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EVOLUTIONARY MECHANISMS FOR STRUCTURED GROWTH OF METROLOGICAL SYSTEMS IN DEVELOPING ECONOMIES

Salvador Echeverría-Villagómez

Centro Nacional de Metrología - MESURA® Interinstitucional Network
CENAM, Querétaro, México

Abstract – The paper presents a robust methodology and an integral strategy to develop optimal metrological infrastructures in unstable economic environments and imperfect markets, as those presented in developing economies. This methodology can be applied at two levels: I.- Within an organization, *e.g.* an industry or company, and II.- Within an economy, *e.g.* an economy, country or region.

The methodology is the MESURA® Program [7,8] which is applied by metrology consultants to particular organizations and the corresponding strategy is the creation of a laboratory network based on a franchise scheme, the MESURA® Network [9,10,11].

The paper presents the objectives, principles and mechanisms of operation of MESURA®. Emphasis is given to the evolutionary principles of the strategy, which allow the implementation of metrological systems and infrastructures with the following characteristics:

- Adapted to their environment
- Viable in technical aspects
- Viable in economical aspects
- Fit for structured growth
- Fit for reproduction

The MESURA® Program and the Network have been developed, implemented and proved in Mexico and have found conceptual acceptance and application also in other countries. The final section includes an evaluation of its development and recommendations for its potential application in other developing economies.

Keywords: strategy, methodology, infrastructure, systems.

1. INTRODUCTION

1.1 Origin of the analogy

Measurement systems and infrastructures can be considered, in a metaphorical way, as living entities that have an active function to perform, have to be fit for their environment and have challenges to face, if they are to survive and be effective in the fulfilment of their aim.

The existence and effectiveness of measurement systems and infrastructures are very often threatened by unstable conditions in some environments. At the micro-level this may happen in companies with strong technological dependence, with little metrological culture or with lack of resources to implement solutions. At the macro-level this may happen in countries or regions with imperfect markets, with not mature industrial chains or with poor metrological infrastructures, as those of most developing economies or regions.

1.2 The viable system model

For the very existence and effectiveness of those metrological systems and infrastructures, some management cibernetics principles can be applied [1]:

Viable systems are those which are able to maintain a separate existence. Such systems have their own problem solving capacity.

If they are to survive, they need not only the capacity to respond to familiar events such as customer needs, but the potential to respond to unexpected, previously unknown events such as the advent of new technologies, or changes in some of their own components.

The latter capacity is the hallmark of viable systems; it gives them the capacity to adapt to changing environments. While a catastrophic event may at a particular instant throw the viable system off balance, the fundamental characteristic of viability lessens its vulnerability to the unexpected, making it more adaptive to change.

1.3 Evolutionary principles

The conditions for existence and evolution of living entities have to do mainly with the living principles of :

i. Self-structured organization of their own components, with drive for purpose, unity and economy of means
ii. Ability to transform elements of the environment into a balance of self nutrition (growth) and action (performance) towards their aim
iii. Ability to reproduce themselves with self-similarity or affinity, but with small controlled changes to allow for better adaptation to the changing environment.

Section 3 describes these general principles in their specific application to measurement systems and infrastructures.

2. MICRO AND MACRO ENVIRONMENTS - CHALLENGES FOR METROLOGY

This section describes some of the problems faced to implement effective and efficient measurement systems (micro level) and metrological infrastructures (macro level).

2.1 Micro level: Challenges in metrology for a company

A company that produces goods or services, and aims to achieve quality, productivity and competitiveness, needs reliable and adequate measurement systems to control and improve its processes. If the measurement capabilities are not balanced with the process capabilities, they can seriously limit the quality and productivity of the company. People within an organization often face problems that could ve solved, in an optimum way, only with the help of expert knowledge about their own processes and applied metrology.

Some of the questions that may arise for any process are:

- *What are the critical variables of the process?*
- *What is the required uncertainty for every measurement?*
- *What is the best instrumentation, what type of metrological confirmation does it require and who could provide it?*
- *What are the right methods for measurement, testing, verification and calibration?*
- *What technical competences and training do staff require and who can provide it?*
- *What is the best combination of measurement elements to structure a system which could achieve optimum results with economy?*

To design, establish and operate effective and efficient measurement systems is not a trivial task. The MESURA® Program was created to provide an optimum solution in an heuristic way for these types of problems, applying balance and economy principles, as shown in section 4.1.

2.2 Macro level: Challenges in metrology for a developing economy

In a similar way as a company, but in larger scale and with less controllable variables, developing countries or regions often face strong problems to define, develop, establish and operate effective metrological infrastructures, adequate to their specific needs, means and resources. These infrastructures should be, typically, conformed by a primary or reference laboratory or National Measurement Institute (NMI), heading a number of secondary calibration and testing laboratories to which it provides traceability. These laboratories should provide traceability and measurement solutions to the rest of society, they should be preferably accredited and linked by mechanisms that guaranty consistency and reliability to their users.

To establish such metrological infrastructures is far from a trivial task, and has taken developed countries many decades with solid support policies, investments and actions. In developing countries or regions, the National Metrology Institutes or government agencies face strong barriers to define, develop, establish and operate adequate metrological infrastructures that promote competitiveness and economical growth.

Some of these barriers are:

- *Lack of enough information for identification, definition and quantification of the measurement needs of society in different sectors*
- *Incomplete knowledge and expertise for the design of adequate infrastructures to meet the needs in an optimum way*
- *Lack of enough economical, material and intellectual resources to establish the designed infrastructures*
- *Imperfect market mechanisms to maintain sustainable growth of the infrastructures*

These situations imply a systemic problem. Efforts to overcome only one of the barriers are deemed to fail. On the other hand, attempts to face all of them simultaneously often fail due to lack of unity of purpose, equilibrium and coordination.

To overcome them in a simultaneous, gradual and coordinated way, CENAM developed a complementary strategy, or emerging property, for the MESURA® Program. This consists of mechanisms to establish a network of metrology laboratories, associated with the NMI as Service Units in a franchise scheme. The principles of unity, balance and economy were applied in the design of the MESURA® Interinstitutional Network, and are described in section 4.2.

3. EVOLUTIONARY PRINCIPLES IN LIVING SYSTEMS AND METROLOGY

The analogy of measurement systems and infrastructures with living entities can be useful in applying some of the basic principles that operate on the latter to the design of the first. The living principles outlined in section 1.3 (3.1 to 3.3 in this section), are proposed to lead to a set of design principles for artificial systems cited below (***a*** to ***f***), which are expected to model some of the essentials of the first.

These design principles, at their own time, would produce a set of consequent properties in the artificially designed systems to be viable. The resulting properties are mentioned after each principle.

3.1 Self-structured organization

The living principle or emerging property of self-structured organization of their own components provide living systems with their most distinctive characteristics. These characteristics cannot be achieved by artificial systems. However, some approximation can be obtained with the following design principles:

Purpose, Unity, Balance and Economy.

A short description of each design principle follows:

a. ***Drive for purpose***. The system must be fit for a specific purpose in a specific time and application to be effective. This aim must be the chief guide for its design.
b. ***Systemic unity***. The design of the system must be unified, systemic, with effective and efficient interactions among its components. The performance of the system is an emerging property of the whole.
c. ***Equilibrium and balance***. The different elements must be combined in a balanced way. Any unbalance is a waste. The chain is as strong as the weakest of its linkages.
d. ***Economy of means***. Nature operates with an economy of means. No truth is more complex than necessary. Any excess that is not employed to produce, may hinder the performance of the system.

These design principles, at their time, would produce systems with the following characteristics or properties that improve their viability and performance:

- **Adapted to their environment.**
  In a measurement system or metrological infrastructure, this means effectiveness in the function for which they are designed and implemented, which is the first requirement of an artificial entity.
- **Viable in technical aspects.**
  In a measurement system or metrological infrastructure, this means performance. It not only implies ability, but also the rigth connectivity to existing providers and users of traceability and other products of metrology such of metrological knowledge and interoperability.
- **Viable in economical aspects.**
  In a measurement system of metrological infrastructure, this means sustainability. This is a high output/imput rate or the ability to produce higher added value for their income resources to justify its existence.

3.2 Ability to transform and use elements of the environment

The ability to transform elements of the environment into a balance of self nutrition and action towards their aim is essential for a system to operate, survive and grow. As in principle 3.1, these characteristic cannot be achieved autonomously by artificial systems. However, if the human component is considered within the system, an approximation can be obtained with the following design and operation principle.

e. ***Equilibrium productivity - productive capability*** [4]**.** The system must be designed with mechanisms that allow that, in its operation, a part of the resources (material, intellectual, etc.) that it gets from the environment are employed in achieving its own productivity and some in the increase of its productive capabilities.

If adequate equilibrium is achieved between these two aims, the system should deploy the following chracacteristics or properties:

- **Enhanced technical and economical viability**
  In a measurement system or metrological infrastructure, these mechanisms will allow enhance performance due to the optimum use of the income resources.
- **Mechanism for growth**
  In a measurement system or metrological infrastructure, the continuous use of a part of income resources to strengthen each of the measurement elements and the whole system should warranty growth. With adequate mechanism of allocation and use of resources, healthy growth will be guarantied since it will be driven by demand.

3.3 Ability to reproduce themselves with self-similarity

In nature, the ability of living systems for unconscious learning from the common experience and the ability to use this information to reproduce instructions for other similar systems is achieved by the genetic code of the organisms. This assimilates information and knowledge to reproduce and multiply the most successful structures of viable systems.

Genetic code and reproduction mechanisms are also expressions of the living principle of economy, since in a global scale the learning of a system through its genetic code is utterly more economical in used resources than the individual learning of each member of a species.

As in principles 3.1 and 3.2, these characteristic cannot be achieved autonomously by artificial systems. However, if the human component is considered to design the systems, an approximation can be obtained with the following design and operation principle.

f. ***Genetic learning capability.*** The ability of externally driven systems, to be reproduced with self-similarity of affinity, but with small controlled changes to allow for better adaptation to the environment, is a major advantage that allows scale economies, continuous iterative improvement and transcendent impact. This principle is applied in design by looking for equilibrium between standardization in the essential characteristics of a system and controlled variability in its accidents.

When applied this design principle to artificial systems, it produces the following characteristic:

- **Modular and/or parametric structure**
  In a measurement system or metrological infrastructure, this implies that each entity must have a modular design which is structured in such a way that can be modified in a parametric way. This would allow the designer to provide taylor made solutions, but in a massive scale, which is in the modern global competition is a condition for competitiveness.

4. THE MESURA APPROACH

The application of the mentioned principles to the design and operation of the MESURA® Program and Network, has allowed CENAM to consolidate this strategy as an evolutionary mechanism for development of measurement systems in industry, commerce and service organizations for strengthening of the metrological infrastructure in the country.

A short description of the key characteristics of the Program and the Network follow. Complete accounts of them can be found in the references..

4.1 The MESURA® Program

The MESURA® Program is basically a methodology for designing and implementing technology transfer packages in metrology, tailor made to the needs of the organizations that contract it. The Program is performed in the companies by a small team of Generalist Consultants or Field Engineers, that coordinate a number of Specialist Consultants in the different fields of metrology, thus optimizing their work.

The methodology of the Program allows the following:

i) A client oriented strategy and systemic approach to measurement needs of an organization or a user sector.
ii) Integral analysis of metrological needs and means of a organization, a region or a country, in a specific moment and situation
iii) Definition, design and establishment of the optimum solution at minimum cost to meet those needs, be it a measurement system or a larger metrological structure, leaving the foundations for modular growth
iv) Growth mechanism to promote metrological awareness among user sectors, promoting a virtuous spiral of use-profit-investment-use in metrology.

References [7,8,9] describe in detail the methodology of the Program.

4.2 The MESURA® Interinstitutional Network

The MESURA® Interinstitutional Network is a virtual integrating company. It has a Coordination Centre within CENAM, formed by a small group of metrology consultants that support and coordinate other metrology laboratories that are established as MESURA® Units. These operate according to the MESURA® methodology and, together, offer the technology transfer Program to industry.

The structure of the Network allows the following:

i) Integration of the best capabilities in metrology in the country, both in infrastructure and expertise, to conform interdisciplinary and inter-institutional groups to design optimum solutions for the measurement needs of the user sectors
ii) Unified code and standardized mechanisms of operation that allow effective interaction among consultants and support institutions, to provide a single standard of quality, service and reliability to client companies.
iii) Widening of the coverage of metrological services through the country, offering ready support to the user sectors near their own premises, due to the geographical distribution of the MESURA® Units.
iv) Favourable environment for growth of the metrological infrastructures of the affiliated laboratories, and for the creation of new ones, since the operation within the Network provides a protecting environment for the recently formed MESURA® Units.

References [9,10,11] describe in further aspects of the conformation and operation of the Network.

4.3 The Key Success Factors

The key characteristics of MESURA®, both in the Program and the Network, are derived from application of the design principles described in section 3, and have promoted the better use of metrology in many companies, and evolutionary growth of metrological infrastructures.

The fulfillment of its aim has been possible due to a number of factors that have made of MESURA® an attractor for integration of metrological services. Among these factors are:

- An unswerving focus on the customer needs and interests
- An integral, logical and systematic problem solving approach to consultancy
- A set of design principles among which are: simplicity unity, balance, economy and connectivity
- A modular structure that allows parametrical design and evolutionary growth by stages
- An adequate modular classification of the consultants functions
- A uniform code of communication among the members of the network.
- A clear-cut definition of the functions of each member of interdisciplinary groups
- A clear-cut definition of the functions of each organization of the Network

4.4 Results

From 1996 to 2002, CENAM has provided technology transfer packages with the MESURA® Program to 170 companies, among which are industries of different sectors (automotive, chemical, alimentary, textile, mining, etc.), commerce and services. The great majority of them have declared the great impact of the Program for increasing the quality and productivity of their processes.

From 1999 to 2002, 5 metrology laboratories have joined the Network. With them, human resources and expertise has been increased with 24 more metrology consultants in 4 fields of metrology. This year, 3 more laboratories are expected to join the Network and about 10 more metrology consultants.

5. POSSIBLE APPLICATION IN OTHER CASES

In order of this strategy to be useful in other cases, an analysis is due to find out whether some of the conditions and premises that were valid in Mexico are also valid in them. The following analysis, though necessarily incomplete, aims to shed some light in this direction for possibly interested parties that would attempt to use similar approaches to develop metrological infrastructures in the macro-level of a country or a region.

5.1 Analysis of the problem's origins

The problems that in Mexico gave origin to the MESURA® approach, and the challenges mentioned in section 2.2 faced by developing economies can be analysed in terms of their origins or components as follows:

a. Problems to identify, define or quantify the measurement needs are due to:
- Lack of objective data in the user sectors to evaluate their real metrological needs, and low metrological culture that makes it difficult to obtain relevant information.
- Many under-developed user sectors that, in case of developing, would have increased demands, but it is difficult to predict them.

b. The design of adequate infrastructures to meet the identified measurement needs is mainly a technical problem that involves:
- Design of laboratories and physical facilities.
- Selection or development of equipment and standards.
- Selection and realisation of adequate training programs for human resources.
- Selection of measurement methods and development of procedures.

c. Problems to obtain the necessary resources are usually due to:
- Limited resources available from the public sectors
- Limited commitment, due to their poor understanding of the importance of metrology, of the private sector.
- Limited investment in both, metrological infrastructures (calibration and testing labs) and metrological services (demand of calibrations, training, etc.)

5.2 Consequences

These problems often represent infranqueable barriers for the regions, economies or countries. The vicious circle imply that:
- It is not possible to determine de real demand of the user sectors, therefore,
- It is not possible for potential investors to define economical viability of investments in metrology, then,
- Since there are not adequate infrastructures, metrological culture does not evolve and the potential users do not become actual users

5.3 Applying the MESURA® Methodology

At the practical level, the MESURA® Program is a consultancy methodology performed in 4 stages:

I. Investigation of metrological needs and means
II. Analysis and diagnosis of traceability
III. Design and program for optimal systems
IV. Realization of the systems according to design, maintenance and continuous improvement of the metrological system.

Each of the stages considers three basic measurement elements:
i) Human resources and their competences
ii) Standards, instrumentation and their traceability
iii) Methods, procedures and their fitness for purpose

5.4 Guiding principles and objectives

The MESURA® strategy implies:
- Definition of the minimum possible investment in metrology to produce the maximum possible benefit-cost ratio
- Establishment and operation of this infrastructure to raise awareness, increase use and benefit of the established infrastructure
- Definition of an administrative mechanism to use of a percentage of the profit to increase investment and promote growth of the established infrastructure.

5.5 The evolutionary mechanism of growth

With the above mentioned approach, principles and objectives, the evolutionary mechanism is achieved since:
- It allows to establish, based on a first investigation, analysis and diagnosis, the minimum basic system or infrastructure to meet a specific set of needs
- This basic system is defined, however, in a structured modular way that allows harmonic future growth with a solid basis
- The embodied operational principles promote the continuity of 1) stimulation of metrogolical needs, 2) satisfaction of them, 3) generation of economical resources, 4) growth of metrological infrastructures, 1') further stimulation of needs…

6. CONCLUSIONS

The MESURA strategy has proven successful in México, and it is believed that similar strategies, that would apply some of the guiding principles that gave rise to it, could prove successful also in other countries or regions, with similar stages of development and industrial structures.

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REFERENCES

[1] Stafford Beer, *Platform for Change*, John Wiley & Sons, England ,1978.
[2] T. Sakaya, *The Knowledge-Value Revolution*, Tokio, 1991.
[3] P.F. Drucker, *Post-Capitalist Society*, New York, 1993.
[4] S.R. Covey, *7 Habits of Highly Effective People*, 1989.
[5] National Research Council, USA, *Learning to Change*, Opportunities to improve the performance of smaller manufacturers, National Academy Press, Washington, USA, 1993.
[6] Carol Croakin, *Measurement Assurance Programs, NIST*, Washington, USA, 1994.
[7] S. Echeverría-Villagómez*, MESURA: Assurance Program of Measurement Elements*, *Proceedings of the conference: Metrology for the Americas*, Miami, USA, 1995.
[8] S. Echeverría-Villagómez, H. Nava-Jaimes, *MESURA Program: a way of creating lean, robust and reliable metrological systems*, *Proceedings of the National Conference of Standards Laboratories*, Atlanta, USA, 1997.
[9] S. Echeverría-Villagómez, *Plan de desarrollo para la Red MESURA Interinstitucional*, CENAM, México, 1997.
[10] S. Echeverría-Villagómez, H. Nava-Jaimes, *MESURA Interinstitutional Network: a way of bringing together suppliers and users of metrological services*, Proceedings of The Role of Metrology in Economic and Social Development, Brawnschweig, Germany, 1998
[11] S. Echeverría-Villagómez, Y. Mitani-Nakanishi, H. Nava-Jaimes, Strategy to *integrate a true communication network of metrology experts with process and product technology experts,* Proceedings of the ASQ, January 2000.

Author: Salvador Echeverría-Villagómez, Centro Nacional de Metrología - MESURA® Interinstitucional Network
CENAM, Querétaro, México; saleche@cenam.mx