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IMPROVING QUALITY IN AN ELECTRICAL SAFETY TESTING LABORATORY BY USING A SIMULATION-BASED TOOL

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ABSTRACT

This paper presents a simulation model developed with SIMIO software for representing the activities performed in an electrical measurement and test laboratory. The main goal is focused on the optimization and monitoring of the performance standards applied in the laboratory to certificate products for selling. The computer model allows identifying the principal weakness and bottlenecks of the process. Moreover, the performance measurements generated by simulation experiments are used for making decisions to enhance the current operation procedures and quality of service.

1 INTRODUCTION

According to the work published by The United Nations Industrial Development Organization (2012), over one and a half billion people, mainly in developing countries, do not have access to electricity. As their fast-growing demand for electrical energy -expected to triple by 2050- is met over the coming years, there will be a rapid increase in the use of electrical household appliances and industrial installations and, with this, a concomitant need to check the safety and quality of electrical equipment on the market. This will be a major challenge for developing countries that lack adequate electrical testing capacity.

Actually, electrical testing laboratories must comply with the requirements of the international standard ISO/IEC 17025, general requirements for the competence of testing and calibration laboratories, for demonstrating that they operate a good quality management system. For MacHaney (1991), a means of certifying quality can be through the use of computer simulation. For this author, the construction of a simulation model will provide the following benefits as recommended by most quality management programs: (i) detection of unforeseen problems prior to the design being finalized, (ii) prevention of error in system design and construction, (iii) providing additional knowledge about the system being designed, (iv) encouraging communication, and (v) helping to build in quality. For Megha (2012), process simulation aids in the improvement of quality-driven measurements, such as service level and waiting time, and resource driven measurements, such as cycle time and activity cost.

This paper aims to develop a discrete event simulation model –DES- for improving the quality procedures of the Electrical Measurement and Test Laboratory (LAMyEN), located in Santa Fe (Argentina). This organization, which complies with the requirements of ISO/IEC 17025 standard, provides services for conformity assessment of performance and safety of low-voltage electrical products in compliance with national and international standards. Actually, the use of DES into quality improvements efforts –QI- remains as an open challenging for research. Only few contributions have been reported in this direction. Spedding and Chang (2001) proposed a simulation model to improve productivity and quality, and reduce cost in manufacturing systems. Rutberg et al. (2013) conducted a simulation project for quality management in health care systems. According to these authors, most systematic QI methodologies include at least 4 phases: (1) definition of the problem to be addressed, (2) measurement and analysis of the system to be improved, (3) testing and implementation of strategies for improvement, and (4) ongoing maintenance of the newly designed process. Particularly, for improving the quality procedures of the laboratory, the DES is suited to support steps 2 and 3. The main goal is focused on the optimization and monitoring of the performance standards. The total testing time and cost are critical variables to minimize. The improvements proposed must ensure that the laboratory fulfills efficiently with the increasing number of testing arrived to the center in the last years.

2 PROBLEM DESCRIPTION

The LAMyEN provides testing services for electrical products in compliance with national and international standards. In order to ensure that an electrical product is safe for use, the product is passed through a rigorous gauntlet of testing. Among these tests are electrical safety test which are designed to test the electrical integrity of the product itself. The families of products covered by the laboratory are:

- Household and similar electrical appliances (HSE)
- Information technology equipment (ITE)
- Luminaires (LUM)
- Hand-held motor-operated electric tools (MOET)
- Special tests (ST)

Sample products are received from clients and subjected to tests that are usually both destructive and time consuming. There are three main categories of test that the laboratory may perform:

1. Type Tests carried out at first time for certifying a product with its particular standards.
2. Reduced Tests probing periodically electrical security basic characteristics after a Type Test.
3. Verification of identity using to identify a product previously tested by a Type Test.

The conformity process of a product is described in Figure 1. When the product to be certified arrives at the laboratory, a new service order is generated. Then, this task is assigned to an operator, who performs the testing and verification of the product. Finally, the resulting data is collected and a technical report is sent to both the client and the certification agency.

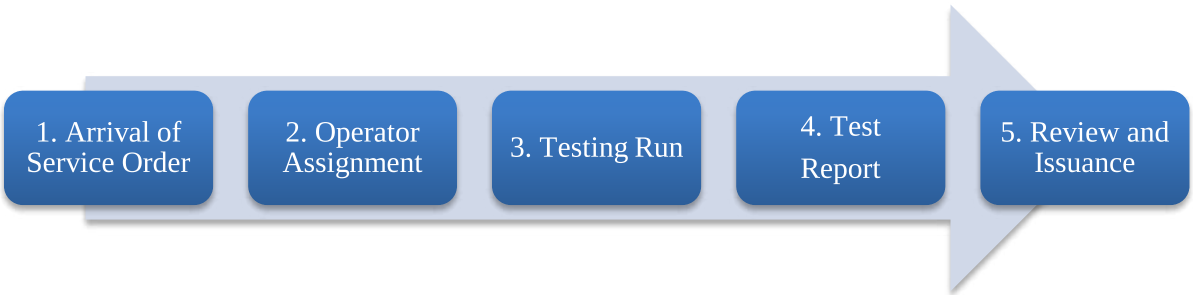


Figure 1: Electrical conformity process.

Stage 3 of conformity process depicted in Figure 1 changes according to both the type of test (type test, reduced test, or verification of identity) and the family of product to analyze (HSE, ITE, LUM, MOET, or DT). All tests are performed in logical sequence as shown in Figure 2. As seen in this picture, the laboratory operates three test chambers, Humidity, Luminaries and Duration. During testing process, the products are placed in these chambers for several hours to see how they react to different climatic conditions and operation cycles. The test chambers have a limited capacity and become critical resources for testing process.

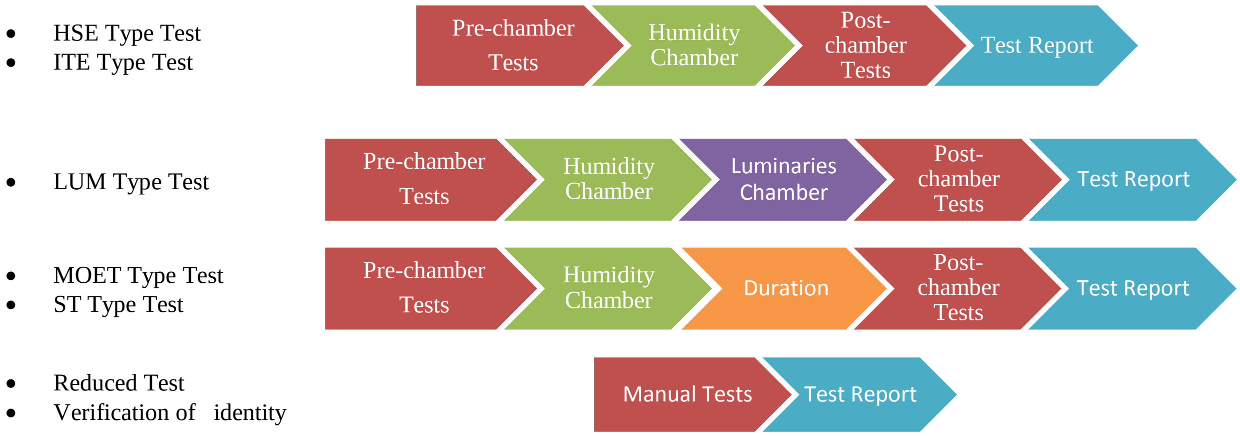


Figure 2: Electrical testing procedures.

The number of tests to be performed will also be determined by (i) the space allocated for the laboratory and (ii) the number of staff. The physical distribution of laboratory room is depicted in Figure 3 while the staff level is described in Table 1. Figure 3 shows the logical sequence that follows the products arriving for electrical testing:

1. The product is kept in administrative area until the service order will be generated and assigned to a technical operator (OP).
2. The item to be tested is transported from administrative area to the storage area.
3. When the OP assigned is available, he takes the product from the storage area and starts with the pre-chamber tests. The pre-chamber tests are performed on a dedicated table.
4. The product is placed in one of test chambers according to its type.
5. The OP collects testing data and prepares a report which is then sent to laboratory head (LH) for its control.

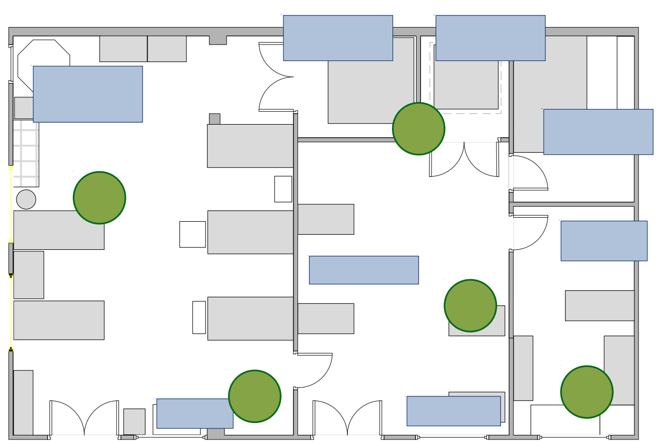


Figure 3: Physical distribution of laboratory room.

Table 1: Staff level.

Type	Number
Administrative Staff (AD)	2
Laboratory Head (LH)	2
Technical Responsible (TR)	1
Technical Operators (OP)	20

3 THE PROPOSED SIMULATION-BASED FRAMEWORK

The operation procedures performed in the laboratory were translated to a simulation model by using SIMIO software (Kelton et al. 2011). SIMIO is a simulation modeling framework based on intelligent objects. Actually, this software is used to represent a wide-range of production and service systems (Básan et al. 2014, Moretti Fioroni et al. 2014). A model in SIMIO is built by combining objects that represent the physical components of the system. An object might be a machine, robot, airplane, customer, doctor, tank, bus, ship, etc. Entities, Resources, Servers, Workstations, Sources, Sinks, Nodes, and Connectors are commonly used Objects from the Standard Library. It is worth to remark that SIMIO allows building 3D animated model which provides a moving picture of the system in operation.

Before developing the computer model, the model conceptualization was determined and then the needed input data from the real system was collected. The dynamic entities were classified according to both the family of product and the type of test to perform. In this way, we can identify the following categories:

1. HSE-T: Household and similar electrical appliances. Type tests.
2. ITE-T: Information technology equipment. Type tests.
3. LUM-T: Luminaires. Type tests.
4. MOET-T: Hand-held motor-operated electric tools. Type tests.
5. ST-T: Special tests
6. HSE-R: Household and similar electrical appliances. Reduced tests.
7. ITE-R: Information technology equipment. Reduced tests.
8. LUM-R: Luminaires. Reduced tests.
9. MOET-R: Hand-held motor-operated electric tools. Reduced tests.
10. VI: Verification of identity

The conformity process was modeled by using the standards objects provided by SIMIO. Figure 4 shows the initial basic structure of the simulation model. The Source object named Source1 is instanced to generate testing arrivals according to a weekly calendar. Once received the product to be test, a new service order is generated by the server object named WorkOrder. In SIMIO, a Server object is used for representing a capacitated process such as a machine or service operation. Then, the product is transferred to Server named Desk where pre-chambers tests are performed. Next, the products are placed in one of climatic chambers for several hours. Note that the equipment needed to perform the technical evaluation of the product is also modeled with Server Objects. Finally, the technical responsible (TR) and the laboratory head (LH) make the summary report and perform control activities, respectively.

When a new service order is generated, it has to be assigned to one of the twenty technical operators available. Each operator was represented in the model trough a Worker Object. Due to a few operators have the qualification and experience necessary to implement the international standards, it was needed to add an Operator Assignment Process to the model (see Figure 5).

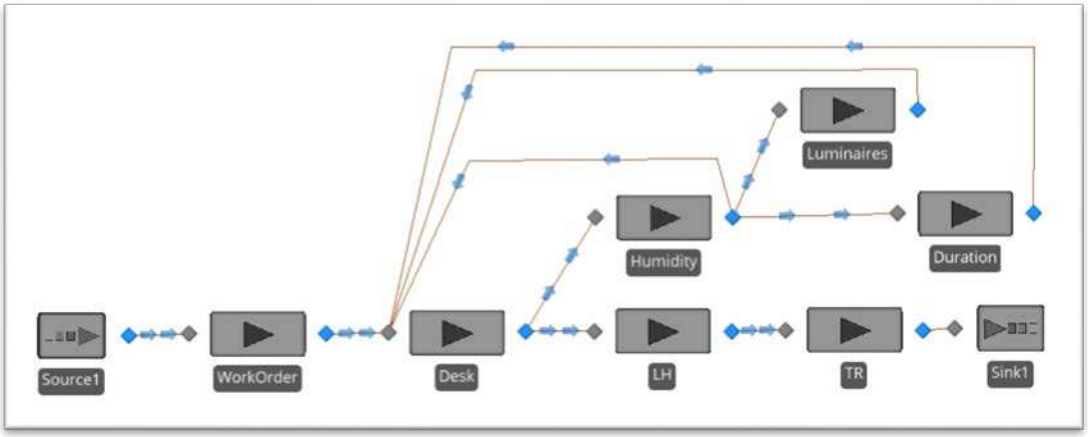


Figure 4: 2D Computer model in SIMIO.

A SIMIO process is an additional logic that can be inserted into the Standard Library objects at selected points to perform some custom logic. The work shifts are based on the work Schedule given in Figure 6. During simulation run, the quantity of orders assigned to an operator is shown in Figure 7.

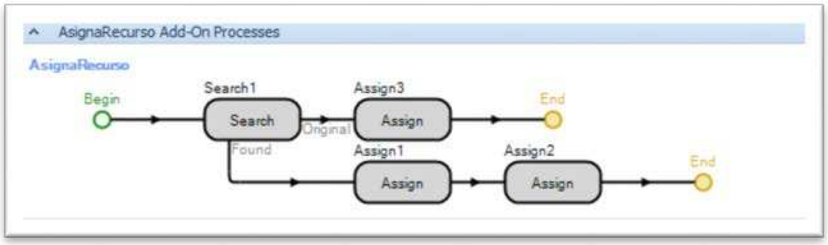


Figure 5: Operator assignment process.

Work Schedules | Day Patterns

Name	Start Date	De...	Days	Monday	Tuesday	Wednesday	Thursday	Friday	S
⊞ AD	06/01/2014		7	StandarDayOpAdmin	StandarDayOpAdmin	StandarDayOpAdmin	StandarDayOpAdmin	StandarDayOpAdmin	
⊞ LH	06/01/2014		7	JLday	JLday	JLday	JLday	JLday	
⊞ TR	06/01/2014		7	RTday	RTday	RTday	RTday	RTday	
⊞ OpDAY2	06/01/2014		7	DAY2	DAY2	DAY2	DAY2	DAY2	
⊞ OpDAY3	06/01/2014		7	DAY3	DAY3	DAY3	DAY3	DAY3	
⊞ OpDAY4	06/01/2014		7	DAY4	DAY4	DAY4	DAY4	DAY4	
⊞ OpDAY5	06/01/2014		7	DAY5	DAY5	DAY5	DAY5	DAY5	
⊞ OpDAY6	06/01/2014		7	DAY6	DAY6	DAY6	DAY6	DAY6	
⊞ OpDAY7	06/01/2014		7	DAY7	DAY7	DAY7	DAY7	DAY7	
⊞ OpDAY8	06/01/2014		7	DAY8	DAY8	DAY8	DAY8	DAY8	
⊞ OpDAY9	06/01/2014		7	DAY9	DAY9	DAY9	DAY9	DAY9	
⊞ OpDAY10	06/01/2014		7	DAY10	DAY10	DAY10	DAY10	DAY10	
⊞ OpDAY11	06/01/2014		7	DAY11	DAY11	DAY11	DAY11	DAY11	
⊞ OpDAY12	06/01/2014		7	DAY12	DAY12	DAY12	DAY12	DAY12	
⊞ OpDAY13	06/01/2014		7	DAY13	DAY13	DAY13	DAY13	DAY13	

Figure 6: Work Schedules for technical operators.

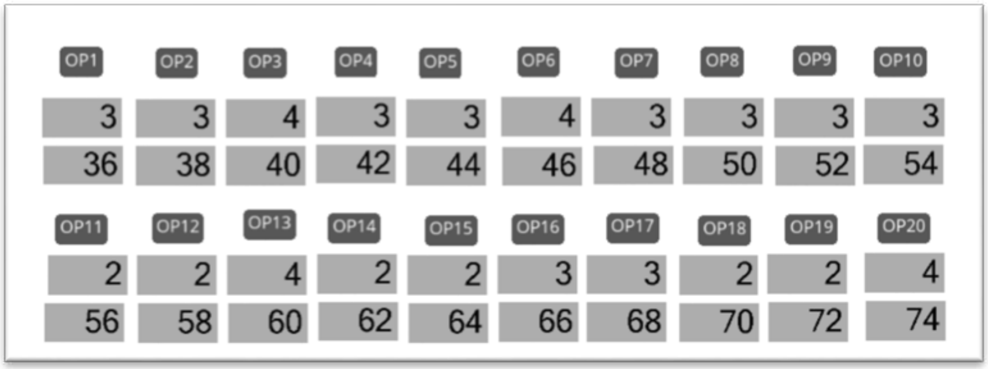
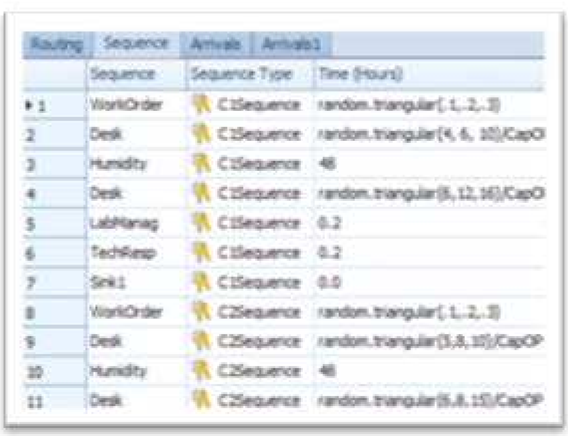


Figure 7: Simulation in-progress, quantity of orders assigned to each operator.

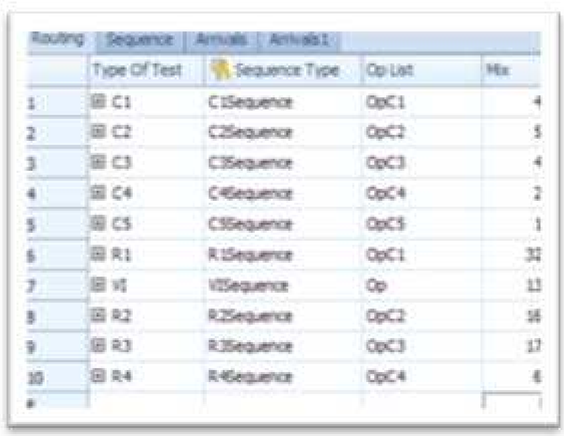
The number of tests to be performed during a time period will be determined by, among others, the equipment capabilities. As seen in Figure 4, these resources are represented as Server objects in the simulation model. At first, the products requiring a type tests are transported to the common tables (Desk) where the pre-chamber tasks are accomplished by the technical operator. The processing time at desk is different for each type of test. Then, each product is transported to the chambers for checking its performance (see Figure 2). The chambers are able to test a limited number of products per time and each product is placed in the chambers for several hours (fixed time). While the product remains in the chambers, the assigned operator is release and he can meet other service orders. Due to some products are not processed in all chambers (see Figure 2), a Sequence Table was defined to determine the routing sequence of equipment to visit for each dynamic entity (see Figure 8). Once the climatic tests were performed, the products are transported again to the desk for the post-chambers tasks. Finally, all technical data collected during the testing process is sent to servers LM and TR representing the Laboratory Manager and the Technical Responsible, respectively. Other important aspect of the real system is the laboratory physical space. Then, the equipment distribution and path spaces are considered as shown Figure 7.

The 3D view of the in-progress SIMIO model is given in Figure 8, where the green and pink rectangles represent the storage of products awaited for processing (Station Objects) while the status labels located at right of the picture shows the number of products actually placed in each chamber.



Routing | Sequence | Arrivals | Arrivals1

	Sequence	Sequence Type	Time (Hours)
1	WorkOrder	C1Sequence	random.triangular(.1,.2,.3)
2	Desk	C1Sequence	random.triangular(4, 6, 10)/CapO
3	Humidity	C1Sequence	48
4	Desk	C1Sequence	random.triangular(8,12,16)/CapO
5	LabManag	C1Sequence	0.2
6	TechResp	C1Sequence	0.2
7	Sink1	C1Sequence	0.0
8	WorkOrder	C2Sequence	random.triangular(.1,.2,.3)
9	Desk	C2Sequence	random.triangular(3,8,10)/CapOP
10	Humidity	C2Sequence	48
11	Desk	C2Sequence	random.triangular(5,8,15)/CapOP



Routing | Sequence | Arrivals | Arrivals1

	Type Of Test	Sequence Type	Op List	Mix
1	C1	C1Sequence	OpC1	4
2	C2	C2Sequence	OpC2	5
3	C3	C3Sequence	OpC3	4
4	C4	C4Sequence	OpC4	2
5	C5	C5Sequence	OpC5	1
6	R1	R1Sequence	OpC1	32
7	VI	VISequence	Op	13
8	R2	R2Sequence	OpC2	16
9	R3	R3Sequence	OpC3	17
10	R4	R4Sequence	OpC4	6

Figure 8: Routing tables.

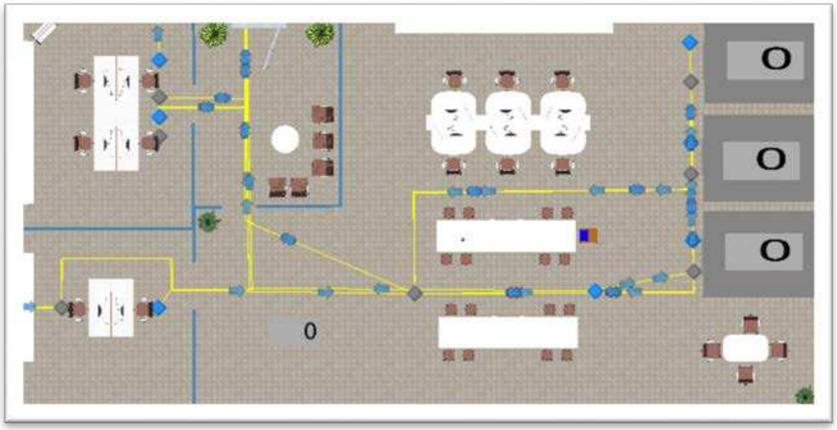


Figure 9: Physical space distribution.

Figure 10: Simulation in-progress.

4 CONDUCTING SIMULATION EXPERIMENTS

Having built the computer model, the next steps in the simulation project were the verification and validation. At first, the operational behavior of the model was observed during the simulation progress in order to detect errors that can be observed through animation. Besides, the status of variables, attributes, queues, and resources was monitored during each simulation run to verify that the model was correctly implemented in the simulation software. Next, for validation, the data collected from the real system was compared with those given by the computer model and additional adjustments were made.

For conducting simulation experiments, a 2^k design was constructed. This is usually referred to as screening design for exploring a large number of factors, each one having just two levels. The factors and involved levels in the experiment are described in Table 2. For chamber capacities, the proposed levels stand for the products number that can be tested at a given time. The skill level 1 refer to the current performance of an operator while level 1.1 represents an operator that is qualified to reduce its services times. For each combination of factor levels, five replications were run. The response variable to measure was the total process time.

Table 2: 2^k experimental design.

Factor	Low	High
Humidity Chamber Capacity (HCC)	5	10
Luminaries Chamber Capacity (LCC)	4	6
Duration Chamber Capacity (DCC)	2	4
Operator Skill (OS)	1	1,1

SIMIO software was used to run the experiments and to obtain total process time. Then, all data was translated to MINITAB 16 software for performing the analysis of variance (ANOVA). For example, for household and similar electrical appliances (HSE-T), the output results showed in the following pictures were obtained. The Pareto Chart and Normal Plot of the factors and interactions effects are given in Figure 11. The Pareto Chart is used to determine the magnitude and the importance of effects while the Normal Plot of the Standardized Effects displays negative and positive effects, both of them on the left side or right side of the line. From Figure 11, factors with significant effects on the response variable are the Humidity Chamber Capacity and the Operator Skill.

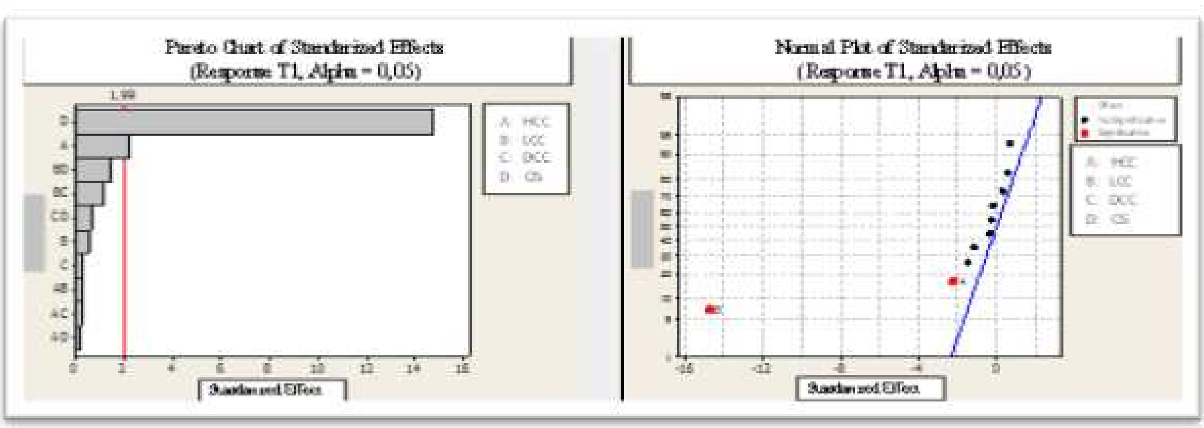


Figure 11: Pareto Chart and Normal Plot of Standardized Effects.

The ANOVA for the HSE-T category is shown in Figure 12. A small p-value (<0.05, level of significance) indicates that the two factors referenced above have statistically significant effect on the response variable. Moreover, the main effects plots and the interactions plot are given in Figure 13. Note that the lines corresponding to Humidity Chamber Capacity and Operator Skill in the main effects plot are not horizontal because they affect variable response. The analysis described above was performed for each product category to test. The factors that have a significant effect on the total process type of each type of test are resumed in Table 3.

Once conducting the simulation experiments, news polices were evaluated in order to enhance the current process performance. In this step, the scenarios described in Table 4 were proposed.

The response variable, i.e. total process time, is decreased in Scenario 1 with regards to the original configuration. In this first scenario, we conclude that the number of operators needed is 11. In Scenario 2, the performance measurements are also enhancement but in this configuration the number of operators used is decreased from 11 to 8. As conclusion, recruiting more highly specialized people is a key to the success of the laboratory.

Source	GL	SC Sec.	SC Ajust.	CM Ajust.	F	P
Principal Efects	4	32,8766	32,8766	8,2191	55,60	0,000
HCC	1	0,7229	0,7229	0,7229	4,89	0,030
LCC	1	0,0444	0,0444	0,0444	0,30	0,585
DCC	1	0,0163	0,0163	0,0163	0,11	0,741
OS	1	32,0929	32,0929	32,0929	217,09	0,000
2-Interactions	6	0,6148	0,6148	0,1025	0,69	0,656
HCC*LCC	1	0,0145	0,0145	0,0145	0,10	0,755
HCC*DCC	1	0,0078	0,0078	0,0078	0,05	0,819
HCC*OS	1	0,0049	0,0049	0,0049	0,03	0,855
LCC*DCC	1	0,1971	0,1971	0,1971	1,33	0,252
LCC*OS	1	0,3253	0,3253	0,3253	2,20	0,143
DCC*OS	1	0,0653	0,0653	0,0653	0,44	0,509
Residual error	69	10,2004	10,2004	0,1478		
Lack of fit	5	1,1618	1,1618	0,2324	1,65	0,161
Pure error	64	9,0387	9,0387	0,1412		
Total	79	43,6918				

Figure 12: ANOVA.

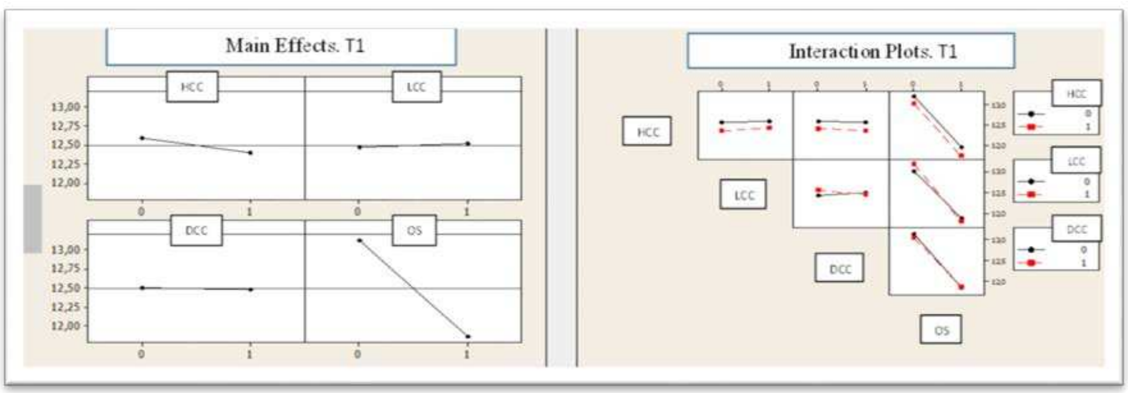


Figure 13: Main Effects and Interaction Plots.

Table 3: Significant factors for each type of test.

HSE-T: Household and similar electrical appliances. Type tests.	– Humidity chamber – Operator skill
ITE-T: Information technology equipment. Type tests.	– Humidity chamber – Operator skill
LUM-T: Luminaires. Type tests.	– Luminaires chamber – Operator skill
MOET-T: Hand-held motor-operated electric tools. Type tests.	– Operator skill
ST-T: Special tests	– Duration chamber – Operator skill
HSE-R: Household and similar electrical appliances. Reduced tests.	– Operator skill
ITE-R: Information technology equipment. Reduced tests.	– Operator skill
LUM-R: Luminaires. Reduced tests.	– Operator skill
MOET-R: Hand-held motor-operated electric tools. Reduced tests.	– Operator skill
VI: Verification of identity	– Operator skill

Table 4: Alternative scenarios.

	New Policies
Scenario 1	Work Shift of 8 hours Each operator is capacitated for performing only one types of test
Scenario 2	Work Shift of 8 hours Each operator is capacitated for performing all types of test

5 CONCLUSIONS

This work has presented the development and application of a simulation-based framework for improving the operational activities of an Electrical Measurement and Test Laboratory for electrical safety security of appliances. The principal aims it to provide a systematic methodology that allows testing different measures of effectiveness and performance rates for the system. SIMIO simulation software and Minitab statistic software were suitable to carry out laboratory activities representation. The simulation model, which presents a user-friendly interface, is actually used for making operative, tactical and strategic decisions though the evaluation of different operative schemas and possible alternatives of investment.

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