Calibration System for Cost Reduction: A Case Study in the Maquiladora Industry

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Abstract

Electronic manufacturing companies spend a significant portion of their quality costs on calibration; which in most cases is done externally to the company. This case study company mainly manufactures remote controls for electronic devices; after carrying out a cost analysis of calibration, it was concluded the resources were allocated for an integral project to implement an internal calibration laboratory. The objectives of the project were: (a) to reduce costs in the payment for calibration services, (b) to evaluate a team as a working standard to carry out internal calibrations with company personnel applying current standards, (c) to record data for the control and administration of the measurement equipment of the company and (d) to train the personnel implanting a metrology culture. Lean Manufacturing and Six Sigma tools were used in the development of this project. The mathematical model for the equipment to be calibrated is based on the NMX-CH-140-IMNC: 2002 (Mathematical Model of the Measured) and NMX-EC-17025:2006 (General requirements for the competence of testing and calibration laboratories). The results reflect the economic feasibility of implementing a calibration laboratory in the company, reducing costs by 20%.

Keywords
Uncertainty, six sigma, quality, metrology.

1. Introduction

Metrology-related activities in the manufacturing industry promote and maintain uniformity and accuracy in measurements. Marbán & Pellecer [1] mention that there is a relationship between metrology and quality, between measurements and quality control, calibration, laboratory accreditation, traceability and certification. Without metrology, it would be impossible to verify the quality of products or processes, as defined in international regulations. In other words, metrology and standardization are essential for quality assurance [2]. Metrology ensures that measuring instruments contribute to quality control of industrial processes; to achieve this, these instruments must be calibrated regularly [3]. According to the Federal Law of Metrology in Mexico, calibration is "a set of operations that aim to determine the errors of a measuring instrument and, if necessary, other metrological characteristics" [4]. On the other hand, the standard NMX-Z-55IMNC: 2009 defines calibration as:

> "An operation that under specific conditions establishes, in a first stage, a relationship between values and their measurement uncertainties obtained from measurement patterns and the corresponding indications with their associated uncertainties; in a second stage it uses this information to establish a relation that allows to obtain a measurement result from an indication "[5].

The calibration of an instrument guarantees a correct operation within the instrument specifications, and it is a fundamental tool to ensure the traceability of a measurement [1]. Performing the calibration, every year or whenever determined, will allow to identify and reveal the possible deviations of the equipment over time. Some of the benefits of calibration are that: (a) it guarantees a level of measurement uncertainty that can be achieved with the measuring instrument, (b) it confirms if there has been any alteration in the measuring instrument that could cast doubt on the results of former measurements, and (c) it determines the deviation between the indicated value, the so-called true

value, through a chain of measurement referred to national or international standards, knowing its uncertainties [6]. According to Hernández, Favela and Martínez [7], test and calibration laboratories play a very important role within an organization, since they are elements that support the determination or verification of the products properties, according to established criteria. The project focused on establishing a calibration system in an electronics manufacturing company in order to reduce costs for this concept. The considerations of the Mexican Official Standard NMX-EC-17025: 2006 General requirements for the competence of test and calibration laboratories were applied [8]; for which it was necessary to develop a solid structure for an internal calibration laboratory including the generation of procedures and formats, internal calibration reports, databases and lastly the training of company personnel in metrological issues [9].
The initial calibration system includes the analysis of equipment that is calibrated externally, when sent to a calibration provider. By means of an analysis of the situation that includes the data presented in figure 1, the purchase of equipment to be used as a benchmark to carry out calibrations internally with the case study company personnel was justified. According to the trend analysis, it is expected that the cost of calibration performed externally will be doubled within four years. The goal was to implement a program for the administration and control of calibrations, as well as a description of the work patterns to perform the calibrations. In addition, a register of calibration providers was carried out to record in detail the existing equipment (brand, model, serial, equipment scope, calibrated points, specifications, manufacturer manual, equipment image, department where it is installed and name of the user who has it under its name). The specific objectives are: (a) to transfer the calibration services of the equipment to internal laboratories, reducing calibration costs by 20%, (b) to evaluate the equipment according to the current national standards NMX-EC-17025 : 2005 [8] and NMX-CH-140-IMNC: 2002 [10] and (c) train the personnel involved with equipment calibration.

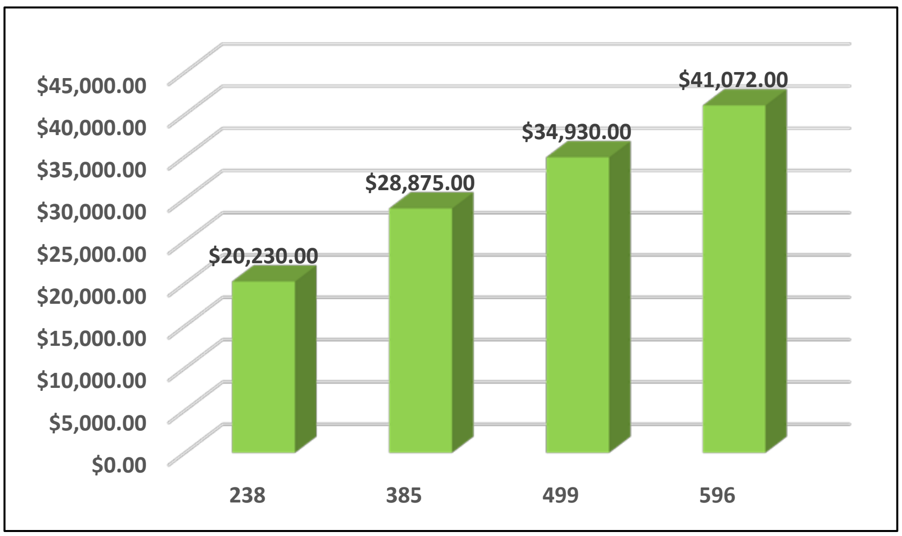


Figure 1. Annual cost of calibration and number of calibrated equipment per year

2. Methodology

The Six Sigma DMAIC methodology was applied for the development of the project, which includes Define the problem, Measure the problem, Analyze the problem, Improve (apply improvement proposal) and Control the process [10, 11, 12] explained in figure 2.

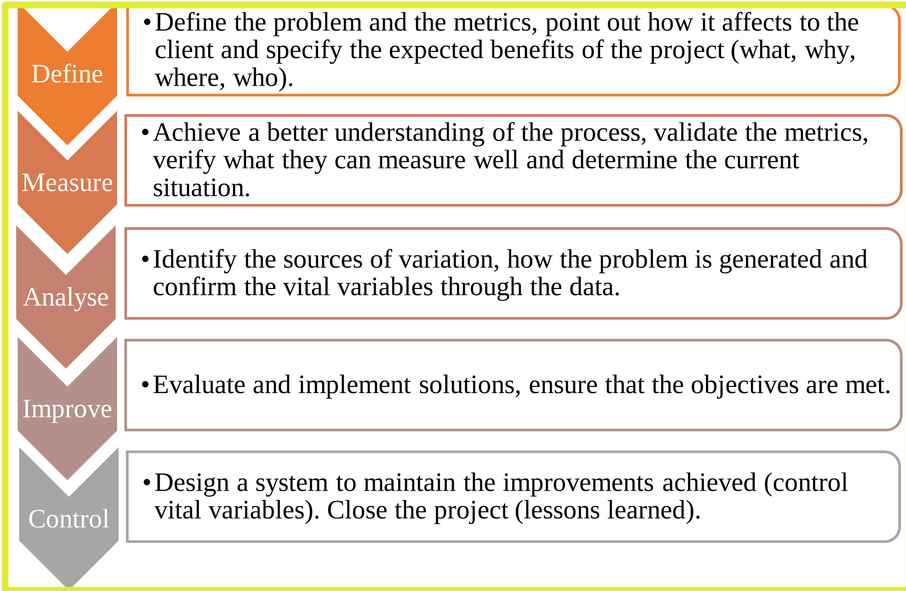


Figure 2. Six Sigma Methodology

3. Case Study

Obtaining accurate and reliable measurements is a fundamental requirement for any company that wants to be among the most competitive, since "what is not measured is not improved". In order to determine the quality of a product and to know if the required quality is achieved, it is necessary to measure the fulfillment of the specified criteria by monitoring the production processes in order to guarantee conformity with the established characteristics for the final product [14]. The quality of the goods or services that are commercialized is assured by the measurements, which generates great relevance when making decisions within organizations [14, 15]. The project was developed in an electronics company in the Northern Border of Mexico as an effort to reduce operating costs in the quality department; in this regard, calibration is the most important concept. The laboratory tests must comply with certain requirements that guarantee the quality of its realization and at the same time, provide information on the characteristics of the product, for it requires a process that assures the customer's requirements and demonstrates the technical competence of the laboratory [16]. In order to ensure quality, a written, authorized and defined plan is required to guarantee the responsibilities and frequencies of the audits, reporting, corrective and preventive actions, raised since the beginning of the activity [16]. The contribution of the internal calibration laboratory should include these factors in addition to the uncertainty associated with the technical calibration capabilities of the accredited laboratory [18, 19], to achieve these objectives DMAIC methodology was applied [11, 12, 13].

3.1 Define

The problem was basically defined as "reducing calibration costs by complying with the SMART (specific, measurable, attainable, relevant and time) characteristics [20, 21]; Table 1 presents the background and data to support the project, while table 2 includes the work team and the functions assigned to each member.

Table 1 Project Definition

Background and supporting data	
Specific Measurable Atinable	Reduce the cost of calibration by 20% per year, from $ 41,042 USD to $ 32,857.60, by transferring the external calibration processes to internal calibration.
Relevant	Impact on the costs of the company positively, being profitable.
Time	Six months.

Table 2. Responsibility of the team members

Work team	
Quality manager	Provides and ensures the needs of the equipment, materials and workplace (the space for the laboratory). Authorizes the project once submitted the analysis of the project considering the return of the investment.
Quality engineer	Analyse the problem and select the appropriate methodology for the type of project. Selects the standard for feasible internal calibration equipment, according to the requirements of the production measurements.
Human Resources	Recruit and select personnel for the position of calibration technician (who will carry out the measurements prior to transfer of calibration from external to internal).
Calibration Technician	Perform calibrations, fill in formats to make internal calibration reports, control the equipment to be calibrated.
Systems Engineer	It performs the programming of a database for the administration, control and management of the calibrations of the company's equipment.

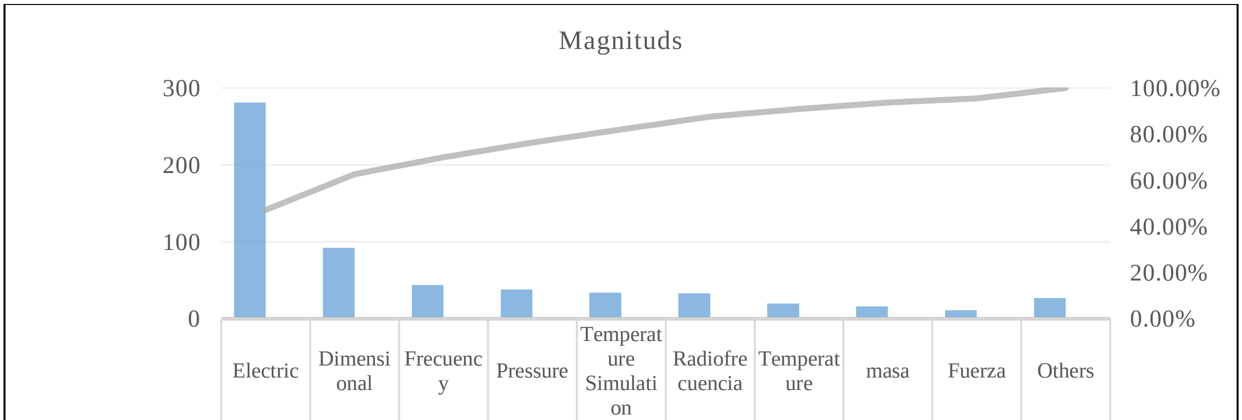
As in any project, it is important to identify those involved in the process to be considered. In this company the related departments are the design, inspection of receipts, warehouses, hazardous waste, paint, top, SMT, wave machine and product assembly cells. Each department was assigned a person responsible for the equipment to be calibrated used in those areas. To register a device in the calibration system, the following procedure is followed:

a. Identification of equipment data such as: brand, model, serial and calibration certificate.
b. Appointment of a person responsible for the team.
c. Defining the location and notifying any department or responsible change.
d. Assigning an identification number for its control.
e. Lastly, the equipment is registered in the calibration system.

At the beginning of the project an evaluation of calibration suppliers in the region was carried out and the suppliers in the country were also investigated, to avoid sending the equipment abroad to be calibrated. The number of suppliers and available equipment was determined. The calibration range includes the following characteristics: color, dimensional, hardness, electric, frequency, force, humidity, light intensity, mass, optics, pressure, radiofrequency, temperature simulation, sound, time, torque, speed, among others. The process with the calibration service provider is done in the following order: (a) request cost quotation, (b) generate purchase order, (c) request and schedule the service, (d) perform the service and (e) pay the invoice.

3.2 Measure

Figure 1 presents the annual costs of calibration and the amount of calibrated equipment, where an upward trend in both variables can be observed. To better understand the situation, a breakdown by characteristic of the test and the accumulated frequency plotted in Figure 3 was performed. The electrical area represents the largest area of opportunity, the short warp with the variable Temperature Simulation to reach 80% of the calibrated equipment (considering only half of the categories). Based on the results, the project is limited to the electrical dimension for the measurement of the calibration costs, which are presented in table 3. The largest devices are multimeters and DC power supplies. In multimeters only the ammeter function is used in direct current, therefore, a requirement is the consideration of a pattern that is specifically for that magnitude, avoiding the purchase of patterns for not necessary functions.



	Electric	Dimensional	Frecuency	Pressure	Temperature Simulation	Radiofrecuencia	Temperature	masa	Fuerza	Others
Quantity	281	92	44	38	34	33	20	16	11	27
Frecuencia	47.15%	15.44%	7.38%	6.38%	5.70%	5.54%	3.36%	2.68%	1.85%	4.53%
Acumulado	47.15%	62.59%	69.97%	76.35%	82.05%	87.59%	90.95%	93.63%	95.48%	100.00%

Figure 3. Calibrated Magnitudes

Table 3 Calibration Total Cost, Electric Magnitude

Description	Equipment	Unit price	Total price
AC Analyzer	1	$35.00	$35.00
AC power supply	3	$35.00	$105.00
Analog ammeter	4	$35.00	$140.00
Audio generator	1	$200.00	$200.00
ESD Charging Unit	1	$40.00	$40.00
Hook ammeter	2	$35.00	$70.00
Bracelet and heel meter	1	$40.00	$40.00
Data Acquisitor	4	$125.00	$500.00
DC power supply	104	$40.00	$4,160.00
Electrostatic Discharge Monitor	1	$60.00	$60.00
Electrostatic Voltmeter	1	$52.00	$52.00
Ground integrity meter	1	$75.00	$75.00
High resistance meter	1	$35.00	$35.00
Insulation Tester	3	$65.00	$195.00
LCR meter	1	$74.00	$74.00
Multimeter	130	$35.00	$4,550.00
Oscillation	11	$40.00	$440.00
Resistive Surface Meter	1	$39.00	$39.00
High resistance tester	1	$65.00	$65.00
Electrostatic Voltage Meter	2	$35.00	$70.00
Antistatic wrist gauge	7	$35.00	$245.00
Total	281		$11,190.00

3.3 Analyse

An effective analysis is crucial for finding and understanding the possible causes of a problem. It is necessary that when identifying the causes, the field and focus is reduced. To determine the scope of the project we used the analysis tool of the "five why's" [22, 23]. The raised questions were: Why is it necessary to reduce the cost of calibrations? Why do costs increase every year? Why more equipment is purchased and not included in the calibration budget? Why do users not know that computers should be calibrated? Why there is no internal calibration system? It was concluded that an internal calibration system was required to create and promote a metrological culture in areas that use that equipment; it is important to propose a training plan on the metrological issues, their importance and their procedures, so as to guarantee their correct functioning and consideration in the calibration budget. In this regard, it is important to certify the calibration technical competence of the equipment users, by applying the current norms and methods [24].

3.4 Improvement

Before implementing an improvement, an investigation about the specifications of the equipment to be transferred to the internal calibration laboratory was carried out [25], these pieces of equipment are known as UUC (Unit Under Calibration). As a requirement, the accuracy of the UUC must be known so that equipment purchased as a reference standard is at least three times more accurate, according to the manufacturer's specifications (accuracy). This ratio of uncertainties is called Test Uncertainty Ratio or TUR [26]. Standard equipment measuring voltage and current (DC) was selected; the pattern-requirement scheme is shown graphically in Figure 4.

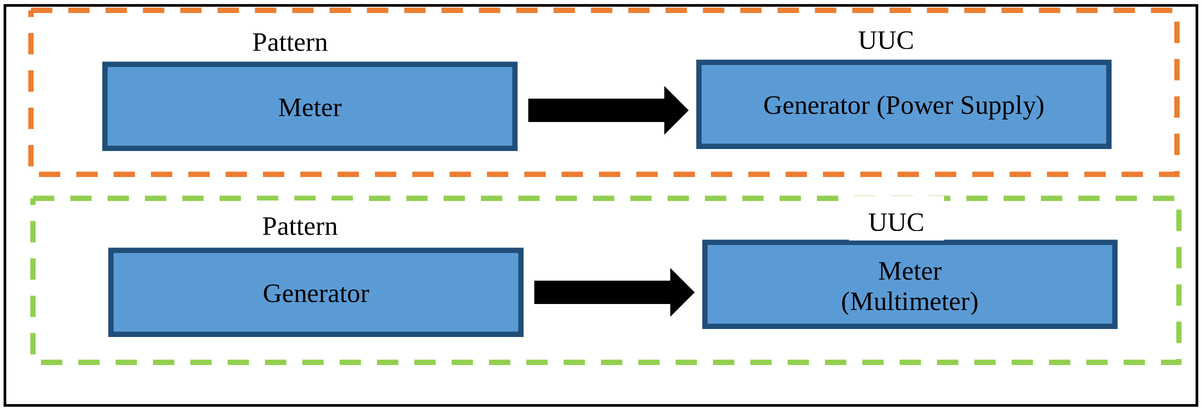


Figure 4. Diagram of requirement between patterns and UUC

The following equation (NMX-CH-140 IMNC: 2002) is used to calculate the accuracy ratio between the standard and the UUC:

$$R = \frac{I}{P} \tag{1}$$

Where R is the accuracy ratio, P is the accuracy of the standard and I is the accuracy of the UUC.

The norm NMX-CH-140 IMNC: 2002 indicates that when reporting the result of the measurement of a physical quantity it is mandatory to provide some quantitative indication of the result's quality, so that the user can appreciate its reliability [10]. Without this indication, the results of the measurements cannot be compared, neither between themselves nor with reference values given in a specification or standard. Therefore, to characterize the quality of the result of a measurement it is necessary to evaluate and express its uncertainty [25, 27].

$$E = f\left(V_m, V_r\right) \qquad o \qquad E = V_m - V_r \tag{2}$$

Where, E is the error, V_m is the average value of the UUC and V_r is the reference value. The coefficients of sensitivity are sometimes determined experimentally, rather than being calculated by the function f, it measures the change in Y produced by a change in the particular X_i, keeping the others constant. When one already has an estimate of the standard uncertainty of the value of each of the sources of uncertainty, it is known as each of them can influence differently in the UUC. It was necessary to partially derive the measurand with respect to each of the input quantities, called the sensitivity coefficient [25].

$$\frac{\partial E}{\partial V_m} = 1 \qquad \frac{\partial E}{\partial V_r} = -1 \tag{3}$$

The estimated uncertainty of the electric magnitude is classified in type A and type B. For type A, it is the estimated variance u_a that characterizes an uncertainty component obtained from a type A evaluation [18]. It is calculated by a series of repeated observations, and it is the most common estimated statistical variance s^2. The estimated standard deviation u is the positive square root of u^2, which is called standard uncertainty type A. In most cases, the best estimate of the expected value of a magnitude is q that varies randomly and from which five independent observations under the same measurement conditions are obtained.

$$\bar{q} = \frac{1}{n} \sum_{k-1}^{1} q_k \tag{4}$$

The individual observations differ in value due to random variations in the magnitudes affecting them (random factors), the following equation is applied, where n is the number of observations collected [28].

$$s(q) = \frac{1}{n-1}\sum_{k-1}^{1}(q_k - \bar{q})^2 \quad (5)$$

$$u_{A=}\ \frac{s(q)}{\sqrt{n}} \quad (6)$$

$$u_{mr\,=}\ \frac{U_A}{Ls}(100) \quad (7)$$

3.4.1 Uncertainty due to pattern

Uncertainty linked to standard stability was the first component used; it is the specification. The manufacturer provides this equation.

$$u_{(esp)}B = \pm(a\% + [c\left(\frac{100}{Lc}\right)] \quad (8)$$

The second component of measurement uncertainty linked to reference standard is the calibration certificate according to equation (9), where *inf* is the uncertainty column indicated in the calibration certificate and *k* is the covering factor of the laboratory that calibrated the standard.

$$u_{inf}\,B = \frac{inf}{k} \quad (9)$$

3.4.2 Uncertainty by resolution of the instrument under calibration

Another uncertainty source from a digital instrument is the resolution of its indicating device, if the repeated indications were all identical, the uncertainty attributable to the repeatability would not be zero, because there is a known interval of input signals that will give the same indication on the instrument. If the resolution of the indicating device is δx the value of the stimulus producing a given indication *X* can be located with equal probability anywhere in the range of $X - \frac{\delta x}{2}$ a $X + \frac{\delta x}{2}$.

The stimulus is described by a rectangular probability distribution of width δx with variance $u^2 = \frac{(\delta x)^2}{12}$ linked to equation (10), where *rls* is the resolution indicating the measurement range at which the instrument is calibrated. Equation (11) is used in the internal calibration report to determine the relative uncertainty due to resolution.

$$u_{rsl}\,B = \frac{rsl}{2\sqrt{3}} \quad (10)$$

$$u_{res}\,B = \frac{rsl}{Lc}(100) \quad (11)$$

3.4.3 Standard Uncertainty Combined

The estimated standard deviation associated with the estimation of the resulting magnitude or the measurement result *y* is called combined standard uncertainty, denoted as $u_c(y)$, and it is determined by the estimated standard deviation associated with each estimated value of the input magnitudes x_i, which is called standard uncertainty and denoted as $u(x_i)$ [29].

$$u_c{}^2(y) = \sum_{i=1}^{N}[\frac{\partial f}{\partial x_i}]\,u^2(x_i) \quad (12)$$

According to the estimated components, the equation is known as error propagation law:

$$u_c{}^2(y) = (\frac{\partial E}{\partial v_i})^2\,(u_{mr})^2 + (\frac{\partial E}{\partial v_i})^2\,(u_{esp})^2 + (\frac{\partial E}{\partial v_i})^2\,(u_{inf})^2 + (\frac{\partial E}{\partial v_i})^2\,(u_{res})^2 \quad (13)$$

All components must be standardized; that is why in the stability component the pattern is divided by the coverage factor *k*. This is chosen based on the 95% confidence level, then the equation is expressed as combined standard uncertainty, in the u_c cell for multimeters.

$$u_c = \sqrt{(u_{mr})^2 + \frac{(u_{esp})^2}{k} + +(u_{inf})^2 + (u_{res})^2} \quad (14)$$

3.4.4 Incertidumbre expandida

The additional measure of uncertainty that meets the requirement of providing a confidence interval is called expanded uncertainty and is denoted by *U*. This is obtained in Eq. (15) [30].

$$U = u_c k \quad (15)$$

The results of the measurement are expressed as $Y = y \pm U$, where y is the relative percentage error and U is the relative percentage expanded uncertainty and the value of k is declared in the section of the notes of the calibration report.

3.5 Control

During the implementation of the internal calibration system, it was necessary to carry out documentary work that was recorded in the Quality Management System (QMS) [31] as a control mechanism [14]. Some of the registered procedures are calibration of generators (power supplies), calibration of meters (multimeters) and logistics for the calibration process. The implementation of calibration worksheets for the registration, download and disposal of equipment was proposed, and so were document control of the units to be calibrated, the environmental conditions and equipment inventories [30]. Because the activities carried out by the calibration technician belong to a newly created position, documentation related to the job description was developed. It was necessary to adjust the database to generate reports with the information of the internal calibration laboratory. A training matrix and didactic resources were developed on this new procedure.

4. Results

4.1 Workspace Assignment

At the beginning of this project, calibration was performed in a production cell, at the same time a laboratory facility was managed. After confirming that there where savings since the first year of implementation, the facility required to the quality manager was assigned. The standard was implemented according the following characteristics: visual, capacity to distinguish the normal from the abnormal, control of the environment.
The entire implementation of the workspace was carried out following the Lean Methodology guidelines related to visual administration [31, 32, 33], in figure 5, at the right side we can see the work area standard, thus maintaining the workspace. Visual controls were also implemented for the accommodation of materials and equipment and the work area metrics that is the equipment to be calibrated this year both internally and externally.

Figure 5. Laboratory of Quality, Area of Metrology with its Visual Standard
Source: own elaboration

4.2 Return on Investment

The company quality manager gave the instruction that only direct current would be calibrated since the process consists in the measurement of that parameter; another instruction was that, when evaluating the project, the investment should be paid in two years at the most, obtaining the following result.
The project return on the investment (ROI) was calculated considering the Keithley 2450 SourceMeter instrument. The cost of the standard equipment for calibration was $ 4,860 dollars. The cost of equipment that would no longer be calibrated by the external calibration provider is $ 8710; dividing the $ 4,860 by the cost of what is paid for calibrating this equipment with the calibration vendor indicates a return on the investment of approximately half year:

- ROI $\frac{\$4,860}{\$8,710} = 0.55$ years

When evaluating how profitable the project is in percentage, the return on the investment has a ROI of 179%, that means that master equipment can be bought with the amount of money needed to pay the external calibration of the equipment and still remains a remnant of that payment.

- ROI $\frac{\$8{,}710}{\$4{,}860} = 179\ \%$

4.3 Reduction of Costs in the Calibration Service

This project avoids paying calibration service costs by an external supplier, thus obtaining a reduction in payment of invoices since the very first year of implementation of the project. The reduction of the calibration cost was evaluated in 2015 and 2016. In 2016 more sources and multimeters were bought, therefore the saving amount was even greater.

4.4 Database Design

A database was designed and implemented by the company's computer programmers. Nowadays there are programs available to manage and calibrate equipment, however, having the company computer programmers performe the job led to a saving of $ 10,000 dollars, plus another $ 47,000 that would have been spent in a comprehensive program for the management and control of equipment.

4.5 Application of Standards in the Calibration System

In this work the norm MNX-EC-17025-INMC "General requirements for the competence of the test and calibration laboratories" has been described. This norm establishes the general requirements shown in table 4. The tests and calibrations that are performed using standardized methods, non-standardized methods and developed by the laboratory itself have been reviewed. This norm is applied to all organizations that perform tests or calibrations [8], so the laboratory was structured according to the guidelines shown in table 4.The presentation of the results in the internal calibration report was elaborated according to the norm, specifically clause 5.10 Results Report, besides the generation of all the documentation was taken as basis to have the management system in the laboratory.

Table 4 Requirements of the Standard NMX-EC-17025-IMNC: 2006

Standard NMX-EC-17025-IMNC:2006	
Management requirements	Requisitos técnicos
4.1 Organization	5.1 General aspects
4.2 Management system	5.2 Personnel
4.3 Documents control	5.3 Environmental conditions and facilities
4.4 Review of orders, offers and contracts	5.4 Test and calibration methods; validation of methods
4.5 Outsource of tests and calibrations	5.5 Equipments
4.6 Purchase of services and supplies	5.6 Traceability of measurements
4.7 Customer service	5.7 Sampling
4.8 Complaints	5.8 Manipulation of calibration test items
4.9 Control of non-conforming test or calibration work	5.9 Assurance of the quality of test and calibration results
4.10 Improvement	5.10 Results report
4.11 Corrective actions	
4.12 Preventive actions	
4.13 Records control	
4.14 Internal audits	
4.15 Management reviews	

Source: Own elaboration

5. Conclusions

According to the results the alternative hypothesis H1 is accepted: It is convenient to implement a calibration laboratory for the SMK electronic company, rejecting the null hypothesis H0: It is not convenient to implement an internal calibration system in the company SMK. Figure 6 shows the decrease in calibration costs in year 2 compared to the first year when transferring equipment internally, lowering the cost of billing for payment of calibration services, thus concluding that the objective of reducing the cost of calibration by 20% was achieved. It is convenient to invest in more equipment as a standard for dimensional, RF (radio frequency), pressure, among others. According to the stratification that was done in the analysis of the magnitudes, it is observed in this case study that when investing in standard equipment the calibration costs decrease.

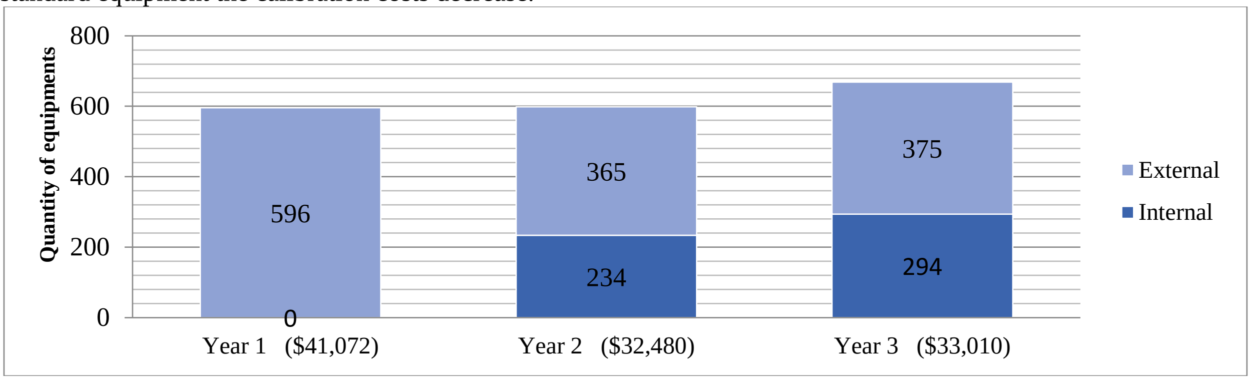


Figure 6. Reduction of External Calibration Cost

5.1 Future Work, Opportunities for Improvement in the Metrology Area

This work was done developing the electrical magnitude, however, there are improvement opportunities in transferring other magnitudes such as: dimensional, RF (Frequency Radio), frequency, pressure, temperature and mass simulation. According to the classification of magnitude analysis, there is also a lot of documentary work to do as it can be seen in figure 5.12 there are sections that were not realized in this project; what was achieved, however, in terms of the clauses of the standard NMX-EC-17025: 2006 were the clauses: 4.7 Customer Service, 4.10 Improvements, 5.2 Personnel, 5.3 Environmental Conditions, 5.5 Equipment, 5.6 Traceability and 5.10 Certificates of Calibration. The opportunity for improvement is the implementation of the other clauses and the transfer of the aforementioned magnitudes.

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