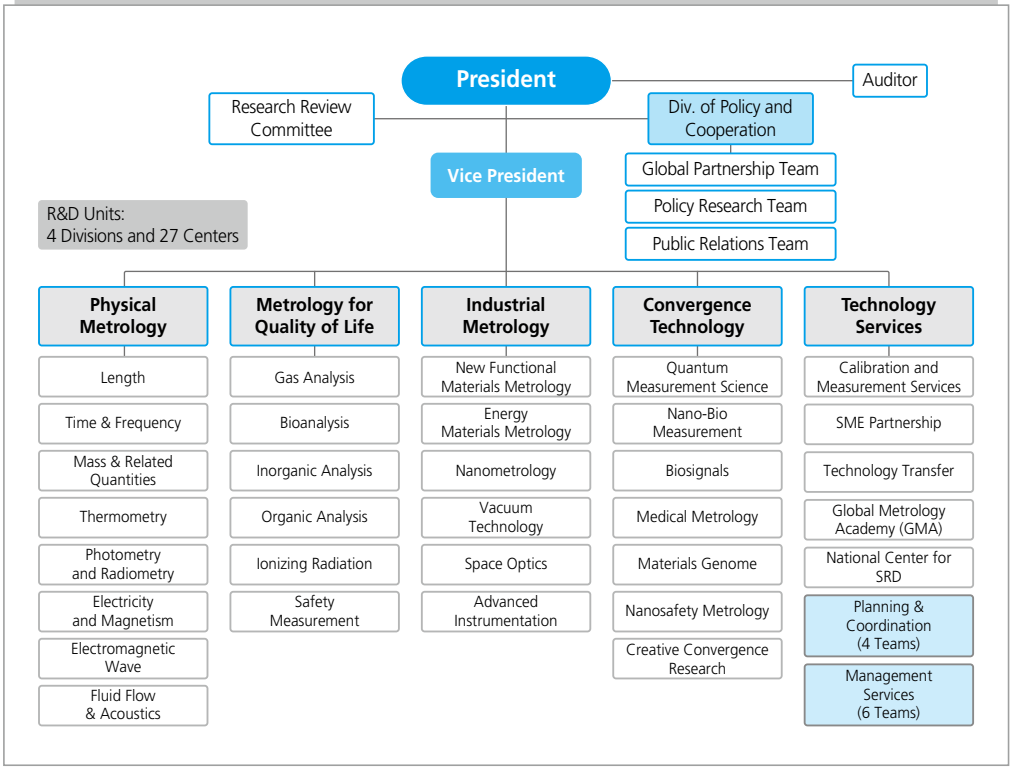


Source: Authors, elaborated on the basis of data from KRISS (2018b).

Meanwhile, KRISS took NBS as its model of development. As stated in Seo *et al.* (2013), "NBS was engaged in more comprehensive functions covering wide areas in metrology comprising metrology in physics, chemistry, and materials, while most of the NMIs in Europe were mainly focused on physical metrology". Besides, NBS made it possible to provide loans for securing funds from the feasibility study for establishment, and also directly participated in executing the loan to select the construction and measurement equipment of laboratory, and consultation on dispatch of experts.

As a result, KRISS has been able to carry out R&D activities across wide sectors of metrology for the development of national measurement standards and precision measurement technology, which are required in various fields such as chemistry and materials, as well as measurement standards in the physical field. The results of R&D in metrology allowed KRISS to provide Korean industries with appropriate service of high precision measurements that were internationally recognized. The financial and technical support of the US government and NBS is considered to contribute greatly to establishing a foundation for the growth of KRISS as a world-class NMI.

[Figure 1-10] Organizational Structure of KRISS



Source: KRISS (2016).

As shown in [Figure 1-10], as of November 2016, KRISS operates a total of 27 research centers under its four research divisions, each of which is assigned to carry out R&D activities regarding national measurement standards and advanced measurement science and technology. Also, KRISS has additional divisions in charge of customer service and management that carry out the tasks of measurement services, strategic policies and, planning and management support.

3.4. Evaluation of the Korean Experience

Korea has promoted industrial standardization in a totally different environment from advanced industrialized countries. While advanced and industrialized countries have promoted standardization as a means of mass production through standardization, simplification, and specialization along with industrialization, Korea promoted standardization to provide support for achieving the goals of the series of 5-year economic development plan starting in 1962. In addition, various NQI policies were introduced to improve the quality of Korean products and to ensure the reliability of Korean products in overseas markets. Korea's experience in NQI policy, that the Korean government has established to support Korea's industrial

development, and its achievements is receiving attention as an important success story for many developing countries that are pursuing industrialization.

In Korea, the KS certification scheme was introduced as a voluntary scheme, but certain countries like Kenya introduced certification schemes to national standards as a mandatory scheme. In developing countries, the voluntary certification scheme is hardly effective because it is generally a supplier-driven market and there is no obstacle to maintaining business even if suppliers are not interested in exporting. On the other hand, adoption of compulsory scheme can result in the increase in the product price, which causes difficulties for consumers with weak purchasing power. Therefore, it is better to introduce a voluntary certification scheme with a supporting measure incentivizing companies that produce certified products in order to enhance the effectiveness of the scheme operation. In Korea, a strong incentive measure, such as priority purchase of KS certified products was introduced in government procurement so that the KS certification could be executed successfully.

Since 1975, the Korean government has been operating the National Quality Awards and held annual National Quality Management Convention to facilitate information exchange on quality management and spread quality management activities across the country. The quality award promotes companies to recognize that their performance is increasingly important as a factor of competitiveness, to share their experience about successful performance strategies, and to facilitate recognition of the benefits of using these strategies. The National Quality Management Convention along with the operation of KS certification scheme significantly has contributed to the improvement of the quality and competitiveness of Korean products. On the other hand, the Quality Master Award has greatly contributed to fostering quality manpower.

As for conformity assessment, the Korean government has fostered non-profit private institutions as export inspection bodies. Along with the incentives granted, the KS certification scheme and the National Quality Award as well as export-led economic development policy of Korean government have created the test demand, thus enabling a stable and active operation of the laboratories and inspection bodies. However, as the demand for export inspection and the need for testing to support the development of new products and new technologies increased, it became necessary to newly purchase and upgrade measurement equipment, appropriately. Thus, the government supported the tax benefits for purchasing testing and inspection equipment and simplified the purchasing process. The government's R&D fund also contributed to acquiring equipment and fostering technical manpower necessary to participate in research activities, as well as to test and inspect products with new technology.

With the launch of the World Trade Organization (WTO) in 1995, the importance of international standards has been increased. As a result, Korea, which is pursuing export-led economic growth, has been urged to introduce international standards and to secure conformity assessment capabilities accordingly. In addition, as products have been diversified and advanced, strengthening the capacity of testing laboratories has become an important issue in order to effectively support technological innovation and exports. Thus, the Korean government provided funds to purchase testing equipment urgently required for export support. These funds have recently been used to support facilities and equipment to support the nation's emerging industries or to develop next-generation technologies. The reason is that in the case of latest high-tech equipment, it is difficult for the testing institute to invest in itself because the equipment utilization and demand are less than that of the general-purpose equipment and the investment cost for the equipment is larger than the profits to be obtained.

On the other hand, the government fund for supporting the purchase of test equipment was also used as a support fund to induce the integration of laboratories to improve their international competitiveness and to effectively support high-tech industries. The funded six laboratories were consolidated into three bodies. As a result, for example, in one of the consolidated laboratories, sales amounted to 87 billion KRW in 2016 and 68.6 billion KRW among sales figures was from testing fee, and the number of employees was 649 including contract workers. The strengthened capabilities of those consolidated laboratories have enabled them to advance overseas.

Non-profit private export inspection bodies, which played an important role in Korea's early development, have grown into a comprehensive testing and research institute leading Korea's testing and certification activities. This can be attributed to the strong and consistent implementation of the government's quality promotion and assurance policies, which have led to on-going demand for testing and certification so as to enable laboratories to respond actively to the need for expansion of the test coverage and sophistication of testing methods.

The KS mark, which has been used since the beginning of industrialization in Korea, is recognized by the Korean people in the sense that it is reliable and offers quality products. However, in the field of mandatory certification, different certification marks have been used for each of the different certification schemes, resulting in consumers' lack of awareness and confusion on various marks and the burden on manufacturers. The introduction of the KC mark system by integrating these various certification marks has had some positive effects. The use of a single mark contributed to the globalization of the KC mark as a national representative brand. For manufacturers, the certification costs or certification period is reduced and

the product design can be optimized. And for consumers, KC mark helps to choose reliable products and frees them from the confusion caused by the use of various marks.

There is an increasing demand for unifying or streamlining the accreditation bodies to enable coherent policy operation in the national conformity assessment system and efficient response to changes in international demand for demonstrating conformance of products. In the case of the EU, a legal basis for the integration of national accreditation bodies (EU regulation 765/2008) was established, and in 2010 all member states completed unification of national accreditation bodies. This included the unification of accreditation bodies in Italy and Germany, which had operated through multiple accreditation bodies. However, there are countries that operate multiple accreditation bodies such as the United States, Japan, Canada, and Thailand. In addition, there are countries operating on multiple accreditation bodies, including Korea, Australia and New Zealand, however, generally the accreditation scopes for each accreditation body are not overlapped (ILAC, 2017).

On the other hand, the use of KOLAS is poor in the conformity assessment procedure for the implementation of Korea's legal certification schemes. It is becoming more difficult for unification of laboratory accreditation bodies because some government regulators have a strong will to operate their own laboratory accreditation program rather than the use of KOLAS. The operation of multiple laboratory accreditation bodies in Korea has hampered the coherent implementation of the accreditation policies. Laboratories have burdens from this in that they are required to be managed by competent regulators in order to participate in conformity assessment procedures while maintaining accreditation from KOLAS for international acceptance of their conformity assessment results. The operation of the multiple laboratory accreditation bodies has caused difficulties in developing and applying coherent laboratory policies, and thus results in a waste of resources. Accordingly, under the leadership of the Office for Government Policy Coordination, related ministries have been involved in consultation to prevent multiple accreditation through the integration and coordination of laboratory accreditation services, but the results have not yet been achieved.

The Korean government has implemented a policy of technological superiority for industrial development and trade expansion. This government policy has become the most important foundation for achieving economic growth through industrial development of Korea. Especially, as measurement science and technology are one of the key factors that successfully lead the industrialization of Korea which adopted the export-led economic growth model. In the early stage of industrialization, the Korean government established KRISS as an R&D institute that would be responsible for the advancement of measurement standards and precision measurement technology, and thereafter provided on-going financial and policy support.

KRISS has strived to advance measurement science and technology with the support of the Korean government to secure excellent human resources in the field of measurement science and technology, and to continuously strengthen precision measurement facilities. As a result, KRISS, despite its short history of little more than 40 years, has built a capability equivalent to that of NMIs in developed countries with a history of more than 100 years. It is evaluated that KRISS's efforts and valuable help from abroad together with the multi-faceted support provided by the Korean government until it gained world-class competence have achieved such remarkable results.

4. Policy Suggestions for Capacity Building in Colombia Laboratories

4.1. Comparing Colombian and Korean Institutions

4.1.1. Use of National Certification Mark

Colombia operates three-mark schemes: Colombia Mark, Environmental Mark, and Tourism Mark. Colombia launched the CO Mark campaign in 2005 to gain a positive image of Colombia overseas. Colombia Mark has contributed to promoting Colombia, investing in national development, and expanding exports and tourism, but it is not a product certification mark. The Colombian environmental labeling system encourages consumers to identify and prioritize environment-friendly products and facilitate their entry into international markets. And certification in the tourism industry helps ensure that Colombian domestic and international travelers are able to identify better tourism services and improve the quality of the tourist services offered in Colombia.

The certification mark is used to operate the product certification system in most countries including Korea today because it enables the identification of certified products and gives additional confidence in quality assurance. In Colombia, however, technical regulations are not operated as marking schemes to ensure product quality or safety. The use of the national certification mark in the operation of the certification schemes is a very useful tool to promote confidence in and awareness of certified products to consumers. In addition, the Colombian products bearing product certification mark will gain additional trust in international and regional markets.

In Colombia, a series of videos aimed at informing end consumers how SNCA member organizations contribute to most of their daily lives are being produced

and disseminated through social networks. However, consumers do not need to understand the function of SNCA or SNCA institutes. It is important for consumers that the safety or quality of the product they are purchasing is assured. And quality products can be easily identified by finding a safety / quality certification mark on the products in the market.

4.1.2. Operation of the Certification Scheme to National Standards

In the early stage of industrial development in Korea, operation of the KS certification scheme enabled differentiation of quality products in the market, contributing to the quality improvement of Korean products as well as the dissemination of standards. In particular, the operation of certification scheme to national standards contributes to increasing the demand for test services needed to support the conformity assessment process. In Colombia certification scheme to national standards is not introduced, yet.

Product certification scheme for national standards may be adopted as either voluntary or mandatory scheme depending on policy of the government. In the case of supply-driven market with low purchasing power of consumers, the mandatory quality certification scheme creates an unnecessary burden on manufacturers and raises the product price to the level that many of the consumers cannot afford. Therefore, in order to promote efficient dissemination of quality management, it is necessary to consider introducing certification scheme as a voluntary scheme rather than a compulsory scheme, unless it is export-oriented product certification scheme. It would even help improving the reliability of scheme if adopted as a marking scheme.

The operation of the national standard certification scheme is effective in promoting the utilization of national standards and is introduced by many countries. In most developing countries, national standards bodies are government agencies. Therefore, government-led national standard certification scheme is being operated. In the case of Colombia, however, since the standard body is a non-profit private body, the approach to operating the national standard certification scheme will be different from those of other countries.

4.1.3. Operation of the National Quality Awards

In Korea, the National Quality Award has been awarded to distinguished personnel and outstanding companies who have contributed greatly to national industrial competitiveness and national economic development by creating excellent performance through quality management innovation activities.

The Colombian government already has operated the National Quality Award. Especially, the government developed a program to link the Quality Awards to the market. In other words, award recipients are supported for a part of the certification cost of products so that the Quality Award contributes to export promotion.

If Colombia adopts certification scheme to national standards, this linkage can be applied to the certified products. And National Quality Awards can be reshaped by awarding companies that not only complies with national standards but also have made outstanding achievements in quality management. Companies that receive quality awards should be subject to benchmarking as an exemplary company with high quality management performance. It is also considerable to make the National Quality Awards as national events such as the National Quality Management Convention and publicize it to ensure that the quality culture is diffused to consumers as well as to companies.

4.1.4. Coordination between Accreditation Authorities

One of the problems identified by Colombian government in relation to the provision of test services is lack of coordination between institutions responsible for accreditation procedures that demonstrate the technical capabilities of the laboratories. In addition to ONAC, the national accreditation body, IDEAM has also been recognized as an accreditation authority in Colombia for implementing technical regulations in the environmental field (including water). As a result, laboratories are in need of accreditation from ONAC to obtain international recognition, and from IDEAM in order to participate in the conformity assessment procedures in the environmental field.

Korea also is in the similar situation that multiple laboratory accreditation bodies are being operated, which has caused difficulties in developing and applying coherent laboratory policies and waste of resources. However, this problem is not easily solved due to the lack of coordination between ministries that operate accreditation programs.

The international trend regarding national accreditation system, except for a few countries, is going to 'one country, one accreditation body.' Each country is allowed only one vote for major decisions in the relevant regional and international accreditation cooperation bodies, regardless of the number of accreditation body members from the country. Colombia needs to address the coordination issue between accreditation authorities for the effective implementation of future national laboratory policies. However, this is not an issue that can be solved easily as the Korean experience says.

4.1.5. Expansion of Conformity Assessment Service

Unlike Korea, Colombia has a large land area. Therefore, providing laboratory services to cover necessary local areas is not an easy task. Nonetheless, it is necessary to establish a public laboratory, a central government agency or a local government agency, in the local area. Private sector laboratories that are seeking for profit will be reluctant to operate a local office unless the sufficient demands are secured to guarantee profit. On the other hand, the operation of the mobile laboratories in the field of calibration is very efficient. However, supporting infrastructure such as road construction and anti-vibration vehicles should be properly established.

In Korea, the concept of networking between laboratories is not institutionally emphasized. However, regulators set the eligibility criteria for conformity assessment bodies and manage their lists for the enforcing of technical regulations. In the field of environment and food safety, regulators operate proficiency tests for laboratories participating in the relevant conformity assessment procedures. As a result, it can be seen that a network has been established between laboratories to implement specific technical regulations. The laboratory networks may help governments seeking to introduce new technical regulations to determine in advance the availability of conformity assessment services needed for implementing them.

Colombia is diagnosing that the accreditation requirement in the qualification criteria for laboratories to participate in conformity assessment procedures results in a restriction of the testing service. However, for assuring consumer safety, it is a good approach to operate technical regulations based on test reports produced from test laboratories with proven competence. In Colombia, when introducing a technical measure, the qualification of laboratories is open to laboratories accredited by ONAC, it is possible to conduct an actual survey of individual laboratories through the accreditation body for conformity assessment capacity needed to implement the measure, or to request the opinion of the accreditation body on the basis of accredited scopes of laboratories in the relevant field. Depending on the results, the potential regulator should establish appropriate strategy regarding adoption and implementation of the measure. It may be possible to postpone the introduction of the technical regulation, or temporarily alleviate the qualification of the conformity assessment bodies and induce them to be accredited for the relevant service scope. Another possible approach may be implementing a policy to support equipment and the training of manpower to secure the conformity assessment capacity required for the implementation of the measures.

4.1.6. Public Laboratories and Government Support

Despite having a short history of 43 years, KRISS has built a capacity equal to that of NMIs in developed countries with a history exceeding 100 years. Such success factors can be found in securing excellent human resources in measurement science and technology, with continuous strengthening of precision measuring equipment, and establishment of quality management system in accordance with the international standards and practices. And these success factors and the advanced operation of KRISS have been possible because of the sustained policy and financial support from the Korean government.

As for INM in Colombia, government support for investment has decreased since it gained independence from SIC in 2014 and financial problems have arisen as there are not many requests for calibration services to INM. An analysis of government resources from 2014 to 2017 shows that government resources declined since 2015 and then increased to recover in 2017 (INM, 2017a). However, the proportion of investment resources for INM dropped by 22.5% in 2015 and has remained at least 20% lower than in 2014 (see Table 1-2 and Figure 1-6). Moreover, the investment resources in 2018 decreased again to 7,213 million COP from 7,902 million COP in 2017 (SIC, 2017). Though the National Development Plan 2014–2018 defined that the national government should maintain the amount of INM's investment resources at the average level of the last three years (DNP, 2015), it has not happened in practice. Accordingly, INM has no capacity to invest in expanding measurement capabilities.

In the case of Korea, it is true that the Korean economy has continued to grow, but in the meantime, the government has also been struggling with the global economic downturn, the oil shock and the foreign exchange crisis. Though, the government has never reduced support for KRISS from 1975 to 2015. The role of NMI is to maintain the traceability of national measurement results through the development and dissemination of national measurement standards. This activity not only cannot be expected to be profitable but also requires good manpower and, precise measurement equipment and facilities. Therefore, sound functioning of NMI shall not be expected without adequate government support for its operations.

Strategies to utilize international loans also need to be considered, given the reality in developing countries with limited resources. Korea actively used public development assistance funds from developed countries for public projects. It is also vital to partner with advanced NMIs with excellent capabilities in the field of measurement standards, as well as extensive experience in collaborations with developing countries.

On the other hand, Colombia wants to develop and implement incentives to ensure that laboratories are able to implement and be accredited for international best practices so that they can participate in R&D for science, technology and innovation. In Korea, GRIs had been established by technical fields. As a result, they have now grown into internationally recognized research institutions in their relevant fields. The government of Colombia can also consider establishing an R&D institutes or assist existing institutes, including laboratories, in strengthening their R&D capabilities. In order to participate in R&D, the necessary equipment, facilities, and professional manpower should be secured, however, these are not an easy task for laboratories to solve on their own. Government support is, therefore, required to encourage their participation in R&D. Such support may include direct support for purchasing equipment or, indirect support through human resource development or government sponsored research projects. The research project can also be carried out with a joint fund from the government and private entities, such as manufacturers and laboratories.

4.1.7. Development of NQI Policy and Management of NQI Institutions

In Korea, KATS operates laws related to NQI such as the Framework Act on National Standards, the Industrial Standardization Act, and the Law on Metrology. KATS is NSB, national authority for legal metrology and administrating national accreditation bodies for laboratories and product certification bodies. KATS is a government body under MOTIE while KRISS is an independent government supported institute. Moreover, the Administrator of KATS serves as the secretary to the National Standards Council as well as the chair for the working committee under the Council. The working committee, like the Council, is represented by the competent ministries. With the power and function given to KATS, KATS takes leadership in coordination of the development and implementation of national policies for NQI, including laboratory capacity enhancement, in practice.

Since MinCIT is the authority overseeing NQI in Colombia, MinCIT should take on a more active role in developing and implementing national policies regarding NQI with the support of National Quality Committee (NQC). In order to facilitate coordination among the stakeholders as well as inter-ministerial coordination, NQC should be a committee in which all relevant ministries and, NQI institutions and agencies are represented. At present CIC seems to take the role of NQC including conducting the coordination between government and SNCA institutes. However, the level of compliance with the agreements reached within CIC is weak since CIC does not have the capacity to make binding the commitments that are already reached.

Some aspects of NQI between Korea and Colombia are compared in <Table 1-10>.

〈Table 1-10〉 Comparison of Some NQI Matters between Korea and Colombia

Subject	Korea	Colombia	Impact
Governance of NQI	* National Standards Council (MOCIE) * National Standards Working Committee (KATS)	* SNCA is part of SNCCTI * CIC (RD of MinCIT) (Decisions are non-binding)	* Low coordination between government and private SNCA institutes
NQI Institutions	* Standards: KATS (public) * Accreditation body: KOLAS (public) * Legal metrology: KATS (public) * NMI: KRISS (GRI)	* Standards: ICONTEC (private) Accreditation body (private) * Legal metrology: SIC (public) NMI: INM (public)	* Low cooperation among SNCA institutes
Creating demand for laboratory services	* Technical regulations (Single National Mark) * Certification Scheme to National Standards * National Quality Awards (Quality Management Convention)	* No product safety/ quality certification mark * No Certification Scheme to National Standards * Only policy tool to promote dissemination of technical standards	* No differentiation for quality products in the marketplace * Low demand for laboratory services * Maybe insufficient to promote quality management nationwide
Incentivizing measure	* Preferential Government * Procurement of products certified to national standards	Not used	* Powerful policy tool to promote product quality and boost lab. services demand is missing
Public laboratories	* Strong government support for NMI * Support for non-profit laboratories' capacity enhancement to meet national and industrial needs	* Not adequately supporting investment in improving national measurement capabilities * Non-profit private laboratories are not being operated	* Unreliable and inactive services * Insufficient scope of laboratory services to promote government policies and meet industry needs

Source: Authors.

4.2. Policy Suggestions

NQI should be well established to efficiently support trade facilitation, enhancing the competitiveness of the national industry and promoting the technological innovation. In particular, reliable and sufficient test and measurement capabilities should be secured to meet the needs of the industries and the government in

promoting product quality and productivity, technical innovation and consumer protection. However, a lack of awareness of quality from manufacturers and consumers results in a low demand for test and measurements, causing laboratories to lose interest in capacity building. Therefore, government should actively intervene to establish a strong institutional plan to foster utilization of standards, and systematically promote quality management and quality improvement of Colombian products, thereby pulling up the demand for conformity assessment services. The following provides suggestions for the Colombian government to consider when establishing national policies for capacity building of laboratories.

4.2.1. Introduction of the National Product Certification Mark

To encourage consumers to gain confidence and awareness of certified products, a National Product Certification Mark can be introduced. The introduction of the National Product Certification Mark requires coordination between competent authorities and regulators as well as stakeholders, depending on the scope of the product sector that the mark would cover.

The National Product Certification Mark can be newly developed, or the existing "CO" mark can be used after further development. "CO" mark is managed by Procolombia, and there is no evidence about a policy to achieve a wider coverage and a clear criterion to allow its use. Thus, there is room to use this stamp to indicate that the quality of the product bearing the stamp is ensured, and, thereby, encourage the purchase of quality products.

Effective and efficient procedures to allow use of and to prevent abuse of the National Product Certification Mark, as well as the range of scope covered by the mark, should be established and implemented. These procedures should also include effective market surveillance procedures and penalties for mark misuse.

When the National Product Certification Mark is introduced, the government should invest in public outreach and awareness campaigns to help not only domestic consumers and manufacturers, but also potential foreign importers understand the purpose and meaning of the mark. Thereby, the product certification mark could contribute to gaining additional trust in the quality of Colombian products bearing the mark so as to promote selection of them in the international and regional markets as well as in domestic market.

4.2.2. Introduction of Certification Scheme to Colombia's National Standards (NTCs)

In order to disseminate the use of standards and encourage the participation of the private sector in the standardization process, it is time to consider introducing the National Certification Scheme to NTCs, which is operated as a voluntary scheme. Effective operation of the certification scheme can contribute to pulling in demand for conformity assessment services and, thereby, creating a momentum for Colombian laboratories to foster capacity building. In order to easily distinguish certified products, it is necessary to introduce NTC Certification Scheme as a certification mark scheme. This mark should be distinguished from the compulsory certification mark operated by regulators.

It is necessary to enhance the awareness of the importance of quality control in the production process by requiring the quality manager to complete prescribed education on quality and quality management before the corresponding company applies for certification. Improvement of the management's understanding of quality will drive the companies to introduce the quality management system, which will further contribute to enhancement of product competitiveness and promotion of exports by improving the productivity and quality of products. Therefore, it is necessary to consider the operation of the quality management education program for the management of companies who seek an NTC certification. The training and education programs regarding implementation of NTC Certification Scheme can be provided by training institute(s) recognized by the competent authority of the scheme.

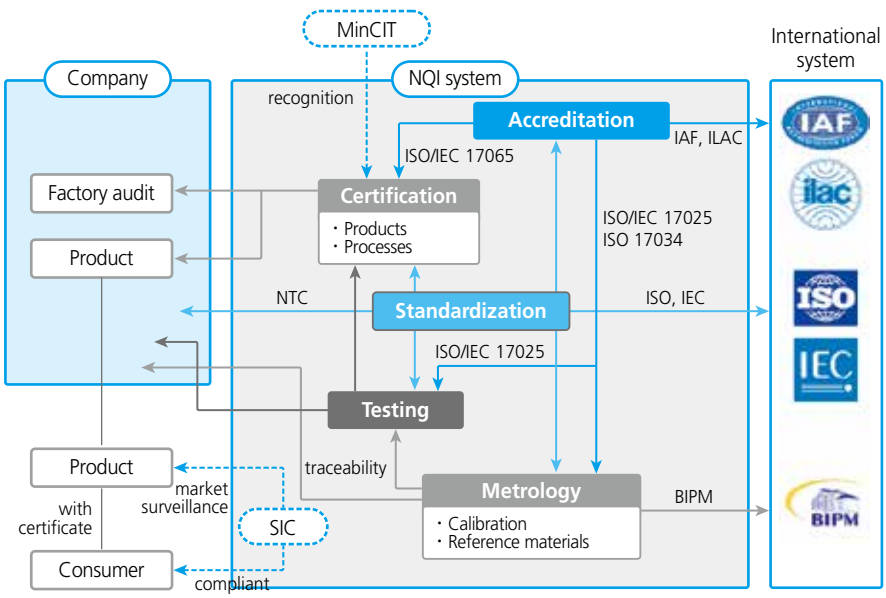
Since Colombia's national standard body is a private body, the government will need to designate certification body or bodies. Also, in order to ensure the proper functioning of the NTC Certification Scheme, market surveillance should be carried out to monitor any misuse of mark or distribution of defective products in the market. In Colombia, the government authority that oversees the NQI is MinCIT, so it is conceivable to consider the approach where MinCIT designates or recognizes the certification body or bodies and SIC conducts relevant market surveillance. [Figure 1-11] shows structure of Certification Scheme to National Standards with the NQI system.

One of the challenges faced by the SNCA is to facilitate close cooperation with the industry. The introduction of the NTC certification system will change industry's perception of standardization because the establishment and revision of a standard are going to directly affect the production and distribution of products when the finalized standard is used as the basis of certification. As a result, companies will be willing to participate in national technical committees for standardization to

seek opportunities to mitigate or eliminate any technical requirements that they find difficult to meet as well as to quickly acquire information on the trends in international standardization in the technology sector involved and reflect them into enterprise operations.

In addition, laboratories and measurement institutes should also have the relevant test and measurement capabilities secured when the standards to be established are incorporated into 'NTC Certification Scheme'. They will, therefore, be interested in participating in the standardization process either to gain information in advance about the standards being discussed or to share information about the testing and measurement capability in Colombia for the relevant technical fields. This will result in strengthening cooperation between SNCA institutions. INM and ONAC also have their roles for the operation of 'NTC Certification Scheme', in terms of assuring accurate measurement results and the technical competence of laboratories to provide relevant testing services, respectively. In this context, it is important to promote the purpose of and benefits obtainable from the scheme, and the role of each SNCA institutes in the operation of the scheme so as to strengthen cooperation between government and private institutes as well as collaboration between SNCA institutes.

[Figure 1-11] Structure of Certification Scheme to National Standards (example)



Source: Authors.

Publicity activities for consumers should also be conducted to raise their awareness of the meaning of the certification mark and encourage them to use quality-certified products rather than uncertified products. In addition, the government may also encourage the use of products certified to quality standards by hosting exhibitions of good quality/certified products and circulating information on the market surveillance results on distributors to reduce the distribution of non-conforming products with the technical criterion set in the national standards.

4.2.3. Introduction of Quality Assurance in Government and Public Procurements

In order to expand the demand and supply of test and measurement services, an environment must be created in which products with proven quality are differentiated and their demand is secured. In this context, to promote the voluntary certification scheme such as 'NTC Certification Scheme', the demand for the certified product must be secured so that the companies concerned would bear additional cost and efforts to obtain and maintain certification. Therefore, it is important to introduce incentives for companies possessing certificates.

Public procurement is considered as a classical and powerful policy tool to promote product quality improvement and related technology development. Colombian government should design a complete strategy to introduce quality assurance in public procurements. For example, an incentive measure such as public procurement policies giving priorities to products and services certified as complying with quality standards can be considered. Preferential treatment may also be provided to the products bearing eco-label and products produced by the National Quality Awards winner enterprises. The possible incentives can be that additional points are given to them in the assessment process for public procurement.

On the other hand, legal product certification schemes, either mandatory or voluntary, can contribute to reducing/elimination in the quality assurance process for procurement because certified product means that its compliance to the required technical criteria has been already proven by competent certification bodies.

4.2.4. Reshaping of the National Quality Award

The National Quality Award should encourage companies to implement quality management by being given to companies who have contributed greatly to enhancing the national industrial competitiveness through improvements in quality and productivity, and cost reduction by conducting excellent quality management strategies. Colombia already has operated National Quality Award approach. However, the awards are given to companies producing products that meet national

standards, and some of the certification fees for the products involved are supported so that National Quality Award contributes to promoting exports.

The National Quality Award is the only policy tool the Colombian government currently has in order to improve the quality of Colombian products and to promote the dissemination of technical standards. The NTC Certification Scheme would be able to contribute more directly to achieving this policy objective when adopted.

Besides, the National Quality Award was created aiming to "recognize the efforts of public and private companies to implement a comprehensive approach that allows them to achieve higher levels of competitiveness and reliability in their products or services" (Dirección de Regulación, 2015). It will be necessary to evaluate whether the National Quality Awards are contributing effectively to achieving this policy objective. The results of the evaluation will provide the evidence of the advantages and disadvantages of the current operational procedures of the national quality awards, so that they can be used as a basis for developing necessary measures for the improvement of this policy tool.

Colombia needs to extend the National Quality Award to big events to boost morale for award recipients and raise awareness of the importance of quality to consumers. For example, an official conference such as a National Quality Management Convention should be held to conduct the awards ceremony and to provide a floor to share the success stories of award recipients in quality management with nationwide leaders in companies. These will encourage other companies to implement quality management for performance improvement and promote the spread of quality cultures. The quality management performance of these awarded enterprises can be also used for technical guidance to SMEs through training programs and seminars, appropriately.

To expand the participation of companies in the National Quality Award event and to improve the quality management capacity of enterprises, training programs on quality management and quality control techniques should also be developed and provided to potential participants in the awards program and any other interested parties, as well. In order to provide such training programs, the fostering of training institutes should be also considered.

4.2.5. On-going Government Support to Public Institutions

Government should strengthen financial support for the operation of public institutions that perform non-profitable activities, such as the development and dissemination of national measurement standards. It is also necessary for the government of Colombia to provide support to public laboratories in order to

secure testing services in industrial sectors where the government is interested in development, but the necessary testing service is not available.

On the other hand, regulatory authority developing technical regulations should consider whether the conformity assessment services needed to implement the potential technical regulations are available. For this, a survey of laboratories, individually or through an accreditation body should be conducted for the national conformity assessment capacity needed. In accordance with the urgency of specific technical regulation to be adopted and the availability of the pertinent conformity assessment capacity, the competent authority can consider postponing the adoption of the regulation, opening the qualification of the conformity assessment body for a limited time, or provision of necessary support to designated public laboratories for ensuring that relevant conformity assessment services are available in the short term in Colombia.

4.2.6. Strengthening NQI Management Capacity

The ministry responsible for NQI in Colombia is MinCIT (Regulatory Directorate). MinCIT needs to use NQC to manage the operation of NQI institutions and to establish the necessary policies. The current CIC can be utilized as NQC after its mandate is strengthened. In other words, the decisions of the CIC do not stop at the recommendations but give the SNCA institutions the obligation to forcibly implement them. The CIC should also be in charge of monitoring and overseeing the implementation of the decisions made. The strengthening of the CIC's mandate will enable it to effectively coordinate the actions of public and private entities within the guidelines for SNCA (DNP, 2006).

On the other hand, according to Decree 3257 of 2008, ICONTEC and ONAC participate in CIC as permanent guests of CIC and may participate, with voice but without vote. However, INM is not included either as a constitution member of CIC or as a permanent guest of CIC. According to Decree 4175 of 2011, INM has the role of national coordinator of scientific and industrial metrology. Moreover, in the proposed scheme for the new structure of RCM, INM is located at the center of RCM and is responsible for the coordination and management of the RCM. In this context, INM should be enabled to take on a more active role in CIC in terms of improving coordination between public and private entities to promote metrology in Colombia as well as in implementation of NLP to be established.

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Chapter 2

Strategy for Infrastructure of Testing and Measurement in Colombia

Strategy for Infrastructure of Testing and Measurement in Colombia

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Summary

According to the National Development Plan (2014–2018), the Government of Colombia is to publish the National Laboratories Policy (NLP) in 2018 in order to establish the metrological traceability and also enhance the measurement competence of laboratories. The objective of the NLP is to improve the national competitiveness, to promote innovation and above all to protect consumers. This report is to provide the policy suggestions and recommendations for NLP from the perspective of metrology, which is the most important component in National Quality Infrastructure (NQI).

The NQI is a technological quality management system in which the five key components, namely metrology, standardization, testing, certification, and accreditation are interconnected and operated systemically. The functions of these components must be coordinated in order to enable the international trade through internationally recognized testing and certification services. Therefore, a developing country has to establish an NQI in order to raise the level of quality for various products and services being used domestically and to later export them to the world.

Keywords: National Quality Infrastructure, National Metrology System, Chemical Metrology System, National Metrology Institute, Metrological Traceability, Reference Material, Laboratory Capacity Enhancement, Quality Management System.

- Action Plans in the NLP with due Consideration to NQI

We found that the diagnoses of the problems present in laboratories in the NLP are consistent with the general quality problems which are commonly found in developing countries. Accordingly, the action plans to overcome the technical and metrological weakness of testing and measurement laboratories are rather well itemized and described.

In NLP, the action plans are categorized into two sections, which are the safety/security and the spirit of global competitiveness. Each section consists of two sub-sections, which are based on the increasing supply and demand of the testing laboratory services. The two categories are consistent with the objectives of NQI, which are to enhance the welfare of the people and the competitiveness of the country as an entity. The necessary activities to improve the technical capacity and quality of measurements are the same for both categories. Moreover, the supply and demand are inter-connected to each other, and the action plans can be related, which may result in unbalanced action plans for each category. In turn, it will divest the action plans of their effectiveness.

Therefore, we recommend regrouping the action plans according to the key steps in the process of establishment of the Chemical Metrology System (CMS). For effective execution of the action plans, it is emphasized that the National Metrology Authority (NMA), Ministerial Metrology Authority (MMA) and the National Metrology Institute (NMI) shall consist the control towers for the NQI and shall lead with the cooperation of Metrology-Accreditation-Standardization (MAS). The cooperation of MAS shall be a crucial requirement in activating the Colombian Metrology Network (CMN).

- Operation of National Metrology System of Colombia

The National Metrology System (NMS) is the NQI viewed from the perspective of metrology. The main objective of NMS is to ensure the quality of measurement in the country. The measurement results fit for the purpose are essential for decision making in every field of safety, regulations, global trade, productions and health, etc.

The current activities of metrology related institutes such as the NMA, MMA, NMI, National Legal Metrology Institute (NLMI), Proficiency Testing Provider (PTP), Reference Material Producer (RMP) are reviewed. In addition, the cooperation among the metrology, accreditation and standardization as well as the activities of CMN are studied.

We found that the most responsibility of the operation of NQI, NMS and CMS belong to NMI and the roles of NMA and MMA are not shown in the current NMS

of Colombia. Therefore, it is recommended that NMA and MMA are defined clearly with regards to their responsibilities and play their key roles in NMS operation. In addition, for the effective operation of CMS, the grouping of the field-specific laboratories such as health, environment, food etc. is recommended. Each Sector-specific Laboratory Group (SSLG) will be led by a corresponding Reference Measurement Laboratory (RML) designated by MMA or NMI.

To share the knowledge base from Korea, the role of the government in NQI and NMS is mentioned according to the Article 127 of Constitution of the Republic of Korea and the Framework Act on the National Standards of Korea which is a subordinate act of the constitution. The 4th Five-Year National Standards Basic Plan (2015–2020) of Korea is shown as an example. The role of the government should be not only as the supporter of NMS but also of the control tower with the assistance of NMI.

- Establishment of the CMS in Colombia

The calibration and Metrology in Chemistry (MiC) are the key components of metrology in NQI. However, many developing countries have left the responsibility of MiC to each sector and do not count it as a national responsibility. Due to the importance of traceability in chemical measurements, it should be dealt at the national level and be confirmed by the CMS. The CMS is shown to be the NMS through Certified Reference Materials (CRMs). The responsibility of the government on CMS is emphasized.

Because of too many types of matrix RM together with too many fields of application, NMI alone cannot be responsible for all aspects of the CMS. A partnership model for NMI to establish the CMS for Colombia is recommended. The role and activity of NMI and partner institute for CMS are also described.

- Activity of Korea Research Institute of Standards and Science (KRISS)

For sharing the knowledge base on the activity of KRISS, the mid- to long-term R&D plans of KRISS during the year 2015 to 2023 on the measurement standards and measurement technology are described to provide as a motive for innovation of INM.

Considering the interests of Colombia on CMS and CRM production, the KRISS plans on CRM and its R&D from 2015 to 2023 are described accordingly. In the plan, KRISS has set up a mid- to long-term strategy by surveying the demand list of CRM expected for the next decade. For the short-term of the next three years, a detailed plan is established, which reflects the current demands. In addition, the KRISS strategy for CRM R&D and service promotions of CRM are also introduced.

In brief, the report shows that the NLP can accomplish the objectives successfully if the action plans are executed systematically. It is empathized upon that the CMS should be established and operated as a system focusing on the process approach.

A system is the collection of the components which work together to achieve the same purpose. A system is the collection of the processes. The NQI as well as NMS should be established and operated as a Quality Management System at the nation level. It is shown that NQI is the system of the Colombian society to enhance the national competitiveness and the quality of life of the people regardless of whether it's because of voluntary standards or technical regulations.

1. Introduction

1.1. Purpose of National Laboratory Policy of Colombia

1.1.1. Background for National Laboratory Policy

In 2006, the MinCIT announced "Guidelines for a National Quality Policy" for effective operation of NQI. According to the National Development Plan 2014–2018, the Government of Colombia is required to publish the NLP that mandates establishment of metrological traceability and enhancement of measurement capabilities of the laboratories for improving national competitiveness, innovation and consumer protection.

The DNP and the MinCIT prepared the draft NLP. The NLP is a national project involving all Colombian ministries concerned with NQI, which will be announced and implemented in 2018. In the draft NLP, various problems, possible solutions and action plans for the Colombian laboratories are presented.

This study reviews the diagnoses and action plans in the NLP to overcome the metrological weakness and the limit of laboratory capabilities of Colombia. It is assumed that NMS can be viewed as the NQI from the view point of metrology.

1.1.2. Brief Outlines of NLP

Over the past few years, more than 10 public agencies, under the guidance of the DNP, have identified the weak measurement aspects of the laboratories as a key problem which is limiting the adoption of quality standards among Colombian firms as follows.

– No inventory of the laboratories in Colombia,

– Lack of supply and demand for laboratory services,

– Unreliable and inaccurate services,

– Not enough coverage of laboratory services for the country,

– Low innovation limited due to deficiencies in facilities,

– Shortage of human capital in the labs and

– No clear responsibilities among institutional (public and private) sectors

As a result, consumers and producers face higher costs. These problems have an adverse effect on the development of the Colombian agriculture and manufacturing industries, also on the capacity of the firms to innovate and create new products, and on the government's ability to ensure adequate and effective consumer protection.

As a first step to solve the problems, National Development Plan (2014–2018) stated that "the National Government will issue a NLP, which includes strategies to improve the technical capacity and the metrological traceability of the laboratories, as a decisive tool for improving competitiveness, innovation and consumer protection" (DNP, 2014).

1.2. Diagnosis in NLP

1.2.1. Survey for Metrological Weakness

It is recognized that the benefits and incentives are not sufficient for networking participation of the CMN, which results in poor dissemination mechanism of metrology.

The testing and measurement labs do not have enough space to make measurements and calibrations properly. They lack continuous funding for purchasing equipment and have a limited supply of maintenance and calibration resources. Moreover, the technical facilities and technological resources are concentrated in specific regions of the country.

Low participation in inter-laboratory comparisons is problematic. It requires a high cost for accreditation. Unsuitable implementation of quality certificates is observed. The insufficient funding for acquisition of CRMs is also a problem. Moreover, the domestic production of CRMs is not enough to meet the domestic demand. The ignorance or reluctance to use CRMs in testing and measurement is often observed as well.

The training programs specific to metrology are insufficient to meet the demand. Similarly, there are no competency guidelines for laboratory personnel and also insufficient allocation of resources for the on-going training courses.

The laboratories are not the central parts of Science, Technology and Innovation (STI) policies yet. The overall quality and competence of testing and calibration laboratories and the R&D centers are not high enough to play their roles in the research and innovation process.

It is also recognized that some regulations are not in line with international standards. In addition, inconsistencies between different standards, institutional incoordination and lack of regulations observance are often noticed.

1.2.2. Diagnosis by DNP

The DNP has diagnosed and organized six issues hindering the technical capacity and metrological traceability of the Colombian laboratories. The issues are:

– Scattered, inconsistent and undisclosed regulations for laboratories,

– Need for the networking skills among labs and institutional actors,

– Insufficient lab infrastructure to carry out testing and calibration,

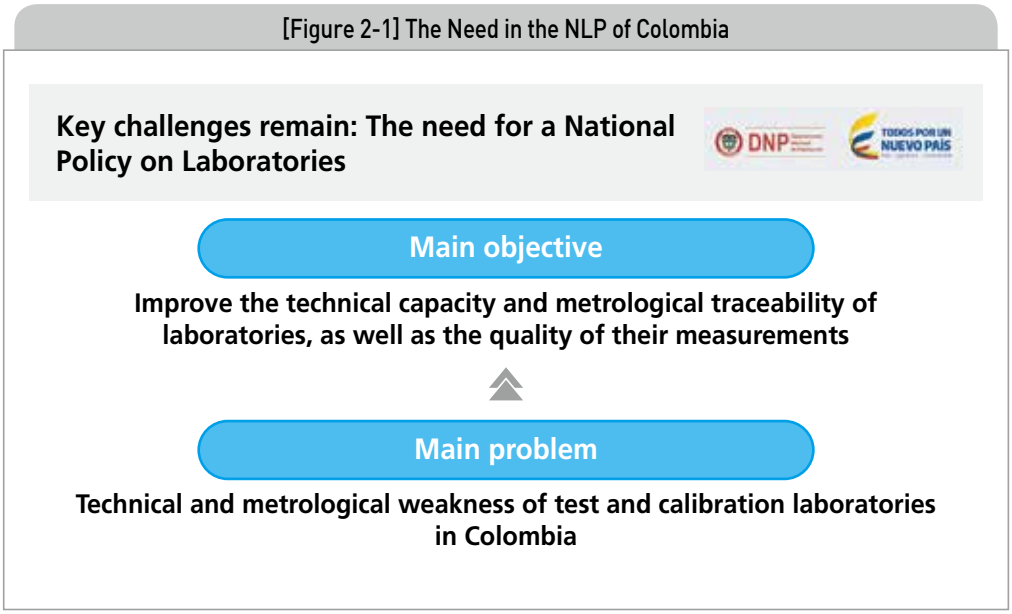
– Limited technical competence of laboratories in providing services,

– Human capital gaps; and

– Limited capabilities of laboratories on Science, Technology and Innovation (STI)

With the results of diagnoses, the NLP is prepared with the main objective to solve the laboratory problems of Colombia (see Figure 2-1). In NLP, the detailed action plans are provided by DNP.

[Figure 2-1] The Need in the NLP of Colombia



Source: DNP (2014).

1.3. Objectives and Action Plans in NLP

1.3.1. Objectives

The overall objective of the NLP is to establish strategies to solve the problem of the market failure and induce the governmental coordination to enhance the metrological capability of Colombia.

- Increase and improve the supply of laboratory services to ensure effective monitoring and control of goods and services, to promote transparency in economic relations and thus effectively strengthen consumer protection, the health of the population and environmental protection.
- Generate incentives to consolidate the supply and demand for laboratory services that facilitate competitiveness in Colombia, also favor both innovation and participation in the global value chains.

The objectives are categorized in two, which are for welfare of the people and for competitiveness in global trade. In NLP, instead of welfare, the wording 'safety' and/or 'security' are employed. Here, instead, welfare is adopted based on general usage in NQI.

〈Table 2-1〉 Objectives in Two Categories from the Action Plans in NLP

Objective	Incentives for Welfare and Competitiveness
Welfare	Increasing the Supply and Demand of Laboratory services
Competitiveness	Incentive the Supply and Demand of Laboratory services

Source: DNP (2017).

1.3.2. Action Plans in NLP

1.3.2.1. Improvement of laboratory services for safety or welfare

In order to promote transparency in economic relations and thus to strengthen the consumer and environmental protection effectively by ensuring of meticulous monitoring and control of goods and services, the action plans to improve the supply and demand of laboratory services are prepared.

〈Table 2-2〉 Action Plans for Welfare

Lab. service	Action plans for Welfare
Supply	– Technical support for traceability – Gap analysis of capability and training – Demands for testing and measurement – Governance for Colombian Metrology Network i) Demand and supply of testing and calibration lab ii) Inter-laboratory programs iii) Reference material providers iv) Enhancing technical capabilities – Function of public labs and updating the lists of regulations – Campaign for vocabulary and regulation of measurement
Demand	– Campaign and education for importance of quality and legal measurement – Response to quality infrastructure, particularly national laboratories

Source: DNP (2017).

1.3.2.2. Improvement of laboratory services for competitiveness

Here, favoring competitiveness and innovation, the strategies and action plans to encourage the demonstration of technical competence, the development of sectoral public goods regions as well as the supplement of technical standards are described.

〈Table 2-3〉 Action Plans for Competitiveness

Lab. service	Action plans for Welfare
Supply	– Centralized measurement services i) Calibration lab ii) Reference material procurement and import iii) Inter-laboratory programs iv) Reference material providers v) Enhancing technical capabilities – Function of local services – Committee for technical standards
Demand	– Strategy and action plans for incentives

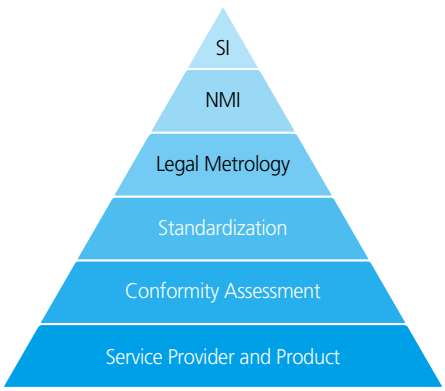
Source: DNP (2017).

1.4. NMS and NQI

The NMS is the NQI viewed from the perspective of metrology (see Figure 2-2). Standardization establishes various technical regulations and document standards necessary for the conformity assessment and for the development of measurement methods, test, inspection and certification. Accreditation is to evaluate the quality system of the laboratory that carries out conformity assessment services.

The NMS is the collective infrastructure of national facilities, expertise, knowledge and research, and is also a legal framework for reliable, consistent and internationally recognized measurement. The NMS encompasses the essential activities of both the public and private sectors.

[Figure 2-2] National Metrology System



Source: Authors.

The main objective of the NMS is to ensure the quality of measurement results in a country taking into account that these results are used to make decisions in fields such as regulation, global trade, products, health, etc.

Compared with the establishment of traceability of measuring instruments in the calibration system, the NMS of the chemical field is formed through the CRMs and is called the CMS. The CMS establishment is described in Section 3 in detail.

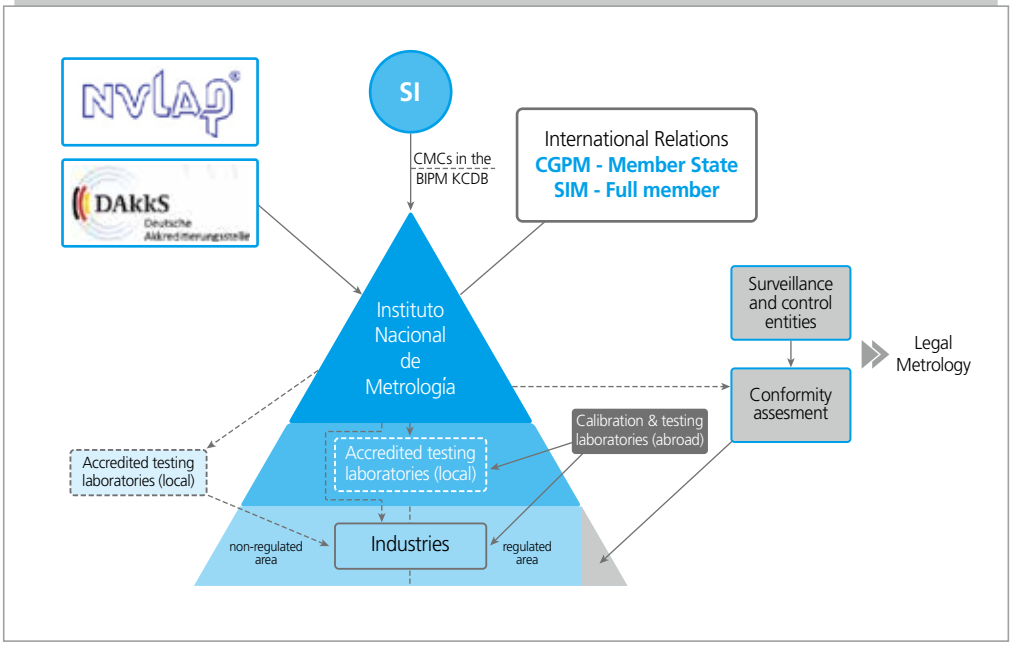
2. National Metrology System

2.1. NMS of Colombia

If we start from the basis of internationally accepted practices and international recommendations regarding the quality infrastructure, the national quality policies and the requirements to achieve an effective coordination of all its components, aligned with the governmental development policies, it can be said that Colombia has the most number of quality infrastructure institutions which are internationally recommended; that they all have well-defined roles and responsibilities that meet national and international expectations, although they require minor modifications to avoid duplication of efforts in some cases and precision of activities in others.

There is also a Ministry that leads the task of quality control in the country, namely the MinCIT. The DNP is aware of the importance of the metrology as the fundamental basis of all the entities of a quality infrastructure. The CMN is a very important tool for the development of INM based on the needs of the laboratories that make it up.

[Figure 2-3] General Structure of NMS of Colombia



Source: Authors.

It is the collective infrastructure of national facilities, expertise, knowledge and research, and is also a legal framework for reliable, consistent and internationally recognized measurement. The infrastructure encompasses essential elements of both the public and private sectors.[1)] The system must contain elements of both metrological control and metrological traceability and must involve different levels of the metrological hierarchy (see Figure 2-3).

The scheme of [Figure 2-3] shows the hierarchical pyramid of Metrology in Colombia. It shows that some of the laboratories of the INM have been accredited by international Accreditation Organizations (NVLAP and DAkkS). Taking into account that the INM already has internationally recognized Calibration and Measurement Capabilities (CMC) within the framework of the CIPM-MRA, this scheme to accredit INM laboratories must disappear for a short term perspective.

2.2. Activities of INM

According to the Asia-Pacific Legal Metrology Forum (APLMF), "Metrology supports the network of services that the community largely takes for granted and whose impact can be noticed in navigation, health and trade measurement services, such as delivery of fuel to customers at a service station. In this way, the

1) Own adaptation from PTB (2016).

metrology services provided by the NMI complement and support all of the activities undertaken by other bodies in the NQI."

In its functions, it has to establish, guard and conserve the national standards of measurement corresponding to the physical and chemical quantities; ensuring the traceability of the measurements to the International System of Units (SI) defined by the General Conference on Weights and Measures of the International Bureau of Weights and Measures (BIPM). Representing Colombia, it is a signatory of the CIPM-MRA since 2013. In addition to what has been described, Decree 1595 of 2015 clarifies the following:

"The INM will provide laboratories, research centers and industrial support with reference materials, inter-laboratory aptitude/comparison testing services and the amalgamation of measurement standards, when they cannot be provided by laboratories or accredited service providers that make up the network."

According to "The National System of Quality in Colombia: A Qualitative Analysis of the Development of the System," which describes the situation of the INM in 2015, Harmes-Liedtke and Oteiza suggested using the number of CMCs that the BIPM provides in their recommendations on the criteria for evaluating the progress or status of the INM. A second indicator is the number of Key or Supplementary Comparisons. Finally, there is the number of technical regulations.

The INM has made recent advances in the recognition of its capabilities to provide industrial and scientific metrology services in the country, despite having recently been created as an independent entity. By the end of October 2015, the INM had 13 CMCs recognized in the areas of time and frequency, well below most of the countries in the region. In November 2015, the BIPM notified the INM of the publication of thirty-seven newly recognized Calibration and Measuring Capacities.

Also, as stated in the aforementioned Inter-American Development Bank document, INM has maintained the accreditation of the National Voluntary Laboratory Accreditation Program (NVLAP) under the ISO/IEC 17025: 2005 standard obtained in 2013 for the Time and Frequency and Temperature and Humidity laboratories and from the Deutsche Akkreditierungsstelle (DAkkS), also under the same standard, for the Mass and Weighing Instruments Laboratory.

The functions of the INM are established in the Decree[2)] of its creation although a modification of said decree is required to complete some features that were not included from the beginning and organize some functions that were redundant.

2) Decree 4175 by which the NMI is created and its objective and structure is established.

2.3. Activities of NQC, NMA, NLMI and MMA

2.3.1. National Quality Committee and Subcommittee

In order to bridge the communication between the High Government and the NQI, the importance of the system for maintaining the quality of the products and the welfare of the population is recognized here:

- Coordinate with the National System of Competitiveness, Science, Technology and Innovation (SNCCTI) the activities referred to by the SNCA
- Provide coordinated leadership for quality in the country
- Propose to competent authorities, the quality policies for the achievement of the objectives of the SNCA
- Provide information based on the needs of the entities represented in the Committee for projection and development of the quality infrastructure entities
- Contribute to the achievement of funds from investment projects for the development of public entities that are part of the NQI
- Support the competent agencies in achieving international recognition for the different components of the SNCA

The thematic subcommittees will be set up, whose function will be to perform diagnostics of specific technical needs in the field of metrology, accreditation, standardization, among others.

Thus, a technical subcommittee will be formed for the Chemical Metrology that will be responsible for the elaboration of diagnoses referring to the production of certified reference materials, metrological traceability in chemical and biological measurements, among other topics.

2.3.2. National Metrology Authority (NMA)

Taking into account that the INM is the coordinator and executor of the metrological activities in Colombia,[3)] it is necessary to establish the position of the rector of metrology in the country or assign it to the INM. This governing body will be called National Metrology Authority (NMA) and among its functions will have to:

3) Decree 4175 by which the NMI is created and its objective and structure is established.

– Formulate, plan, direct, coordinate, and execute the national and sectoral policies of Metrology applicable to all levels of the government.

– Issue standards and technical guidelines for the adequate execution and supervision of national and sectoral metrology policies, the management of resources for the development of metrology; as well as for the granting and recognition of rights, inspection, sanction and coercive execution in the matters of its competence.

– Conduct the national metrology system.

– Carry out the follow-up and evaluation regarding the performance and obtaining of the achieved results of the policies, plans and programs regarding their competence, at the national, regional and local levels, as well as other actors of the National Metrology System throughout the national territory and adopt the actions required according to law.

– Grant and recognize rights through authorizations, permits and designations, in accordance with the rules of the matter, within the scope of its competence.

– Officialize the national measurement standards.

2.3.3. National Legal Metrology Institute (NLMI)

There is no such institution in Colombia but there are several state entities with functions in this field such as the Superintendence of Industry and Commerce and INVIMA.

2.3.4. Ministerial Metrology Authority (MMA)

This level of authority does not exist in Colombia, but it is advisable to establish one, which could be the highest decision-making body at the level of the NMA.

As proposed in document D1 of the OIML, the hierarchical structure of the National Metrology System must have a NMA that coordinates the metrological policies and activities in the country through other instances of the pyramid, namely the NMI, the National Legal Metrology Institute (NLMI) and the MMA, each of them with a clearly defined role that must contemplate at least the following tasks:

In the document "Guide for the Development of National Quality Policies,"[4] UNIDO describes an Inter-ministerial Coordination Committee as follows:

4) UNIDO (2016).

"In order to obtain a buy-in from all relevant government departments, the NMA should be supported by a committee in which all the relevant Ministries and even QI institutions and agencies are represented, because the National Quality Policy, especially if it also deals with the technical regulation regime, will be cross-cutting, i.e. impacting many Ministries. This coordinating committee/structure should be approved by the Cabinet to ensure the full and unreserved cooperation from all Ministries. The coordinating committee/structure should be authorized to:

- Commission studies, request information from concerned institutions and conduct research to obtain information and data;
- Review and adopt findings of investigations on the current status of the Quality Infrastructure system;
- Develop and endorse recommendations with regards to establishing policies, functions and roles of the institutions concerned and in relation to developing or revising the enabling legislation for the Quality Infrastructure;
- Adopt plans for the modernization of the Quality Infrastructure and assign implementation to specific agencies or persons;
- Progress the decisions and recommendations made to the highest level of the government for modernizing the legislation rules and procedures for the concerned departments as provided for in the procedures and practices established by the government;
- Monitor and oversee implementation plans on a regular basis until successful implementation"

2.4. Activities of Labs, RMP and PT Provider

2.4.1. Reference Laboratories

Laboratories that have been named by a law or a decree as reference in the fields in which they are authoritative, and which are served as a reference in terms of test methods, should also be a metrological reference for other laboratories in their network, in case of which has it constituted, or of the other laboratories that perform functions in its field of activity.

Thus, the authority recognized by law as a reference in food is responsible for the quality of the measurements carried out by the laboratories in its network and to ensure that metrological traceability is achieved through the services provided by the INM of Colombia.

2.4.2. Calibration Laboratory

In Colombia we have a total of 130 calibration laboratories accredited under ISO 17025 and that covers a large percentage of the country's needs. The laboratories, accredited under the ISO 17025 standard, are grouped into 55 accredited areas.

Laboratory accreditation bodies use the ISO 17025 standard specifically to assess factors relevant to a laboratory's ability to produce accuracy, accurate test and calibration data, including:

– Traceability of measurements and calibrations to national standards

– Technical competence of staff

– Maintenance of test equipment

– Quality assurance of test and calibration data

– Validity and appropriateness of test methods

– Appropriate handling and transportation of test items

– Quality of testing environment and sampling.

2.4.3. Testing Laboratory

Colombia has 218 accredited testing laboratories under the 17025 standard in 98 different areas.

2.4.4. Inspection Laboratories

The National Accreditation Body of Colombia (ONAC) evaluates the inspection bodies and their compliance with the requirements of the international standard "ISO/IEC 17020 Evaluation of Conformity. Requirements for the Functioning of Different Types of Organizations that Carry out the Inspection," for their accreditation since the standard establishes the criteria and other aspects that configure the capacity of an inspection entity to produce reliable and well-founded results.

2.4.5. Reference Material Producer (RMP)

Just as calibration laboratories are accredited, producers of reference materials must be developed in such a way that they are accredited under the standard that qualifies their technical competence. Taking into account that the INM cannot

supply the demand for reference materials from all national sectors, it is necessary to establish and/or develop its local offer in a way that meets the technical requirements and ensures the traceability of the measurements in chemistry and biology when it is possible.

Accreditation allows RMPs to demonstrate their competence by complying with the international criteria. For those who use reference materials, such as calibration and testing labs, accreditation provides assurance of the quality of reference materials produced according to specific technical and management system requirements.

In Colombia, there are no accredited producers of reference materials, but there is a local supply of chemical solutions and substances that must be strengthened and directed towards accreditation with the ISO 17034 standard.

2.4.6. PT Provider

The local proficiency testing provider (PTP) should be created and strengthened so that the necessary critical fields are covered. These fields of interest for the development of proficiency testing should be prioritized in the NQC and its Subcommittees. Again, the accreditation, in this case under the ISO 17043 standard, ensures the competence of the provider. In Colombia, three providers of proficiency tests have been accredited under this standard.

2.5. Cooperation of Metrology-Accreditation-Standardization

Cooperation agreements have been established between the INM and the ONAC and ICONTEC of Colombia so that the missionary functions of each of these entities are strengthened with the technical expertise of all of them. Thus, the INM facilitates its experts to act as technical auditors in accreditation processes and ONAC auditing experts perform audits to the Integrated Management System of the INM. As for Standardization, the INM regularly participates in standardization tables, reviews technical standards and supports others in metrology issues.

2.6. Colombian Metrology Network (CMN)

2.6.1. Objectives of the CMN

The CMN has the following general objectives.

– Identify metrological technical capacity in terms of the existing national supply.

– Determine the needs, requirements and metrological expectations of the Colombian laboratories.

– Encourage and support the establishment of joint processes and projects that allow the generation of products and services in accordance with the needs and requirements.

– Generate, update and exchange the metrological knowledge among its members to integrate and strengthen its metrological capacity.

And the activities to achieve the following specific objectives are:

– Support the establishment of metrological traceability of measurements made in the country's laboratories, support the dissemination of metrological traceability and support in the improvement of the metrological culture in different regions.

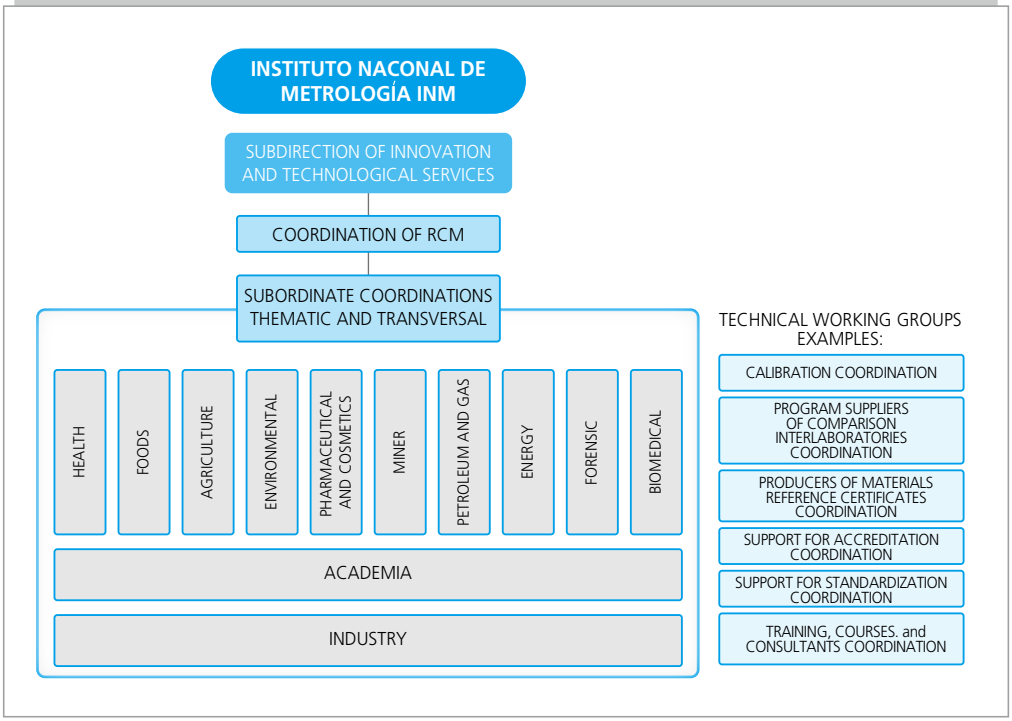
– Promote a constant updating of theoretical and practical knowledge in the industrial and scientific metrological area and encourage technical cooperation between institutions involved in the metrological area.

– Promote the generation of face-to-face and virtual spaces that facilitate socialization, dialogue and integration among its members and disseminate the existing metrology based technical capacity in the RCM laboratories.

2.6.2. Structure of the CMN

At present, the structure of the CMN is as it appears in [Figure 2-4]. Currently, and due to deficiencies that have been found in the initially proposed scheme, the CMN is being restructured so that it can comply with the institutional objective of promoting metrology at all levels of the country's economy and be a source of information of the needs of its users that can be used to project the development of the National Institute of Metrology.

[Figure 2-4] Current Structure of the CMN



Source: RCM Website.

2.6.3. Activities of the CMN

Among the activities developed by the Colombian Metrology Network here are a few prominent ones:

- Design a methodology to identify metrological capabilities with a sectoral approach
- Develop forums and/or national dissemination and training events in metrology
- Conduct metrological evaluation visits to public entities and private companies
- Compile and manage information on the measurement capabilities of the laboratories registered in the network.

Set of testing and calibration laboratories, suppliers of comparison programs, producers of reference materials and natural persons involved in the topics of metrology, coordinated by the National Institute of Metrology.

2.6.4. Weakness of the CMN

Some problems have been detected related to the current structure of the CMN that make its restructuring necessary. Among these problems, the following can be mentioned:

- The structure of the Network is limited to the regulated framework,
- The quality requirements of the control entities are limited to compliance with national technical regulations, which limits developments and projects aimed at promoting the export of products,
- The public entities that coordinate the sub-networks do not assign an item in their budgets for the development of metrology as an activity of strategic importance for its development and operation,
- It is not clear the coordination that INM performs in the Network,
- The CMN database is not functional and does not contain useful information for the fulfillment of its objectives,
- The interaction of the components of the Network is not clear. The relationships or the network work of its components are not clear,
- Industry, which marks the economic growth, is not clearly inserted in the subnetwork scheme.

2.7. Knowledge Sharing with Korea

2.7.1. Metrology and NQI

"Measured once, accepted everywhere" is used in the view of metrology, whereas "One standard, one test, and accepted everywhere" is used in terms of testing institutes. It is mainly used for international trade and commerce. Now it is widely used for quality of life such as safety, health, and medical field. It is the expression that emphasizes the reliability of measurement. In addition, the importance of measurement and quality in all fields of environment, safety, and medical care is emerging, including the producer and supplier of the products that are the customers of the testing laboratories and certification bodies.

For the purpose of globalization of international trade and consumer protection, the quality term that is born with the aim of collecting the quality that includes the producers and consumers as a whole is the NQI. General producers and consumers should not be at all aware of this. For example, in the case of the use of scales and gasoline purchase, NQI makes it possible for us to live without worrying about the

quality and reliability of general products or services. It is the fundamental system of a society.

Thus, NQI consists of three major components: metrology, standardization and accreditation. Metrology provides the measurement standard, which requires the measurement capability of international equivalence. The document standard, which is the product of standardization, is the document which is essential for conformity assessment and the standardized test methods. Accreditation is the evaluations of a management system and that of measurement capabilities of a laboratory based on the international standards such as ISO/IEC 17025.

2.7.2. NMS and NQI of Korea

In Korea, from the viewpoint of metrology, the NQI is called as the NMS. On the other hands, from the view point of standardization, the NQI is viewed as the National Standards System. The most frequently employed term is the 'National Standards System'. The Article 127 of Korean Constitution has stated that the government shall establish the national standards system (see Table 2-4). Based on the Article 127, the Framework Act on National Standards is established.

〈Table 2-4〉 Article 127 in the Constitution of Korea

Constitution of Korea
Article 127
(1) The government shall endreavor to develop the national economy through innovation of science and technology and development of information and manpower.
(2) The government shall establish a national standard system.
(3) The President may have the necessary advisory bodies to achieve the purposes of paragraph(1)

Source: Authors.

The Framework Act is for the establishment and realization of a national standards system. In other words, the Act is designed to improve the national competitiveness and the national welfare through the advancement, the effective and efficient operation and management of the national standard system (see Table 2-5).

The contents of the Framework Act are shown in <Table 2-6>. The chapter 3 of the Act describes the NMS. The chapter 4 covers the management and operation of the national standard system.

〈Table 2-5〉 General Provisions in the Framework Act on National Standards

Framework Act on National Standard
Chapter 1. General Provisions
Article 1 (Purpose) This act is to contribute to the enhancement of national competitiveness and the improvement of the walfare of the people through the innovation of science and technology, the advancement of industrial structure and the promotion of information society. (rev.2009.4.1)
Article 2 (Scope of application) This Act is shall apply to all areas of economic and social activity that must comply with national standards based on science and technology.

Source: Authors.

〈Table 2-6〉 Contents of the Framework Act on National Standards

Chapter 1: General Provisions – Scope – Term, etc
Chapter 2: Establishment of national standards System – Preparation of measures – National standard council etc.
Chapter 3: Advanced National Standards System – Measurement unit – NMI – Establishment of measurement standards – Calibration system – Reference material – Reference standards data – Legal metrology – Industrial standards,etc
Chapter 4: Operation and Management of National Standards System – General management of national standard system – Construction of conformity assessment system – Certification – Accreditation, etc – Testing and certification bodies
Chapter 5: Supplementary Provisions

Source: Authors.

As shown in <Table 2-7> together with <Table 2-6>, all the constituents of NQI are included in the Framework Act on National Standards, thereby it can be called as the Law of NQI in Korea.

〈Table 2-7〉 Articles in the Framework Act on National Standards

Framework Act on National Standards	
Article 5 (National standard council)	Article 17 (Lagal metrology)
Article 13 (NMI)	Article 19 (Establishment of national measurement standard)
Article 14 (Establishment of the national calibration system)	Article 20 (Overall management of the national standards system)
Article 15 (Certification and dissemination of reference material)	Article 21 (Establishment of conformity assessment system)
Article 16 (Establishment of standard reference data)	Article 23 (Approval of testing and Inspection Institutions, etc)

Source: Authors.

2.7.3. Policy of the Fourth National Standards Basic Plan

In order to realize the Article 127-(2) in the Constitution of Korea, the Framework Act on National Standards is established. Since 2001, according to the Framework, the Korean government, including all the related ministries, has to establish a 5-year National Standards Basic Plan and publicize their contents.

The first to third Basic Plans were to promote the formation and consolidation of the national standard system by expanding the participation of the private sectors and strengthening the participation of ISO, ITU and IEC. The current 4th Basic Plan is to re-establish the direction through the new internal and external environment and evaluation of the 3rd Basic Plan. The 4th Basic Plan is to "Enhance the competitiveness of the enterprise, to create the market and to support the growth of the enterprise by implementing the advanced economy and by upgrading the national standards system"

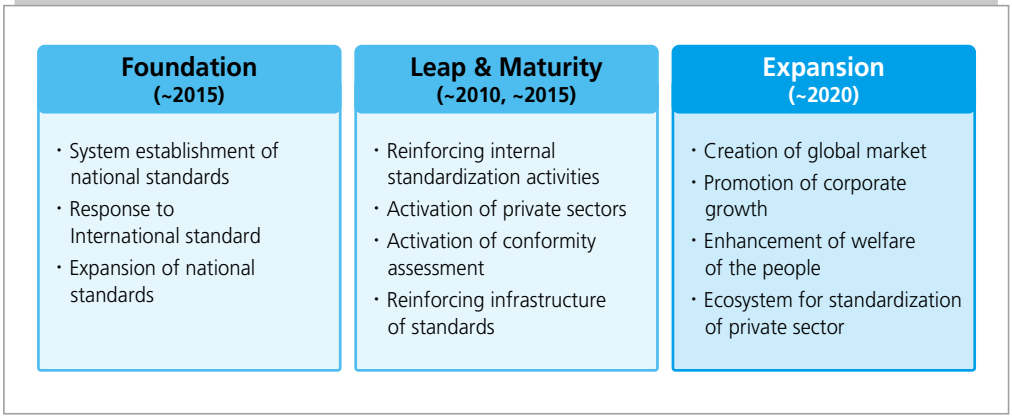
- Supporting the creation a of global market by expanding standardization of new industries such as smart fusion merger, manufacturing base service and international standardization
- Supporting the improvement of the certification system, support for resolving the TBT problem, and industrialization of measurement and reference standards to promote corporate growth and overseas expansion

– Increasing public life by expanding standardization in tourism, Korean wave, odor and fine dust measurement, health care, industry and life safety

– Cultivating private standards organizations and human resources, and further spreading the private standard-oriented ecosystem through communication and settlement of open standards culture.

Currently, establishing the performance indicators for the effective implementation of the 4th Basic Plan, the National Standards Council of all ministries and private sector representatives are endeavoring to improve the Korean NQI with the directive strategy (see Figure 2-5)

[Figure 2-5] Direction of Policy for the Fourth National Standards Basic Plan



Source: Authors.

Since 2001, the Korean government has established and implemented a Five Year Basic Plan in accordance with the National Standard Plan. Following the 'Framework Act on National Standard', after the deliberation of the National Standards Council, the Basic Plan is confirmed and announced to the public. The overview of the 4th Plan is summarized in <Table 2-8>.

〈Table 2-8〉 Overview of the Fourth National Standards Basic Plan

Name of Plan: The 4th National Standards Basic Plan

- Plan Period: 2016–2020
- Eatablishment and implementation of the national standard basic plan for the National standard Act

Backgrounds

- Establish and implement a basic plan every five years in accordance with the National standard Act(Article 7(1))
- In accordance with the 「National standard Act」(Article 7.2(2)), after the deliberation of the National standards Council, the basic plan is confirmed and announced (Article 7 of the Enforcement Decree of the National Standards Act)

Main contents (Article 7.(3) of National Framework Act)

- The establishment, maintenance and management of national standards
- Establishment and maintenance of measurement standards of national measurement standard representative organizations
- The maintenance, improvement and mutual harmonization of the written statement standard operated by each central administrative agency
- Research and development of standards related technology
- Mutual recognition agreements between countries and cooperation with international standards related organizations
- Education and training for training professional manpower of standard related institutions
- Financing and operation of standardization tasks by each central administrative agency
- Other matters concerning national standards

Source: Authors.

2.8. Activity of KRISS

2.8.1. Missions and Functions of KRISS

Operating under the Constitution of the Republic of Korea, article 127, §2, and the section 13 of the Framework Act on National Standards, KRISS sets forth its mission in the article 2 of its statute. The article states that "KRISS, as the NMI of Korea, has been assigned to conduct its missions to promote industrial competitiveness of Korea by advancing measurement standards, science and technology in ways that enhance the nation's economic performance and secure a better quality of life for all."

2.8.2. Plan for Measurement Standard

In order to strengthen the knowledge base for national quality and innovation, a total of 12 areas including length, time, mass, force, temperature, photogrammetry, electricity, magnetism, electromagnetic wave, fluid flow and acoustic vibration. The

development plan for measurement standard focused on consumer is established for 2015~2023 and is in progress (see Table 2-9). The plan is for 9 years (3 years for each phase) from 2015 to 2023, and the 147 projects are composed of 70 % for the establishment of new measurement standards and 30 % for improvement. The plan is established and detailed with the yearly step-by-step goals. KRISS will provide measurement services in Korea and abroad after newly establishing or improving 33 measurement standards in the first phase (2015~2017), 46 in the second phase (2018 ~2020) and 46 in the third phase (2021~2023).

〈Table 2-9〉 Plan of Measurement Standards of KRISS

2015–2023 Mid- and Long-term Plan for Measurement Standards
Establishment and service plan of national measurement standards
1. Length 2. Time 3. Mass&force 4. Temperature 5. Photometry 6. Electromagnet 7. Electromagnetic waves 8. Fluid flow 9. Sound&vibration 10. Amounts of substance 11. Ionizing radiation 12. Material properties
Appendix 1: New establishment and enhancement list of measurement standards Appendix 2: External Expert Review Comments

Source: Authors.

2.8.3. Plan for Science and Technology Development

The Plan for Measurement Technology Development and Utilization, which has been spread over 9 years (3 years in 3 phases) from 2015 to 2023, is to investigate the total R&D target of 160 measurement science and technology fields and sectors. The expectation to complete development for each phase is 20 projects (13%) in the first stage (2015~2017), 82 projects (50%) in the second stage (2018~2020) and 58 projects (37%) in the third stage (2021~2023). During the second phase (2018~2020), 82 projects (50%) will be completed including 13 projects in energy and resources sectors, 12 projects in healthcare sectors, 9 projects in semiconductor display fields and 9 projects in military defense fields.

〈Table 2-10〉 Plan for Measurement Science of KRISS

2015–2023 Mid- and Long-term Plan for Metrology (KRISS)
Comprehensive plan of measurement science and technology development and utilzation
1. Automotive, shipbuilding and offshore plant 2. Space and Aviation 3. Semiconductor and Display 4. Enegy and Resources 5. Information and Communication 6. Defense 7. Healthcare 8. Environmental 9. Disaster, disaster, safety 10. Measurement equipment
Appendix 1: Measurement Science and Technology R&D List Appendix 2: External Expert Review Comments

Source: Authors.

2.8.4. Plan for CRM

For CRM, KRISS's CRM R&D and Service Plan (2014–2023) are described in section 4.

3. Chemical Metrology System

3.1. General

3.1.1. Chemical Metrology System in NMS

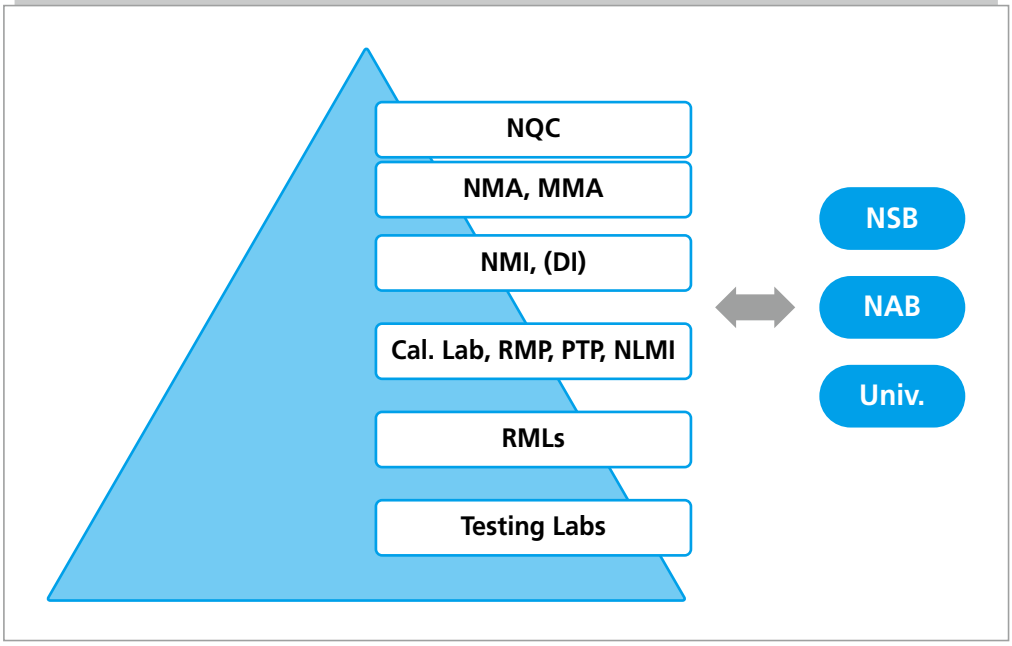
The perception of chemical metrology is spreading rapidly in recent years. This area is called MiC. The MiC includes biology, environment, clinical and medical in addition to chemical fields. There is no doubt that chemical measurements are important to society. There is also a general consensus that there should be a unanimous acceptable quality, which requires the foundation of good measurement science (i.e. metrology). Compared with the establishment of traceability of measuring instrument in the calibration system, the NMS of the chemical field is formed through the CRM and is called as CMS.

Now, the standards in the field of calibration and chemistry are the key components of metrology in NQI. However, many developing countries have left

the chemical testing at the field level and do not consider it as a governmental responsibility. Due to the importance of traceability in chemical measurements, it is about to be dealt at the national level, which shall be covered by CMS in NMS.

Therefore, with the calibration activities, the MiC activities by NMI and testing labs as well as RMP shall establish the NMS of a country (see Figure 2-6).

[Figure 2-6] NMS including CMS



Source: Authors.

3.1.2. Development of Chemical Measurement Technology

In addition to changes in the quality of life of the people, the demands for CRM in the high-tech industry are increasing. For example, now the bio-medicine, medical industry, and high-tech material industries shall have the technical capability to test the materials that were not necessary in the past.

In order to verify and improve the analytical measurement capability on high concentrations for new materials, NMI should supply the corresponding CRMs. The competence of NMI becomes a crucial factor for industrial development. Therefore, it should ensure their high-level R&D capability in order to respond to the demand of the advanced industry. If the competence of NMI for the field is recognized at the international level, the international recognition of the related domestic industry can be enhanced as well.

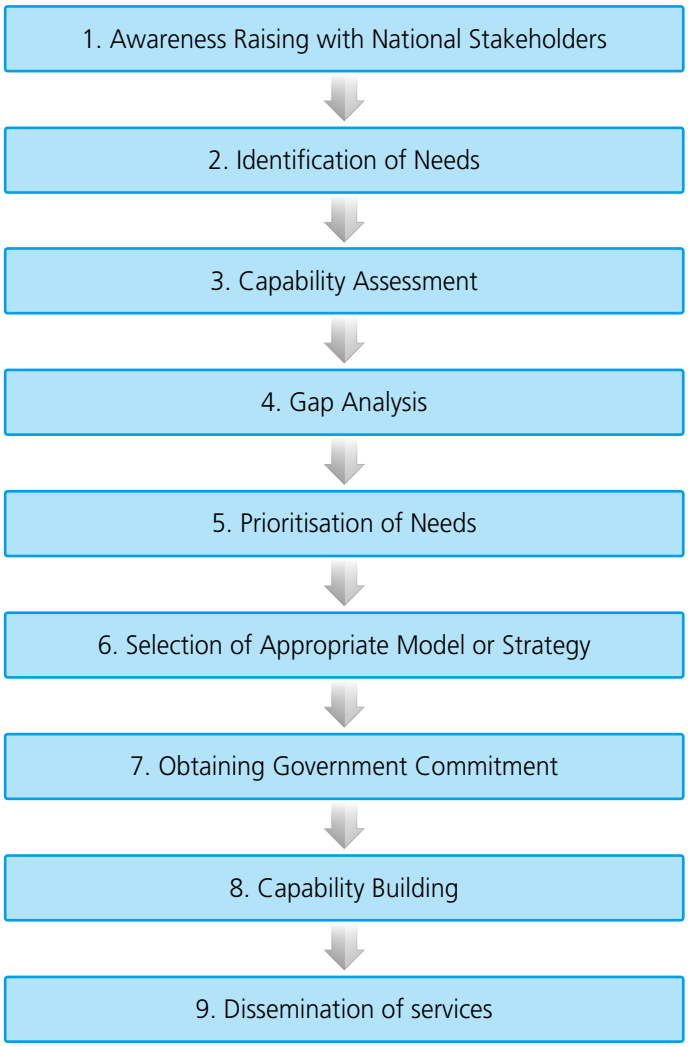
It is an important decision for the Colombian government to establish the CMS by the National Development Plan. It is the basis for the production of reference materials. It is also to be recognized by the government that the establishment of CMS requires a large investment in terms of a vast range of chemical measurement facilities encompassing many analytical instruments and matrix-to-matrix combination for CRMs.

3.2. Role of Government on CMS

3.2.1. Responsibility of the Government

The government is responsible for establishing and maintaining the CMS as part of the NMS in NQI. In fulfillment of its role, the government shall act in the interests of the country. The actions are jointly governed with transparency, coordination and cooperation amongst the various sectors and the ministries. In order to create a CMS with a properly functioning NQI, the government should carry out a profound restructuring of the technical regulations and standards in order to satisfy the international obligations and the national requirements. The main goal of CMS in a country is to establish its own internationally recognized chemical measurement capabilities. The duty of laboratory services to governments, the industries as well as people to solve the international and domestic disputes in measurement issues in areas such as health, environment and trade should be successful. The CMS should be designed, cooperating with the NMI, RMP and testing laboratories for enhancing national competitiveness and welfare of the people. The government support should not be limited to one-time input at the time of its establishment. The operation of CMS should be monitored and improved by the government.

[Figure 2-7] A Guide for CMS by APMP and PTB



Source: PTB and APMP (2009).

3.2.2. CMS Model for Colombia

3.2.2.1. A Partnership in the CMS Model

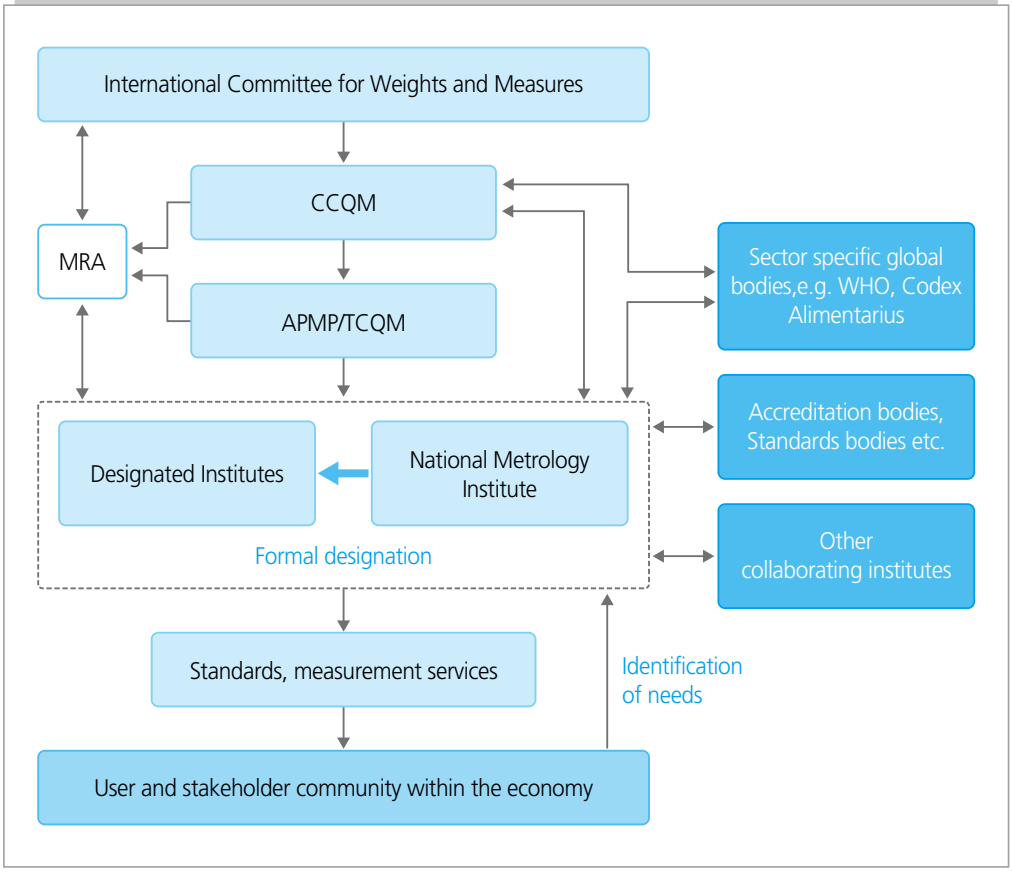
The guide by APMP and PTB suggests some selections for the model of CMS suitable for a nation, which requires the decision of the government and the NMI. Many countries are using the partnership model. After selection of the model, it is shown here how to set up the chemical metrology system step by step in the

guide (see Figure 2-7). Based on the guides some suggestions are provided for the infrastructural construction considering the current situation of Colombia. The model for Colombia has already been discussed during the last two visits of Colombian officials.

In this model, NMI forms partnerships with a number of institutions specialized in chemical measurement technologies of the specific fields. The partnership organizations should have the specific service capabilities required for the fields and the NMI should be able to provide the metrological expertise of MiC. The cooperation between the partnership organizations and NMI is to be emphasized upon by the government policy and realized during the CMN operation.

The "Partnership Model" may include an official designation agency and other organizations where the NMI can add value. The partner organizations work on field-specific key technical services. They link domestic stakeholders with relevant customers. In addition, the organizations should play an important role in the area of technical regulations and standardization of NQI. The operation of the CMS is centered on the NMI. The NMI provides core metrological expertise to the partner organizations and links activities to international metrological organizations such as ISO, BIPM and OIML.

[Figure 2-8] The Partnership Model for CMS



Source: PTB and APMP (2009).

3.2.2.2. Requirements on DI

Depending on the degree of cooperation, the partner organization can be a Designated Institute (DI) by NMI. Their appointment is based on proven measurement capabilities. The DI needs to be decided at the national level in consideration of the need for activities by the CIPM-MRA. The CIPM-MRA activities should involve participating in international key comparisons (KC), providing the Calibration and Measurement Capability (CMC), and maintaining quality systems.

The DI will act as a "National Measurement Standards Agency" identified for a particular measurement service (e.g. specific analysis of a particular matrix) that has been coordinated with the NMI. NMI should support DI to fulfill their role. They also have a duty to demonstrate measurement capability regularly in open and transparent manner.

3.3. Role of NMI in CMS

3.3.1. Trend for MiC

The absence of a credible, country-based MiC infrastructure means that the field laboratories are unable to secure the quality of measurements. It is a worldwide phenomenon that the interests in metrology are shifting from the traditional industrial measurements to the quality of life improvement and the support for new growth engines of a high-tech industry.

As a result, the interests and activities of the chemical industry, which produces RM and CRM, have been greatly increased. However, there is still a lack of recognition on the importance of CRM and quality of the chemical measurements. Therefore, the NMI shall pay attention on MiC and play the most important role to establish CMS. The CMS cannot be operated properly and improved upon continuously without the cooperation of NMI and Colombian government.

3.3.2. Role of NMI for CMS

3.3.2.1. Communication with Stakeholders

First of all, NMI shall prepare for CIPM-MRA in the necessary areas of chemistry as a NMI and shall provide its competency to the field laboratories. The NMI shall dedicate sufficient resources, especially for the process of knowledge transfer, metrological advice and coordination across the industrial sectors. This can be achieved by providing education/training, supporting certification body, involving government agencies, assisting laboratory accreditation, standardization and supporting enforcement of laws.

Then, it is good to institutionalize the communication between the stakeholders in NQI. The National Metrology Board or National Quality Council (NQC) can be an appropriate sponsor for this task. The NMI together with NQC should facilitate communication between field laboratories, accreditation bodies, reference laboratories, RMP, the government and industry users.

3.3.2.2. Activity of NMI in CMS

Generally speaking, many NMIs are lacking in capability for their specific field of chemical measurement, which should be overcome. The NMI should have background knowledge of chemical measurements, firstly. Since it may be difficult to acquire all the measurement technology in chemical measurement, the NMI should

play a leading role in the dissemination of the basics of metrology such as vocabulary in metrology, traceability, uncertainty, validation, and so on.

In order to respond to the demands of the field labs, the activities of NMI should be performed at the national level through training, educational endeavors, seminars and workshops. It is the most effective way to identify what can actually be done to help a CRM/field/accredited laboratory. It is known as a 'bottom-up approach'. A strategic alliance with the chemical education programs by the academia and a multitude of long-term incentive schemes are recommended for a long-term impact on CMS. For education on MiC in academia, the NMI should provide its metrological expertise for the cause of education programs.

4. CRM R&D and Service of KRISS (2015–2023)

4.1. Introduction

The CRM should be developed and distributed to the measurement fields to establish the reliable NMS or CMS. The high-quality measurements are required in the chemical, biological, and radiological fields, which are increasing in their prominence day by day. This is a prerequisite for the advancement of the high-tech industry and for the improvement of quality of life of the people.

In this chapter, sharing the knowledge from Korea, the CRM R&D and the Service Plan (2015 ~ 2023) of KRISS are discussed (see Table 2-11). KRISS has set up a mid- to long-term strategy while closely surveying the demand for CRM expected over the next decade. In the short-term plan for the next three years, a detailed plan was established and reflected on the basis of the current information on demands.

〈Table 2-11〉 CRM R&D and Service Plan of KRISS

2015–2023 Mid- and Long-term Plan for CRM (KRISS)			
CRM development and service			
1. Introduction			
1-1 Necessity of R&D and Promotion		1-2 R&D and domestic&international distribution	
1-3 strategy for R&D and promotion			
2. R&D and Promotion Plan			
2-1 Food	2-2 Environment	2-3 Bio-and Clinical analysis	2-4 Industry
3. Outcome and expectation			
4. Conclusion			

Source: Authors.

A feasible target was set based upon the estimated demand, but rapid technological development and social transformation is anticipated, which requires room for flexibility. In order to respond effectively to the existing or soon-to-be realized agenda for the society, researchers related to food, environment, biotechnology, clinical, and new industries keep monitoring the emerging analytical measurement issues with the help of their own technical backgrounds.

4.2. Domestic and Foreign Status

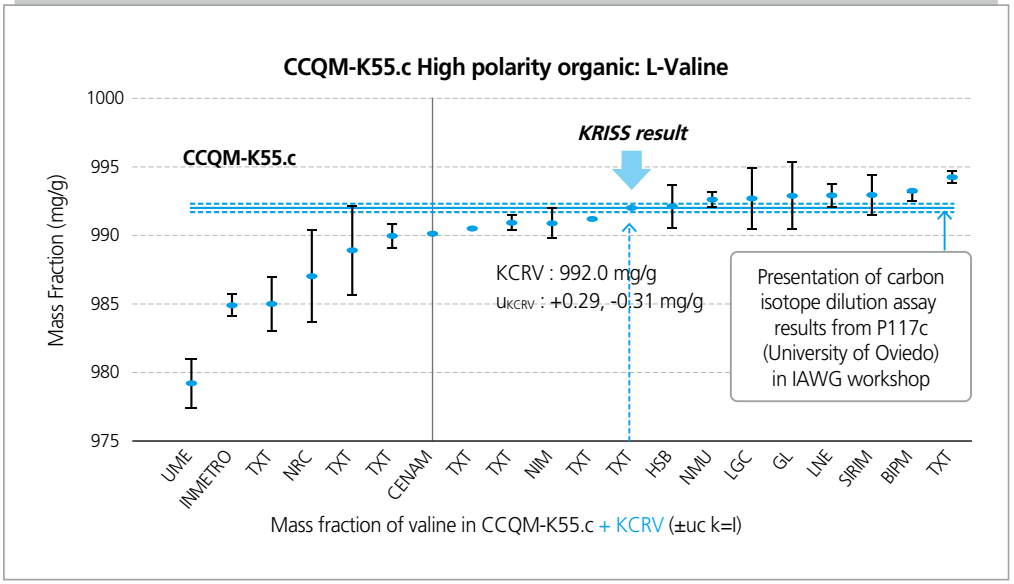
4.2.1. Current Status of Korea

For the supply of CRMs, KRISS has developed and distributed them for the NMS of Korea. The CRMs, not developed by KRISS, have been imported from the NIST and IRMM. As the significance of CRM has been steadily highlighted over time, KRISS has been greatly expanding the development and production capabilities of CRMs since the early 2000s. Nevertheless, due to the characteristics of a large spectrum of CRM, which requires production of a small amount, it is not possible to produce all CRMs by KRISS. Currently, KTR has started to produce CRMs, cooperating with KRISS.

In addition, the Asian CRM network (ACRM) activities are being actively carried out in order to reduce the burden of each NMI by the cooperation between Korea, China, and Japan. In this international cooperation some major issues that have been recorded are the usage of raw materials that are difficult to obtain and the cooperative analysis of high-grade CRMs.

KRISS has recently made a great deal of effort to ensure excellent purity analysis capability (see Figure 2-9) which is often one of major contributing factors in measurement uncertainties.

[Figure 2-9] Purity Analysis Capability of KRISS



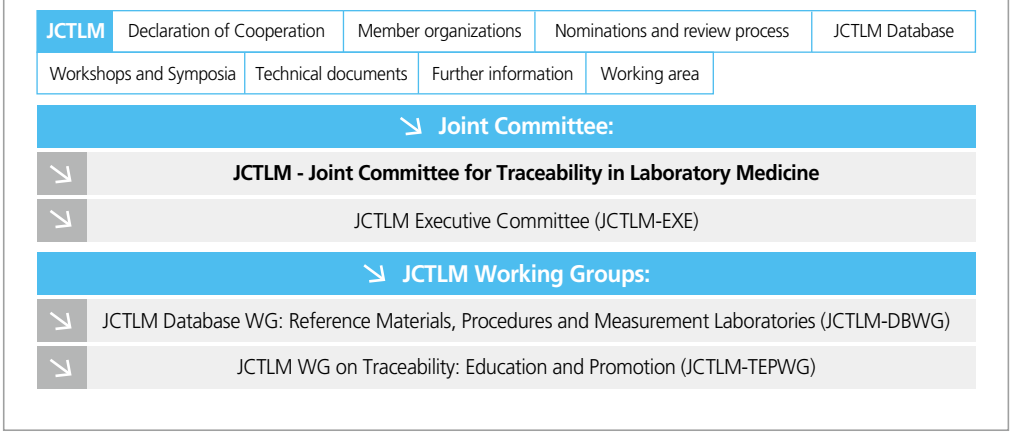
Source: KRISS (2015a).

4.2.2. Foreign Status

There has been a fierce debate among field scientists about using reference materials that are prepared by existing practices. From the debate, the international harmonization of the measurement results is supported by a number of international organizations, such as International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) and World Meteorological Organization (WMO). The recognition of CRMs has been greatly improved by World Health Organization (WHO), Codex Alimentrius and International Atomic Energy Agency (IAEA).

CCQM is actively working towards strengthening NMI's competence in CRM and its international equivalence. To this end, various forms of cooperation are promoted with other international organizations (see Figure 2-10). The objectives of the international organizations are to achieve the international harmonization of measurement results. The IFCC, WMO, WHO, Codex Alimentrius, and IAEA have greatly improved the recognition of CRMs world-wide.

[Figure 2-10] Joint Committee on Traceability in Laboratory Medicine



Source: JCTLM Website.

In order to solve the measurement problems in the various fields as well as to obtain the high purity standards for metrological traceability, a number of NMI are actively engaged in the extensive preparations of the matrix CRMs. IRMM of the European Union, NIST of USA, PTB and BAM of Germany, LGC of England and NIM of China are some examples. In particular, IRMM is rapidly developing and disseminating a variety of the matrix-CRMs to respond to the European measurement challenges.

In China, the use of CRMs is already mandated under the government-led NMS and NMI is actively responding to the demands for various matrix-CRMs. LGC of UK has established a subsidiary called LGC Standards to build a commercial network of business models that collects and supplies CRMs from various sources from around the world. In the case of NIST of US, SRM, which is a proprietary brand, is supplied not only in the domestic market but also in a similar magnitude for the world. A closer look at the NIST has developed about 1300 CRMs and served about 32,000 items annually. It is anticipated that international supply will be somewhat reduced as other NMIs are strengthened.

Along with the strengthening of commercial competitiveness, the cooperation between the NMI is very active in order to cover the various matrix-CRMs. Typically, IRMM, LGC, and BAM have created the ERM® (European Reference Materials) brand to increase the reliability of quality standards and to expand the range of applications. Similarly, the NMIs of Korea, China, and Japan have also established the Asian CRM network to promote the international quality CRM brand.

4.3. KRISS Strategy for CRM R&D

4.3.1. Introduction

There are two major difficulties in establishing a national CMS through CRMs. One is the problem of poor utilization due to the lack of awareness of the field users. The other one is that there are too many different types of matrices, making it difficult to develop and produce. Despite these difficulties appearing one after another, it is necessary to publicize the use of CRMs in order to improve quality of measurement such as chemical, biological, and radiation fields, and to provide the new growth engine for a high-tech industry.

The KRISS mid- to long-term research and development promotion plan of CRM has been designed to overcome these problems as much as possible and ultimately reach the establishment of CMS through CRMs. In the meantime, KRISS has reviewed other related issues and established the following strategy to activate R&D and service promotion.

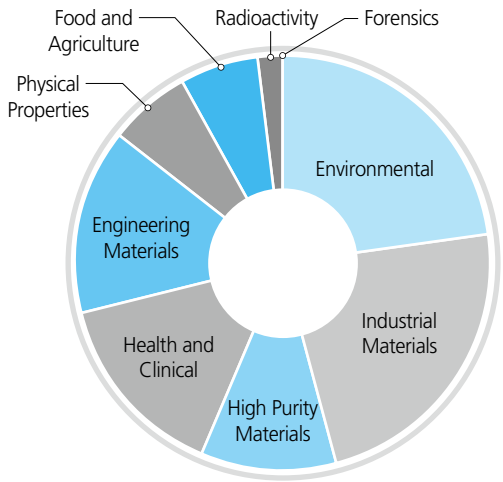
4.3.2. Priority Setting

KRISS CRM had been developed by researchers, anticipating the demands of CRM in the relevant technical field. This approach has been successful in that the experts know the demand and the technical situation of the field laboratories. Until now, KRISS CRM has been developed efficiently in this way. However, the CRMs were likely developed from the supplier's viewpoint, which may result in focusing on technologically easy targets. Since the very basic CRMs for the field laboratories have been developed to a certain degree, it is necessary to change the development viewpoint from being supply-friendly to meet consumer demands.

It is considered appropriate to classify the CRMs into food, environment, bio-technology, as well as clinical and new high-tech industries. The classification is closely related to the improvement of the quality of life of the people and the inclusion of the new high-tech industry which is the future growth engine of Korea.

Therefore, it reflects the current and future issues of the society, which is the final beneficiary of the KRISS CRM project. The list of the CRM production of NIST confirms that this classification is appropriate. As shown in [Figure 2-11], NIST's major CRM areas are industrial and engineering, environmental, health, and agricultural products, as well as high-purity materials and physical properties.

{Figure 2-11] CRM Distribution by NIST



Source: KRISS (2015c) adapted from NIST.

4.3.3. Challenge I: High-Difficulty CRM

The development of the sophisticated CRMs is a challenging task and requires a new level of R&D capability. There are many creative approaches using the convergence of technologies. As a representative example currently underway, the Bio Clinical Standards Center of KRISS apply the conventional representative which is the amino acid substrate's quantitative analysis method to certify the protein CRM and then the Inorganic Analysis Standards Center applies the inorganic element quantitative analysis method in the protein to obtain the matching measurement results.

It is possible to give an authentic value of high reliability which has not been achieved thus far. By developing a high-level CRM through a technology convergence across the Center, it is possible to level up the status of KRISS CRMs. Although it is not easy, KRISS will continue to develop barrier-breaking high-level CRMs to strengthen the R&D capability of CRM.

4.3.4. Challenge II: Multi-Purpose CRM

One of the biggest challenges in establishing and implementing the CRM production is how to handle the demand for the various matrix types of CRMs. For the development and production of CRM, it is necessary to apply the metrological principle thoroughly with a high degree of attention to be paid due to its

characteristics. Therefore, it is technically impossible to develop and produce many types of CRM in a short period of time with the limited manpower available.

If CRM is produced by grouping matrices with similar characteristics, the representative matrix can be selected. It is necessary to concentrate the research capability on the development of the CRMs based on new concepts by designing and developing it with such intention as was done for "Designed CRM (multi-purpose CRM)" with multi-purpose characteristics.

This concept of the design CRM has recently been established. Once the feasibility is confirmed to fit the purpose, it can be expanded to joint researches with peer CRM organizations in addition to individual researchers, thereby enhancing international awareness and enhancing the efficiency of R&D. It is expected that international joint research among NMIs will be carried out, specifically through ACRM community of Korea, China and Japan.

4.4. Promotion of KRISS CRMs

CRMs are a very important tool for managing the quality of measurement and for improving measurement capabilities. Since it requires additional work and adds up costs to use the CRMS, it is not easy to bring up the voluntary usage without legal or institutional constraints.

Recognizing the importance and necessity of CRMs and enabling the use of CRMs at the appropriate level in the laboratory accreditation system, it is naturally possible to achieve the establishment of CMS through CRM. Since the government officials have the authority to maintain and enforce the laws, KRISS makes efforts to persuade government officials to set up such a system. As part of these efforts, KRISS has actively participated in government-led laboratory proficiency testing programs, which have in turn significantly improved the measurement capabilities of the testing and measurement laboratories of Korea.

Based on these experiences, efforts should be made to incorporate the use of CRM in legal obligations. In the era of globalization, it is necessary to recognize the inevitability of using CRMs. Therefore, it is necessary to continue to discuss legal and institutional arrangements with the government officials, which will accelerate the usage of CRM.

In addition, it is necessary to cooperate with the Korea Laboratory Accreditation Scheme (KOLAS), which is responsible for the accreditation of laboratories in Korea. The KOLAS has provided PT with the APLAC PT T093 of toxic elements in cabbage and with T094 of pesticide residues in cabbage for Asia Pacific Laboratory

Accreditation Cooperation (APLAC). KRISS plans to upgrade the international status of KOLAS and to strengthen the cooperation with KOLAS by performing the international PT successfully.

Various domestic and international proficiency testing providers based on CRM shall be developed. The cooperation between NMI and CRM producers can be a driving force for the development of the chemical, biological, and radiation related measurement industries, while improving the national measurement capability. It is also expected to develop various national new growth engines based on the improved measurement capabilities of the high-tech industry.

5. Conclusion and Policy Suggestions

5.1. Suggestion on Action Plans in NLP

All the activities in the action plans are important in order to overcome the technical and metrological weakness of testing and calibration laboratories in Colombia. Using a systematic approach, it is recommended to reorganize the activities in the action plans according to the process shown in strategy for CMS establishment (see Figure 2-7).

1. Reorganize the activities in action plans according the corresponding activities in each step in the CMS establishment.
2. Determine the control tower and cooperators for each step.
3. Determine the priority of the activities in each step.
4. Execute the activities for each step simultaneously with pre-determined priority.
5. Monitor the progress and outcome of the steps and activities.

All the activities are supposed to be sponsored and monitored by the government throughout the execution. For more effective execution, it is recommended to assign the responsible owner for the grouped activities based on the level in the CMN, which is described in the next section.

〈Table 2-12〉 Regrouped Action Plans based on CMS

1. Awareness Raising 6. Selection of Model 7. Government Commitment	– Governance for Colombian Metrology Network – Responese to quality infrastructure – Centralized measurement services – Funding for local service – Committee for technical standards – Strategy and action plans for incentive
2. Identification of needs 5. Prioritization of needs	– Technical Support for traceability – Function of public labs and updating the lists of regulation – Demends and supply for testing and measurement – Calibration lab – Reference material procurement and import
3. Capability assessment 4. Gap analysis 8. Capacity building	– Gap analysis of capability – Enhancing technical capablities – Reference material provision – Inter-laboratory programs – Campaign for vocabulary and regulation of measurement

Source: Authors.

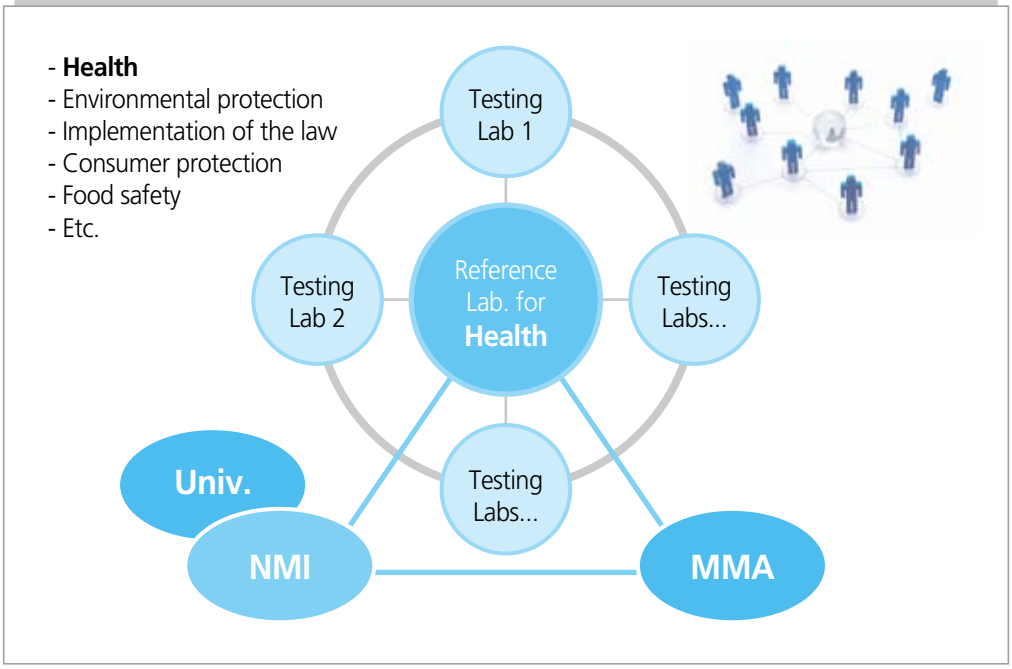
5.2. Colombian Metrology Network

5.2.1. Sector-Specific Laboratory Group

Regardless of the testing and measurement fields, almost all the necessary activities in NQI such as method development, testing, measurement, traceability and proficiency testing are the similar to those in metrology. For example, a health-related laboratory group has common interests on specifically health-related activities and shall share the common metrological principles. Therefore, grouping the SSLG with common interests from various fields of testing and measurement can facilitate the communication for sector-specific issues.

Examples of SSLG can be health, environmental protection, and food safety (see Figure 2-12). A RML can be assigned by MMA as a group representative. The RML will lead its SSLG for NQI and/or CMN activities with the cooperation of NMI, MMA and academia. The corresponding activities in action plans of NLP shall be executed by the team of SSLG, MMA and NMI under the sponsorship of NMA and NQC.

[Figure 2-12] SSLG with Cooperation in NQI



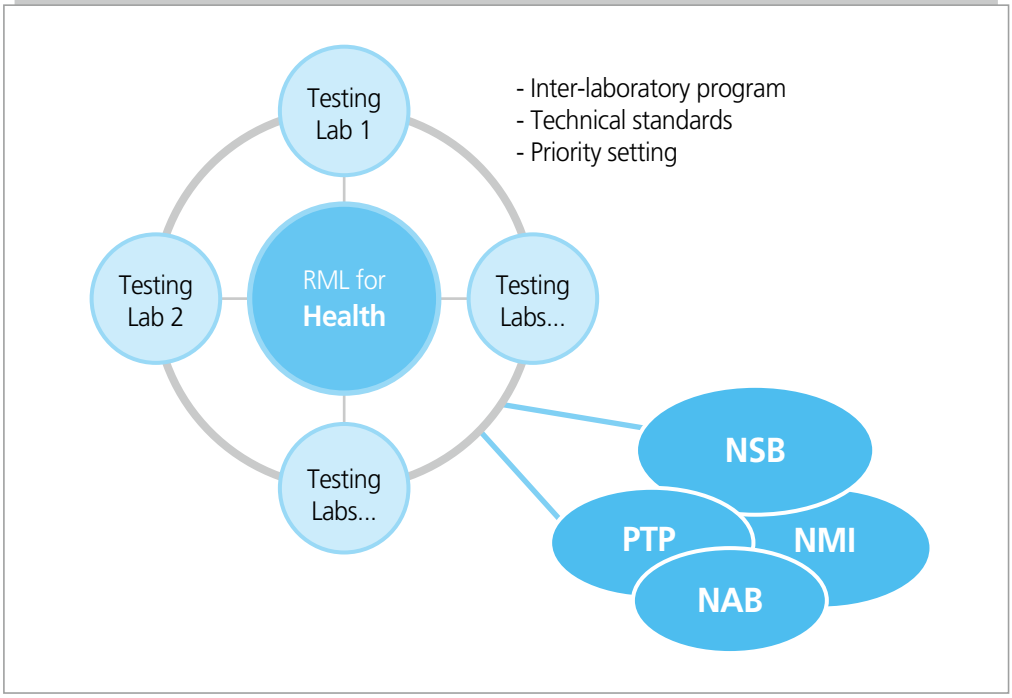
Source: Authors.

5.2.2. Standardization in CMN

One of the fundamental aspects to consider, which majorly matters to the metrological standardization, ICONTEC as a standardization body represents the country in the ISO committee. However, due to the low participation of national and government experts in the standardization committee, the decision of the standardization body will be not to represent the country as a full member in this scenario and to degrade it as an observer member only. This results in the country no longer having a voice or vote on international standardization from the perspective of metrology.

More than 70% of standardizations are related to metrology and measurement methods, which are usually unnoticed by the government. In Colombia, the following [Figure 2-13] can urge the cooperation of SSLG with NSB in the activity of standardization. For each specific sector with the cooperation of NSB and NMI, it will be helpful for ICONTEC to recognize the standardization activities through CMN. It is strongly recommended that NMI shall participate in the standardization activity with its metrological expertise, regardless of the fields of testing and measurement, including in international events and activities.

[Figure 2-13] Standardization with Cooperation in NQI

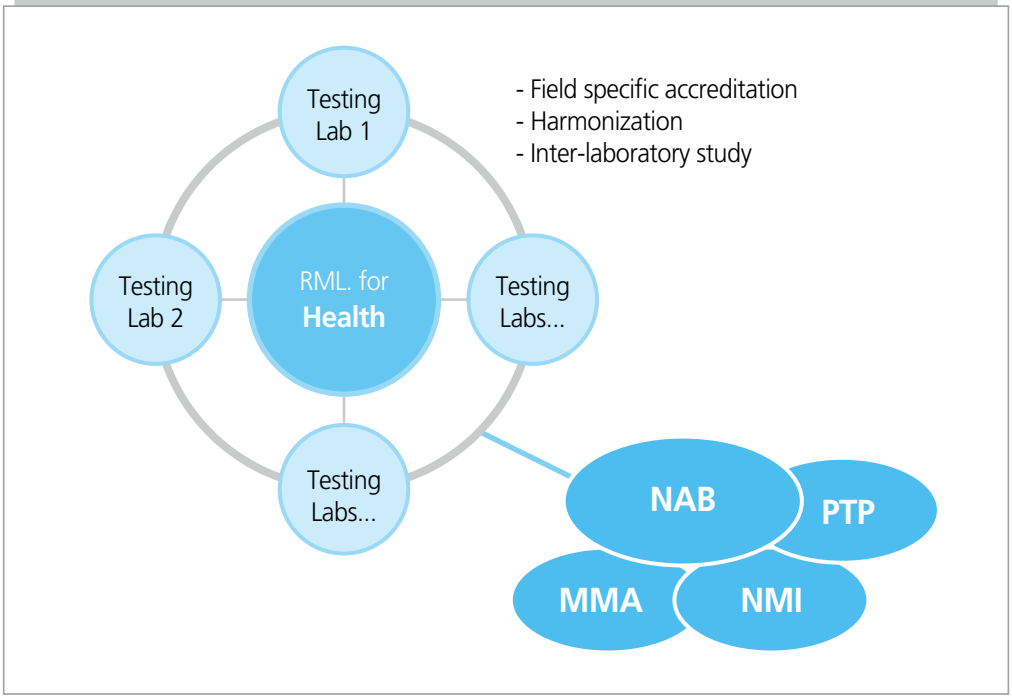


Source: Authors.

5.2.3. Accreditation in CMN

Accreditation is the third-party attestation related to a conformity assessment body conveying the formal demonstration of its measurement competence to carry out the specific conformity assessment tasks according to the international standards such as ISO/IEC 17025. In its process, the assessment of technical capability is the most crucial factor. For specific fields, the staff, set of equipment and working environment are similar. Therefore, experts for sector-specific field are expected to participate as technical experts for the sector-specific accreditation activities. As such, it is strongly recommended that NMI experts in standardization participate in the accreditation process with their metrological expertise and involve in the national accreditation committee.

[Figure 2-14] Accreditation with MMA

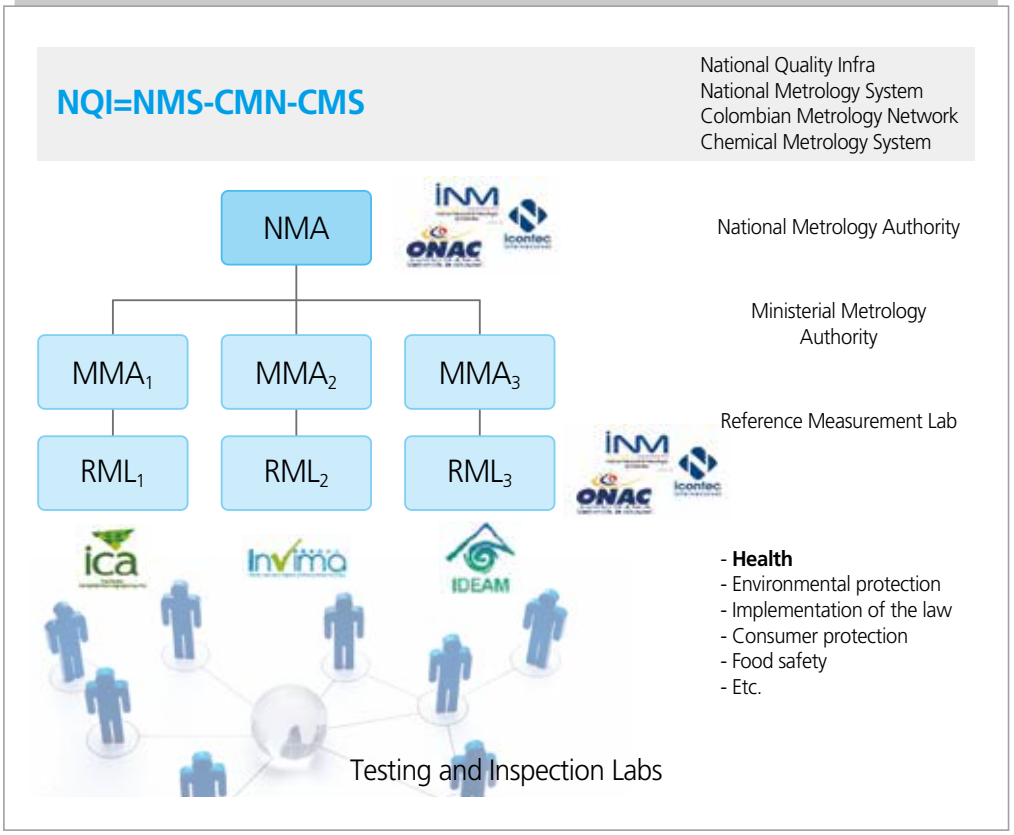


Source: Authors.

5.2.4. Enhancing the CMN Activity

Taking the above descriptions into account, a new structure of the CMN is proposed taking into account the needs of the industry and other sectors (see Figure 2-15).

[Figure 2-15] CMN from the View Point of Metrology



Source: Authors.

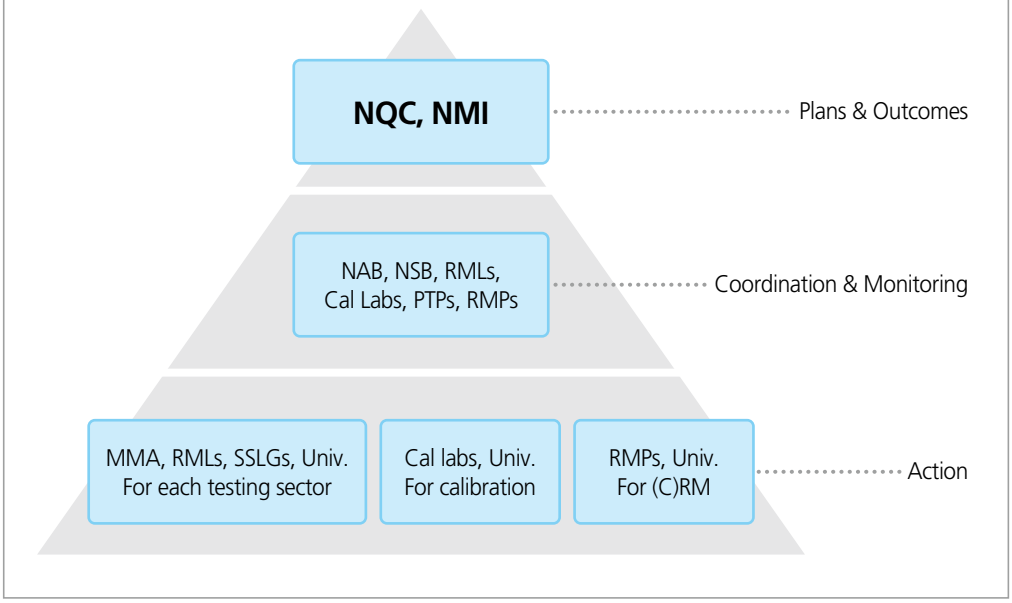
The driving force of the CMN is the industry, not only with its requirements of calibrations, technical assistance, reference materials, proficiency tests and training but also the requirements related to Standardization, Accreditation, Regulation, etc. The control entities are represented and will play a role proportional to the importance of the regulations for each specific case, which is also developed within the CMN.

It is good to take into account that if the industry meets the quality requirements to export its products to the international markets, it will also comply (because it is less demanding) with the quality requirements demanded by control entities within the regulated framework. Accredited laboratories for calibration and testing are the most important components to satisfy the needs of the industry, which is their main role in CMN.

5.2.5. Authority of NQI

As described in the document guide for the development of National Quality Policies of UNIDO, "In order to obtain a buy-in from all relevant government departments, the NMA should be supported by a committee in which all relevant Ministries, even the QI institutions and agencies are represented, because the National Quality Policy, especially if it also deals with the technical regulation regime, will be crossing ministries, i.e. impacting many Ministries. This coordinating committee/structure should be approved by the cabinet to ensure the full and unreserved cooperation of the regarding ministries."

[Figure 2-16] CMN with Metrology Hierarchy of Colombia



Source: Authors.

In order to operate the NQI and CMN effectively, control tower for all NQI related activities is from the perspective of metrology (see Figure 2-16). It should be noted that NQC is composed of the members from NMA, MMA, NMI, NSB, NAB, academia as well as private coordinators.

5.3. Law on Metrology

According to OIML (2012), the role of the Government in what the NMS is concerned with is described as "the role of the government in metrology is to provide society with the necessary means to establish confidence in measurement

results. This requires the government to undertake a number of necessary actions to promote metrology, to develop the appropriate infrastructures, to support research in metrology and to protect both individuals and companies against possible abuse related to measurements. It must be organized in a comprehensive and coherent policy, for which a Law on Metrology is advisable. (…) In setting up the NMS, governments should ensure that adequate transparency exists such that all parties are able to make informed decisions."

In fact, the OIML document proposes a hierarchical structure in cooperation with the NMA that coordinates policies and activities in the field of Metrology in the country. In addition, it must be taken into account that the structure of the NMS must respond to the needs of the country in terms of the size of its economy, its infrastructure and industrial projection, not to forget its government policies, consumer protection and its degree of scientific development among other aspects.

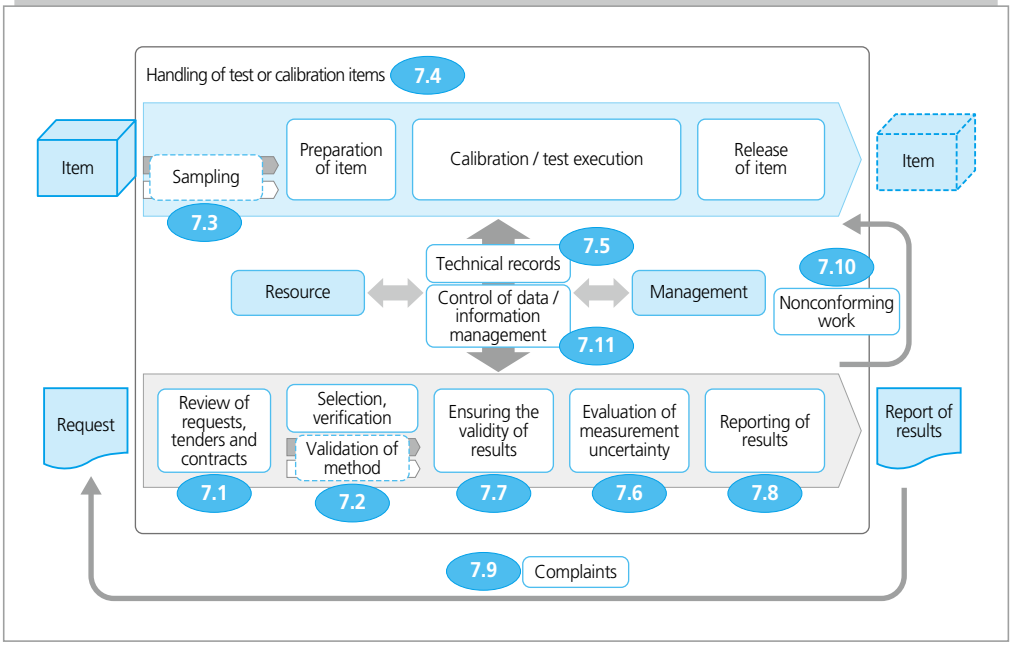
This document proposes a hierarchical metrology structure with a National Metrology Authority (named Central Metrology Authority in OIML document) to coordinate the metrology policy and activities across the country. The NMA would normally be part of an existing government department and should also actively cooperate with the national bodies responsible for accreditation and standardization activities, as well as the relevant international metrological organizations (i.e. the OIML and BIPM (the Meter Convention).

5.4. Process Approach for Quality Management System

5.4.1. Process Approach

Recently, ISO/IEC 17025:2017 has introduced the concept of process-based approach, which is the international standard of quality management system for calibration and testing laboratories. Compared with the ISO/IEC 17025:2017, the previous ISO/IEC 17025 was based on procedure approach.

[Figure 2-17] Process Approach in, ISO/IEC 17025:2017

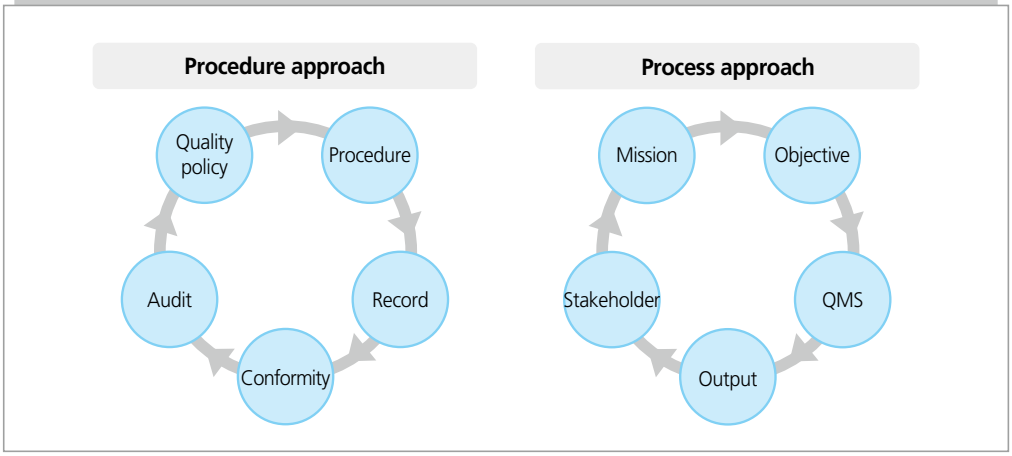


Source: ISO/IEC 17025:2017.

5.4.2. Process Approach versus Procedure Approach

In a procedure-based approach, the quality management system (QMS) is a system composed of documents, which means that we need to work according to the procedures and record the conformity to these standards. The purpose of the system is to prove the conformity to the international standard.

[Figure 2-18] Procedure Approach vs. Process Approach

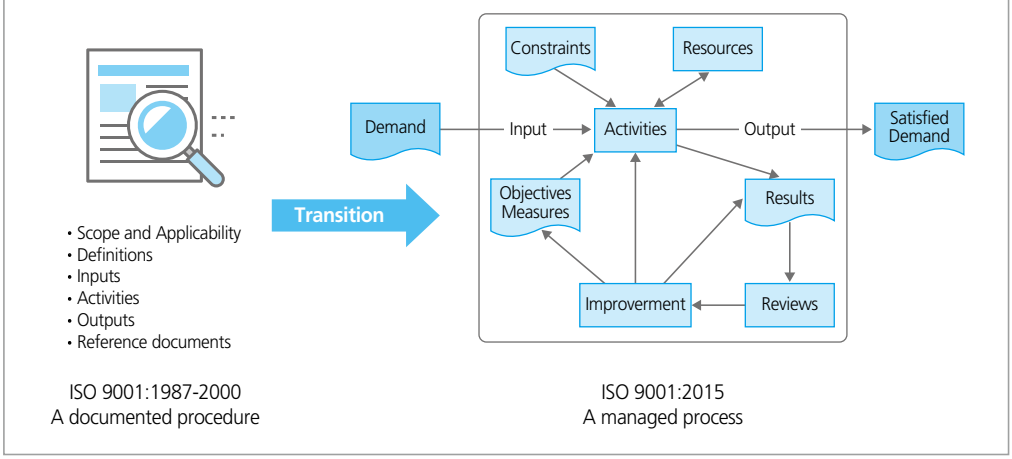


Source: Authors.

To the question of what QMS can do for our organization, the procedure approach can't give a clear-cut answer to our members or management. It is a system that is not related to the accomplishment of the business purposes of an organization or company.

The QMS should be used as a tool to achieve business objectives as a management cycle. The QMS composed of processes fulfills the objectives of the project and meets the expectations of stakeholders. It is time for all organizations to meet all stakeholders including customers, for sustainable management, based on a process-based approach

[Figure 2-19] Change from Procedure to Process



Source: Transition Support Website.

The concept of the QMS has changed from a set of procedures to a set of business processes, including members, proprietary technologies, materials and equipment, operators and work environments. It is a systematic approach. The system is a collection of components which work together to achieve the same purpose. The NQI can be viewed as the nation-wide system management. A NQI is the nation's system to enhance the national competitiveness and the quality of life of the people by working together with institutions and members related to standardization, metrology, accreditation, testing and certification.

Therefore, it is strongly recommended to employ the process approach of the ISO/IEC 17025:2017 for the management of testing and calibration laboratories. The ONAC shall recognize the difference between procedural approach and process approach and then utilize it accordingly for the accreditation. The process approach will be helpful for the management of the laboratories as well as the operation of NQI.

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of Korea for Promoting Industrial Development
of Colombia

Chapter 3

Sharing Korea's Experience for the Promotion of HRD in Metrology of Colombia

Sharing Korea's Experience for the Promotion of HRD in Metrology of Colombia

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Summary

The economic performance of Colombia has improved in the recent years, and it is forecasted that it would continue to rise at the rate of 3% in 2018–2019 (OECD, 2017). For Colombian economy to stay competitive in the global marketplaces, however, there is rooms for further improvement in its fundamental resources that are required for fueling its robust economic growth. As diagnosed by the draft report of "National Policy of Laboratories" drawn up by the National Planning Department (DNP) of Colombia,[1)] the subject of "National Quality Infrastructure (NQI)" was chosen to be the core foundation that underpins productive development and economic sophistication of Colombia. The DNP's report has identified key challenges and main problems that remain to be overcome in the practices of NQI in Colombia: regulations, institutional framework, infrastructure and equipment, technical competence, and human capital.

Chapter 3 addresses one of the key policy issues identified by the DNP, human resources development (HRD) in the sector of NQI in Colombia. Focused on HRD in metrology, the scientific basis of the NQI, discussion at the chapter 3 begins with a brief overview of the official education system and some statistics of HRD in

Keywords: Human Resources Development in Metrology in Colombia, Human Resources Developmnet in Metrology in Korea, Korea Research Institute of Standards and Science (KRISS), Instituto Nacional de Metrología (INM), Colombia, Government Role in Promotion of HRD in Metrology, Government Investment in Metrology, Graduate School of Metrology.

1) DNP (2017).

metrology of Colombia. Discussion further moves on to the practices of metrology education and training services in Colombia so as to find facts, obstacles and future tasks to be tackled for further advancement.

Lack of metrology based learning opportunities due to insufficient training providers, professional trainers and quality training programs remain as the root cause which is weakening the competence of the metrology community of Colombian. As the national metrology institute (NMI) of Colombia, Instituto Nacional de Metrología (INM) is playing as the principal service provider of HRD in scientific and industrial metrology in Colombia. Separately from the INM, a couple of institutions are offering HRD in metrology services: the National Learning Service (SENA) of Colombia and the University of Cartagena. It should be noted that the training programs offered by all of them cover narrow horizon of very basic subjects of measurement. Advanced educational service in metrology is not available in Colombia which keeps it from fostering its younger generation with advanced academic degrees in measurement science and technology. Low salary scale of employees in the metrology community of Colombia leads to high employee turnover rate across the NQI sector including even in the INM - the NMI of Colombia. It can hardly attract its young generation in this manner, for it to be willing to enter the metrology community and take up a career of experts in measurement science and technology. These factors are all putting significant obstacles that should be overcome so as to achieve sustainable development of the NQI in Colombia.

With a view to sharing good practices of HRD in metrology, Korea's experience in training and education service of metrology is presented, together with that of selected advanced countries. Korean Research Institute of Standards and Science (KRISS), the NMI of Korea has long served as a single service provider of HRD in metrology since early the 1980's, which lasted for around two decades. It is only from 2002 that several institutions have been joining efforts to provide services of the HRD in metrology as designated by the Korea Laboratory Accreditation Scheme (KOLAS), the national accreditation body of Korea. KRISS and the designated institutions are operating HRD programs that range from basic measurement techniques to advanced scientific metrology, along with the subjects of quality management system (QMS).

In view of the fact that the NMI is at top of the traceability system of any country, the level of metrological capability of NMI holds a crucial role for the nation's competitiveness in NQI. In this context, this chapter presents what KRISS has been doing for the cause of strengthening its own human capital. It has enabled KRISS to achieve excellent performance in international activities such as participation in the key comparisons (KC) and registration of calibration and measurement capabilities (CMCs).

It should not be overlooked, however, that there were significant contributions of the Korean government that have made such an excellent performance of KRISS possible. To learn lessons from good practices in advanced countries, presented also are metrology HRD programs that are available in France, Germany and Korea. It includes short-term ordinary training services and advanced academic degree courses in measurement science and technology as well.

Reviews, presentations and investigations regarding the current practices of Colombia in HRD in metrology, followed by the analysis of experience and good practices in Korea and other selected advanced countries have led to ten (10) policy recommendations. They are summarized in the three categories as below.

〈Table 3-1〉 Policy Recommendations for Promoting HRD in Metrology in Colombia

Categories	Recommendations
Service Provider	- Increasing Training Providers (institutions) - Creating Graduate School of Metrology - Improving Contents of Training Programs - Securing Competent Trainers
Customer & Regulation	- Expanding Potential Customers of Training Services (trainees) - Effective Use of Training Certificates for Accreditation - Expanding Proficiency Testing and Setting Mandatory Calibration Intervals
Strategic Support by Government	- Sophisticating Functions of INM, the NMI of Colombia - Cultivating Good Work Place across the Metrology Community in Colombia - Raising Investment in NQI by Government

A couple of recommendations (6 and 7) are suggested as complementing tools that should also have been taken into consideration while cultivating good practices in the sector of NQI in Colombia. They are to promote proficiency testing activities and to set calibration intervals for measuring equipment until good practices are settled down across the metrology community in Colombia.

It is advised that the DNP and the Colombian government should take actions to turn the policy recommendations into winning strategies for advancing the competence of the metrology community of Colombia enough to underpin its sustainable economic growth. When it comes to the priority of action programs and financial investments to bring them into existence, it is recommended that the priority is placed on INM, among others: in promoting the metrological capability of INM, as the competitiveness of the NQI definitely depends on the scientific and technological capability of the NMI .

1. Introduction

People play a key role in creating advancements and success in business, research, development, and in any social and economic activities. Even in the sectors of science, technology and innovation, an essential pre-requisite to success is professional human resources. It takes the leading part in meeting the societal needs for a better quality of life as well as in clarifying undisclosed principles of nature's phenomena. As described in the preceding chapters of this report, the NQI serves as scientific and technical foundation that underpins sustainable development of the economy. Composed of the three pillars of metrology, standardization, and conformity assessment, the competence of NQI heavily depends on how effectively it can secure professional human resources in metrology - the science of measurement and its applications.[2)]

The DNP has reported of the policy issues in its NQI. It states that Colombia is faced with a lack of competent human resources in metrology. It remains as one of the hurdles that should be jumped over for advancing the NQI, and a key challenge that enables the continued economic growth of Colombia.[3)] One of the target goals of the 2017/2018 KSP II with Colombia is to share Korea's experience in developing HRD in metrology.

To diagnose the root causes that are weakening the competence of human resources in metrology, the study begins with an overview of the practices regarding the official education system and the metrology training services currently available in Colombia. For a comparative analysis, practices of HRD in metrology are presented in case of Korea and other selected advanced countries. The final section provides policy recommendations that the DNP, in close communication and collaborations with the relevant ministries and agencies of the Colombian government and its metrology community, should take into consideration in order to draw up effective action programs for advancing the competitiveness of HRD in metrology services of Colombia.

2) BIPM Website.
3) DNP (2017).

2. Review of Practices of Metrology HRD in Colombia

2.1. Overview of Formal Education System in Colombia

2.1.1. Scheme of Formal Education in Colombia

Education is one of the basic human rights in Colombia, declared by its Constitution of the year 1991 (Articles No. 54 and No. 67). In addition, receiving good education service is guaranteed as an individual right, and the State is responsible for the regulation, enforcement, and supervision of the educational services in order to ensure their quality and compliance with its purposes of the highest moral, intellectual and physical cultivation of students (Vice-Ministry of Pre-School, 2017). Education service for the people is mandatory for ten years (from five to fifteen years old). Furthermore, it is envisaged that the mandatory education service will be further expanded to encompass the high school education service as well by the year 2030 (DNP, 2015).

The Colombian education system is composed of four stages: (1) early childhood and preschool education, (2) basic education (five grades of primary and four grades of secondary education), (3) high school education (two grades), and (4) higher education for undergraduate and graduate studies (Vice-Ministry of Pre-School, 2017). <Table 3-2> presents the age groups and grades by the levels of the school education service in Colombia of today.

〈Table 3-2〉 Age Groups and Grades by Education Levels in Colombia

(Unit: Numbers)

Age	Grade	Levels
3–4	-	Early Childhood Education
4–5	-	
5–6	-	Preschool Education
7–8	1	Basic Education (Primary)
8–9	2	
9–10	3	
8–10	4	
9–11	5	

〈Table 3-2〉 Continued

(Unit: Numbers)

Age	Grade	Levels
8–11	6	Basic Education (Secondary)
9–12	7	
13–14	8	
14–15	9	
15–16	10	High School
16–17	11	

Source: Own elaboration, based on data from the Ministry of National Education Website.

In regard to the higher education service in Colombia, there are various institutions that provide undergraduate and graduate studies. Besides the ordinary courses for the degrees of Bachelor, Master and Ph.D., there are special education programs offering titles such as "Professional Technician," "Technologist," and "Specialist." <Table 3-3> shows the opportunities of advanced academic degrees currently available in Colombia.

〈Table 3-3〉 Education Programs of Advanced Academic Degrees in Colombia

Courses	Title of Degrees	Duration of Study
Undergraduate Study	Bachelor	4–5 years
	Professional technician	2 years
	Technologist	3 years
Graduate Study	Ph.D.	3–5 years
	Master	1–2 years
	Specialization	1 year

Source: Own elaboration, based on data from the Ministry of National Education Website.

2.1.2. Schools and Students by the Level of Education in Colombia

As of 2016, there were more than eight million students in Colombia who were studying at all levels of schools except undergraduate and graduate schools. The table below presents the number of students enrolled and studying at each level of school in Colombia. The statistics tell us that a good number of schools are

concentrated in a few states and cities. Around 30% of basic and high schools are located in Bogota and the three states of Cundinamarca, Antioquia, and Valle del Cauca. In addition, the number of students enrolled at the high schools drastically decreases down to by around 70% of that in the secondary school.[4] It is largely owing to the fact that the mandatory education service only applies up to the students of the secondary school.

〈Table 3-4〉 Number of Students Enrolled at Each Level of Schools in Colombia (2016)

Grade	Levels	Number of Students Enrolled
	Early Childhood Education	207,249
	Preschool Education	718,020
1–5	Basic Education (Primary)	3,681,362
6–9	Basic Education (Secondary)	2,902,315
10–11	High School	1,031,633
Total		8,603,579

Source: Own elaboration, based on DANE (2016b).

2.1.3. Students in Advanced Academic Courses in Science, Technology and Engineering

Below tables provide information about number of students newly admitted in undergraduate and graduate courses in different subjects in 2016. Less than 29% of the students of undergraduate courses chose to study science, technology and engineering.

〈Table 3-5〉 Number of Newly Admitted Undergraduate Students in Colombia (2016)

(Unit: Numbers)

Fields	Disciplines of Study	Number of Students Newly Admitted
Science, Technology and Engineering	Mathematics and Natural Sciences	33,690
	Engineering	490,172
	Sub-total	523,862

4) DANE (2016).

〈Table 3-5〉 Continued

(Unit: Numbers)

Fields	Disciplines of Study	Number of Students Newly Admitted
Economy, Humanity and Social Sciences, Others	Economy, Administration, Counselling	632,266
	Humanity and Social Sciences	253,251
	Health Sciences	205,647
	Education Sciences	115,493
	Fine Arts	56,905
	Agronomy, Veterinary and Related	33,128
	Architecture and Others	27,317
	Sub-total	1,324,007
Total		1,847,869

Source: Own elaboration, based on data from DANE (2016b).

〈Table 3-6〉 Number of Newly Admitted Graduate Students in Colombia (2016)

(Unit: Numbers)

Fields	Disciplines of Study	Number of Students Newly Admitted
Science, Technology and Engineering	Mathematics and Natural Sciences	311
	Engineering	19,495
	Sub-total	19,806
Economy, Humanity and Social Sciences, Others	Economy, Administration, Counselling	62,994
	Social and Human Sciences	38,505
	Health Sciences	36,643
	Education Sciences	25,721
	Architecture and Others	1,867
	Agronomy, Veterinary and Related	1,038
	Fine Arts	992
	Sub-total	167,760
Total		187,566

Source: Own elaboration, based on data from DANE (2016b).

It should be noted that the number of newly admitted students to the graduate courses in the disciplines of STEM fields in 2016 was still much less compared with those admitted in economy, humanity and social sciences. It was 10.5% of the total number of the newly admitted students in the graduate courses of the year.

2.1.4. Graduates from Universities and Colleges in STEM Fields

The following two tables present recent statistics of students graduated from universities in 2015 with bachelor, master and Ph.D. degrees by the fields of study.

〈Table 3-7〉 Number of Graduates from Undergraduate Course of Colombia in 2015

(Unit: Numbers)

Fields	Disciplines of Study	Semesters		Total
		2015 – I	2015 – II	
Science, Technology and Engineering	Mathematics and Natural Sciences	26,582	42,403	68,985
	Engineering	1,488	2,535	4,023
	Sub-total	28,070	44,938	73,008
Economy, Humanity and Social Sciences, Others	Agronomy, Veterinary and Related	2,211	3,349	5,560
	Fine Arts	5,359	7,139	12,498
	Education Sciences	6,190	8,174	14,364
	Health Sciences	7,544	11,959	19,503
	Social and Human Sciences	18,588	20,501	39,089
	Economy, Administration, Counselling	34,096	54,816	88,912
	Unclassified	0	33	33
	Architecture and Others	1,765	2,121	3,886
	Sub-total	103,823	153,030	254,732
	% occupied by STE fields	27%	29%	28%

〈Table 3-8〉 Number of Graduates from Graduate Courses per Semester in 2015

(Unit: Numbers)

Fields	Disciplines of Study	Semesters		Total
		2015 – I	2015 – II	
Science, Technology and Engineering	Mathematics and Natural Sciences	2,861	4,233	7,094
	Engineering	482	607	1,089
	Sub-total	3,343	4,840	8,183
Economy, Humanity and Social Sciences, Others	Agronomy, Veterinary and Related	139	193	332
	Fine Arts	159	242	401
	Education Sciences	2,187	3,541	5,728
	Health Sciences	2,239	3,633	5,872
	Social and Human Sciences	6,260	8,470	14,730
	Economy, Administration, Counselling	10,977	14,769	25,746
	Unclassified	2	1	3
	Architecture and Others	199	344	543
	Total	25,505	36,033	61,538
	% occupied by STE fields	13 %	13 %	13 %

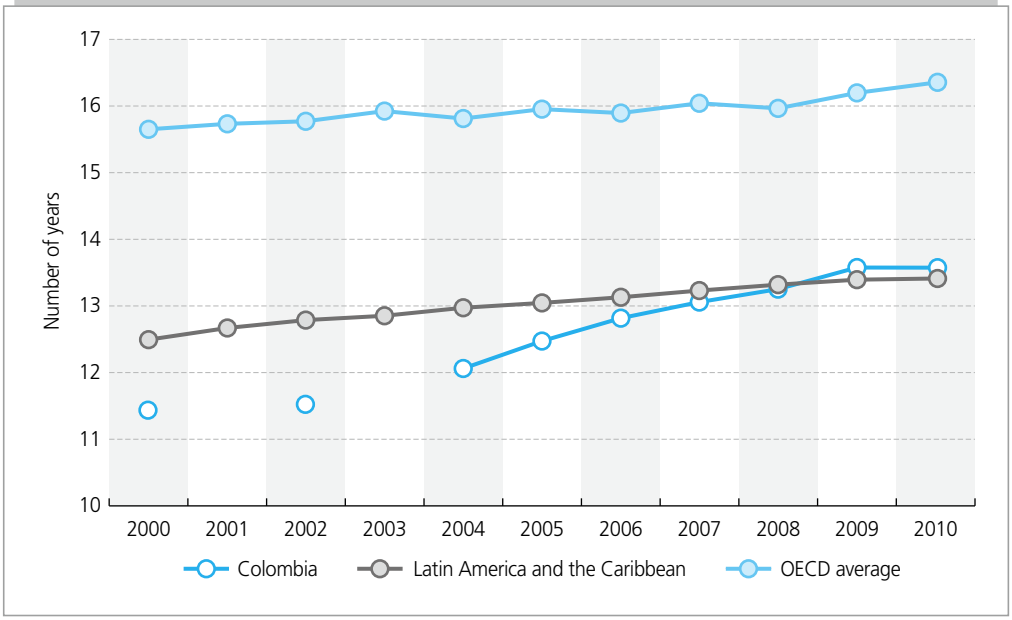
Source: Own elaboration, based on data from DANE (2016b).

As shown in above tables, the undergraduates in STE fields were less than 30% of the total. For graduate courses, the number of graduates in the fields of engineering, mathematics and natural sciences remained low at slightly more than 10% of the total. These figures indicate that the Colombian official education system should bring students to choose to take a career as professional experts in various fields of STE so as to serve as the core driving force for the sustainable advancement of the nation's competitiveness.

2.1.5. Competitiveness of the Colombian Education

Over the past two decades, the Colombian official education system has progressed with new strategies and policies implemented at all levels of education. Consequently, the coverage of the mandatory education service has expanded, which has in turn significantly increased the time spent in formal education.

[Figure 3-1] Time Spent in Formal Education in Colombia



Source: OECD (2016a).

However, there are challenges faced by Colombia in the quality and competitiveness of its education services. The following <Table 3-9> shows a comparative analysis of educational competitiveness in selected indicators of Colombia compared with OECD.

〈Table 3-9〉 Comparison of Educational Competitiveness between Colombia vs. OECD

(Unit: Percentages)

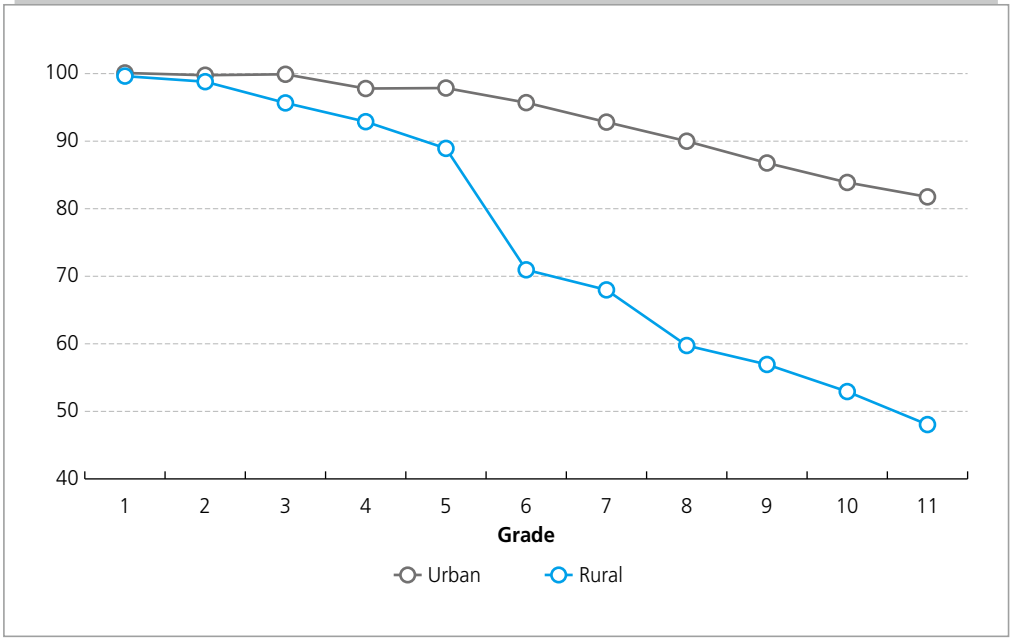
Basic Indicators (2012 or latest year available)	Colombia	OECD
Proportion of population age below 15 out of total population	28%	19%
Public expenditure on education per GDP	0.53%	0.31%
PISA mean performance in mathematics	376	494
Share of low achievers in PISA[5)]	74%	23%
Share of top performers in PISA	0.3%	13%
% of 25-34 years of age groups who have attained tertiary education	26%	41%

Source: OECD (2016a).

5) Program for International Student Assessment.

Besides, high suspension rate of studies and failure to complete full education courses are serious problems that need to be solved. The situation in rural areas is more serious as less than 50 % of students remain to be enrolled up to grade 11 as shown in [Figure 3-2]. It certainly has negative impact on the balanced development of the nation.

[Figure 3-2] Trends of Students Who Remain Enrolled up to Grade 11 in Colombia



Source: OECD (2016a).

In brief, the formal school education service in Colombia needs to be improved in different aspects. The problem of geographical imbalance in supplying educational institutions is one of the main tasks to be solved. Also, graduate courses in the fields of STE need to be expanded so that much more of young talents could be flowed into and fostered in those fields. It should be noted that the rate of completing official education even grows lower up to the grade 11 (high school). Restructuring of the nation's vulnerable formal education system in Colombia should be focused on fostering competent human resources in STE sectors among others. It will lead to the promotion of the national competitiveness of Colombia based on strong human resources in STE.

2.2. Overview of Metrology HRD Services in Colombia

2.2.1. Service Providers and Programs of Metrology HRD in Colombia

In Colombia, like almost all other countries, NMI plays a key role in offering services of HRD in the field of metrology. INM operates short-term training courses covering fundamental subjects of physical metrology and metrology in chemistry in part. In addition, the INM offers a metrology diploma program in cooperation with the National University of Colombia. Besides, there are a couple of institutions in Colombia providing metrology HRD services, which include SENA and the University of Cartagena. Unlike the metrology HRD service offered by INM, the programs of SENA and University of Cartagena put more focus on vocational training on measurement techniques for young generations who are looking for jobs in the industrial measurement service sectors.

〈Table 3-10〉 Programs of Metrology HRD in Colombia

Institutions	Types / Programs of Training Services	Areas Covered	Remarks
INM	Short-term Group training	Physical metrology, Metrology in chemistry	Around 50 regular courses each year with 30 subjects of metrology
	Metrology Diploma (once a year, irregular)	General concept and application of metrology	Joint program with the National Univ. of Colombia
SENA	Long-term Group training	Industrial measurement techniques	Vocational training for young generations
Univ. of Cartagena	Long-term Academic programs	Industrial measurement, Metrological process	Vocational training for young generations
ITM	Master's Course	Measurement Science (under development)	Approved in 2017 (not open yet)
Santo Thomas Univ.	Master's Course	Quality management system (QMS)	Joint program with ICONTEC
Univ. of America Foundation	Master's Course	Integrated Management of Quality & Productivity	Newly open in 2018

Source: Own elaboration based on data from websites of the above institutes.

As regards to advanced academic studies in metrology, Instituto Tecnologico Metropolitano (ITM) has been approved to offer a master's study program in measurement science and technology. The ITM, however, has no record of offering its metrology education services yet, as it was approved only recently in 2017 and has been busy in the course of developing its curricula and other details in cooperation with the INM. Meanwhile, there are a couple of master's courses in the field of quality management system. Santo Thomas University has been offering a master's course in cooperation with ICONTEC, the standardization body of Colombia. The University of America Foundation has recently launched its educational service of a master's course focused on management of quality and productivity.

2.2.2. Customers of Metrology HRD Services in Colombia

As of December 2017, there are 129 calibration laboratories and 222 testing laboratories which have been accredited by ONAC, the national accreditation body of Colombia. Based on the ONAC's statistics, it is estimated that currently around 2,800 technical staff members are engaged in calibration and testing services. In addition, there are around 150 people working for the INM. It is estimated that there are 3,000 workforces in the field of measurement services nationally, whom are the main customer base for the metrology HRD services in Colombia at the moment.

Meanwhile, rapid technical progress of industries called for an ever growing need for better metrological services. Also, new and better metrological services across the emerging sectors such as health, food, energy, and the environment are desired. Technical staff engaged in emerging sectors should also be drawn into the potential customer base of metrology HRD service to become ready to offer quality measurement services. It implies that the potential customers for metrology HRD services will grow larger over wider sectors. In this context, the metrology community should be prepared to secure customer groups from both the traditional and emerging sectors by exploring diverse education and training programs and service providers to meet emerging demands.

2.3. Metrology HRD Services by the INM of Colombia

2.3.1. Programs of Metrology HRD Service Offered by the INM

The INM serves as the principal organization that provides HRD in metrology service. Their training programs deliver fundamental subjects both in physical and chemical metrology, along with selected subjects relating to QMS as well. Most services are offered in the form of short-term group training program (see Table 3-11).

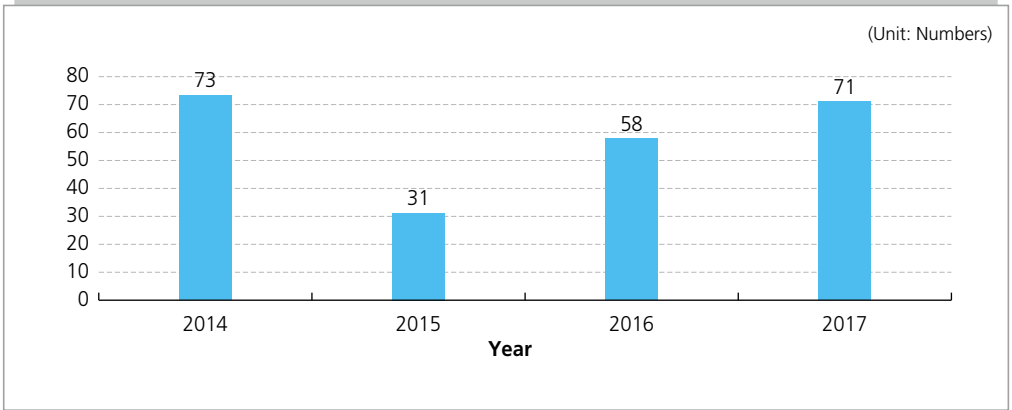
〈Table 3-11〉 Subjects of Metrology Training Services Offered by INM, Colombia

Fields of Metrology	Subjects of Training	Remarks
Physical Metrology (18)	Electricity, density, mass, length, volume, torque, temperature, humidity, time and frequency, etc.	Focused on basic subjects in physical metrology
Metrology in Chemistry (7)	pH measurement, Electrolytic conductivity, UV-vis spectrophotometers, method validations,	Covering only a few basic subjects of metrology in chemistry
QMS and Fundamentals of Metrology (5)	Basic metrology, uncertainty in measurement, statistics, ISO/IEC 17025, ISO10012	
Total	30 subjects	

Source: Own elaboration based on data of INM (2018b).

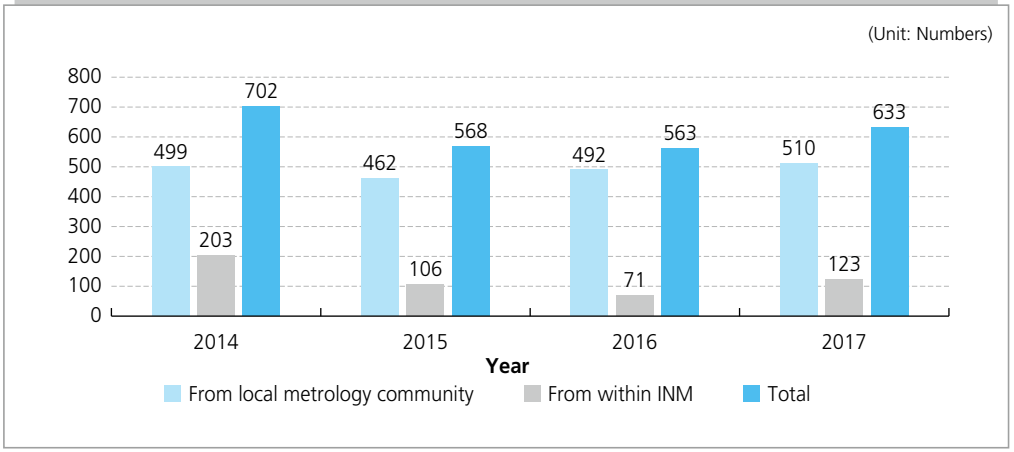
INM operates more than 50 short-term group courses each year covering around 30 subjects of metrology and quality management system. For the past four years of 2014–2017, the number of trainees who enjoyed the INM's metrology training service were roughly 500–700 people each year. The two figures below illustrate the quantitative achievement of INM's metrology training services in terms of the number of training courses offered by INM and its beneficiaries.

[Figure 3-3] Metrology Training Courses Offered by INM in 2014–2017



Source: Own elaboration based on data of INM (2018b).

[Figure 3-4] Beneficiaries of Metrology Training Service Offered by INM in 2014–2017



Source: Own elaboration based on data of INM (2018b).

〈Table 3-12〉 Achievement of HRD in Metrology Services Offered by INM (2014–2017)

(Unit: Numbers)

Number of Subjects Participants of Training	2014		2015		2016		2017	
	Ext	Int	Ext	Int	Ext	Int	Ext	Int
Physical Metrology	231	79	209	46	210	16	211	43
Density	4	2	1	1	3	0	7	2
Force	5	4	10	1	14	0	5	2
DC	19	2	13	5	11	1	8	2
Pressure	38	2	38	2	42	1	29	5
Mass level 1	26	8	28	9	25	4	19	5
Mass level 2	20	7	17	7	9	1	17	3
Mass Level 3	2	2	1	0	5	1	4	1
Geometric Measurements (Length)	4	2	3	0	4	0	3	1
Length Level 1	14	6	9	2	13	1	14	1
Length Level 1	2	2	5	0	4	0	3	1
Standards Power and Energy - EPM	3	1	8	0	4	0	3	2
Calibration Power Meters	0	4	3	0	0	0	4	2
Temperature and Humidity	37	14	17	8	35	1	47	6

〈Table 3-12〉 Continued

(Unit: Numbers)

Number of Subjects Participants of Training	2014		2015		2016		2017	
	Ext	Int	Ext	Int	Ext	Int	Ext	Int
Advanced Temperature	14	3						
Time and Frequency	5	4	12	4	11	0	10	0
Torque	8	4	6	1	6	2	6	1
Small Volumes	30	12	29	5	17	3	24	6
Big Volumes			9	1	7	1	8	3
Metrology in Chemistry	75	62	45	17	47	23	39	23
Basic Concepts of Metrology in Chemistry	15	20	3	8	16	5	7	5
Introduction of Good Practices in Chemical Weighing							0	4
Calibration UV-vis Spectrophotometers							8	2
pH Measurement	13	8	9	3	11	2	7	5
Measuring Electrolytic Conductivity	11	8	8	3	7	2	3	5
Validation Quantitative Chemical Methods	25	13	18	0	10	7	9	0
Uncertainty in Quantitative Chemical Methods	11	13	7	3	3	7	5	2
QMS and Fundamentals of Metrology	193	62	208	43	235	32	260	57
Basic Metrology	74	15	71	4	97	7	119	6
ISO/IEC 17025	43	10	53	17	50	10	55	
ISO 10012	2	15	11	8	17	3	7	13
Basic Statistics	23	9	24	8	33	5	25	14
Measurement uncertainty	51	13	49	6	38	7	54	15
Total number of participants	499	203	462	106	492	71	510	123
Total Courses	73		31		58		71	

Note: 1) ISO/IEC 17025: General Requirements for the Competence of the Testing and Calibration Laboratories.
2) ISO11012: Measurement Management Systems.
Source: Own elaboration based on data from INM (2018b).

Recent achievements of INM's metrology training service are presented in more detail in the <Table 3-12>. Its metrology training programs are open to customers both from within and outside the INM. For the single year of 2017, more than 120 people of INM attended its own metrology training programs. It should be encouraged to continue as a practice, as it will help them to learn more from each other about different subjects of metrology and to come up with new ideas and opportunities of collaborations between different areas of metrology.

2.3.2. "Metrology Diploma," an INM-University Joint Program

In close cooperation with the National University of Colombia (NUC), INM offered the "Metrology Diploma" courses in 2015 and 2016. Each course, running for 120 hours for two months, presented the general concepts of metrology. The program includes hands-on practices taking place in the laboratories of INM. Lectures were delivered by trainers from the NUC and from the INM[6]. Attendees of the program consist of technical experts and research laboratories from across wide sectors such as calibration, health, food, automobile, electro medicine, pharmaceutical industry, education, etc. <Table 3-13> shows the number of participants in the Metrology Diploma courses offered in the past two years, while the [Figure 3-5] illustrates the distribution of participants by sector.

The brief statistics below show that there are potential demands, across wide sectors in Colombia, for opportunities of in-depth training in metrology. With this context, the Metrology Diploma program needs to be made available as a regular HRD program in metrology. It will help the metrology community of Colombia to broaden the scope of metrological services for a lot more number of customers across a wide range of sectors.

〈Table 3-13〉 Number of Participants in "Metrology Diploma" (2015–2016)

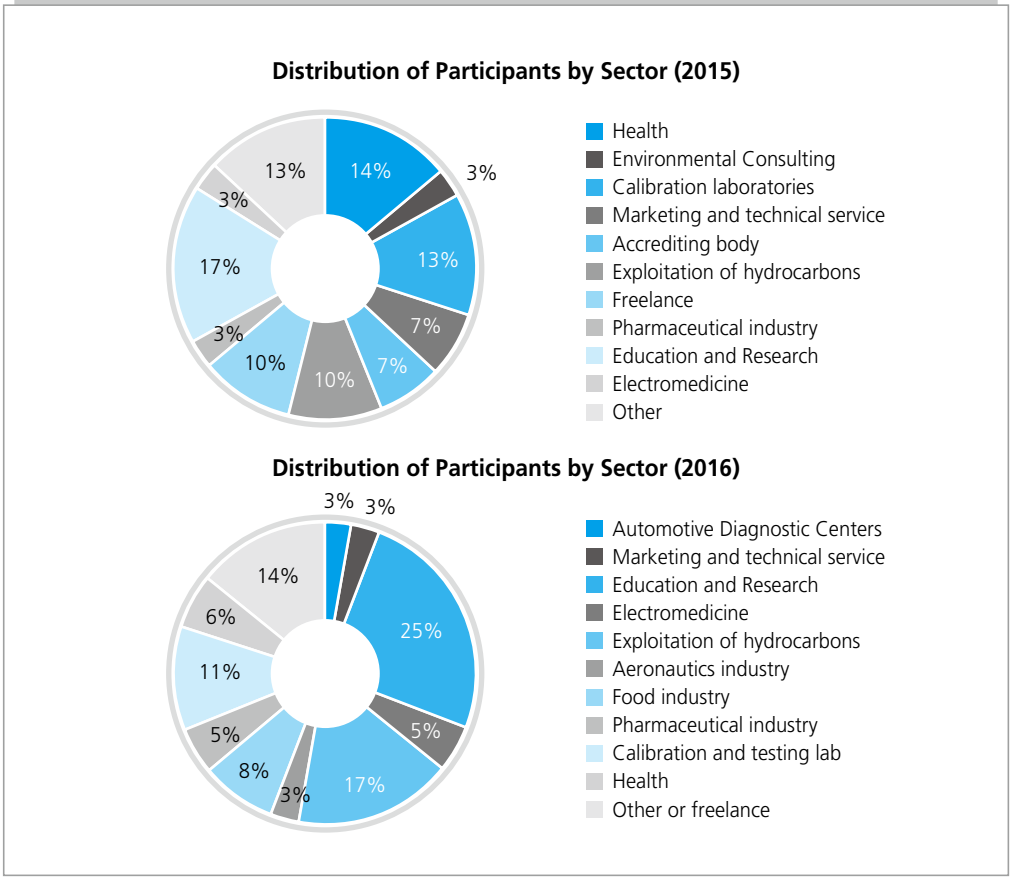
(Unit: Numbers)

Year	2015	2016	2017	Remarks
Number of participants	35	44	0	Not established as a regular program

Source: Own elaboration based on data from INM (2018b).

6) Five experts of INM joined the metrology diploma program giving lectures on metrology such as temperature, mass, pressure, metrology in chemistry.

[Figure 3-5] Number of Participants in "Metrology Diploma" (2015–2016)



Source: Own elaboration based on data from INM (2018b).

2.3.3. Professional Trainers Available from INM

INM has a permanent staff team of around 100. Out of them 65 people are engaged in technical activities in the three divisions of physical metrology, metrology in chemistry, and innovation and technical services.

The division of Physical Metrology has a total of 31 professionals, 23 of which are participating as instructors in the metrology training courses of the INM. And four (4) experts of the division serve as instructors in the metrology diploma courses that were operated in partnership with the National University of Colombia. In the Division of Metrology in Chemistry, there are 18 professionals, six (6) of whom shared their efforts as instructors in the regular metrology courses organized by the INM, and four (4) experts joined efforts for the diploma course as well. From the Division of Innovation and Technical Services, one (1) professional takes part in the

INM's regular metrology training programs that address the subject of statistics in metrology.

〈Table 3-14〉 Human Resources of INM Available for Metrology Trainers

(Unit: Numbers)

Division	Number of Personnel	Number of Professionals Serving as Metrology Trainers
Physical Metrology	31	23
Metrology in Chemistry	18	6
Innovation and Technical Services	16	1
Management	35	
Total	100	30

Source: Own elaboration based on data from INM (2018b).

2.4. Other Institutions Providing Service for Metrology HRD in Colombia

Besides the INM, there are two institutions in Colombia who are serving as the major service providers of HRD in metrology: University of Cartagena and the SENA. The programs offered by the two institutions are designed to provide vocational training in metrology to young generations. Both are public institutions.

2.4.1. Programs Offered by the University of Cartagena

The University of Cartagena offers a couple of metrology HRD programs entitled "Professional Technician in Metrological Processes (PTMP)" and "Technologist in Industrial Metrology (TIM)" courses. With its main customer group of young generations who are looking for jobs in the industry, the University operates this course. Both courses have been in operation as permanent educational programs offered by the Faculty of Natural Sciences of the University.

Running for 24 months of its curriculum duration, the PTMP program puts emphasis on fostering skilled technicians who would be capable of metrological process of measuring devices and instruments. Its curriculum includes six months of internship at industries and laboratories, following 24 months of theoretical study at the University. Students of the TIM program are supposed to study for six semesters (36 months) to complete the whole study course. Just like the PTMP program, the students of TIM program are also given opportunities of internship for

six months. The two programs are in common in that they intend to foster technical human resources appropriate for metrology laboratories and industries concerned. Difference between them lies at the level of studies with a bit advanced studies required for the TIM course students. <Table 3-15> presents a brief overview of the metrology education programs offered by the University of Cartagena of Colombia.

〈Table 3-15〉 Metrology Education Program Offered by the University of Cartagena

Program	Years of Study	Objectives of Education
Professional Technician in Metrological Processes (PTMP)	4 semesters (24 months, including six months of internship)	To foster skilled technicians in metrological processes of measuring devices
Technologist in Industrial Metrology (TIM)	6 semesters (36 months, including six months of internship)	To foster technologists capable of offering quality measurement services

Source: Own elaboration based on data from the University of Cartagena website.

The specific technical capability that students learn from the PTMP and TIM programs include the following:

- Calibration of components and instruments according to manufacturing specifications, including dimensional measuring equipment;
- Determination of testing procedures and maintenance of instruments used in the measurement and control in the basic fields of pressure, temperature, humidity and other quantities;
- Inspection, testing and operating instruments and systems to diagnose errors and faults using measuring devices; and
- Repairing and replacing systems and parts according to metrological requirements.

In addition to the above disciplines, the TIM program pursues to teach advanced metrological capability to students, such as:

- To perform monitoring of equipment of calibration and measurement services
- To inspect equipment and product as compliant to specifications
- To perform calibrations services to meet the requirements of international standards
- To draw up documentation and to keep records of process and product quality

– To evaluate uncertainty in measurement and in the calibration of measuring instruments

– To analyze measurement data to identify deviations, trends and predictions of future values

– To learn and develop basic preventive actions such as adjustment, replacement, correction factors, identify measurement errors

– To draw up calibration reports

– To generate and develop inspection procedures and control process

– To generate and develop standardized procedures metrological calibration

– To constantly update the current regulations as guidelines defined by the ONAC

– To promote continuous improvement processes

– To promote inter-comparison processes with national and international laboratories.

As regards to the tuition fee categories of the two programs, the fees are varied to the economic performance of the students. For some of them, tuition fees are waivered (free) in case of those unemployed and with low level of income of the student's family. The following two tables show the recent achievement of the students who entered and completed the two metrology education programs offered by the University of Cartagena.

〈Table 3-16〉 Number of Students Admitted in Metrology Education Courses Offered by the University of Cartagena (2013–2016)

(Unit: Numbers)

Programs	2013	2014	2015	2016
Professional Technician in Metrological Processes (PTMP)	82	64	62	38
Technologist in Industrial Metrology (TIM)	4	11	31	24

Source: Own elaboration, based on data from the University of Cartagena website.

〈Table 3-17〉 Number of Students Completed the Metrology Education Courses Offered by the University of Cartagena (2013–2016)

(Unit: Numbers)

Programs	2013	2014	2015	2016
Professional Technician in Metrological Processes (PTMP)	0	7	32	24
Technologist in Industrial Metrology (TIM)	0	0	1	1

Source: Own elaboration, based on data from the University of Cartagena website.

It seems that the two metrology education programs by the University of Cartagena have strong potential of growth; in the light of its clear target group of customers and its curriculum that comprises of basic and comprehensive disciplines for measurement techniques. However, it is noted that the number of students who completed the whole course of TIM program was only one for the recent years, while those for the PTMP program were between 20 and 30 people. In view of the number of accredited calibration and testing laboratories in Colombia, which exceeds 350 as of December 2017, the number of graduated student needs to be increased to the extent that could meet the need of human resources for those laboratories. It should be pointed out that the metrology education programs of the University have been in operation, independent from the NMI of Colombia. They have 19 trainers engaged in the above metrology education programs, and they are all from within the University with no one provided by the INM.

2.4.2. Programs Offered by the National Learning Service

SENA also serves as one of the core service providers of HRD in metrology. Operated in different places of Colombia, including Bogota, Medellin and Cali, SENA's metrology training programs are running for about two years now. Its main customers are the people from the younger generation, who are looking for jobs as industrial technicians responsible for metrological services.

During the four semesters of study under the SENA program, the students learn theoretical knowledge and skills required for offering metrological services. Just like other vocational training programs of metrology in Colombia, SENA also provides its students with opportunities of internship for six months. <Table 3-18> presents the recent trend of a growing number of graduates who completed their study with the SENA's technician program in industrial metrological service (SENA, 2017).

〈Table 3-18〉 Graduates of Metrology Training Programs of SENA (2012–2017)

(Unit: Numbers)

Year	2012	2013	2014	2015	2016	2017	Total
Number of Students Graduated	8	25	34	26	63	73	229

Source: Own elaboration, based on data from SENA (2017b).

For its metrology training services, SENA has secured 18 professional trainers as of December 2017, nine (9) of whom are engaged in teaching technical subjects of metrology. The tuition fee for the SENA's HRD service program is free, which acts as a strong advantage to get young generations into the metrology community. Nevertheless, seats with the SENA' metrology program are insufficient to accommodate the large demand of young people to be trained as professional technicians in metrological services. It should also be noted that there are no substantial collaborations between SENA and the INM for the operation of the metrology program of SENA. Out of all the metrology trainers of SENA, there is no one provided by the INM.

〈Table 3-19〉 Composition of Trainers by Teaching Subject of SENA Metrology Program

(Unit: Numbers)

Field	Number of Trainers	Remarks
Technical Knowledge	9	Trainers are not provided by the INM, the NMI of Colombia
General Knowledge	6	
Complementary studies	3	
Total	18	

Source: Own elaboration, based on data from SENA (2017b).

SENA operates a Committee for Metrology Education, which is aiming at promoting the reliability of industrial measurements by assuring metrological management in the process of measurement services. Members of the committee consist of representatives from the industry, academic organizations such as universities, government institutions and one member of the NMI (SENA, 2017).

2.4.3. Master's Course of Quality Management System in Colombia

As of December 2017, there are two advanced education programs in Colombia that are offering master's study on quality management system. In partnership with

ICONTEC, the standardization body of Colombia, the University of Santo Tomas operates a graduate course focused on "Quality and Integral Management." The University of America Foundation recently launched its advanced education service of "Integrated Management of Quality and Productivity."

The master's program jointly operated by ICONTEC and the University of Santo Tomas provides opportunities to learn about theoretical knowledge and practical solutions to integrate different management quality systems with the principles of sustainable development (Universidad Santo Tomas, 2017). Running for two years of study, the program offers students to learn a wide spectrum of subjects related to quality management system as listed in the table below. The master's course delivers such subjects as public management, management in education, and health management as well, in addition to the subjects directly relevant to quality management system. It is to help the students increase their abilities to better understand comprehensive solutions in quality and integrated management practices.

〈Table 3-20〉 Subjects of Study in the QMS Master's Program at Santo Tomas University

Semesters	Subjects of Study	Remarks
Semester 1	Introduction to quality management Risk management Planning and processes Strategic management Humanism, society and ethics Research I	Subjects relating to metrology are not given as mandatory classes but one of electives.
Semester 2	Operation and control of the quality management systems Audits and improvement Financial management Leadership and human talent management Research II	
Semester 3	Environmental management Integral management Security and health at work Research III Optional Research	
Semester 4	Combined audits Social responsibility Optional subject I Optional subject II	
Total	Four (4) Semesters for Two (2) Years	

Source: Own elaboration, based on data from the University of Santo Thomas website.

It is noted that the program does not have any compulsory subjects relating to metrology, which is offered as one of the electives that students may choose. In the very beginning of this QMS master's program, there used to be metrology subjects that were offered as compulsory: because there were many students who were working in the manufacturing sector. Currently, however, almost all of the students are coming from the sector of the service industries, and metrology subjects have been shifted as one of the electives. For the trainers of the QMS master' course, five (5) professors of the University work together with 3-4 experts from ICONTEC. <Table 3-21> presents the number of students who graduated with their master's degrees in quality management system.

〈Table 3-21〉 Number of Graduate Students with Master's Degree in QMS (Joint program between ICONTEC and Santo Tomas University)

Year	2008	2009	2010	2011	2012	2013	2014	2015
Number of Students Graduated	5	21	39	6	40	33	41	42

Source: Own elaboration, based on data from DANE (2015).

Another master's course in QMS has recently been launched by the University of America Foundation located in Bogota. Entitled "Integral Management of Quality and Productivity (IMQP)," the master's course aims primarily at developing competencies in integrated quality management system applicable over wide business sectors. It also pursues to help students in obtaining skills of leadership, teamwork, and communication in ways that make differences in the economic, social, technological and cultural environment of Colombia (University of America Foundation, 2018). For the two (2) years under the IMQP program of the University of America Foundation, students are supposed to study more than 20 subjects. They are much similar to those of the QMS master's course offered by the Santo Tomas University.

For the IMQP course, five (5) professors of the University are selected to serve as trainers. There are nine (9) students admitted for the spring semester of 2018 for the first time of its service. It should also be noted that just like the master's course jointly offered by the ICONTEC and the University of Cartagena, the IMQP course does not have any mandatory subjects of study related to metrology yet.

2.4.4. Master's Course of Metrology in Colombia

The ITM created a master's degree course in metrology in April 2017 for the first time in Colombia. It is a great advance for the HRD service in Colombia in the field of scientific metrology. Located in the city of Medellin, however, ITM has not accepted

students yet, as preparatory procedures are still in progress. It is likely that it will take some time until the Institute gets ready to officially launch its metrology master's programs.

Different from any other metrology HRD service provider in Colombia, the ITM has been working closely with the INM, from designing to operating the metrology master's course in every detail. Securing trainers from both institutions will also enable the ITM's metrology master's course to be more competitive and effective in fostering the next generations of experts in measurement science and technology in Colombia.

2.5. Engagement of Colombia in the International Metrology Communities

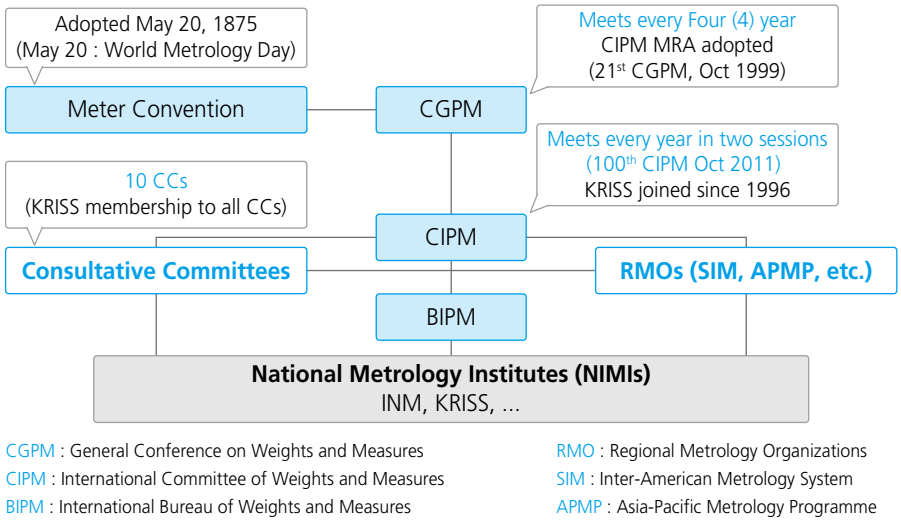
Engagement of an entity in the activities organized by the relevant international community might be one of objective indicators by which we can make out its capability and estimate its competitiveness in the arena it plays in. There are two key players of Colombia who are engaged in the service of metrology. The INM is the one in charge of scientific and industrial metrology. The other one, the Superintendence of Industry and Commerce (SIC), is assigned for serving as the governmental authority for legal metrology.

2.5.1. By INM, the National Metrology Institute of Colombia

The scheme of international organization in scientific metrology is originated from the Meter Convention that was adopted in 1875 (see Figure 3-6). The International Committee of Weights and Measures (CIPM) serves as the highest international authority making the decisions for all important issues relating to scientific metrology. The principal task of the CIPM is to promote world-wide uniformity in the units of measurement. The CIPM is made up of eighteen individuals, each of a different nationality, who are all renowned for their professional achievement in scientific metrology.[7)]

7) BIPM Website.

[Figure 3-6] Organizations of International Metrology Community



Source: Seo (2012).

Colombia joined the Meter Convention in 2013, and the INM has been representing Colombia to the CGPM, with no membership to the CIPM yet.

For the effective operation of the committee, the CIPM has set up Consultative Committees (CC). The world's experts meet regularly and provide advice on scientific and technical matters for each CC. Among the tasks of these CCs, are the detailed considerations for advances in physics that directly influence metrology, along with the preparation of Recommendations for discussion at the CIPM, the identification, planning and execution of key comparisons of national measurement standards. Currently, there are 10 CCs under the CIPM as listed in the <Table 3-22>. With no full membership to any CCs, the INM has been attending as an observer to three CCs: CCM, CCT, and CCTF.

〈Table 3-22〉 List of Consultative Committees of the CIPM

Name of CC	Field of Metrology in Charge	Set up in
CCAUV	Acoustics, Ultrasound & Vibration	1998
CCEM	Electricity and Magnetism	1927
CCL	Length	1952
CCM	Mass and Related Quantities	1980

〈Table 3-22〉 Continued

Name of CC	Field of Metrology in Charge	Set up in
CCPR	Photometry and Radiometry	1933
CCQM	Amount of Substance	1993
CCRI	Ionizing Radiation	1958
CCT	Thermometry	1937
CCTF	Time and Frequency	1956
CCU	Units	1964
Total	10 Consultative Committee in operation	

Note: Each CC operates Working Groups with different functions.
Source: Own elaboration, based on information at BIPM (2018).

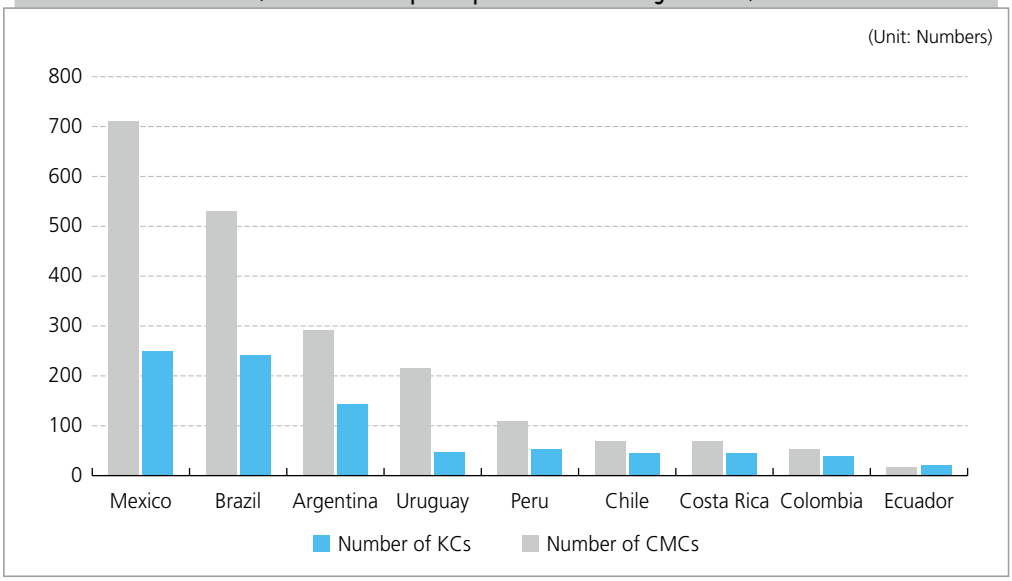
Under the globalized economic environment of today, the priority mission of the NMI of every country is to secure international equivalence of its national measurement standards. The CIPM developed the Mutual Recognition Arrangement (CIPM MRA), which was accepted at the 21st CGPM in October 1999. Signatories to the CIPM MRA comprised 98 countries and 4 international organizations as of December 2017. The INM of Colombia joined the MRA in 2013.

The CIPM MRA states that its objectives are to establish the degree of equivalence of national measurement standards by the NMIs; and to provide for the mutual recognition of calibration and measurement certificates issued by NMIs.[8] Key comparisons (KCs) of measurement and quality system demonstrations were taken as the core process to reach the goal of the CIPM MRA. Participating NMIs are working closely with the CIPM and the regional metrology organizations (RMOs). The RMOs are responsible for carrying out KCs and other actions within their regions to support mutual confidence in the validity of the calibration and measurement certificates by their member NMIs.

The outcomes of the MRA are the internationally recognized (peer-reviewed and approved) CMCs of the participating institutes. Approved CMCs and supporting technical data are publicly available from the CIPM MRA database (KCDB).[9] As of December 2017, the INM has been participating in 41 items of KCs, while publishing its CMCs in 56 items to the KCDB. Compared with those of other NMIs in the South American region, the INM's achievements in the CIPM MRA activities remains to be further improved (See Figure 3-7).

8) CIPM MRA (2018).
9) BIPM (2018).

[Figure 3-7] Achievement of the CIPM MRA Activities of Selected Countries in South America (in terms of KC participation and CMC registration)



Source: Own elaboration based on the date from BIPM KCDB (2017).

The table below sums up the current level of engagement of the INM in the international activities of scientific metrology, in terms of membership to the CIPM, Consultative Committees, and participating in the KCs and registration of its CMCs.

〈Table 3-23〉 Engagement of International Activities of Scientific Metrology by INM

Category	Status of Engagement	Remarks
Membership to the CIPM MRA	Signatory	2013
Membership to the CIPM	No membership	Individual competence
Membership to the CIPM CCs	No full membership to any CCs (observer to three CCs)	Individual and NMI's competence
Participation in KC	41 items	Mass related quantities
Registration of CMCs	56 items	Thermometry

Source: Own elaboration, based on information at BIPM (2018).

2.5.2. By SIC, the Legal Metrology Authority of Colombia

Superintendence of Industry and Commerce is representing Colombia to the international community of legal metrology. SIC has a membership to the

International Organization of Legal Metrology, OIML, since 2012. The OIML operates 18 technical committees, and the SIC has a membership to the committee of breath testers of OIML.

2.5.3. By ICONTEC for Standardization and ONAC for Conformity Assessment

ICONTEC has been authorized by the government to represent Colombia to the international community of standardization. ICONTEC has been participating in the activities of the International Organization for Standardization (ISO) since 1963 and of the International Electrotechnical Commission (IEC) since 2000. As regards the membership in the level of technical committee activities, ICONTEC has been participating in only one TC of ISO TC 12 (Quantities and Units), with no membership to any other TCs.

In the field of conformity assessment, National Accreditation Organization of Colombia, ONAC, has been assigned to participate in the international activities. ONAC has been actively working with International Accreditation Forum (IAF) since 2013, International Laboratory Accreditation Cooperation (ILAC) since 2014, and Inter-American Cooperation for Accreditation (IAAC) since 2015. As a full member of the ILAC MRA, ONAC participates in a couple of committees of ILAC including Laboratory Committee. ONAC's engagement with IAF includes its membership to technical committees of management systems certification and production certification. In the regional activities with the IAAC, ONAC maintains membership to the Executive Committee, as well as being in charge as Treasurer and President of the MRA Committee.

2.6. Investment in Metrology HRD in Colombia

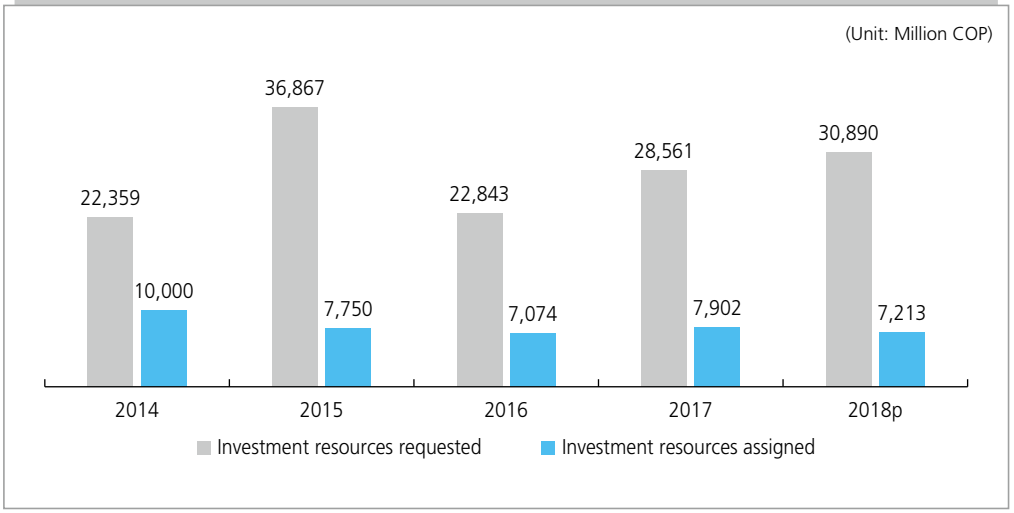
In almost all countries, with a few exceptions, metrology has been under the direct responsibility of the government. Services of metrology heavily depend on financial support from the government. There are two organizations in Colombia who are engaged in metrology services with the financial support from the government. They are INM and SIC who are responsible for scientific metrology and legal metrology in Colombia, respectively.

2.6.1. Investment in Metrology HRD for INM

The INM is the only public entity in Colombia that directly receives financial support from the government. The subject of metrology appears as an item within the national budget since 2012 with the creation of the INM as a public institution in charge of scientific metrology in Colombia. Financial support for the INM has

been stagnant for the past years. The assigned value has been staying less than 30 % to the amount of budget request proposed by the INM. It should be noted that there has been no apparent investment earmarked for the HRD in metrology for the technical staff of INM or for its metrology HRD service for the local customers.

[Figure 3-8] Trend of Government Investment in the NMI of Colombia (2014–2018)



Source: Own elaboration based on data from INM (2018a).

2.6.2. Investment in HRD in Legal Metrology Service for SIC

By Decree 4886 of 2011, the Superintendence of Industry and Commerce was restructured with new missions for the legal metrology in Colombia. SIC has been assigned to act as the legal authority to supervise and control the compliance of technical regulations regarding legal metrology provisions, control of liquid fuels from oil stations and river traffic services throughout the country. This Decree also enforces the rules on price control, investigation and report of failure rates regarding medicines, milk and agrochemicals (SIC, 2017). In consideration of such expanded missions of the SIC, the budget scale of the SIC has been on the steady rise since 2014.

<Table 3-24> and [Figure 3-9] show the trend of annual budget scale of SIC as request and approval for the fiscal years of 2014–2017.

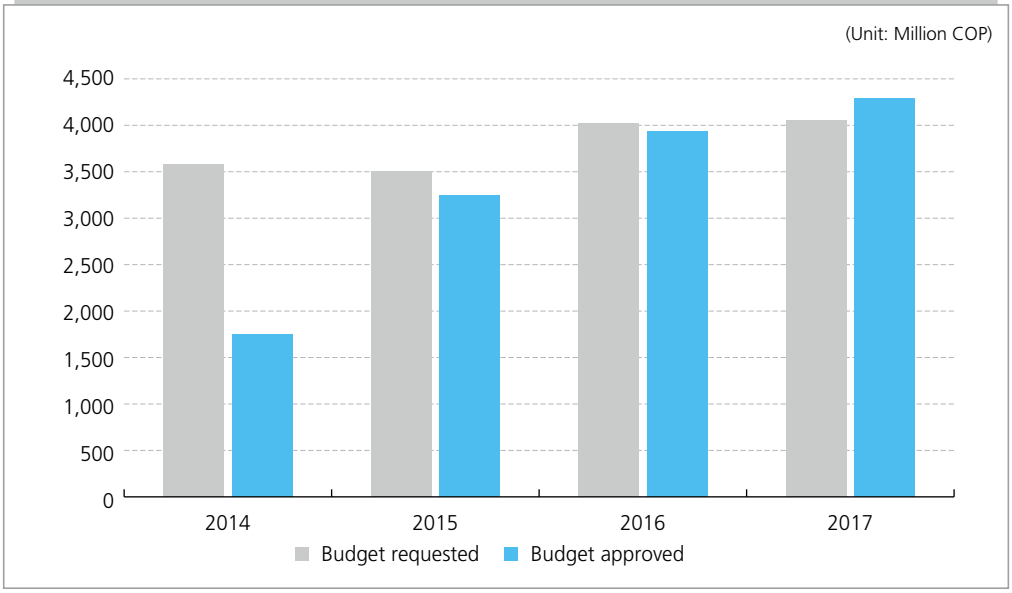
〈Table 3-24〉 Annual Budget Scale of the SIC (2014–2017)

(Unit: Million COP, Percentages)

Fiscal Year	Requested	Assigned	%
2014	3,585	1,747	49%
2015	3,500	3,248	93%
2016	4,013	3,933	98%
2017	4,052	4,282	106%
		Average	86%

Source: Own elaboration, based on data from DNP (2017).

[Figure 3-9] Trend of Annual Budget Scale of SIC (2014–2017)



Source: Own elaboration, based on data from SIC (2017).

SIC has been offering training services, covering the subjects of legal metrology. For the two years of 2014–2015, SIC organized 73 training programs in legal metrology in different cities, where more than 1,200 people attended. For the recent two years of 2016–2017, five (5) short trainings programs in legal metrology were organized by SIC in Bogotá. Nevertheless, it should be pointed out that SIC's expenditure does not explicitly state investment in HRD in legal metrology for its own technical staff (SIC, 2017).

2.7. Obstacles and Futures Tasks for Improvement

The preceding sections intended to find facts regarding the formal education system and HRD in metrology services in Colombia. For the subject of education system, facts were analyzed in terms of the number of students in undergraduate and graduate courses in the fields of science, technology and engineering, among others. In the service of HRD in metrology, analysis was made in different aspects: service providers (institutions); programs, and trainers. Engagement in international community activities in the fields of NQI was briefly reviewed as an essential complement to diagnose the competitiveness of the NQI of Colombia. The level and trend of investment in HRD in metrology for the two key players in the NQI of Colombia was also reviewed. The analysis results turned out to be consistent, as a whole, with what was indicated in the draft CONPES report of "National Policy of Laboratories" which has been under development by the DNP. Obstacles and tasks for further improvement in the HRD in metrology service in Colombia might be summarized as follows.

2.7.1. Potential of Education in Science, Technology and Engineering and Metrology

A good number of schools are concentrated in a few cities and provinces of Colombia. It keeps the next generations of Colombia from taking equal opportunities of quality services of education throughout the country. Students in the fields of science, technology and engineering occupy less than 30 % out of the total number of students graduated from undergraduate courses. It is much lower in the number of students who graduated from graduate courses, being slightly above than 10 % of all of the graduates. In the field of scientific metrology, there is no educational institution yet who is offering advanced academic degree courses. They are all together acting as root causes that lower the potential and competitiveness for cultivating and supplying better qualified human resources in metrology.

2.7.2. Potential of Service of HRD in Metrology

In terms of the number of the service providers of HRD in metrology in Colombia, there are only three (3) institutions today that are operating the training and education programs in metrology. As the NMI of Colombia, INM takes the leading role in offering services of HRD in metrology. However, the volume and scope of metrology HRD services offered by INM is far behind enough to meet the growing needs of competent human resources as required by the metrology community in Colombia, including the emerging sectors.

There are a couple more institutions offering metrology training programs: SENA and the University of Cartagena. They have well-organized training and education programs in metrology that run for two to three years, including internship opportunities for six months. However, their metrology HRD programs are focused on vocational training to help the young generation in getting their jobs in the industry, who are not quite well qualified for the advanced metrology laboratories. It should also be noted that the number of successful graduates are still small to be around 20–70 a year, which falls behind enough to meet the needs of more than 300 accredited laboratories in Colombia. The programs of SENA and the University of Cartagena are offered without collaborations with the INM. They need to join forces to improve upon the quality of HRD in metrology services.

Lack of competent trainers in metrology should be noted. It remains as a critical obstacle that needs to be overcome to innovate on the current practices of the metrology HRD service. There are only around 30 technical staff members of INM who are available as trainers for their metrology training programs. The scope of its metrology HRD services stays limited to cover very basic subjects of metrology. It needs to be expanded so as to address the ever growing demands from new emerging sectors and to find metrological solutions to the global issues such as health, climate change, energy, and the environment as well. It should also be pointed out that there is no collaboration between the INM and other metrology HRD service providers such as SENA and the University of Cartagena. They need to work more closely together for sharing trainers and refining metrology training programs, so that their metrology HRD services could be further developed to accommodate for the practical needs of the metrology community of Colombia.

2.7.3. Potential of the NMI, the Key Player of NQI

The NMI plays a key role in the operation and advancement of the NQI. As discussed in the preceding section, the INM needs to develop its potential in wide areas of measurement enough to be the full-fledged NMI of Colombia. With regards to the potential of its human resources, it should be noted that INM has no one with a doctoral degree in either laboratories or management as of December 2017. Out of around 100 permanent personnel, only a few people have their master's degrees. In terms of the engagement in the CIPM MRA activities - KC participation and CMC registration, the INM remains on the low level of achievement among the NMIs in the South American region. Such a low potential of INM keeps it from providing sufficient service of HRD in metrology throughout the country. It might lead its customers to be dependent on services from foreign institutions and international organization.

2.7.4. Investment in Metrology HRD by the Colombian Government

As discussed in the preceding section, only two organizations in the metrology community of Colombia receive direct financial investment from the government. The INM receives financial support from the government. However, there is no explicit expenditure earmarked for the capability building for its technical staff in laboratories. Investment in metrology R&D occupies merely around 5% of the total amount of annual budget of INM. Lack of financial support for INM can hardly bring its technical staff access to opportunities that can further expose them to an advanced research environment. As the governmental authority for legal metrology in Colombia, SIC receives its operational budget from the government. It is on a steady rise in the recent years. However, expenditure for promoting its technical staff of SIC is not clearly stated.

The obstacles and tasks as defined herein will serve as essential ground sources to identify policy recommendations that will be proposed in the section 5 of this report, with reference to the practices of HRD in metrology of Korea and selected advanced countries.

3. Practices of HRD in Metrology of Korea

Service of HRD in metrology in Korea has been provided by the NMI in cooperation with other training institutions which are officially designated by the Korea Laboratory Accreditation Scheme (KOLAS). Being the NMI of Korea, the Korea Research Institute of Standards and Science, KRISS, has been taking the leading role in offering service of metrology HRD in Korea over the past decades since the early 1980's. It used to be the single service provider of HRD in metrology in Korea until 2002, when the government developed a new policy to increase the number of training institutions of metrology. Designated by KOLAS, six institutions were authorized to serve as metrology training providers in addition to KRISS, the NMI of Korea.

There is well defined and harmonized division of responsibilities between the NMI and other metrology training institutions, which is based on the professional expertise and the functions of the service providers. While KRISS puts an emphasis on HRD service in advanced scientific metrology and its applications, other designated institutions are in charge of training service in calibration and testing techniques meeting the demand of customers in the field. KRISS provides trainers, where appropriate, for selected metrology training courses organized by other designated training institutions in order to secure the quality of training services for the metrology community of Korea. In addition, KRISS operates a graduate school

of metrology in close cooperation with the University of Science and Technology (UST). It offers a unique opportunity for students to learn fundamental and applied knowledge in scientific metrology.

〈Table 3-25〉 Service Providers of HRD in Metrology in Korea

Classification	Service Providers	Scope of Metrology HRD Service	Remarks
National Metrology Institute (NMI)	KRISS	In-depth calibration/testing techniques, Advanced measurement technologies, Uncertainty in Measurement	services that are not available at any other training provider
Designated Metrology Training Institutions	KASTO, KTL, KTR, KCL, KOTICA, KAB	Calibration/testing techniques, Quality management system, Certification, Inspection, Uncertainty in measurement	Designated by KOLAS (since 2002)
Graduate School of Metrology	KRISS-UST	Fundamental and applied scientific metrology	Master and doctoral studies

Source: Own elaboration based on the data from websites of the above institutes.

This section will discuss what the Korean metrology community has been doing for promotion of human resources in metrology. It will also present the significant role that the Korean government has been playing in the support of HRD in metrology for KRISS, the NMI of Korea. It has led Korea up to the leading-edge in the global metrology arena.

3.1. Metrology HRD Services Offered by KRISS, the NMI of Korea

HRD in metrology service by KRISS has been developed for over decades that could be characterized into two different phases. In the beginning of its metrology HRD services, KRISS was the unique organization who was devoting itself to providing services of training, mainly on calibration and testing techniques covering wide areas of measurement. It was to meet the increasing needs of measurement capabilities required by the local customers mainly from industry, calibration and testing laboratories. It lasted for around two (2) decades until the early 2000's when other metrology training providers, who were authorized by the KOLAS, began services of training in the subjects of calibration and testing techniques. It has led KRISS to shift its HRD service towards advanced scientific measurement technology fields and in-depth calibration and testing techniques which are not available by any other organization in Korea.

3.1.1. Programs of Metrology Training/Education Offered by KRISS

Until the early 2000's when KRISS shifted its service to advanced scientific metrology, KRISS had developed and offered training programs in two different categories, in terms of the nature and technical functions of its customers. The first one was "expert courses," whose target audience was set for managers in charge of calibration and testing laboratories. The other was "technical officer courses," the attendees of which were technical staff who were offering calibration and testing services on site. KRISS developed 14 programs for the expert courses, and up to 29 programs for the technical officer courses. <Table 3-26> shows a brief statistics in the beginning stage of its service of HRD in metrology. Achievements in terms of the number of training courses and beneficiaries (organizations and trainees) offered by KRISS are presented in <Table 3-27>.

〈Table 3-26〉 Training Programs of Calibration and Testing Techniques Offered by KRISS (in the initial stage of service 1985–2002)

Type of courses	Expert courses	Technical officer courses
Number of Programs	14	29
Length of Training (Days)	3–6	2–6
Number of Participants (Each course)	10–40	10–50
Main Subjects Covered	Mass, Optics, Vacuum, Inorganic Analysis, Gas Analysis, Materials Characterization, Trace Organic Element, X-ray Diffraction, Radioactivity, Surface Analysis, Thermometry, etc.	Length, Colorimetry, Fluid Flow, Mass, Acoustics, Vibration, Thermometry, Torque, Electricity, Pressure, Time, Hardness, Humidity, Materials testing, etc.

Source: KRISS (2012).

〈Table 3-27〉 Training Courses and Beneficiaries of Training Services Offered by KRISS

(Unit: Numbers)

Programs (No. of courses offered)	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Expert course	8	9	10	4	7	10	12	13	16	11
Technical officer course	18	19	20	20	22	19	18	23	19	22
Tailored courses	8	5	6	14	14	10	3	6	15	9
Total	34	33	36	38	43	39	33	42	50	42
No. of Organizations	439	514	903	962	790	690	545	452	475	652
Number of Trainees	519	642	1,103	1,182	991	805	646	556	615	826

(Unit: Numbers)

Programs	1995	1996	1997	1998	1999	2000	2001	2002	Total
Expert course	11	14	14	14	14	13	12	12	204
Technical officer course	25	24	24	25	29	29	28	22	406
Tailored courses	10	15	12	11	4	10	11	8	171
Total	46	53	50	50	47	52	51	42	781
Number of Organizations	760	935	780	519	619	674	643	560	11,912
Number of Trainees	996	1,193	992	694	846	839	937	792	15,174

Source: KRISS (2012).

It is noteworthy that each of the KRISS metrology training course did consist of technical sessions as well as a session of the "fundamentals of metrology" as an integral part of the training program. The session presents lectures such as the International System of Units (SI) and uncertainty in measurement through the exercises included. It helped them obtain the comprehensive knowledge and technical skills that anyone engaged in the metrology community should have.

Over the past decades, its service has made significant contributions to advancing the metrological capabilities of its beneficiaries mostly from calibration and testing laboratories and small and medium enterprises. They were in need of skilled metrological staff as a key towards improving the quality of their goods and services so that they are acceptable in the global marketplaces.

Currently, KRISS offers training focused on advanced scientific measurement and its applications such as surface analysis, electromagnetic wave, materials testing, uncertainty in measurement, etc. that are not made available by any other organizations in Korea. In addition, the KRISS-UST graduate school of metrology takes on the role of fostering the young generations who are going to play a leading role in further enhancing the competitiveness of the NQI of Korea.

3.1.2. Evolving Services of HRD in Metrology by KRISS

HRD in metrology service of KRISS began in early 1980s with training programs on calibration and testing techniques. As needs for training in metrology and QMS grew bigger, the Korean government introduced a new policy of NQI in early 2000's. The new policy has brought a drastic paradigm change of HRD in metrology practices in Korea. KOLAS introduced the program for designated metrology training institutions in 2002 to create and provide more opportunities for the local customers to get easy access to metrology HRD services offered by different training providers.

It has helped KRISS to share the responsibilities of training services in calibration, testing, QMS, and regarding uncertainty in measurement. At the same time, the new policy of NQI in Korea has led KRISS to shift its metrology HRD services towards cultivating competent human capitals in advanced scientific measurement technology. The two types of HRD in metrology service of KRISS remains the same as before with its group and individual courses. The group training service offered on a regular basis was limited to the local customers in Korea until 2012. It has been made open to the global community since 2013 when the Global Metrology Academy (GMA)[10] of KRISS officially launched its services of group and individual training for foreign customers. <Table 3-28> shows the scope and types of the metrology HRD service of KRISS, along with its major customers, which have been gained over decades for better developing human resources in metrology.

10) Even before the GMA started its service in 2013, KRISS offered training services to foreign customers. Group training was offered once a year funded by the Korean government, and individual courses were subject to the request of the foreign customers. GMA offers group training courses 2-4 four times a year, funded by KRISS and with support from PTB, the German national metrology institute.

〈Table 3-28〉 Expanded Scope of Metrology HRD Services of KRISS

Years	Scope of Education/ Training Subjects	Major Customers	Type of Classes (*)[11]	Remarks
1983–2002	Calibration/ Testing Techniques	Local customers	Group, Individual	Currently offered by KOLAS designated training institutions
2002–Present	In-depth Calibration/ Testing Techniques	Local customers	Group, Individual	Where no training providers are available by any other institution
	Advanced Scientific Measurement Technologies	Local customers	Group, Individual	
	Fundamental and Applied Scientific Metrology	Open to all nationals	Individual	Graduate School of Metrology (KRISS-UST)

Source: Own elaboration, based on data from KRISS (2018b).

Currently KRISS offers training services under the following two categories: regular group courses and tailored individual courses. Beneficiaries to the same have been around 350–400 each year. The table below presents summary of the achievement of training service offered by KRISS in 2017. As an effort to raise awareness about metrology, science and technology among the middle and high schools, KRISS operates metrology school for science teachers twice a year. In each of the three-day metrology schools, up to 15 science teachers are invited to join so that they could learn more about metrology and bring their achievements back to their classrooms.

〈Table 3-29〉 Achievement of Metrology HRD Service Offered by KRISS in 2017

Programs	Subjects	Number of Operations (Year)	Number of Participants
Group courses	7	10	205
Individual courses	17	21	195
Metrology School for Science Teachers	2	2	21
Total	25	33	421

Source: Own elaboration, based on data from KRISS (2018b).

11) Individual course: tailored training upon request of customers (Group course: regular on an annual basis).

The two tables below present details about the subjects, duration, number of participants of the group and individual courses offered in 2017. For some of the tailored individual courses, training service is offered on-site for the customers. In response to the government's initiative for promoting competitiveness of the small and medium enterprises (SME) in Korea, KRISS has been offering bespoke training services with a view towards helping the selected promising SMEs to enhance their R&D capabilities.

〈Table 3-30〉 Achievement of Group Training Service Offered by KRISS in 2017

	Subjects of Training Programs	Durations (Days)	Number of Participants
1	Electromagnetic Wave: VNA	4	14
2	Calibration of Gas Measuring Devices	3	13
3	Introduction to Measurement Uncertainty	1	8
4	Uncertainty in Measurement (1)	3	22
5	Surface Analysis (I)	2	9
6	Surface Analysis (II)	4	10
7	Radioactivity	3	47
8	Ionizing Radiation/Neutron	3	44
9	Uncertainty in Measurement (2)	3	27
10	Surface Roughness	3	11
Total		29	205

Source: Own elaboration based on data from KRISS (2018b).

〈Table 3-31〉 Achievement of Individual Training Service Offered by KRISS in 2017

	Subjects of Training Programs	Durations (Days)	Number of Participants
1	Preparation and analysis of Standard Gas	180	2
2	Radioactivity for technical officer	3	12
3	Viscosity measurement and calibration (1)	2	4
4	Medical gas and its quality management	2	57

〈Table 3-31〉 Continued

(Unit: Days, Numbers)

	Subjects of Training Programs	Durations (Days)	Number of Participants
5	Inorganic analysis for managers	5	14
6	Acoustics measurement and calibration	2	5
7	Shock testing and calibration	3	5
8	UV radiometric photometer calibration	3	3
9	Measurement of magnetism (1)	1	2
10	Magnetism basics: standards and calibration	2	13
11	Optical measurement and calibration	2	2
12	Electrical conductivity and resistance	4	3
13	Measurement of magnetism (2)	1	3
14	Vibration measurement and calibration	2	7
15	Vibration measurement and sensor calibration	2	4
16	Analytical chemistry for nuclear power plan	3	9
17	Viscosity measurement and Calibration (2)	2	4
18	Magnetic shielding	2	7
19	Imaging sensors	2	11
20	Pressure and vacuum	2	12
21	Uncertainty in measurement	1	16
Total		78	195

Note: Programs 17–20 were strategically organized for selected SME's for their R&D capacity building.
Source: Own elaboration based on data from KRISS (2018b).

Learning from its experience over decades, KRISS has become able to offer HRD in metrology services covering almost all subjects of fundamental metrology and related subjects including materials evaluation and uncertainty in measurement as listed below.

〈Table 3-32〉 Potential Subjects of Metrology Training Service Available at KRISS

No.	Items	No.	Items
CCAU (2)	Acoustics, Vibration	CCRI (3)	Ionizing, Radiation, Radioactivity, Neutron
CCEM (5)	AC/DC Resistance, LRC/ Power, Magnetism, EMI/ EMC, Electromagnetic Wave	CCT (2)	Thermometry, Humidity/ Moisture
CCL (2)	Length, Surface Roughness	CCTF (1)	Time & Frequency
CCM (6)	Mass, Density, Pressure, Vacuum, Fluid/Flow, Torque/ Force	Materials Evaluation (9)	Materials Testing, NDE, Surface Analysis, Shock, Hardness, X-ray Analysis, Life Assessment, Thin-film Characterization, Thermophysical Properties
CCPR (3)	Photometry, Radiometry, Colorimetry	Uncertainty (2)	Uncertainty and Traceability, Evaluation of Uncertainty in Measurement
CCQM (3)	Gas Analysis, Organic Analysis, Inorganic Analysis	Total	11 Fields / 38 Subjects

Note: Fields are categorized basically by the measurement fields as classified by the CIPM.
Source: Own elaboration based on data from KRISS (2018b).

Furthermore, in cooperation with the UST in Korea, KRISS started offering graduate courses on measurement science and technology and related disciplines. KRISS-UST Joint Graduate School of Metrology (GSM) is a unique institution that is designed for fostering future professional metrology experts. Accepting both Korean and foreign nationals, there are around 70 students currently enrolled including around 20 from overseas. During the past 10 years of 2006–2015, there were 55 graduates from the GSM who obtained their master's and doctoral degrees in measurement science and technology. The Graduate school is described in more detail later in the section 4 of this report.

3.1.3. Professional Metrologists of KRISS Serving as Trainers

It is widely known that there are three core factors in HRD services: customers, trainers, and programs. From the viewpoint of the service provider, whether or not to secure a sufficient number of competent trainers is critical for the provider to achieve the quality of service and to create values to its customers. That is, the trainer is the key determinant of the sustainability of HRD services in metrology.

As of the end of 2017, KRISS has some 300 professional research scientists who are engaged in R&D and services in its metrology laboratories. More than 95 % of them hold their doctoral degrees in various fields of measurement science and technology. All of them are professional scientists who are serving or have potential to serve as trainers for the diverse metrology HRD programs offered by KRISS. For each training course, around five (5) trainers are working together delivering lectures and leading hands-on exercises with the support of technical experts at individual laboratories.

<Table 3-33> presents the professional human resources of KRISS who are all available to serve as trainers for the metrology HRD services offered by KRISS. Furthermore, trainers are invited, where appropriate, from outside KRISS. University professors, research scientists at other institutes, and experts in the private industries are invited to such courses as surface analysis and ionizing radiation, to name a few.

〈Table 3-33〉 Professional Human Resources of Metrology at KRISS

Functions	Number of Staff	Remarks
Research Scientists	294	286 doctorates (97.3%)
Engineers/Technicians	115	
Administration/Management	59	
Total	468	Permanent staff

Note: In addition, KRISS has some 300 people working on a contract basis, includuing 223 research students and postdoctoral fellows.

Source: Own elaboration based on data from KRISS (2018a).

3.2. Metrology Training Services of the Institutions Designated by the National Accreditation Body

As of November 2017, there are six (6) institutes in Korea who are authorized to offer training services on subjects related to metrology. They have been officially designated by the KOLAS. Different from those offered by KRISS, whose metrology HRD service delivers advanced scientific measurement technology, they are offering training with emphasis on calibration and testing techniques that are required on-site by the metrology community. KASTO is the major partner of KRISS in offering services of training on measurement techniques, while other five institutes provide training services mostly on quality management system. <Table 3-34> shows a list of metrology training institutions designated by KOLAS, along with the scope of their services.[12)]

12) A recent discussion raised a need to adjust the current policy of metrology training institutions; the need that the entities whose function includes certification are not eligible to be training providers to

〈Table 3-34〉 Metrology Training Institutions in Korea Designated by KOLAS

Institutions	Scope of Training Programs	Remarks
KASTO	Calibration, QMS, Uncertainty, Assessor, Internal auditor	Major metrology training provider
KTL	Calibration, Testing, QMS, Uncertainty, Assessor, Internal auditor, Certification of foreign standards, Industrial techniques	ISO 9001, ISO 14001, OHSAS 18001
KTR	QMS, Uncertainty, Assessor for Calibration, Testing, Inspection, RM providers, PT providers, Quality management for Testing and Inspection Organizations of Food and Drug, Cosmetics, Medical devices	ISO/IEC17025, 17043, ISO 17034,
KCL	QMS, Uncertainty, Internal auditor, Safety on building materials (asbestos)	Including ISO/IEC 17020, 17043, 17034 Guide 35
KOTICA	QMS, Uncertainty	ISO/IEC 17025
KAB	QMS, Uncertainty, Assessor for Testing and Inspection Laboratories	ISO/IEC 17025

Source: Own elaboration based on data from KOLAS website.

3.2.1. Programs of Metrology Training Offered by the Designated Institutions

KASTO serves as the major training provider of calibration and testing techniques. Having its members from all of calibration and testing laboratories in Korea, the KASTO organizes and provides various training programs in metrology covering calibration and testing techniques, QMS, uncertainty in measurement, assessors, etc. The recent achievement of training services offered by the KASTO is described in <Table 3-35>.

keep the impartiality of its certification services.

〈Table 3-35〉 Recent Achievement of Metrology Training Services Offered by KASTO

(Unit: Numbers)

Subject	Frequency(per year)	No. of Participants
QMS	17	875
Uncertainty in Measurement	7	275
Calibration and Testing Techniques	32	1,109
Total	56	2,259

Note: Subjects of training under the calibration and testing techniques:Length, mass/volume, temperature, electricity, pressure, force/torque, fluid flow, electromagnetic wave, hardness, time and frequency, humidity/moisture, radiometry, radioactivity, ionizing radiation/neutron, surface analysis.
As KASTO does not have its own metrology research laboratories and research staff, its training services depend mostly on the trainers invited from outside the organization, with a few exceptions. KRISS also provides trainers for some metrology training courses organized by KASTO.

Source: Own elaboration based on data from KASTO website.

Metrology training programs offered by other five institutions are almost all about the quality management system, assessors, and internal reviews. KTL, Korea Testing Laboratory operates training on a couple of subjects of calibration and testing techniques such as density and measurement uncertainty.

3.2.2. Qualifications to become a Metrology Training Institution

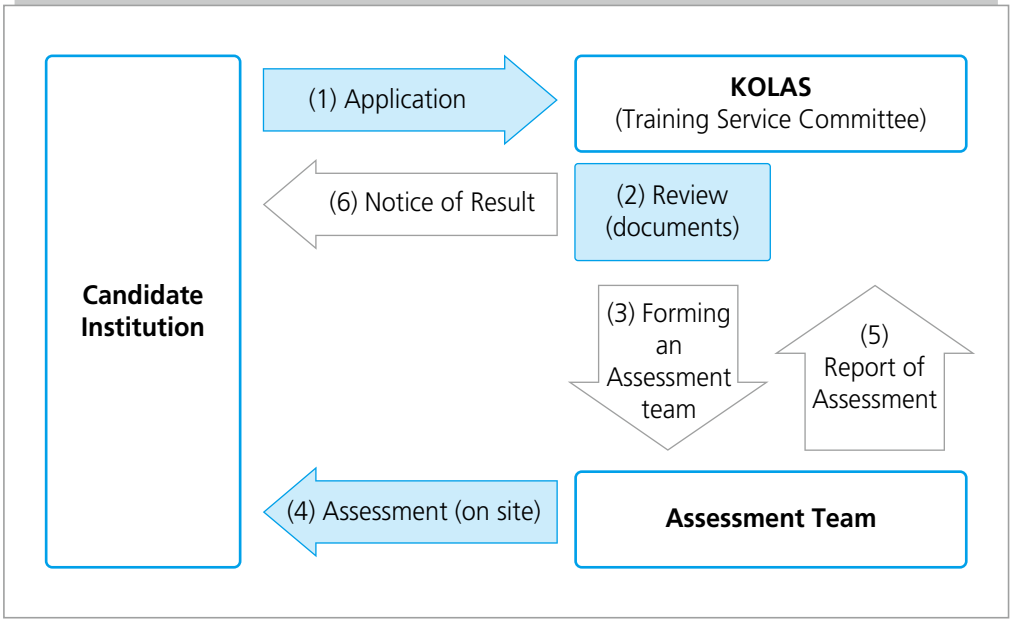
According to the "Operational Regulations on Metrology Training Institutions Designated by KOLAS" (KOLAS-R-007: 2012), it specifies basic requirements to be a training institution. Requirements include training service operating unit, QMS, document management, trainers and staff, etc. As regards the trainers, the applicant should secure at least two trainers for one single subject of a training program who are having educational and professional career with enough experience to organize and offer the subject training.

〈Box 3-1〉 Key Requirements to be a Training Institution Designated by KOLAS

- Training service operating unit
- Trainers (at least two professionals for one single program)
- Training programs
- Coordinating staff
- QMS in operation
- Documentation and management

By the Regulations (KOLAS-R-007: 2012), all of the procedures from application to the final announcement of result shall be made complete within 60 days of initial application. [Figure 3-10] shows the procedures to be a designated metrology training institution in Korea.

[Figure 3-10] Procedures to be a Metrology Training Institution Designated by KOLAS



Source: Own elaboration based on data from KOLAS website.

Once the candidate has successfully gone through all of the procedures, he/she is officially designated to serve as a metrology training institution. Its validity of designation remains effective for four (4) years. Post-review is to be carried out by KOLAS on an annual basis during the initial designation of four years. After successful renewal of designation, the post-review is done every two years.

3.3. Participation of KRISS in the International Metrology Communities

The NMI plays a key role in effectively operating and continually advancing the competence of the NQI. In terms of scientific and technological capability, NMI is on the highest level from all the NQI partners. The primary function common to all NMIs of the world is to maintain and disseminate the national measurement standards of international equivalence. Traceability of measurement could then be made available to all the users and customers throughout the country that the NMI serves.

One of the common indicators employed to evaluate an NMI's metrological competence and global competitiveness is to analyze its engagement in the activities organized by international metrology communities such as the CIPM. Effective collaboration in the communities allows it to help get its competence strong enough to be acceptable in the communities as well as to meet the growing demand of better and new measurement services for its local customers. Over the past four decades of its operation, KRISS has become one of the world-leading NMIs with its strategic engagement and contribution to the activities of the global metrology community. This section presents the excellent achievement of KRISS that it has made, while working with international metrology organizations while strengthening its leadership in those organizations.

3.3.1. Participation in the CIPM MRA Activities (Key comparisons, CMC registration)

The Mutual Recognition Arrangement (MRA) initiated by the CIPM in 1999 provides for the mutual recognition of national measurement standards and of calibration and measurement certificates issued by NMI (BIPM, 2017). Signatories to the CIPM MRA consist of NMIs and international organizations. They are supposed to participate in the key comparisons (KC) for the purpose of securing international equivalence of national measurement standards they keep. In addition, each NMI participating in the CIPM MRA needs to establish and operate quality management systems in compliance with the provisions set forth by the relevant international standards such as ISO 9001, ISO/IEC 17025 and ISO 17034.

Outcome of the CIPM MRA is the statement of CMC of each NMI. Approved by peer reviews, the CMCs of each NMI are put in the KCDB, key comparison database, which has been maintained by the BIPM located at the outskirts of Paris, France. The information about CMCs of each signatory NMI has been publicized on the website of the KCDB, after due procedures of review by the peers and then approval by the regional metrology organization and finally by the Joint Committee of RMOs and BIPM.[13)]

The three tables below <Tables 3-36, 3-37, and 3-38> show the excellent achievement that KRISS has been making with regards to the activities of key comparisons and CMC registration posted in the KCDB. In terms of KC participation and CMC registration as demonstrated in the KCDB, KRISS is placed as one of the top seven NMIs of the world.

13) The essential points of the CIPM MRA.

〈Table 3-36〉 Achievement of KC and CMC by KRISS

(Unit: Numbers)

Field	AUV	EM	L	MRQ	PR	QM	RI	T	TF	Total
KC	20	58	24	74	25	131	63	32	1	428
CMC	56	90	41	59	41	510	214	74	24	1,100

Source: BIPM KCDB.

In a quantitative analysis of KC and CMC achievements, KRISS has already been at par with advanced NMIs such as those of USA, Russia, Germany, China, UK, and Japan. For each KC program, there is one NMI designated to serve as the pilot lab (PL), who is responsible for organizing and operating the KC and for writing drafts and final reports of the KC. The role of PLs could only be taken by the NMIs who are regarded to have leading capability in the subject field of measurement. KRISS has been taking the role of PL for 79 KCs as of December 2017. It has placed KRISS to be one of the leading NMIs in terms of the capability of national measurement standards.

〈Table 3-37〉 Comparative Analysis of Achievement of CMC of Selected NMIs

(Unit: Numbers)

Country	USA	Russia	Germany	China	UK	Japan	Korea
CMC	1,889	1,728	1,556	1,523	1,128	1,126	1,100

Source: BIPM KCDB.

〈Table 3-38〉 Comparative Analysis of Achievement of KC and PL of Selected NMIs

(Unit: Numbers)

Country	Germany	USA	UK	Japan	France	Korea	Russia
KC	720	506	486	496	481	428	422
KC-PL	187	123	108	105	64	79	73

Source: BIPM KCDB.

3.3.2. Leadership of KRISS in Global Metrology Community

A way of evaluating the leadership of an NMI might be found by studying how significantly it serves the regional and global metrology communities. The CIPM is the top decision-making body in metrology created by the Meter Convention. It is made up of 18 individuals who are regarded as the leading metrologists in different

areas. Being a CIPM member implies that he/she has proved excellence in his/her professional career as a metrologist. KRISS people have been elected as a CIPM member from since the mid-1990's to date.

The CIPM operates with assistance of consultative committees (CC). Currently, there are 10 CCs in operation under the CIPM. For each CC's activities, the world's experts in their specific fields of metrology get together to provide advice on scientific and technical matters. The primary task of each CC is placed on the identification, planning and implementation of KCs.[14)]

KRISS has become a full member of all of the 10 CCs. The membership to a CC allows the NMI to participate in the meetings and workshops organized by the CC. Promoting collaborations among the member NMIs and sharing the most up-to-date information about what's going on in the subject measurement field might be the significant benefits that the full membership brings to the participating NMIs. In this sense, being a member of the CCs is one of the most important target goals that emerging NMIs should make their best efforts to reach at.

〈Table 3-39〉 Membership of KRISS to the CIPM and its Consultative Committees

Membership	Years of Service	Qualifications	Remarks
CIPM	Since 1996 - present	One individual of world-leading metrologist	Criteria and procedures for the CIPM members under revision
CCs	Since 1989 - present	Leading scientific and technology capability in each field of metrology	Securing full membership to all of the 10 CCs of the CIPM

Source: BIPM KCDB.

In order to be a full member of the CC, the candidate NMI should have proved its competence based on the achievement of papers published in the journals of global reputation, demonstrated performance by a record of participation in international comparisons, and with the possession of advanced measuring equipment and technical staff in its laboratories.[15)] Each CC operates working groups (WG) for an effective coordination of its activities. While the chair of each CC is taken over by one of the CIPM members, the leadership of WG is open to members of each working group. As of Nov 2017, there are two people of KRISS who are serving as the chairperson for working groups.

14) Written based on "The Role of the Consultative Committees" available at BIPM website.
15) Criteria for membership of a Consultative Committee can be found in BIPM Website.

APMP, Asia-Pacific Metrology Cooperation is the regional metrology organization where the NMIs of the countries and economies in the Asia-Pacific region work together. As of Nov 2017, the NMIs from 24 full members and from seven (7) associate members are joining efforts for the activities of the APMP. Under the chairperson, APMP has an executive committee (EC) as its decision making organ. It has 12 technical committees corresponding to the CIPM CCs. The technical committees of Quality System, of Fluid Flow, and of Materials Metrology are unique to the APMP. It also operates a special committee named DEC, Developing Economies' Committee. DEC is assigned to closely communicate with its members and connect its activities with other technical committees, so that APMP could develop its technical programs to bring benefits to promoting the metrological competence of the DEC member NMIs.

Leading NMIs of the APMP take turns exercising the responsibilities of the Chairperson and TC chairs. KRISS has been sharing efforts for the regional collaborations by taking the responsibilities of chairperson and executive secretary. Selected research scientists of KRISS have been serving as the chair for different technical committees of the APMP, while serving as a member of EC, and the lead TC chair.

While the CIPM is working on global collaborations for securing international equivalence of national measurement standards across the globe, among others, the International Measurement Confederation (IMEKO) is serving as a forum for promoting international exchanges of technical information in measurement and instrumentations. It also pursues to enhance international cooperation among metrologists from research community and industry (IMEKO, 2017).[16] Membership to the IMEKO is open to any research institutions, societies, and associations, and NMIs, who are concerned with the advancement of measurement technology.

As a non-governmental federation, IMEKO has 42 member organizations coming from all over the world. They have 22 Technical Committees whose activities cover wide areas of measurement and related technologies. Under the President, there are three vice-Presidents. Currently, leading research scientists of KRISS share effort for the IMEKO activities for posts as below: Vice President, Vice chairperson of TC 3 (force, mass, torque), Vice chairperson TC 23 (metrology in food and nutrition), and Chairperson of TC 24 (chemical measurement).[17]

Based on its metrological capabilities and outstanding performance, KRISS has been working actively with international metrology communities including the CIPM, APMP, and IMEKO. The INM of Colombia needs to broaden its engagement

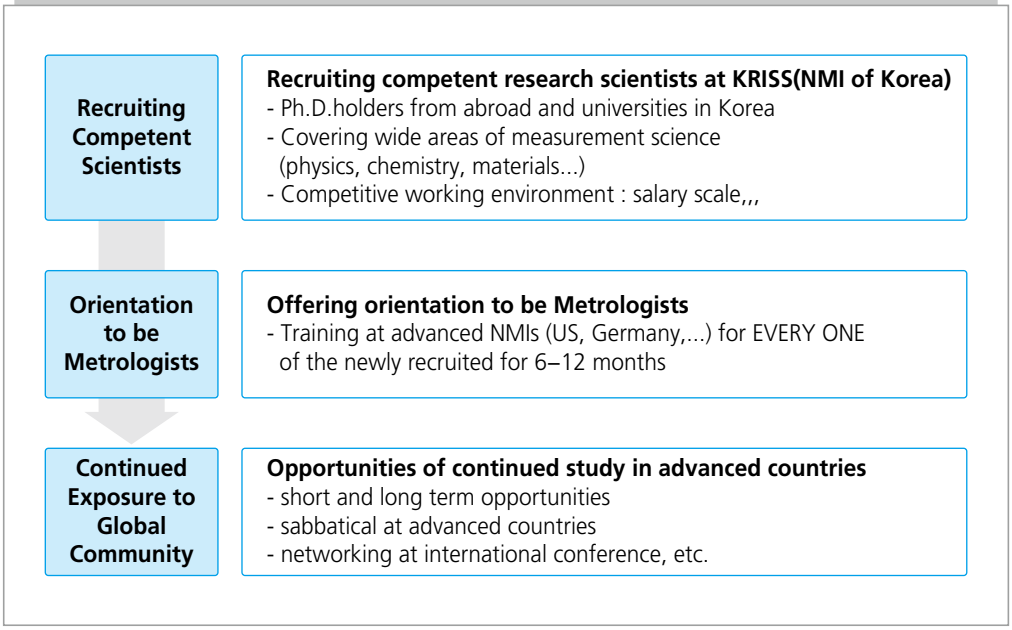
16) IMEKO (2018).
17) IMEKO (2018).

with such global metrology communities by sending its researchers to the technical activities organized by the global communities starting from the SIM (Inter-American Metrology System), the regional metrology organization in America.

3.4. Experience of Promoting its Own Human Resources in Metrology of KRISS

In order to continue to serve as the key provider of national measurement standards, which is necessary for ensuring the sound operation of the NQI, the NMI should maintain and develop its metrological capabilities including its human capital among others. This section will discuss what KRISS has done for developing its own human resources. [Figure 3-11] shows the strategic effort that KRISS has made to secure and maintain the competence of its human resources in metrology.

[Figure 3-11] Strategic Approach to Developing its Own Human Resources of KRISS



Source: KRISS (2018a).

3.4.1. Recruiting Outstanding Scientists with Orientation at Advanced NMIs

As an effort to advance scientific and technological capabilities in Korea, the Korean Government has been establishing research institutes since early the 1960's. The GRIs have been devoted to their missions to be the mainstay of support for scientific and technological advancement of Korea till date. KRISS is one of the

GRI's founded in 1975 with its main functions to develop national measurement capabilities that can be internationally accepted. Competent human resources are the critical factor for the GRIs to effectively carry out their missions.

Like all other GRIs, almost all of the first generation of its research scientists were recruited from abroad, mostly from the USA. Needless to say, they were all promising young scientists. However, in order to train them as a metrologist appropriate to serve for the NMI of Korea, each and every young recruited scientists of KRISS were sent to the NMI of the USA before coming back to Korea. They stayed at the laboratories of the National Bureau of Standards (NBS) for 6 to 12 months. By doing so, they were well ready to serve as metrologists in many different fields of measurement. Although it depended on loans from the USAID (US Agency for International Development), the orientation programs at such an advanced NMI enabled KRISS to get ready to provide measurement services for the Korean industry that were in need of calibration and testing services that can be acceptable in international marketplaces. Using the financial resources acquired by the USAID, more than 60 people of KRISS including those recruited in Korea were given chances to visit different laboratories of NBS for their technical training on measurement and calibration.

It has made great contributions to laying the technical foundation of KRISS that can serve the metrology community and industries of Korea with measurement capabilities as internationally acceptable. It has in turn helped the Korean industry to explore and broaden access to the international trade markets.

3.4.2. Offering Continued Exposure to Advanced Research Environment

For promoting individual competence as a research scientist and a metrologist, KRISS offer its employees as much opportunities as possible such that they could be exposed to advanced research environment. Traveling to international academic conventions, collaborating with advanced NMIs and renowned scientists in foreign universities and research institutions, enjoying sabbatical leaves after every seven years of service at KRISS, and attachment to advanced metrology laboratories are the main portfolios available for the KRISS research scientists.

For one single year of 2017 only, 255 people of KRISS were traveling abroad 437 times for different purposes. Most of them were permanent employees. However, a few of contracted staff members were also given chances to travel abroad mostly for presenting papers in international academic conventions. For a couple years of 2016–2017, more than 30 people of KRISS were supported for their stay abroad for a long-term basis such as six to twelve months. They were staying at the NMIs,

universities, research institutions in advanced countries such as USA, Japan, Germany, France, etc. All of the financial resources are supported by KRISS enough to cover all of the expenses required for their traveling to and from the destinations and accommodations.

Almost all of their collaborations with partners in advanced countries bring valuable achievement in different forms such as papers, joint research projects, new ideas of measurement techniques and instrumentations, etc. The potential value created thereby is unknown and far beyond the investment made in offering opportunities to be exposed to advanced research environment for its employees.

〈Table 3-40〉 Exposure to Advanced Research Environment Offered for KRISS Researchers (2016–2017)

(Unit: Numbers)

Purposes	Number of Beneficiaries	Partner Institutions
Research Collaborations	5	PTB, BIPM, etc.
Attachment	17	PTB, NIST, NPL, NRCC, etc.
Sabbatical Leave	13	PTB, NIST, NMIJ, etc.

Source: KRISS (2018a).

3.4.3. Sharing its Metrological Assets within KRISS

As an effort to meet the requirements of the CIPM MRA, KRISS has until recently been offering in-house programs on quality management system and uncertainty in measurement. For over more than four decades of its operation, the human resources of KRISS has been growing. A lot of senior researchers are retiring while a number of young generations regularly join KRISS laboratories and management every year. KRISS finds it necessary to further improve its in-house metrology training programs so that new young generations could have good understanding and enough knowledge of what KRISS has developed over decades, and is supposed to do as the NMI of Korea.

The Global Metrology Academy (GMA) of KRISS has redesigned the in-house metrology seminar that will allow all of the KRISS people to share the core knowledge of metrology and its relevant information. In close cooperation with the senior members of KRISS, GMA has selected 16 subjects of presentations under four courses, as described in the <Table 3-41>. All but a few speakers for the subjects of the in-house metrology seminar are invited from within the KRISS laboratories and sections in charge. More than 100 people of KRISS enjoyed the seminar in 2017.

〈Table 3-41〉 In-House Metrology Seminar for KRISS People

Courses	Subjects of Presentations
Fundamentals of Metrology	(1) NQI and KRISS
	(2) Standards and Standardization
	(3) Traceability and Uncertainty in Measurement
	(4) Fundamental Constants and Revised SI
	(5) QMS for Why and for What
QMS for KRISS	(6) QMS of KRISS
	(7) ISO 9001: Concept and Applications
	(8) ISO/IEC17025 Technical Requirements
	(9) QMS in Practice at KRISS: from Lab to Services
CRM Services	(10) ISO 17034
	(11) ISO Guide 35
	(12) CRM: Preparation to Certification
CIPM MRA	(13) CMC and KC
	(14) Peer Review
	(15) Internal Audit
Uncertainty in Measurement	Measurement: Traceability and Uncertainty

Source: KRISS (2018a).

It is obvious that the refined in-house metrology seminars enable the KRISS people to more effectively share than before, the key metrological knowledge and experience among all generations of KRISS. It also helps in soft-landing the generation shift in the metrology laboratories of KRISS. Furthermore, it is envisaged that the values of community & culture of KRISS - communications and sharing - could be better formed and widely spread over the campus in the course of frequently getting together face-to-face through the KRISS metrology seminars that are operated several times a year.

3.5. What the Korea Government has done for Promoting HRD in Metrology of KRISS

At the end of the Korean War in 1953, there was nearly nothing left to survive with in Korea. All was destroyed into ashes in the Korean peninsula. Human resource was the only one strong point that Korea, at the time, could make use of for its industrial development and economic growth. With no financial or technical resources available at hand, Korea could not help but depend on loans and technical assistance from abroad.

How to secure and supply technical human resources was one of the critical national agenda for Korea. Its economic performance was at the level of being the second to the lowest one in terms of GDP per capita. While then the Economic Planning Board of the Korean Government was looking for financial resources from abroad, the Ministry of Education was striving to explore ways to foster and supply technically competent human resources. However, only less than 5% of high school graduates in Korea were able to advance to universities. It was at that time that the Korean Government introduced a new approach to fostering technical human resources of young generations. It was to establish "Technical High Schools" in every province and major cities.

In 1960's when the Korean Government tried to shift its industrial frame from agronomy to light industry, the key policy measure taken by the government was to realize the national growth based on export-driven economic development. For this purpose, the Korean government set up a series of five-year economic development plans, for every five years since 1962. Quality of goods is the primary proposition for any economy at any time in order for it to access and stay competitive in the international marketplaces. As discussed in the Chapter 1 of this report, the Korean Government took a strategic policy measure to secure and promote the quality of goods by establishing testing and inspection laboratories. The laboratories served for quality control and quality assurance of exporting products even though there was no good knowledge or practices about NQI in Korea until that time. As the industrial structure of Korea rapidly grew to be sophisticated with time, there emerged a need for better measurement services and proper quality management systems that should be made to come into practice over wide sectors of industry. Under the circumstances and upon the advice of the US government and its NMI, the NMI in Korea was born to be the key provider of measurement services and to underpin the progress of advanced NQI in Korea.

It should be noted that the Korean government worked out a series of science and technology development plans executed in harmony with the economic development plans. As an action program to find solutions of science and technology

development, the Korean government started establishing GRIs, each of which was assigned to carry out research and development while offering services as required by the local customers mainly from the industry. KRISS was created in 1975 at an early stage of the GRI history. It was to help the exporting industry to get access to international markets with quality products and goods. As discussed above, there were nearly no financial resources that are required to turn these development plans into practice. Nevertheless, the Korean government elaborated plans for establishing the NMI in Korea and has been providing continued support so as to promote its competitiveness by means of:

– Providing Financial support by using foreign resources (loan and technical cooperation);

– Laying legal foundation for KRISS to act as the NMI of Korea; and

– Providing a competitive work environment.

3.5.1. Loan and Technical Cooperation Projects in Support of KRISS

For establishing its NMI in Korea, the Korean government should get a loan from the US AID. The loan project includes activities for establishing the laboratories of KRISS, purchasing measuring equipment, and recruiting promising young Korean scientists from abroad. As discussed in the preceding section, every one recruited to KRISS was sent to the NMI of US to train them to be experts, who are appropriate for carrying out missions such as offering measurement services to industries. Korean government continued to seek financial resources that can help KRISS to construct laboratory building at the KRISS campus, to be equipped with advanced measuring facilities, and to provide technical training for its research scientists at advanced NMIs. The loan projects for KRISS were initiated by the Korean Government, and continued for almost 20 years until the mid-1990's, making use of resources from Asian Development Bank (ADB), Overseas Economic Cooperation Fund (OECF), and International Bank of Reconstruction and Development (IBRD).

In addition to the loan projects, the Korean government was seeking more resources in the form of technical cooperation from advanced countries such as Germany and Japan. The technical cooperation projects between the governments allowed KRISS to obtain more resources to secure more advanced measuring equipment, to get technical advice from foreign experts, and to have opportunities of learning at advanced institutions for its research scientists and engineers. Below <Table 3-42> presents the selected loan and technical cooperation projects initiated by the Korean government which were invested in promoting human capital for KRISS, the NMI of Korea.

It should be noted that the training programs under the loan and technical cooperation were offered on a long-term basis: for longer than three months to one year. It is certain that such long-term training programs had brought substantial effect on strengthening the capabilities of the metrology laboratories of KRISS.

〈Table 3-42〉 Loan and Technical Cooperation Invested in HRD in Metrology for KRISS[18]

(Unit: Numbers)

Resources (period of project)	Number of KRISS Staff Trained	Remarks
USAID (1975–1980)	72	Long-term training at advanced countries
PTB (1979–1996)	48	
JICA (1991–1996)	21	

Source: Own elaboration, based on data from KRISS website.

Investment in metrology - investment in KRISS, which was making use of the Government's loan projects coupled with technical cooperation projects, was regarded as an excellent strategic approach taken by the Korean government. It enabled KRISS to quickly grow up to be one of leading NMIs in such a short period of operation compared with the NMIs of advanced countries. Almost all of them have more than one hundred years of history. Ultimately, it has led to invaluable contributions to such an unprecedented rapid economic growth of Korea. The competitiveness of products in the global marketplace is basically dependent on the quality of products, which can be assured with international equivalence of measurement. Competent human resources of NMI act as the key to making it all possible.

3.5.2. Laying Legal Foundation for KRISS and NQI of Korea

The Korean Constitution states that "The State Shall Establish a System of National Standards."[19] The paragraph was first adopted in the amendment made in 1980 and still remains as it is. The statement clarifies that the government is responsible for establishing and developing the national standards system and the NQI in Korea. Later in 1999, the Korean government adopted a new legal foundation named "The Framework Act on National Standards," by which KRISS was officially entitled to act as the NMI of Korea. Much earlier than the two legal foundations, there was an act in 1973 – Specific Research Institutes Support Act. The Act has since continued to be developed over the past decades and is still in effect being the legal basis to fund the R&D activities of KRISS towards scientific and industrial metrology.

18) Technical cooperation projects were official development assistance offered free by the two governments of Germany and Japan.

19) The Constitution of the Republic of Korea (as of 2017): paragraph 2 of article 127.

The legislative arrangements led by the Korean government served a great deal for advancing the competence of KRISS to the level that it has today. The Korean government was able to secure and provide financial resources required for KRISS to carry out its diverse activities of R&D and services for the metrology community and wide industrial sectors in Korea.

〈Table 3-43〉 Legal Foundations the Korean Government Laid for the NMI of Korea

Name of Legislation	Year Enacted	Remarks
The Constitution	1980	Declaring the government's responsibility for NQI
Framework Act on National Standards	1999	KRISS being entitled to officially act as the NMI of Korea
Specific Research Institutes Support Act	1973	Providing financial support for R&D activities of KRISS

Source: Own elaboration, based on data from KLRI website.

3.5.3. Providing Competitive Work Environment for KRISS

The economic performance of Korea in 1970's until the early 1980's was on the rise in spite of the global economic crisis that took place due to oil prices in the middle of 1970's. However, it was still far behind that of advanced economies. Many young Korean scientists who studied abroad with advanced academic degrees could not find justifications that they should come back home to Korea. There were no jobs available with good salary in Korea at that time. In addition, they preferred to work in universities because of the reputation and high salary they can enjoy as a university professor.

In order to call them back to Korea, the Korean government needed strategies to attract young Korean scientists to the GRIs, including KRISS. They received financial inducement from the government, which was three times higher than that of university professor at that time. Besides, newly built apartment complexes near the institutes were provided. They were allowed to live there without paying rental fee for as long as they wanted to stay there. Monthly salary paid to the ordinary staff working for KRISS was also significantly higher than that of the private industries in Korea.

〈Table 3-44〉 Competitive Work Environment of KRISS

Considerations	Contents	Remarks
Salary Scale	Three times higher than University Professors	For recruiting qualified competent research scientists in early stage (*now on a similar scale)
Residence	Resident apartment free to stay	Without rental fee
Autonomy in operation	Non-profit organization	Avoiding bureaucracy Seeking effectiveness Encouraging creativity
Funding for Budget	More than 80 % by government resources	For operations, R&D, services

Note: The considerations were common to all GRIs while the funding by government a bit varied.
Source: Own elaboration.

In spite of low economic performance in the 1970's until 1980's, the Korea government did take aggressive inducement approach for supporting GRIs, and it cultivated favorable work environment such that KRISS could become Korea's mainstay of research, development, and innovation by attracting competent human resources.

4. Practices of HRD in Metrology in Advanced Countries

4.1. Metrology HRD Services Available in Selected Advanced Countries

Almost every country operates one or more organizations with responsibilities in providing scientific, industrial and legal metrology services. One of their fundamental functions is to disseminate national measurement standards in different tools of services, one of which is HRD in metrology service. <Table 3-45> presents the scope of metrology training and education services offered by the selected advanced countries.

〈Table 3-45〉 Scope of Metrology HRD Service in Selected Advanced Countries

Country	Service Providers	Legal Status	Scope of Training/Education
France	LNE	NMI	- Scientific Metrology: 6 fields (58 courses) - Legal Metrology
France	ESM	Metrology Education Institution	- Metrology in general, QMS - Instrumentation - Measurement Science (elective) - Legal Metrology (elective)
Germany	B-IGSM	NMI & University	- Graduate School of Measurement Sciences (doctoral courses only)
Germany	DAM	Training Institution	- Legal Metrology (governmental officers, approved test centers)
Japan	NMIJ	NMI	- Legal Metrology (for governmental officers)
Australia	NMIA	NMI	- Physical Measurement (10 courses) - Metrology in Chemistry (2 courses) - Legal Metrology (9 courses)
USA	NIST	NMI	- Legal Metrology for State Officers - Fundamental Metrology
UK	NPL	NMI	- Physical Measurement (12 courses)
	LGC	NMI (DI)	- Metrology in Chemistry and Biology (6 courses)

Note: LGC is acting as a designated institute to be responsible for metrology in chemistry in the UK, while NPL for physical metrology.
Source: Own elaboration, based on data available at websites of the above institutes.

The NMIs of Japan and the USA operate training programs with emphasis on the subjects of legal metrology rather than scientific metrology. In Germany, there is an independent educational institution, Deutsche Akademie für Metrologie (DAM), which is responsible for training in legal metrology in cooperation with the verification offices located in different regions. DAM offers lectures on theoretical aspects of legal metrology, while the verification offices accept the trainees for practice on site. The National Physical Laboratory (NPL) of UK has been working closely with universities and private companies for expanding its metrology training services.

Out of the above service providers of HRD in metrology, it seems that the Laboratoire National de Métrologie et d'Eessais (LNE) of France has been operating a most comprehensive scope of metrology HRD service. Its service covers five sectors such as metrology, quality management system, building and construction materials,

packaging and food industry, and medical devices. Under the coverage of scientific metrology, there are five (5) categories of chemical and biological metrology, mechanical metrology, thermal metrology, optical metrology, and electrical metrology. They operate programs for legal metrology with five modules such as fundamentals of legal metrology, metrological control of prepackages, and quality management system in legal metrology.

Under the five categories of scientific metrology, LNE operates more than 30 modules of technical training courses. Systematically multi-linked combination among the related modules allows each trainee to learn where to begin and what and how many modules to study in order to become a qualified technical expert in the field he/she might choose to work. In addition to the technical courses, LNE offers programs addressing policy and management issues of metrology as well, that provide basic knowledge and information for those who are engaged in laboratory services or management.

〈Table 3-46〉 Scope of Metrology Training Programs of LNE[20]

Category of Service	Modules of Training	Remarks
Fundamentals of Metrology	26 modules, including Organization of metrology; calibration interval, Essentials of metrology (concepts-missions-organization), Function of future manager, Quality in testing/calibration laboratories (ISO/IEC17025), Evaluation of uncertainty in measurement, statistics, Inter-laboratory comparisons, method validation	Policy and management issues, Running for 1–10 days
Metrology in Chemistry and Biology	4 modules, including Reliability of chemical measurements at laboratory, Molecular biology (practical metrology for controlling thermal cyclers)	Technical subjects of scientific metrology, Running for 1–4 days
Mechanical Metrology	9 modules, including Calibration in dimensional metrology, Metrology of pressure applied to industrial needs (A, B), Force calibration and uncertainty evaluation, Metrology for volume	
Thermal Metrology	8 modules, including Basic module of practical metrology of temperatures, Characterization of climatic chambers & drying chambers, Calibration at fixed-points of the ITS-90; Anemometry	
Optical Metrology	1 module: Spectroradiometry/Photometry: measurement techniques	

20) LNE (2018).

〈Table 3-46〉 Continued

Category of Service	Modules of Training	Remarks
Electrical Metrology	9 modules, including: DC and AC low frequency, Resistance and impedance, Characterization of multimeter or calibration	
Legal Metrology	5 modules, including, Fundamentals of legal metrology, QMS in legal metrology to ISO 9001, Metrological control of pre-packages	1–2 days

Source: Own elaboration, based on data from the website of LNE.

4.2. Graduate Course of Metrology Available in Selected Advanced Countries

There are two countries operating unique advanced education programs in scientific metrology. The NMIs of Korea and Germany have been working closely with its respective partner universities offering masters and doctoral courses in metrology. They serve for cultivating professional human resources for advancing the fields of measurement science and technology. They are KRISS-UST Joint Graduate School of Metrology in Korea and the International Graduate School of Metrology in Germany.

4.2.1. KRISS-UST Joint Graduate School of Metrology (Korea)

KRISS, the NMI of Korea, operates a graduate school of metrology program in cooperation with UST, the University of Science and Technology in Korea. Founded in 2002, the UST has been offering its education programs for graduate studies. Its faculty members are invited from the government-funded research institutes and national institutes of Korea. As of Dec 2017, there are 32 institutes who are providing faculty members for the UST. The education program of UST features its on-site learning system that allows students to take courses through participating in national research projects carried out in the research laboratories where they are staying.

Students of the graduate school take classes at the laboratories of KRISS. All of the professors are metrologists from KRISS having a professional career in the different fields of measurement science and technology. Financial support for the students includes tuition fees and stipend, which are provided until students complete their studies. The financial support comes from the resources of the KRISS and the laboratories accepting the students.

The graduate school offers integrative courses where the students can choose to continually study their master's and doctoral courses without dividing the two stages. Another type of course offered by the UST is the industry contract course. Some Korean industries support a certain number of students of the UST under the contract that students could be employed once they successfully complete their studies at the UST. The supporting industry provides financial support for the students. The UST graduate school is open to any nationals of the world. As of 2017, there are around 80 students in progress of their studies for their master's and doctoral degrees at KRISS, including around 20 students coming from abroad.

〈Table 3-47〉 Students of KRISS-UST Graduate School of Metrology Enrolled (2017)

Courses	Number of Students Enrolled (as of Dec 2017)	Years of Study for Completion
Master's	36	Normally two years
Doctoral	26	Around 4 years
Integrative (master + doctoral)	14	Around 5 years

Source: Own elaboration, based on data from KRISS and UST websites.

4.2.2. Braunschweig International Graduate School of Metrology (Germany)

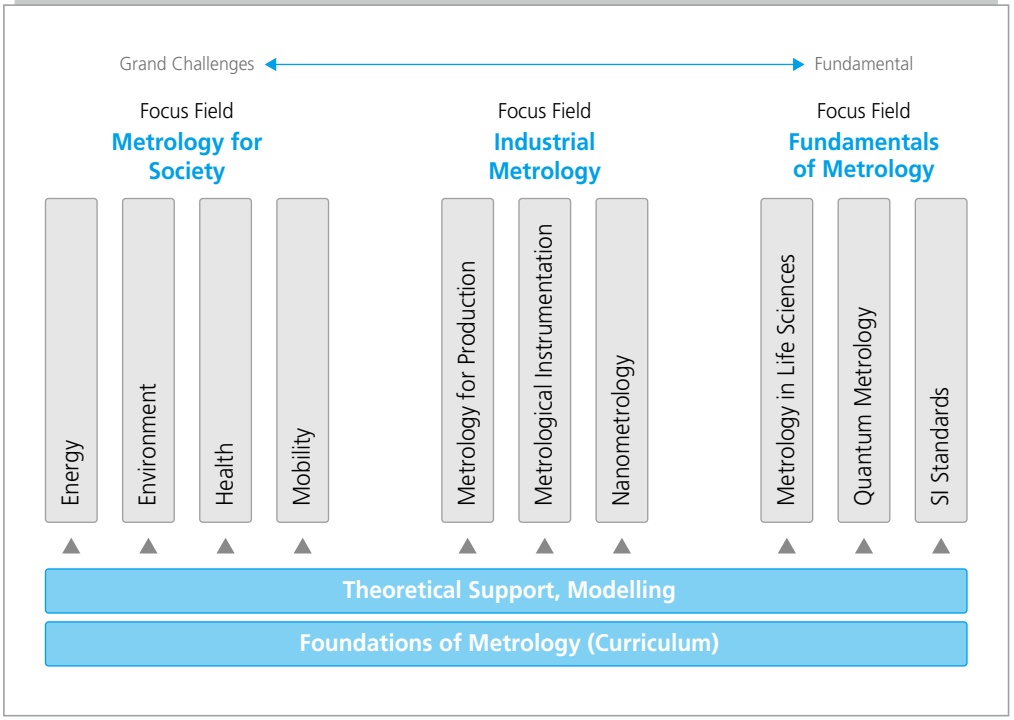
The PTB, the NMI of Germany, and the Technical University (TU) Braunschweig are working together in fostering doctorates in metrology. Located in Braunschweig, the two partners have founded a joint graduate school under the name of "Braunschweig International Graduate School of Metrology" (B-IGSM).

Within the scope of a structured doctoral program, the B-IGSM accepts doctoral students who are supposed to study advanced measurement science and technology such as electrical engineering and information technology, physics, mechanical engineering and life sciences. The education programs of the B-IGSM comprises of lectures, seminars, topical workshops and international summer schools. The B-IGSM operates with the financial support of the State of Niedersachsen (Lower Saxony).

Since its foundation in 2007, around 50 doctoral candidates from 20 countries have passed through the graduate school with their doctoral degrees and the B-IGSM metrology certificates. Doctoral candidates are provided with assistance from the B-IGSM while writing their theses. Scientists from PTB and TU Braunschweig jointly supervise the doctoral program and impart the knowledge of metrological concepts and principles.

High level research opportunities in various fields are provided for B-IGSM's students, who in addition profit from the unique infrastructure and facilities. Research topics for PhD works are organized in the three focus fields - metrology for society, industrial metrology and fundamentals of metrology. The topics range from cutting-edge development in quantum standards to calibration methods for industrial applications.[21)]

[Figure 3-12] Focus Fields of Graduate Studies Offered by the B-IGSM of Germany



Source: BIPM IGSM website.

4.3. Metrology HRD Programs Available for the Developing World

The NMIs of selected advanced countries operate HRD in metrology programs which are designed mainly to help enhance the metrological capabilities of the NMIs in the developing world. KRISS, in the early stage of its operation, used to be a beneficiary of the HRD in metrology programs offered by the NMIs of advanced countries such as the USA, Germany, and Japan. The success story of KRISS has proved that opportunities at advanced research environment enable the trainees to get

21) IGSM.

better performance in learning the knowledge and skills that are required for them to be professional metrologists.

Developing countries are heavily dependent on financial and technical support from advanced countries and international organizations for developing the competence of their NQI. In the field of scientific and industrial metrology, support from advanced countries has been offered in different forms; donating measurement facilities, providing technical training and expert advice, and building laboratories. Germany and Japan take the leading role in offering the official development assistance (ODA) in the field of NQI including metrology. Korea also joins effort for sharing support for ODA in metrology for the developing world. Korea is unique in the fact that it has been the only one country in the world who has become a donor out of numerous recipient countries of ODA.

ODA opportunities are made available in two categories of financial resources; loan or grant(technical cooperation). In order to explore ODA projects of NQI with advanced countries, it is prerequisite that the applicant government should be ready with its national development plan in which the NQI or metrology is specified as one of the target development goals of the nation. The partners of the ODA project of NQI or metrology are usually the NMIs of the donor countries, such as the KRISS of Korea, the PTB of Germany, the NMIJ of Japan, for example. In order to secure ODA projects of NQI, therefore, it is critical that the NMIs of the applicant countries should keep in close touch with the NMIs and the ODA organizations in the donor countries. <Table 3-48> shows the list and contact address of the NMIs and the ODA organizations in selected advanced countries.

〈Table 3-48〉 NMIs and the ODA Organizations in Selected Advanced Countries

Countries	Organizations	Contact Address for ODA Project	Remarks
Germany	PTB	https://www.ptb.de/cms/en/ptb/fachabteilungen/abt9/fb-93.html	Technical cooperation
Japan	NMIJ	https://www.nmij.jp/~imco/en/	International cooperation
	JICA	https://www.jica.go.jp/english/about/oda/index.html	ODA of Japan
USA	NIST	https://www.nist.gov/pml/weights-and-measures	Training on metrology
		https://www.nist.gov/iaao	International and academic affairs

〈Table 3-48〉 Continued

Countries	Organizations	Contact Address for ODA Project	Remarks
China	NIM	ws@nim.ac.cn	Foreign affairs
Korea	KRISS	http://www.kriss.re.kr/eng/global/global01.html	International cooperation
		http://www.kriss.re.kr/eng/global/global02.html	Metrology training
	KOICA	http://www.koica.go.kr/	ODA of Korea

Source: Own elaboration, based on the data from the websites of listed organizations.

5. Conclusions: Lessons Learned and Recommendations

5.1. Analysis and Lessons Learned

In the preceding sections, we looked into the performance of metrology HRD services in Colombia, focusing on service providers, trainer, and programs. We also discussed the competitiveness of the INM, the key player of NQI in Colombia, in the international metrology arena. As a comparative study to come up with ideas that might be of reference for Colombia to step into better practices in metrology HRD, we investigated practices and the experience of Korea and selected countries. The problems and impact to be solved in the practices of metrology HRD service of Colombia are summarized in the <Table 3-49>.

〈Table 3-49〉 Problems and Impact of HRD in Metrology Practice in Colombia

Factors of Analysis	Problems	Impact
STE Education System	Schools are concentrated in a few cities and provinces. Students in the fields of STEM are staying around 10 % out of the total number of graduates. → Structural weakness of official education in fostering young generations of science & technology	Causing low competitiveness in sustainable development through innovation
Human Resources Available in Metrology	No graduate course of metrology available Small number of technical staff at NQI with advanced academic degrees (no doctorate at INM)	Weakening competence of NQI sector of Colombia as a whole

〈Table 3-49〉 Continued

Factors of Analysis	Problems	Impact
Metrology HRD Services	Insufficient service providers (INM, SENA, Univ. of Cartagena) Lack of qualified trainers in scientific metrology Programs limited to covering basic subjects only → Not ready to meet the evolving needs of new and better measurement services for emerging sectors	Remaining low quality of measurement services for local customers
Competence of the NMI	Low level of engagement and leadership in the CIPM MRA activities (KC and CMC); Lack of competent metrological experts and equipment → Unable to provide measurement services of international acceptance	Causing dependence on services by foreign countries and international organizations
Financial Investment by Government	Limited investment in NQI with two organizations funded by government: INM, SIC No explicit expenditure for HRD in metrology; Rare opportunities for stakeholders to be exposed to advanced R&D environments; Questions to be competitive workplaces for young generations → High turnover rate in NQI sector including INM, stagnant in strengthening potential of the NQI	Causing technical and metrological weakness of test and calibration laboratories in Colombia

Source: Authors.

5.2. Recommendations

Reviews and analysis of the practices of Colombia in metrology HRD, with reference to the experience and good practices in Korea and selected advanced countries, have led to the understanding of the potential for competitiveness of metrology HRD in Colombia. At the same time, significant obstacles and future tasks have been identified, along with lessons that may help overcome those obstacles so as to reinforce the HRD in metrology services in Colombia. It has come up with policy recommendations as listed out in the <Table 3-50>.

The recommendations are supposed to be transformed into substantial action programs coupled with effective funding strategies in ways that can bring the competitiveness of the human resources in metrology of Colombia up to an advanced level as a whole. It will ultimately serve for enabling sustainable growth of Colombia on the sound and robust foundation of its NQI.

〈Table 3-50〉 Policy Recommendations for Promoting HRD in Metrology of Colombia

Categories	Recommendations	Remarks
Service Provider	Increasing Training Providers (institutions) Creating Graduate School of Metrology Improving Contents of Training Programs Securing Competent Trainers	Priority of strategic support and investment should be placed on promoting capability of INM in terms of human resources and measuring equipment
Customer & Regulation	Expanding Potential Customers of Training Services (trainees) Effective Use of Training Certificates for Accreditation Expanding Proficiency Testing and Setting Mandatory Calibration Intervals	
Strategic Support by Government	Sophisticating Functions of INM, the NMI of Colombia Cultivating Good Work Place across the Metrology Community in Colombia Raising Investment in NQI by Government	

Source: Authors.

5.2.1. Increasing Training Providers (Institutions)

At the present time, the INM is the single metrology training provider in Colombia. It is far behind enough as it is to meet the needs of fostering professional technical staff in metrology. Therefore, it is necessary that the INM and ONAC to be working together to designate additional training providers out of competent accredited calibration and testing laboratories. The programs of SENA and of the University of Cartagena should also be further expanded in close partnership with the INM. The "Metrology Diploma" program should also be operated as a regular program in cooperation between the INM and National University of Colombia. For HRD in metrology services for emerging areas other than traditional physical metrology and metrology in chemistry, other competent institutions could be designated to serve as metrology training providers in the specific subjects of measurement services.

Harmonized division of tasks among the training providers might be suggested as follows:

– Short-term training of metrology
  → to be offered by designated metrology training institutions & the INM

– Long-term training/education of metrology
  → to be offered by universities, joint graduate school of metrology & the INM

In the areas of legal metrology, it is recommended that SIC could continue its training services, covering the legal measuring instruments as specified by the OIML. Not only that, training and other types of relevant services should also be expanded over to the newly defined legal metrology areas subject to enforcement. It is recommended that SIC and INM should be working more closely with each other so as to play a leading role on the training and measurement services on those areas as well.

5.2.2. Creating Graduate School of Metrology

It is one of the priority actions that the government of Colombia should take in order to lay advanced educational foundation to cultivate future leaders of measurement science and technology. The first step might be taken in the form of joint graduate schools of metrology, to be operated in cooperation between the INM and renowned national universities in Colombia, to begin with the ITM, which was already approved in 2017 to start a master's course in metrology. Programs and curricula of the graduate schools should be developed in close cooperation between the INM and the partner universities. It should include both the fundamentals of metrology and advanced scientific metrology. Selected researchers of the INM should also be given opportunities to study with the graduate school of metrology.

By the time there are a number of national and public research institutions who are carrying out leading-edge R&D in wide areas of science and technology, it is recommended that the Colombian government set up one special graduate school of science and technology, such as the UST in Korea. A joint graduate school of metrology would then be one of the programs within the graduate school.

5.2.3. Improving Contents of Training Programs

The INM runs training programs in metrology with emphasis on basic measurement techniques. As the industry advances, better and newer measurement capabilities are required. The INM needs to make an effort to widen the scope of its metrology training services, enough to accommodate the evolving needs for HRD in metrology. Energy, climate change, health, food, safety, materials, nano-bioanalysis might be among the potential areas that the NMI should have capacity to offer metrology training services relevant to such emerging areas. Such advanced programs could also be offered by the joint effort of the INM and selected universities who are forerunners in those areas. International organizations who are in charge of the specific tasks could be partners in developing training programs as required.

5.2.4. Securing Competent Trainers

The INM of Colombia needs to secure more number of professional research scientists who can serve as trainers as well as researchers in the field of metrology. Currently, there are no staff members of INMI who have their doctoral degrees. Only a few have their master's degrees. In addition, the INM should take over functions such as training the trainers of metrology for the metrology community of Colombia, in order to foster potential metrology training providers in Colombia other than the INM. As the INM is at the top of the metrological traceability and measurement capability in Colombia, it should be ready to serve as the mainstay that supplies knowledge and skills in metrology across the metrology community and industry of Colombia. It is strongly recommended that the technical staff at the INM laboratories are given priority to study advanced degree courses in metrology when the programs are ready to open in Colombia.

As regards the trainers for the graduate school of metrology, it is recommended that competent metrologists of INM, Colombia and senior metrologists, including retirees, from advanced NMIs and regional/international organizations be invited as professors at its early stage of operation. It will enable the graduate school to secure competent faculty members in a short period of time, to raise awareness of its service not only in the country but across the region, and to facilitate the competitiveness of the metrology HRD service of Colombia. A couple of ways this could be sought is by collaborations with the SIM and BIPM, and bilateral relations with partner NMIs abroad, including KRISS, Korea.

Trainers might be qualified and/or recognized by the INM, all of whom are listed into the national registry of metrology trainers. Competent trainers as registered might be eligible for serving as trainers for metrology HRD programs in the relevant subjects of their expertise.

5.2.5. Expanding Potential Customers of Training Services (Trainees)

According to the statistics made in the previous section 2, there are thousands of potential trainees who are working for the accredited calibration and testing laboratories in Colombia. The scope of target audience of the metrology training services might be further expanded to cover those from the emerging industry sectors comprising of fields like energy, climate change, health, food, safety, materials, nano-bioanalysis, etc. It depends on how well the INM and other potential metrology training providers might secure and expand their capacity in fundamental and advanced measurement technology. Securing new customers is a pre-requisite for enabling the sustainable growth of the metrology HRD service itself.

5.2.6. Effective Use of Training Certificates for Accreditation

For the purpose of promoting the technical competence of calibration and testing laboratories in Colombia, it might be considered that training certificates on the subject measurement fields should be one of the requirements in the process of accreditation for every candidate laboratory. The metrology training certificates could be those issued by the INM and other officially designated training providers.

This is legally enforced for a certain period of time until good practices are fully established and settled down across the metrology community of Colombia in terms of securing competent technical staff required for their calibration and testing services.

5.2.7. Expanding Proficiency Testing and Mandatory Calibration Intervals

A couple of recommendations are added in terms of calibration interval and proficiency testing activities. There are calibration intervals set for measuring equipment and devices. Practically, the calibration intervals are kept on a voluntary basis. In order to raise the awareness of the significance of calibration services, however, it might be recommended that the calibration intervals should be made mandatory for a certain period time until good practices firmly settle down over the metrology community and industry sectors of Colombia. In addition, it is recommended that failure and success stories led by calibration could be collected and used for raising awareness of the significance of calibration service widely across the general public. It will help improve the financial sustainability of the accredited laboratories for the time being.

In view of the fact that proficiency testing programs contribute to promoting measurement capabilities of the participating laboratories, it is recommended that the INM and ONAC closely collaborate to explore more opportunities of proficiency testing so that more candidate laboratories could participate in the PT programs.

5.2.8. Sophisticating the Functions of INM, the NMI of Colombia

The INM of Colombia is assigned to serve as the NMI of Colombia. It is primarily supposed to develop, maintain, improve and disseminate the national measurement standards that are traceable to the international system of units and equivalent to those of other NMIs. In order to effectively carry out such functions, they need to secure research capacity enough to not only meet the current needs of the customers but also to get ready to respond to future needs of better and new measurement services. However, the INM's function of today mostly remains to

provide calibration. In this sense, the INM needs to work out its mid- and long-term development plans to expand its function with more emphasis on research and development in wide areas of measurement science and technology. Competence of R&D in advanced measurement science and technology can make a difference in the INM's competitiveness, which in turn will enhance the capability of the metrology community of Colombia. For this, strategic funding support is required so that INM could secure sufficient resources of people, equipment, and budget.

It should be noted that only with the effective achievement of strong engagement in R&D activities covering wide ranges of measurement science and technology, INM could be stepping forward beyond the level of the calibration service providers in Colombia.

5.2.9. Cultivating Good Work Places across Metrology Community

As diagnosed by the draft CONPES report of DNP, the high turnover rate is prevalent over the whole of the metrology community of Colombia. The INM is no exception. For promoting competitiveness of the human resources in metrology, there should be quite a few new measures that can attract a good number of young promising professionals into the metrology community. High salary scale should be applied to the INM first of all. Advanced measuring equipment should be supplied to the INM and to other potential metrology training providers. Research scientists should be given opportunities to be exposed to advanced research environment and international community of metrology. It includes scientific exchanges and research cooperation with advanced NMIs, renowned research institutes and universities, and training and education in advanced countries.

For encouraging the engagement in metrology training service activities, there should be a method of compensation for the trainers. The revenue from tuition fee should be reinvested in compensation given to the trainers and for developing lecture and practice materials. Lecture materials should also be refined enough to provide substantial solutions to the measurement problems faced by the customers on site. It will lead to better quality of training services and to better performance in learning by the customers. In the same context, revenue from calibration service could also be reinvested both in compensation for the calibration service staff and in renovating the laboratory environment and strengthening the measuring equipment.

In order to turn all the above into reality, autonomy in management of INM should first be established, so that they can make decisions by their own for dealing with the matters of personnel affairs, organizational structure, management planning, financial arrangements, and administrative practices.

5.2.10. Raising Investment in Metrology by Government

Traditionally metrological service has been assigned as one of the primary missions that the government should be responsible for, expressly for the purpose of securing trust and reliability for the economic activities and consumer safety in daily lives of the people. Almost all of the NMIs are given its status either because of being national or public laboratories. Financial resources required for operating the NMIs and for the NQI come from the government.

In order to take "substantial" action programs based on the policy recommendations provided in this report, the government of Colombia needs to drastically increase its financial investment in metrology for promoting the metrological capability of its NMI, among others, and for enhancing the competitiveness of the NQI as a whole. Creating a new legal basis could be considered so that the government's investment in metrology should be sustained for a certain period of time until the competitiveness of the NQI of Colombia is regarded to have reached to an international level. According to a policy brief published by the World Bank in 2013 (Christina Tippmann, 2013), it takes a significant amount of time and financial investment until the NQI can be upgraded to a harmonized level.[22] As for the NMI in developing countries, the report estimated that it takes US$2,000,000 of investment to be endured for 15 years (see Table 3-51) at the very least.

NMI needs human resources with advanced educational background coupled with professional experience, who are able to make the very best use of advanced measuring equipment and facilities. Therefore, it takes a much longer period of time and much higher level of investment for an NMI, than in any other component of the NQI, to get ready to properly operate.

〈Table 3-51〉 Estimated Costs and Time Involved in Developing an NQI

Components	Investment Cost (Million USD)	Development Time for Harmonization (Years)
National Metrology Institute	5–200	15
Legal Metrology	0.5–5	5
National Standards Body	0.5–2	5
National Accreditation Body	0.5–2	5

Source: World Bank (2013).

22) World Bank (2013).

The two recommendations made to the calibration interval and proficiency testing activities, they might seem to be out of the scope for the subject of HRD in metrology. In order to raise better awareness of the significance of calibration services and to get it into practice, however, the calibration intervals should be made mandatory until it is in practice across the metrology community and the relevant industry sectors of Colombia. It will enhance the competence and quality of measurement services to be conducted by the metrology laboratories in Colombia. It is certain that proficiency testing activities help promote the technical capability of the staff in the laboratories as well. For this, it is recommended that INM and ONAC work together and develop more opportunities of proficiency testing for the metrology laboratories in Colombia.

Last but not least, it is the priority of action programs and investment that should be considered by the policy makers in the government of Colombia. It is recommended that the priority be on promoting the metrological capability of INM, as the competitiveness of the NQI definitely depends on the capability of the NMI among others. It might take time, but rather it will allow saving resources through a systematic approach, step by step, to taking each action program into substantial practice.

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9 791159 323188 94320
ISBN 979-11-5932-318-8
ISBN 979-11-5932-302-7(set)

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