TÉCNICO LISBOA

Application of the Lean Six Sigma methodology (DMAIC) in accredited metrology Laboratories ISO/IEC 17025:2005

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Abstract

The DMAIC (Define-Measure-Analyse-Improve-Control) methodology is generally described as a methodology for solving problems and improving standardized processes. The improvement due to competitiveness in companies is increasingly for those who wish to remain strong in the market where they belong. For this approach's methodologies such as Lean and Six Sigma, brings quality and improvement proposals based on the objectives sought by the companies. This Master's Dissertation aims to apply the Lean Six Sigma methodology, following the DMAIC methodology, in the Electrical and Radiofrequency Laboratory of the ISQ of Lisbon. The business area of this laboratory focuses on the calibration and certification of electrical equipment. With this methodology it's intended to reduce wastes from the Lean perspective, within the main process in the laboratory, such as the calibration. For this process, it was observed, understood, analysed and later we will be able to identify possible bottlenecks in the process. The main waste identified was the movement of the technician during the calibration, which through some changes in the layout of the laboratory, it was possible to reduce the calibration time, giving the possibility to make another 287 calibrations per year of the electrical equipment studied.

Keywords: Lean, Six Sigma, Continuous Improvement, Quality, Metrology.

1. Introduction

Nowadays, every product that arrives to the market, must offer great value to customers, to achieve a higher level of competitiveness. This need of competitiveness results from the pace of innovation, that we were facing over the last decades. With this, the companies look for methods that improve their service, in order to guarantee a good service level, and maintain a good competitiveness against their competitors. And with that, need to increase the quality of the service to stay and thrive in the market.

For a company to maintain itself in the market, it's important to provide to the client the product expected, at the right time, at the right location, and at the right quantity. These three aspects are essential to make the client satisfied with the product provided, after all, it's the customer that maintains the business working, without customer there's no lasting business.

Therefore, using a method that improves the efficiency of processes, like LSS, it's helpful because it intends to reduce the waste and the variation of new and existing processes. The Lean part aims to reduce and/or eliminate the waste; the six-sigma part, aims to evaluate and check the efficiency of the implementation of a Lean project, by statistical methods.

Although these projects bring benefits for the business, there's some adversity on the implementation of these type of projects, because people tend to create barriers against changes on their working environment.

The implementation of the Lean Six Sigma project on the Electrical and Radiofrequency laboratory, will focus on the calibration of a particular set of equipment's. These calibrations must be error-free, because the smallest error can bring high costs for the labs and to their customers. The studied equipment's usually can take two different courses, where they can be delivered to the customer calibrated with the certificate and calibrated without the certificate that it's delivered after. The second course it's an undesirable course, but sometimes it

happens because it's missing a second signature on the certificate.
During the implementation of the LSS, the interpersonal interactions were essential and through face-to-face meetings with the principal stakeholders of the environment studied.
The purpose of this paper is to present the main aspects addressed in our LSS project, namely: data survey, collecting and analysing data, to later implement a solution that integrates several tools of continuous improvement. These aspects are described during the implementation of the methodology DMAIC.
The section 2, contains a short bibliographical review, about the Lean Six Sigma. Section 3 describes the implementation of the LSS, and on the section 4, the conclusions.

2. Literature review

2.1. Lean

The Lean concept originated at the Toyota Motor Company shortly after the end of World War II. At that time was called the Toyota Production System (TPS) (Monden, 2012). This concept was intended to maintain a continuous steady flow in a given production system. In Lean production, the Pull strategy is used, meaning producing only what the customer asks for. Lean methodology aims to achieve perfection and reduces the number of defects and therefore the associated costs (Castro, 2016; Womack and Jones, 2003).
This methodology has been improved over the years, starting with Lean Production, more focused on production and later leading to the emergence of Lean Thinking.
The Lean Thinking is to think about the waste and the good management of resources that we have, in order to create something with value, avoiding to use resources with activities that don't bring any type of value to the company. These wastes can be identified by observation, if they are easy to identify, or by data analysis. The seven wastes that Lean addresses are (Pinto, 2016): overproduction, waiting times, transport, movements, excess of processes, inventory and defects. Lean is implemented through tools and methodologies such as:

- 5S, a systematic tool, created by the Japanese industry, to improve the condition of the workplace such as tidiness, order. Vijaymohan and Aravindha (2014) presents evidence that, through the application of this methodology in a factory, with the objective to reduce lead-times through better storage, resulted in a reduction of waste and improvement of safety standards.
- Cause-Effect Diagram, which provides an easy view of the root causes, which are causing a certain unwanted effect. This diagram also helps us to organize the reasoning, and can be done by an individual, or by a group of individuals (Kume, 1993).
- Poka-Yoke is composed by mechanisms, which aim to reduce the possibility of appearing errors, reducing the probability of creating waste.
- Value Stream Mapping, Rother and Shook (1999), consider VSM, a graphical representation of a process that is easy to understand. It is for these reasons that this method is a great aid in the visualization of waste.
- Five Why's (5W), as many resources are not needed, nor from any statistical analysis, we can say that this is a method does not bring many associated costs and it can be very helpful (Sondalini, 2011).

2.2. Six Sigma

The Six Sigma concept emerged in Motorola's quality department on the decade of 1980, using William Deming's concepts of process variation to reduce unwanted variations. In the case of Motorola, the goal was 6σ, that is, the variation of the response characteristics analysed was of six standard deviations around the expected value. This methodology aims to improve repetitive processes, because is known that it is only possible to have continuous improvement in processes that are in a certain way standardized so that we can measure and evaluate the current situation of a process or service.
In the business environment, there's an issue that must be taken into consideration, the end customer doesn't feel averages, feels variations. For such variations to be reduced, it's implemented an approach called DMAIC (Define, Measure, Analyse, Improve and Control). According to the Six Sigma Guide (2001-2004), the DMAIC methodology is essentially used in processes, products or services that already exist, with the main

objective being their improvement. The projects that consist of this methodology, aim to help on the effectiveness of processes, without major changes in the organization when there are products with more than three or four sigmas. Next, a description of the 5 phases and some of the tools used in each one, are presented:

- Define: where are defined which processes will undergo an improvement project, are used at this stage to help define the Lean Six Sigma project tools such as Project Charter, which is a document where all the information related to the project, where the project objectives, the team, the expected benefits, the schedule, the risks, the estimated costs and the necessary resources are defined, and the SIPOC that is the elaboration of a process flow chart that will be improved.
- Measure: this phase aims to establish the baseline, that is, the current capability of the process. This phase, according to ISO13053 (2011), can follow the following steps: select one or more critical variables to improve, define the samples to be collected, develop a plan to collect the samples, validate samples collected through Control Charts, measure the process through DPMO. Also used are tools such as: brainstorming, cause-effect diagram and spaghetti diagram
- Analyse: at this phase, the data acquired in the previous phase, is analysed statistically and aims to identify wastes, select and classify the variables of the key processes and find the bottlenecks of the current process. At this phase, we use the Boxplots to detect outliers.
- Improve: this step - through the pilot test - will present statistically the level of success of the LSS project. At this stage it is where we move from the role to the action, where we create innovative ideas and solutions. In this phase are used tools like: Brainstorming, 5S, pilot test, test to normality, DPMO and Level Sigma, are commonly used
- Control: after an LSS implementation, it is important that there is a continuous improvement and a good use of the solutions found through the implemented project. For this to happen, it is necessary to control it.

2.3. Lean Six Sigma

This methodology emerged through the combination of the Lean and Six Sigma methodologies, after it was realized that together they created a synergy (Salah et al., 2010). It aims to optimize the performance of any type of company by reducing waste and variability, creating standardized processes, reducing the possibility of defects close to zero (Smith, 2003).

According to Antony (2010), the main characteristics of this methodology are: identification of opportunities, creation and definition of projects that are focused on the objectives of the company, concern with the demands and expectations of the client, improvement of processes and the promotion of continuous improvement and increase of the company's profit.

As a rule, the application of the Lean Six Sigma methodology is applied to a process that is not guaranteeing the desired quality. One of the critical factors for the successful implementation of this methodology is the involvement of stakeholders, which sometimes create a barrier to change, and are one of the most important factors for successful LSS projects. But there are also indispensable factors for the success of these projects, such as: the involvement of top management, the understanding of Six Sigma and Lean methodology and tools, the review and follow-up of the project, the extension of a good organizational infrastructure, change of thought, among others.

According to Achanga et al. (2006), there are companies that apply Lean Six Sigma, but not always have benefited from the adoption of this methodology. The authors argue that one of the greatest barriers to the application of Lean Six Sigma is the lack of information regarding costs, results and benefits of implementing the methodology, which can lead to the failure of these projects.

3. Implementation of Lean Six Sigma

3.1. Introduction

In a first phase of this project, information was collected from the databases provided, it was possible to understand the process, and helped to lead the project in a right way, so that this Lean Six Sigma Project had the greatest possible benefit for the company and for the conclusion of this work in less than six months. It's possible to realize that a great variety of calibration equipment arrives at the laboratory: precisely 182 different types of equipment, where the multimeters and amperimetric clamps are the equipment that arrive more frequently to the laboratory. At the beginning of this project the aim was to pick up 8 types of equipment, which were the ones that came most frequently to the laboratory, that were calibrated in the same place, that use the same accessories and together represented 47% of the laboratory turnover; but it soon became clear that the time available for the project was short for such dimension, it was then decided that it would take the equipment designated by multimeters first, and if it were possible, pick up another equipment.

3.2. DMAIC

3.2.1. Define

In this phase, it was filled in the project charter as complete as possible, which was adapted to the project throughout the phases. Some aspects of the project were defined in this document as:

- Name of the project: Reduction of the time spent by the technicians who are calibrating the equipment calibrated in the first three positions;
- The location: ISQ, Tagus Park, Oeiras, Lisbon, Portugal;
- Objective: To reduce the time per point in the calibration of multimeters in 25% of the time in seconds until June 30, 2018; the time per point is the total time of calibration divided by the total points measured during the calibration;
- Importance of the problem: increased competition over the years in this sector;
- Scope of the project: measure from the moment the technician makes the first measurement to the last;
- Project calendar:

	Beginning	End
Define	10.02	24.02
Measure	24.02	23.03
Analyse	23.03	18.05
Improve	18.05	15.06
Control	15.06	30.06

Figure 1 – Calendar of each phase of the project

- Communication Plan: Meeting at Friday and Extra Meetings at Wednesday, at 09:00 a.m. until 10:00 a.m.;
- Definition of the Project Team: Marco Ferra (Champion), Sara Moreira (Team Leader), Jorge Silva (Project Owner), Technicians (Lab Technicians).

After defining the scope of the project, the SIPOC diagram was elaborated, which indicates possible relationships in the process, from the supplier to the client.

Supplier	The equipment is supplied by the laboratory coordinator, who distributes the equipment to calibrate, in the different workstations
Inputs	1. Specifications of the equipment delivered by supplier 2. Existing laboratory equipment 3. Technical procedures 4. Computers and accessories (fuses, cables, etc.)
Process	1. Initial process, in which the necessary materials for the calibration to be performed are collected 2. Calibration process 3. Collection process of materials needed for calibration (during calibration)
Outputs	Equipment calibrated with certificate and without certificate
Customers	The customer is a worker from the metrology reception, who will collect the equipment already calibrated, to be delivered to the final customer

Figura 2 – SIPOC Diagram

3.2.2. Measure

In this phase, we measure the main variables of the calibration process. Using the internal system called "LabMetro", we can see the impact of the multimeters in the laboratory, represents 18% of the Lab's turnover due to the high frequency of arrival, and there are at least 3 multimeters calibrated per day. This means that a small reduction in the calibration time spent in this calibration represents a major impact at the end of the year.

Observations were made of the calibration times (from the first measurement to the last), the position where it is being performed, the number of measured points and the type of equipment. During the calibration were found 14 occurrences that interrupted the calibration, where the most critical are highlighted in the Analyse phase. During these observations *Spaghetti* diagrams of the initial state of the system were elaborated, as shown in fig. 3 and 4.

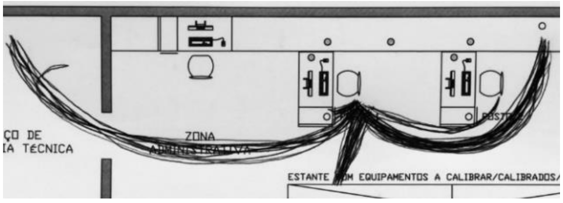

Figure 3 – Spaghetti Diagram of Post 1

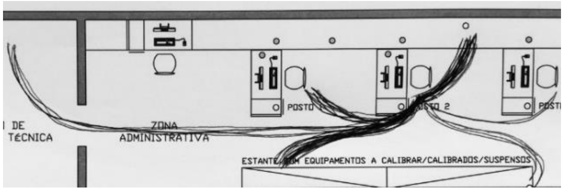

Figure 4 – Spaghetti Diagram of Post 2

A Cause Effect diagram has been developed, which helps us to have an easy view the causes that are blocking a given objective.

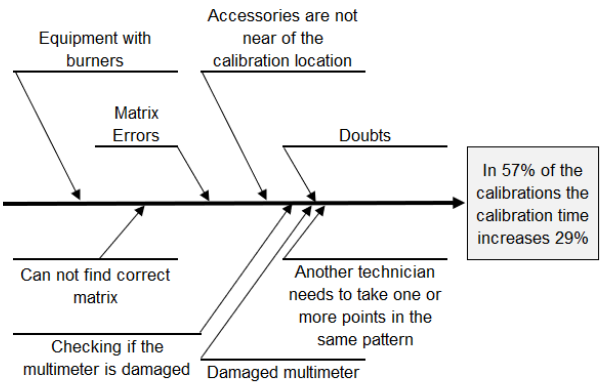

Figure 5 – Cause-Effect Diagram, 57% time increase of multimeter calibrations.

Since it was possible to collect data through observations in a daily basis, the technicians were asked to complete a document with more information about the multimeter to be calibrated. This task took a month: the process reference, the calibration technician, the day, the calibration start time, which was the type of multimeter (3,4,5,6 digits) and which posts of work were being used in the calibration (there are 3 different ones). The purpose of these observations was to understand which the most used posts and type of multimeter that arrived more frequently at the laboratory.

In this phase, we measured the sigma level of the multimeter calibration process, considering the value of the DPMO (Defects per million of opportunities), so that we can compare the impact of the Lean Six Sigma project after the Improve phase. The results are shown in the following figure.

Table 1 – DPMO and Sigma level at initial state

Measures	Initial state
DPMO (%)	41%
Sigma Level	0,2

3.2.3. Analyse

At this stage, the data collected in the Measure phase are analysed statistically, to extract relevant information, and to identify existing waste.

Regarding the sample of the calibration times, it was concluded that due to the great variability of matrices (the excel sheet were they put the measured points), where some have 10 points to measure and others have 80 points, it made more sense to use the time of the calibration divided by number of points of each matrix, in order to reduce the variability of the sample and therefore the sample size studied is in seconds. The boxplot ~~of~~ for the data in this sample showed two outliers, as can be seen in the figure 6.

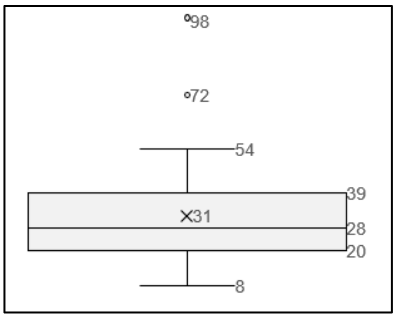

Figure 6 – Sample of times per point, with outliers (in seconds)

These two values were eliminated, and a new boxplot was performed, which did not present outliers. The sample to be used to evaluate the process is the initial sample without the observations of 98 seconds and 72 seconds.

Next, we build control charts of for the sample of calibration times per point, without the outliers. According to Costa A. et al. (2004), if the variable to be controlled is a continuous variable, it's normal to monitor this variable through two control charts, one to monitor the centrality and another to monitor the dispersion of the variable.

The graphs that are generally used to ensure this monitoring are: the sample mean (Chart I) and the sample amplitude (Chart MR).
We can conclude from Control Chart I on the figure 7, that there's a centralization of the process around the mean of the individual values, with an interval of three sigma from the central value. There's a point, observation number 25, which is slightly above the control limit, but it was decided to maintain it, as it did not have a significant discrepancy in relation to all other observations. On the Control Chart MR, we can conclude that there is not a great variation in the analyzed process. We can also see, on Chart I, that there is an initial tendency, where the time of the calibrations performed increased until the observation number 13, this can be related to the fact that the calibrations were done by two trainees, in which one of them were in the lab for the first time, and the other was a more experienced trainee.

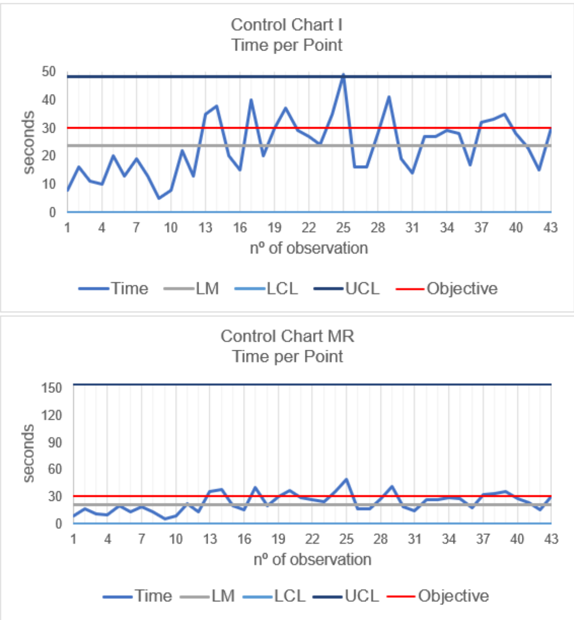

Figure 7 –Control Charts of the time per point, without outliers

There's also a limit shown - red line -that is the objective: 30 seconds. This is the time that the laboratory finds desirable for the measurement of each point.
The control charts of the total calibration time were also performed, and it was noted that there was a great variability in the process due to the variability of points to be measured, as expected.

After eliminating the outliers, the following information was obtained:

- On average the technician takes 29 seconds per point, partly fault of the occurrences;
- Calibration of a multimeter takes on average, 22 minutes;
- It's possible to calibrate 3282 multimeters annually.
- It's possible to calibrate 13 multimeters.

Through these observations it was possible to see in Figure 8 which were the most frequent occurrences (disturbances) during the calibration of multimeters, 14 in were identified, which 5 of which were highlighted by their importance.

Occurrences	Frequency	Average Time [mm:ss]
Find fuses and replace fuse	24%	06:41
Clarify doubt	16%	03:33
Fuse change	14%	03:43
Search temperature cable	11%	01:12
Change in programming	8%	10:03
Search banana cables	5%	01:06

Figure 8 – Most critical occurrences

These occurrences allowed us to understand the spaghetti diagrams presented, where the movements (lines) represent paths that the technicians make whenever any of these occurrences occur

The document completed by the technicians gave us additional information to the sample collected, such as:

- Multimeters are calibrated mainly at post 1, 51% of the time and at post 2, 48%. Only 1% of the multimeters were calibrated in post 3.
- Most multimeters are of 4 and 5 digits, 66% and 29% of the time, respectively;
- It is concluded that there is no difference in the number of calibrated multimeters during the morning and afternoon, for this analysis the available working time in the morning and in the afternoon was considered without pause times.

3.2.4. Improve

Through the results obtained in the Measure and Analyse phase, it was proposed a new layout, presented in the figure 9, that would help to reduce wasted time when occurrences happen.

In the new layout, we have the main posts standing with their backs to each other to promote the sharing of the same space, the same drawer and the same material. In the drawer between the stations, all necessary accessories for the calibration of the multimeters are placed, reducing the need to search them during the calibration. With this new layout it is expected to reduce the time of the most critical occurrences mentioned in the Analyse phase.

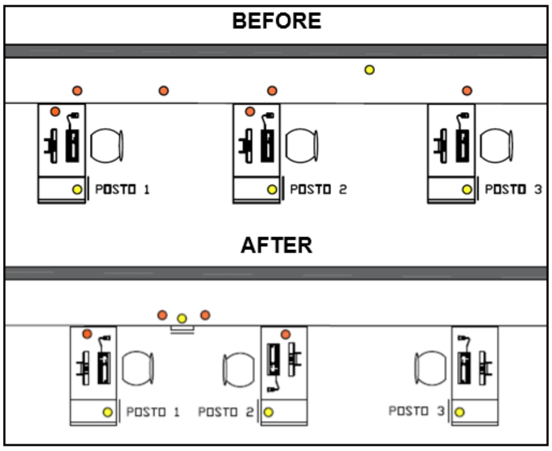

Figure 9 – Layout (Before and After)

In Figure 10, the central drawer is shown, with all the necessary accessories for the calibration of the multimeters, where there is a box with several types of fuses. The drawer is divided into two parts, on the left side we find the accessories of post 1 and the right of those of post 2, the boxes of fuses is shared.

Figure 10 – Central drawer

The necessary material exists in duplicate, to reduce the risk of the materials not being in the correct place, not interrupting the calibration.

After the layout change, a week was given before starting with the pilot test. This was because every time a process is renewed there is a period of adaptation.

During the pilot test, new spaghetti diagrams and a new sample were elaborated again, to compare the improvement of the process of the calibration of multimeters.

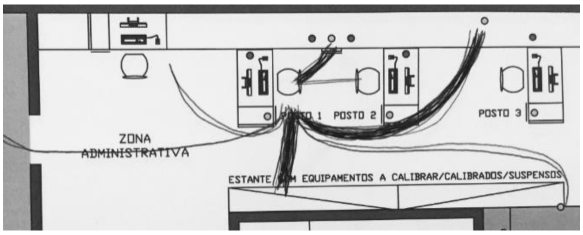

Figure 11 – Spaghetti Diagram of post 1

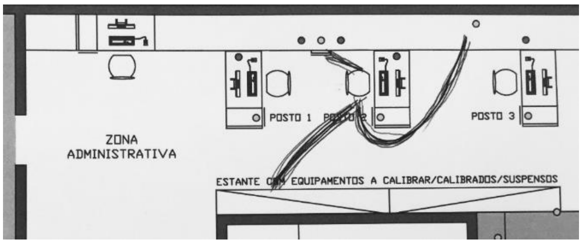

Figure 12 – Spaghetti Diagram of post 2

We can conclude that with the improvement implemented, we were able to eliminate one of the technician's major paths during the calibration and thus the technician who is in the service area is not interrupted during the meticulous work that he performs.

After the collection of new observations, the existence of outliers in the collected sample was verified, but there were no outliers. And so, we were able to analyse the new sample and verify the impact on the improved process, through the percentage of defects per million of opportunities and the sigma level, presented in the following table.

Table 2 – DPMO and Sigma level after Lean Six Sigma Project

Measures	Before	After	Difference
DPMO (%)	41%	33%	8%
Sigma Level	0,2	0,5	0,222

We can conclude that through the improvements implemented there was an improvement in the process, as we can see on the values presented in the last column of the table.

3.2.5. Control

In this phase, the 5S toolset was used, that helped to control/monitor the improved process, through the organization and management of the materials. The intention to not let the effects of the Lean Six Sigma return to as the process was before.

As the equipment is taken to outside work, and they leave the place where they usually are, have been placed shadows on the work table, which define the location of the various equipment used in these stations, identifying the location of each equipment, as we can see in the following figure.

Figure 13 – Above, post 1, below, post 2

In the central drawer shown in figure 10, the drawer material always returns to the place where it belongs, the accessories are properly identified with the place where they should be stored, and whether they belong to the post 1 or post 2.

4. Conclusions

With this work we were able to define several plans, that made this work comes to an end and be successful. The fact that this 6-month Lean Six Sigma project was implemented at the Institute of Welding and Quality posed a number of risks to this project, such as lack of commitment on the part of the company, failure of the Lean Six Sigma objectives, the project taking longer than expected, too optimistic goals and lack of time on the part of the main players of the team, causing delay in the Lean Six Sigma project. But it was with great pleasure that this project was successful, having overcome all the risks that could put at risk this work and brought benefits both to this work and to the Electrical and Radiofrequency Laboratory that was available to receive the Lean Six Sigma project.

Through this Lean Six Sigma project, it was possible to improve the process and reduce the time taken to measure each point. We can conclude that the sigma level increased by 0.3 sigma, there was an increase in the number of annual calibrations by another 287 annual calibrations, per day released enough time to do one more calibration of a multimeter and with respect to the time per point that was the main goal of this project, dropped 10 seconds, which represents a 26% decrease of time, ie exceeded the initial goal of 25%.

Although there has not been enough time to study all the equipment chosen for this project, it does not mean that it cannot be done, and therefore, future Lean Six Sigma projects can be created, following the same process used for the calibration process of the multimeters. Based on the results of this project, we can say that future projects of the same character, can improve the effectiveness and efficiency of the Laboratory, as well as increase profit.

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