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How to compare energy efficiency inspection tests on TVs?

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Abstract

It is a case study conducted in company X of the electronic branch located in the Industrial Pole of Manaus (PIM), the capital of Amazonas–Brazil. The problem was the need to develop a benchmarking involving energy efficiency inspection tests on televisions. The objective is to compare the performance of the standard method and the new method of performing the energy efficiency inspection test. To this end, quality tools were applied with data collected from the use of the time study of each test step. After data collection and analysis, it was concluded that the new test: a) has 67% of its steps performed automatically and 43% manually, its average lead time is 4h14min34, a gain of 33.5% in total time required to perform the test; b) can be developed with the application of Brainstorming, Ishikawa Diagram, GUT Matrix, PDCA, Vertical Flowchart in conjunction with Chrono-analysis. It is worth highlighting the importance of the local top management support so that each of these tools is used with autonomy and creativity by the collaborators involved in the project.

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1. Introduction

The Manaus Industrial Pole (PIM) is located in the State of Amazonas (Brazil) and has three economic poles: commercial, industrial and agricultural, with the industrial pole being its base of support. PIM has about 600 high-tech companies creating more than half a million direct and indirect jobs, mainly in the electronics, two-wheel and chemical segments (SUFRAMA, 2016). PIM concentrates some of the largest and most important electronics manufacturers in Brazil. The electronics sector is the largest employer of laborer and receives the most investments among all segments.

According to data from the Manaus Free Trade Zone Supervisor (SUFRAMA), 46 companies are responsible for the electronics production that involves more than 27,000 employees (SUFRAMA, 2015), primarily mobile phones, audio, and video devices, as well as televisions, etc. Among the electronics companies, this study was conducted in an organization responsible for producing tablets, smartphones, media players, video cameras, computer monitors, televisions and appliances.

For private reasons, the organization in question will be named as Company X and the study took place in June 2016 in the quality assurance sector, responsible for performing reliability tests on televisions, before and after being introduced into the market.

However, it focused on one of the reliability tests, the energy efficiency verification test, considered relevant both to guide customers and televisions to receive Inmetro's National Energy Conservation Label (ENCE), the Procel Seal that ranks products according to energy consumption and/or energy efficiency, measured in kWh/month.

1.1 Problem formulation

The Energy Efficiency Inspection Test on televisions, conducted manually at Company X, was not reaching the high volume of new television models to be inspected, leading to delays in completing the reliability tests. Given this scenario, senior management opted in July 2015 to automate the energy efficiency inspection test on televisions to make it more efficient in facing the volume of televisions to be inspected. This required investments in new equipment, training of employees, proper space for testing and installation of equipment. Since the implementation of the new inspection test (January 2016), no studies had been conducted to measure the efficiency of the new test, comparing it with the previous one.
So, the main question of the research is “how to analyze the efficiency of a new inspection test method aimed to reach the increase in TV set production volume?”
To this end, a bibliographic study on the quality tools was performed, as well as quantitative considering the time variable as the object of research, both for the old and the new inspection test, since the collection of the execution time of each method operations.

1.2 Importance of Research

At the time the study was being designed, data from the 25th Annual Survey on the Use of Information Technology (FGV, 2014) were used to identify that in 2013, 97% of the Brazilian population (Table 1) had a television in its residence, above worldwide average (72%).

Table 1 - Consumer electro-electronics and appliances in Brazilian households (value in millions).

PRODUCT	2007		2008		2009		2011		2012		2013	
Stove	55,282	99,9%	56,541	98,2%	57,638	98,4%	60,447	98,8%	62,063	98,75%	64,323	98,76%
Television	53,218	96,2%	54,753	95,1%	56,043	95,7%	59,381	96,9%	61,092	97,20%	**63,281**	**97,16%**
Refrigerators	51,158	92,4%	52,989	92,1%	54,716	93,4%	58,690	95,8%	60,744	96,65%	63,315	97,21%
Radio	49,641	89,7%	51,173	88,9%	51,466	87,9%	51,135	83,4%	50,821	80,86%	49,311	75,71%
Washing machine	22,259	40,2%	23,899	41,5%	25,968	44,3%	31,250	51%	34,654	55,14%	37,421	57,46%
Freezer	9,188	16,6%	9,236	16%	8,919	15,2%	10,077	16,4%	10,460	16,66%	11,103	17,05%

Source: FGV (2014).

Analyzing the evolution of the numbers in Table 1 for the year 2019, in May 2019 (FGV, 2019 p. 7) the percentage of households with TV was 119%, while the world average was 91%. Given the above, there is a need for companies to increasingly present products with high-quality standards to meet the demands of customers and regulatory agencies, focusing on continuous improvement of processes and products.
Thus, to remain competitive, Company X realized the need to improve the efficiency inspection test on televisions, which is why this study is relevant because it seeks to complement the investments made by comparing the performance of two methods of performing the television inspection test to simplify

processes, reduce lead time and increase the capacity of inspection samples. The research is relevant to the academy, as it offers a case study involving the use of quality tools in conjunction with the scientific methodology, whose knowledge generated can serve for the reflection of interested researchers on the subject, as well as for teachers for discussion in the classroom. For customers, the research contributes to guarantee the quality standard, by inspecting the energy consumption values of televisions in a more thorough and agile way. For the environment, it has its importance, as it reduces energy consumption in Brazil, minimizing environmental impacts and promoting the rational use of energy.

1.3 Objectives

The overall objective is to compare the performance of two methods (standard and experimental) for performing the energy efficiency inspection test on televisions.

The specific objectives are:

(a) to diagnose the performance of the standard inspection test used to estimate energy efficiency on televisions in the quality assurance sector;

b) to analyze the performance of the experimental (new) energy efficiency inspection test on televisions applied in the quality assurance sector;

c) to identify the positive points acquired as a consequence of the automation of the experimental inspection test, as well as propose the suggestion of new research for the academy and managers of the organization.

2. Theoretical Referential

2.1 Regulatory Agencies

Brazil has several institutions that regularly deal with energy efficiency, such as:

• Ministry of Mines and Energy (MME);

• ELETROBRÁS, responsible for the execution of the National Program for Conservation of Electric Energy (PROCEL);

• PETROBRÁS, responsible for the execution of the National Program for the Rationalization of the Use of Oil and Natural Gas Derivatives (CONCEP);

• National Agency of Electric Energy (ANEEL), responsible for the performance of the Energy Efficiency Program of the Electricity Distribution Concessionaires (PEE);

• The distribution concessionaires;

• National Institute of Metrology, Standardization and Industrial Quality (INMETRO), responsible for the achievement of the Brazilian Labeling Program (PBE).

In addition to these institutions, there are also industrial companies that have internal energy conservation programs. Others deal with the theme transversely or even sporadically. However, for this research, the INMETRO regulatory agency will be emphasized, more specifically for being responsible for the PBE.

2.2 INMETRO and PBE

INMETRO is a federal agency, linked to the Ministry of Development, Industry and Foreign Trade, which acts as Executive Secretariat of the National Council of Metrology, Standardization and Industrial Quality

(CONMETRO), inter-ministerial collegiate, which is the normative agency of the National Metrology System, Standardization and Industrial Quality (SINMETRO). In its institutional mission, INMETRO aims to strengthen national companies, increasing their productivity through the adoption of mechanisms aimed at improving the quality of products and services. Its mission is to provide Brazilian society with confidence in measurements and products through metrology and conformity assessment, promoting the harmonization of consumer relations, innovation, and the country's competitiveness.

The Brazilian Labeling Program (PBE) is a performance labeling program coordinated by INMETRO. The PBE emerged from an initiative by INMETRO with society to create performance-focused conformity assessment programs to contribute to the rationalization of energy use in Brazil by providing information about the energy efficiency of the equipment available in the market. Therefore, there are conformity assessment programs that use the National Energy Conservation Label to provide information on product performance concerning energy efficiency (VIANA et al., 2012).

According to Viana et al. (2012), the objectives of the PBE are:

• Provide useful information that influences consumers' purchasing decisions, which may take into account other attributes than the price at the time of product purchase;

• Stimulate industry competitiveness by inducing the process of continuous improvement promoted by conscious consumer choice.

Products are subjected to laboratory testing, where they receive labels that differentiate them by the efficiency rating from “A” (most efficient) to least efficient “G” depending on the product.

2.3 Energy efficiency label

The energy efficiency label is the seal of conformity that evidences the fulfillment of the performance requirements established by the technical norms and regulations, being this one of the product entry points to the sales points. Its main purpose is to inform consumers when buying the characteristics of appliances using the efficiency rating to identify the most and least efficient.

Each appliance line has its label, changing according to the technical characteristics of each product. For televisions, the rating ranges from A (most efficient) to E (least efficient). Figure 1 is an example of a standard label for televisions. It contains the Manufacturer Name (Nome do fabricante), equipment type (tipo de equipamento), logo, Energy Efficiency Indication (indicação da eficiência energética), Model, Screen Size in cm (tamanho da tela em cm), Screen Size in inch (tamanho da tela em polegada), Energy Consumption Indication in kWh/month (consumo de energia em kWh/mês).

2.4 Energy efficiency (EE)

Because of the 1970s`s oil crises, several countries sought to find other ways to generate and conserve energy. However, the issue involving EE becomes relevant in the 1990s because of the greenhouse effect, widely debated at international events as Stockholm Conference 1972; Rio 92, Rio +10 (MENKES, 2004 p. 1).

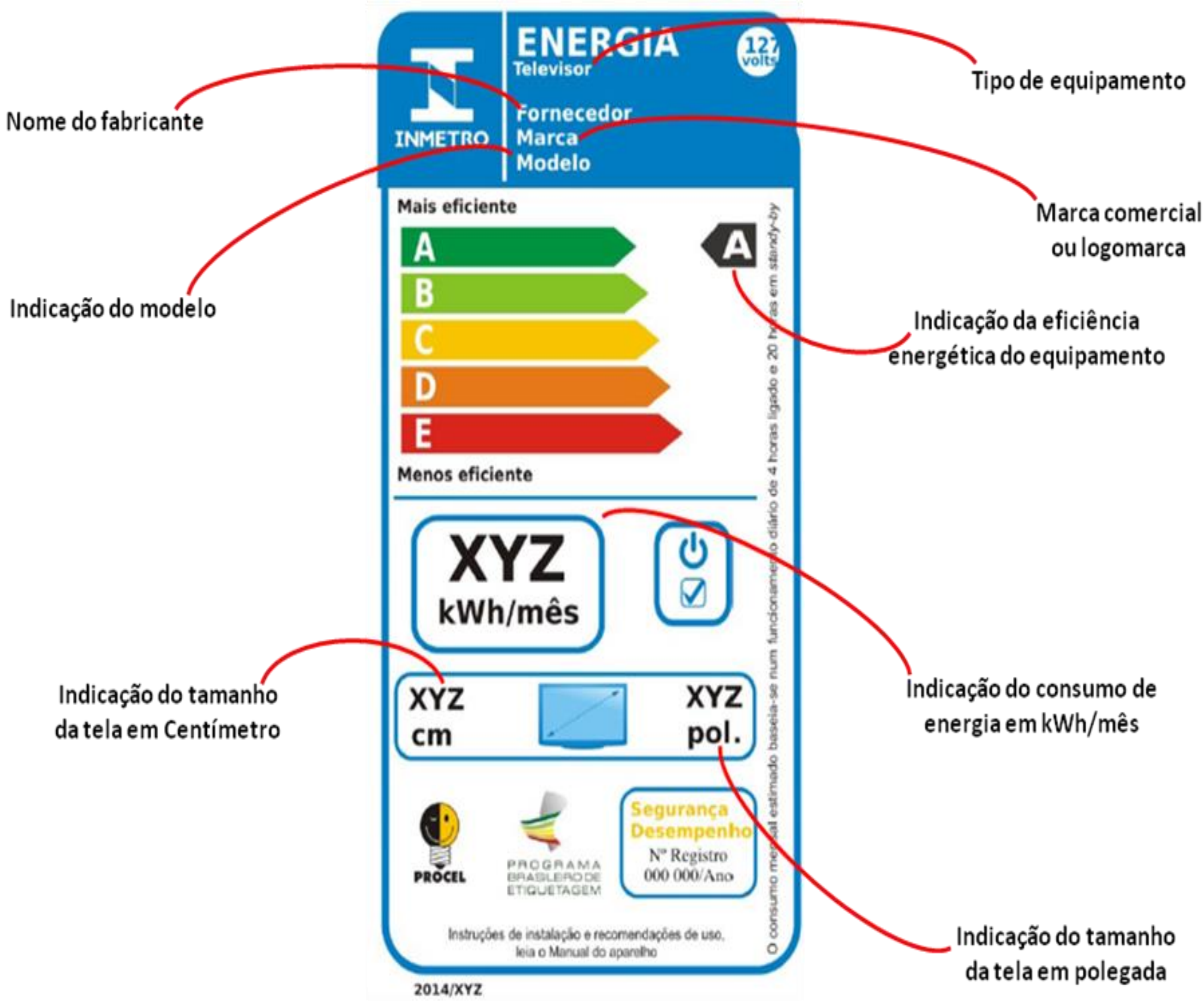


Figure 1 - Energy Efficiency Standard Label of televisions in Brazil
Source: Adapted from Portaria n.º 563 – INMETRO (2014).

According to the US National Policy Development Group, EE is the ability to use less energy to produce the same amount of lighting, heating, transportation and other energy-based services.

For the Brazilian Association of Energy Conservation Service Companies (ABESCO), EE is an activity that seeks to improve the use of energy sources, trying to do more with less. EE comes from the relationship between the amount of energy employed in an activity and that which is available for its performance.

Some authors believe that EE can be used as one of the best policies to be adopted by countries to reduce the greenhouse effect and contribute to the economy (CALILI; SOUZA, 2013 p.85).

Based on the previous definitions, the concept adopted about EE in this research is the optimization of the use of the electric power supplied to reduce the waste and still obtain a great performance of the appliance.

2.5 Quality

It may not be important to have a universal definition of the term quality, but it is important to understand it, regardless of the industry in which it operates, since quality is fundamental for companies, not only because of the offer of good products and services but also due to the continuous improvement of their production processes (ALGARTE, 2000).

Kotler (2000) says that, according to the American Society for Quality Control, quality is the totality of attributes and characteristics of a product or service that affect its ability to satisfy stated or implied needs. In summary, there are several concepts of quality in the literature, some famous for the spread of various gurus:

For Deming, quality means satisfying customers now and in the future; for Juran, it means suitability for use or conformance to specifications, while Crosby defined quality as an adaptation to the requirements; Ishikawa believed that quality is an opportunity for continuous improvement, while Feigenbaum focused on total quality involving all sectors of the organization, Taguchi saw quality as a value for society (HASSAN et. al., 2000).

The term quality has been used in many situations and has evolved following administrative thinking over time, so each company must reflect and adopt its concept, the most appropriate tools and methodologies for your reality. Regarding the classification of the use of quality tools with some methodologies used in quality management, it is recommended to read the article "Basic Quality Tools in Continuous Improvement Process" written by Sokovic et al. (2009).

This article present the use of the 7 quality tools (Figures 2, 3 and Table 2) in the process of problem identification and analysis, as well as in three methodologies used for continuous improvement such as PDCA-Cycle, DMAIC and DMADV.

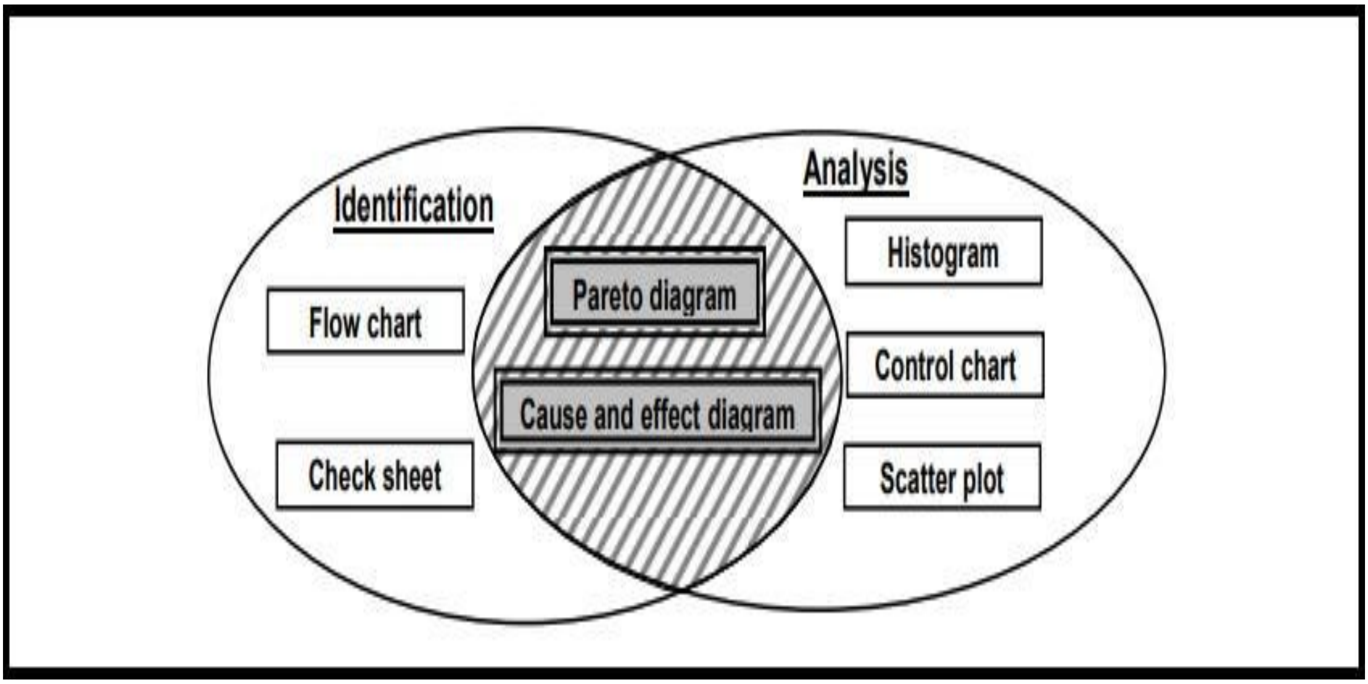


Figure 2 – Use of 7 quality tools in the process of identify and problems analysis.

Source: Sokovic et al. (2009 p. 2)

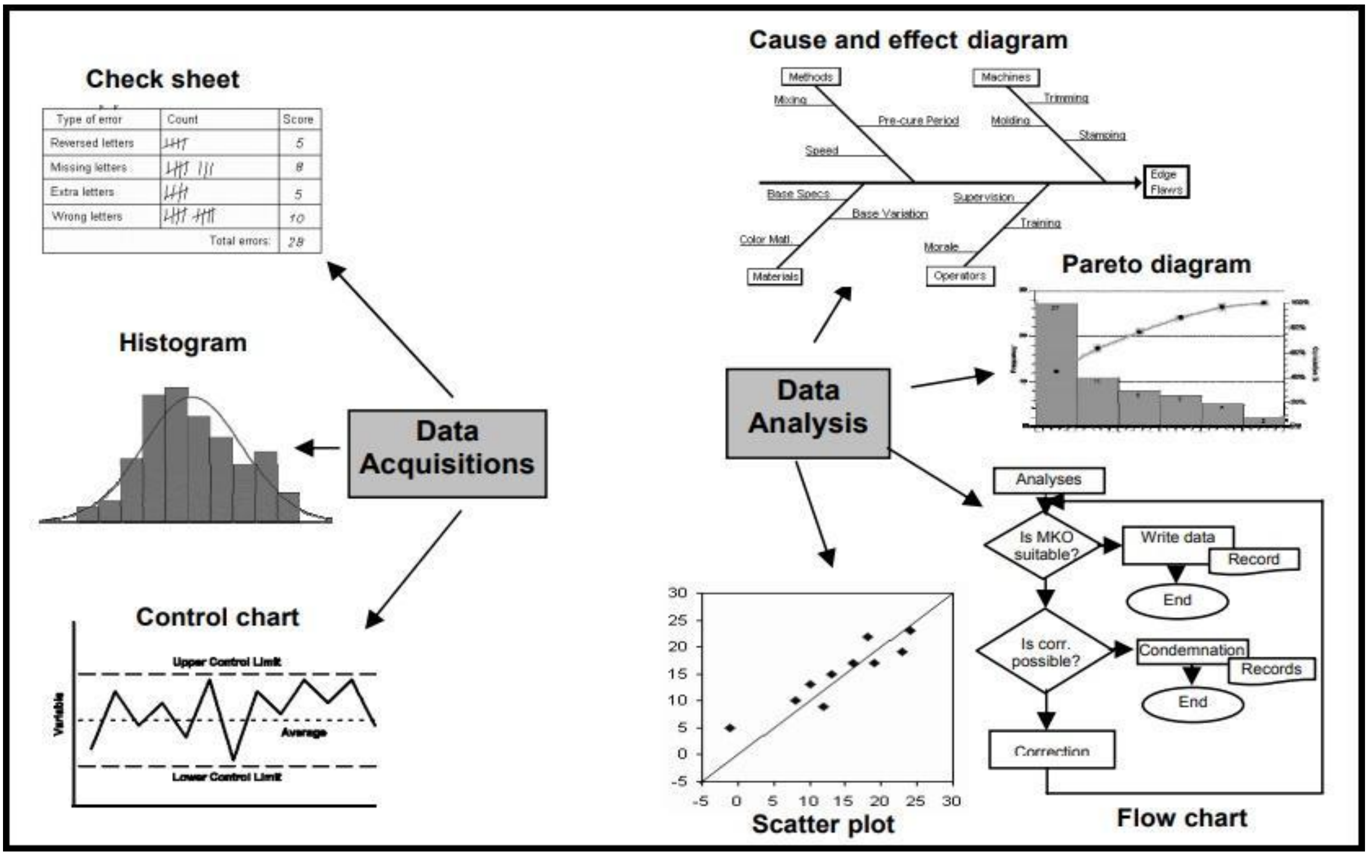


Figure 3 – The 7 traditional quality tools for data acquisition and analysis

Source: Sokovic et al. (2009 p. 3)

Methodology / Tools and techniques	Continuous improvement (PDCA-cycle)							Six Sigma (DMAIC)					Design for Six Sigma (DMADV)				
	Identify opportunity	Analyze the process	Develop solutions	Implement solutions	Evaluate results	Standardize solutions	Plan for the future	Define	Measure	Analyze	Improve	Control	Define	Measure	Analyze	Design	Verify
7 QC tools																	
Cause-and-Effect diagram		x								x				X			
Control chart			x		X				x		x	x				x	x
Check sheet	x												x				
Histogram	x								x				x				
Pareto diagram					X				x		x		x	X			x
Scatter diagram		x			X					x		x		X			
Flowchart																	
• Deployment flowchart	x	x	x			x							x				
• Linear or activity flowchart	x	x	x			x							x				
• Opportunity flowchart		x	x			x							x				

Table 2 – Application of quality tools in 3 continuous improvement methodologies

Fonte: Sokovic et al. (2009 p. 7)

The concept of continuous improvement was a cornerstone of the Eastern quality model, with the systematic use of the PDCA cycle (Plan, Do, Check, Action), created by Dr. Walter Shewhart in the 1920s and disseminated by Dr. Edward Deming during the reconstruction of Japan, which became known as the organizational learning cycle.

In summary, the PDCA represents the problem-solving cycle, used to perform stepwise improvements and repeat the cycle several times (SHIBA, 1997). According to Werkema (1995), the PDCA cycle is a management method that represents the path to be followed so that the established goals can be achieved. In the use of the method, it is necessary to employ several tools, it may constitute the necessary resources for the collection, processing and administration of the information necessary to conduct the PDCA steps.

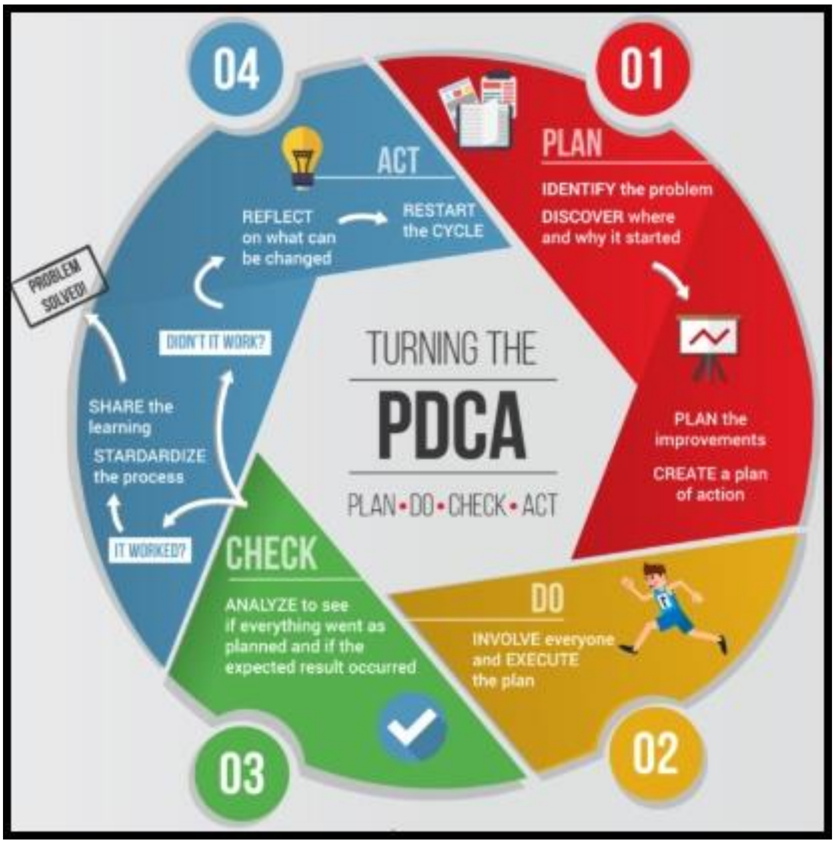


Figure 4 – Ciclo de Aprendizagem Organizacional PDCA
Source: Siteware < https://www.siteware.com.br/en>

The organizational learning happens when the cycle rotates over time with a series of actions involving clearly defining the problem, goal, plan building, plan implementation, training, delegation of responsibility, resource allocation, development of structures, definition of indicators, evaluation of results, standardization and dissemination of documents and good practices, correction plan, etc.

By completing one rotation over time, the company or team has accumulated enough experience for the next rotation, errors are reduced, and actions are performed more efficiently and effectively.

That is why PDCA is more than a tool, it is a powerful methodology in the process of continuous improvement of the organization (Figure 5), being used today with a high degree of evolution in several companies in Japan, considered the benchmark in quality.

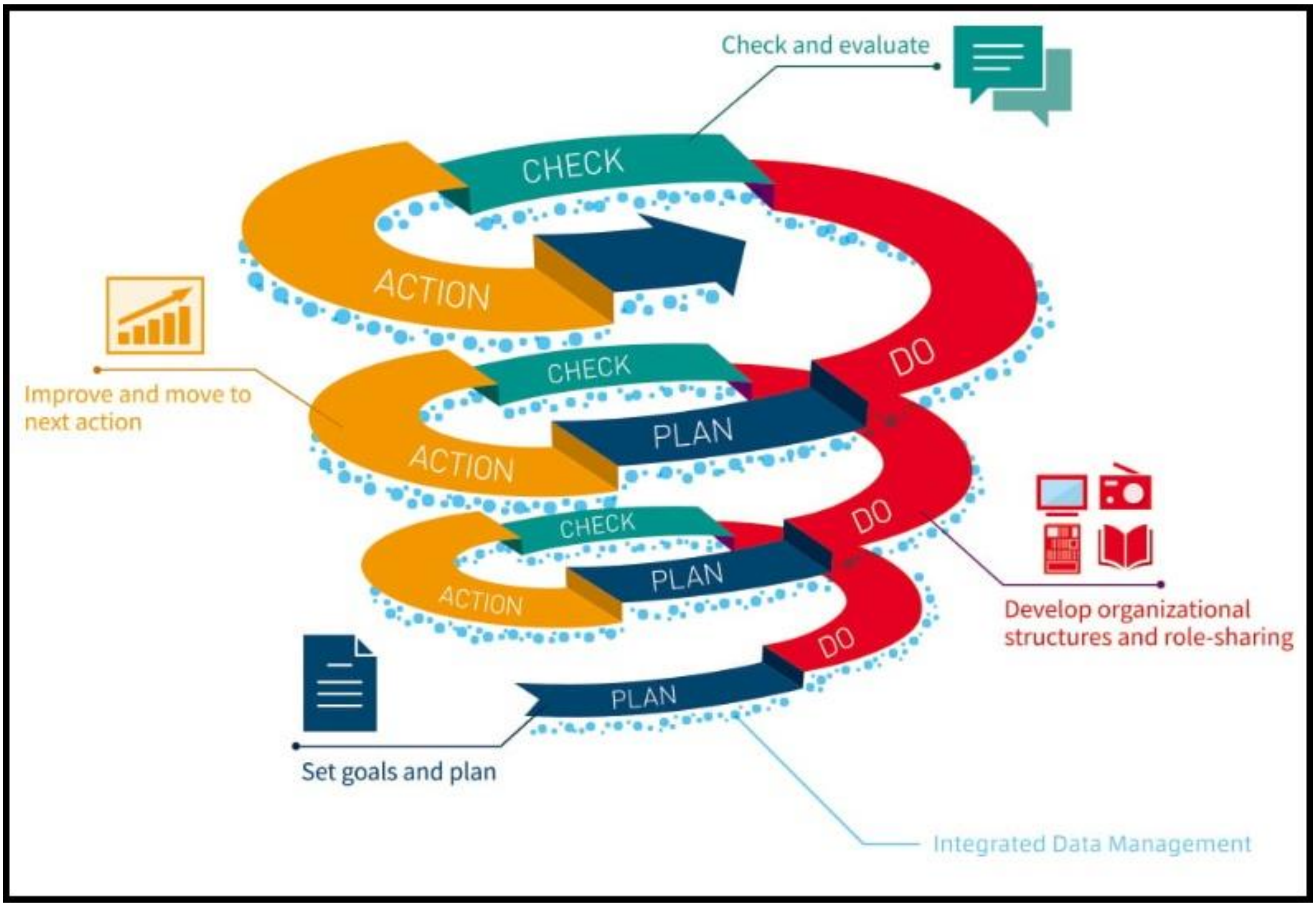


Figure 5 – Improvements promoved by the PDCA rotation
Source: Asahi advertising <asakonet.co.jp>

Regarding the quality tools, only the Flowchart, the GUT Matrix, and the Ishikawa Diagram will be reviewed, because of their application in this research.

2.5.1 Vertical Flowchart to compare process

A flowchart is a type of diagram that describes the processes. Although it is one of the most widely used tools in quality management, it is not clear who invented it, but the first records of documented standardization of flowcharts were introduced in 1921 by the Frank and Lilian Gilbreth (GILBRETH; GILBRETH, 1921) when presented to members of the American Society of Mechanical Engineers (ASME) a method called "Process Charts: First Steps in Finding the Best Way to Work."

The document with 24 pages is organized with the following topics: a) First step in finding the one best way to do work; b) Place of Process Chart in Management; c) Field of application; d) Simplicity of the process chart; e) Collecting the information; f) Utilising information; and g) Relation to standardization with symbols introduction and application (Figure 6 left side).

Besides, it is worth remembering that for the field of mathematics and electronic computing, two researchers made their contribution, Goldstine and Neumann (1947 and 1948) when they published a report at the Princeton University Institute for Advanced Studies, containing 194 pages on logical aspects and mathematicians of an electronic computing instrument (Figure 6 right side).

The preface of the report contains: 7.0 General principles of coding and flow-Diagramming; 8.0 Coding of typical elementary problems; 9.0 Coding of problems dealing with digital character of the numbers processed by machine; 10.0 Coding of some analytical problems; 11.0 Coding of some combinatorial problem.

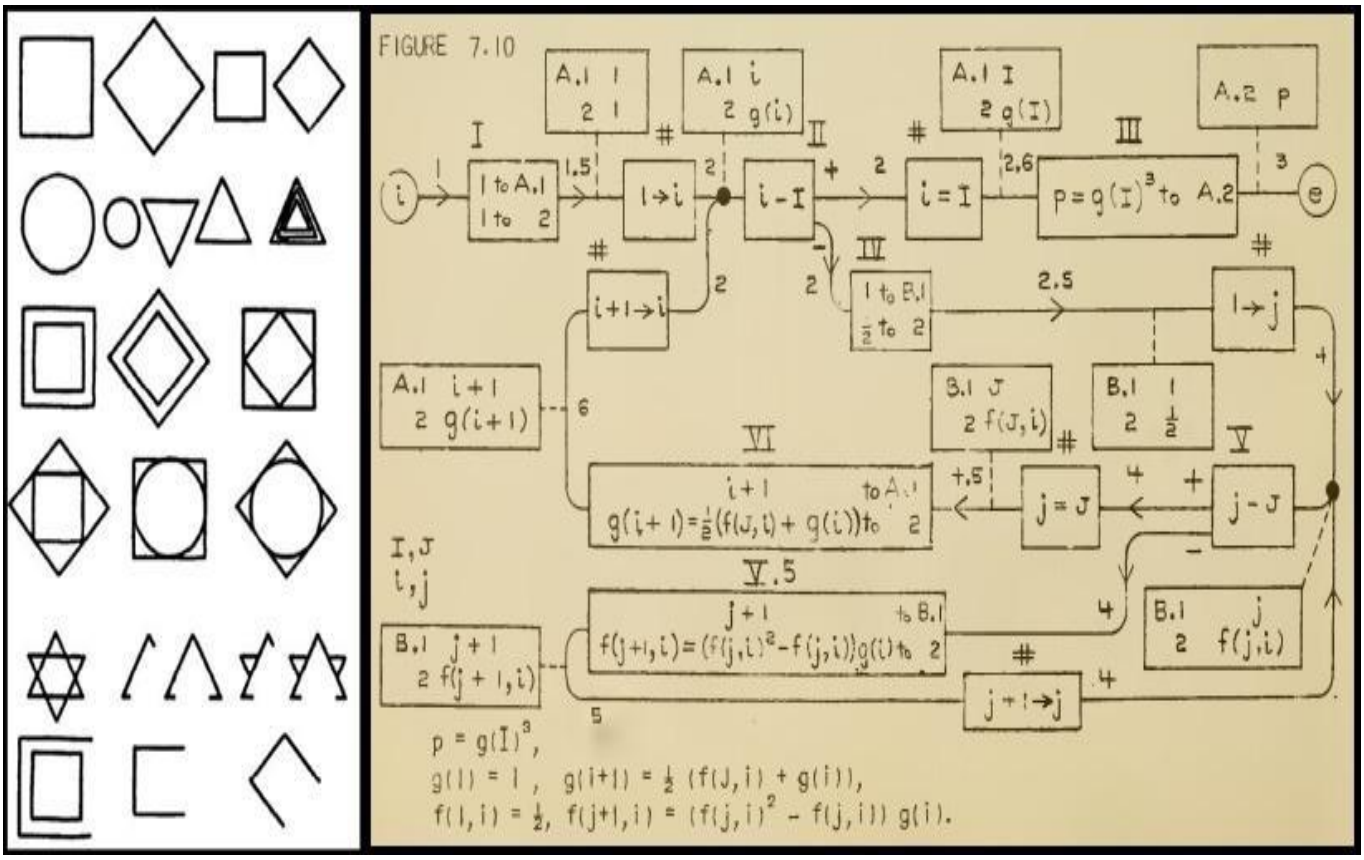


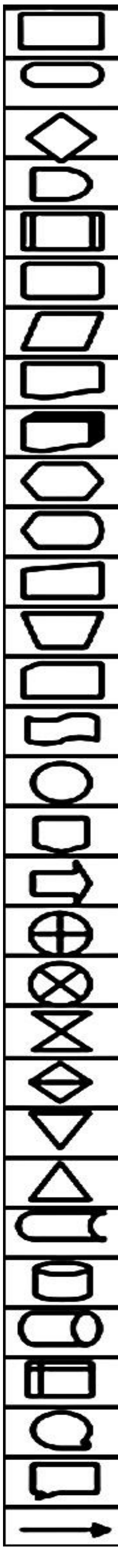
Figure 6 – Symbols examples used for Flowchart developed by Gilbreth, Goldstine and Neumann
Sources: Gilbreth and Gilbreth (1921 p.11); Goldstine and Neumann (1947 and 1948 p. 18)

Although the presentation was made in 1921, ASME only adopted the Gilbreths, Goldstine, and Newmann symbols in 1947.

However, it was from 1949 that the flowchart was used on a larger scale in companies (Figure 7) and universities when the American National Standards Institute (ANSI) set standards for flowcharts and their symbols in 1960 being revised over the years (eg ANSI X3.5, 1970), as well as the International Organization for Standardization (ISO 1028: 1973), adopted ANSI symbols in 1970, revised in 1985 (ISO 5807: 1985 replaced ANSI X3.5, 1970).

Currently, the flowchart is widely used by production managers to analyze production systems, seeking to identify opportunities to improve process efficiency (PEINADO; GRAEML, 2007).

In the market, there are several types of flowcharts, but for the purpose of this research, it is approached about the Vertical Flowchart, as it is very useful to present the basic information of the sector or department, to map processes, to connect the symbols, as well as to insert the execution time of each activity and the space traveled by the person responsible for the activity.



Process	An operation or action step.
Terminator	A start or stop point in a process.
Decision	A question or branch in the process.
Delay	A waiting period.
Predefined Process	A formaly defined sub-process.
Alternate Process	An alternate to the normal process step.
Data (I/O)	Indicates data inputs and outputs to and from a process.
Document	A document or report.
Multi-Document	Same as Document, except, well, multiple documents.
Preparation	A preparation or set-up process step.
Display	A machine display.
Manual Input	Manually input into a system.
Manual Operation	A process step that isn't automated.
Card	A old computer punch card.
Punched Tape	An old computer punched tape input.
Connector	A jump from one point to another.
Off-Page Connector	Continuation onto another page.
Transfer	Transfer of materials.
Or	Logical OR
Summing Junction	Logical AND
Collate	Organizing data into a standard format or arrangement.
Sort	Sorting of data into some pre-defined order.
Merge (Storage)	Merge multiple processes into one. Also used to show raw material storage.
Extract (Measurement) (Finished Goods)	Extract (split processes) or more commonly - a measurement or finished goods.
Stored Data	A general data storage flowchart symbol.
Magnetic Disk (Database)	A database.
Direct Access Storage	Storage on a hard drive.
Internal Storage	Data stored in memory.
Sequential Access Storage (Magnetic Tape)	An old reel of tape.
Callout	One of many callout symbols used to add comments to a flowchart
Flow Line	Indicates the direction of flow for materials and/or information

Figure 7 – Symbols used to develop flowcharts

Source: BreezeTree < https://www.breezetree.com/downloads/flow-chart-symbols.pdf>

Because of its simplicity in filling and the volume of useful information, it is the recommended a vertical flowchart type for comparing processes that are being modified.

An example of Vertical Flow Chart is presented in Figure 8, where you can check:

a) the basic information of the sector where the process occurs;

b) the number of each step;

c) the Distance (m), the Time (s);

d) four types of activities (operation, transport, inspection, wait and storage);

e) the description of each step.

Current process:								Process Flowchart	Sheet nº:
Proposed process:									
Process: Manufacture of soap bars								Date:	
Sector:								Responsable:	
Step	Distance (m)	Time (s)	Operation	Transport	Inspection	Wait	Storage	Description	
1			●	⇨	□	D	▽	Separation of raw material	
2			○	➡	□	D	▽	Transport from the RM to the weighing site	
3			●	⇨	□	D	▽	MRI fractionation	
4			○	➡	□	D	▽	Transport from MR to the place of waiting for ma	
5			○	⇨	□	◗	▽	Waiting for production	
6			○	➡	□	D	▽	Transport to processing machine	
7			●	⇨	□	D	▽	Base mass mixing with RM	
8			●	⇨	□	D	▽	Rolling of the mass	
9			●	⇨	□	D	▽	Extrusion	
10			●	⇨	□	D	▽	Separation of soap bars	
11			●	⇨	□	D	▽	Pressing	
12			●	⇨	□	D	▽	Finishing	
13			○	⇨	■	D	▽	Inspection	
14			○	➡	□	D	▽	Transport to the packing location	
15			●	⇨	□	D	▽	Product packaging	
16			●	⇨	□	D	▽	Pallet assembly	
17			○	➡	□	D	▽	Transport from the pallet to the warehouse	
18			○	⇨	□	D	▼	Product batch storage	

Figure 8 – Example of Vertical Flowchart

Source: Think Lean Sigma <https://www.thinkleansixsigma.com/article/flowchart>

2.5.2 GUT Matrix to prioritize problem

The GUT Matrix was developed and disseminated in the 1970s by Kepner and Tregoe (1976 and 1981) to rationally prioritize actions or problems, taking into account Gravity (G), Urgency (U), and Trend (T) of the studied phenomenon, being a tool used by authors (GRECCO et al., 2011; VASCONCELOS et al., 2013; OLIVEIRA et al., 2016; PESTANA et al., 2016; VERZOLA, MARCHIORI AND ARAGON, 2014; BRANDÃO AND MESQUITA , 2018) to achieve various objectives.

Gravity refers to the cost, what is the economic gravity for the sector or company analyzed if nothing is done, and the scale from 1 to 5 can be used as shown in Char 1.

Urgency refers to the timeframe for solving the problem, while Trend concerns the evolution of the problem, the potential for growth. After recording each value, the multiplication G x U x T is done resulting in the total score and then the priority level classification is found.

The case of Chart 1 points out that of six problems analyzed of a car, the first to be attacked is the Bald

Tire (100 points), the second is the brake leak (45 points), while the least priority problem is the mudguard wrinkled. Thus, it is noticeable that one of the main advantages of this Matrix is that it helps the manager to more objectively assess the company's problems, contributing to the prioritization of corrective and preventive actions.

ESCALE	GRAVITY (G)	URGENCY (U)	TENDENCY (T)	
1	No gravity	No urgency	Unchanged	
2	Low gravity	Low urgency	Worst over time	
3	Gravity	Urgency	Worst in the medium term	
4	High gravity	High urgency	Worst in the short term	
5	Extreme gravity	Immediate action	Worst quickly	
PROBLEM	G (Cost)	U (Timeframe)	T (Evolution)	SCORE G x U x T
Bald Tire	5	5	4	100 (First)
Mudguard wrinkled	2	2	2	8 (6th)
Broken brake light	3	5	2	30 (4th)
Break leak	3	3	5	45 (2nd)
Broken Light bubs	3	3	1	9 (5th)
Flooded Engine	3	3	4	36 (3d)

Chart 1: GUT Matrix example using car problems
Source: MELO (2014, p. 23)

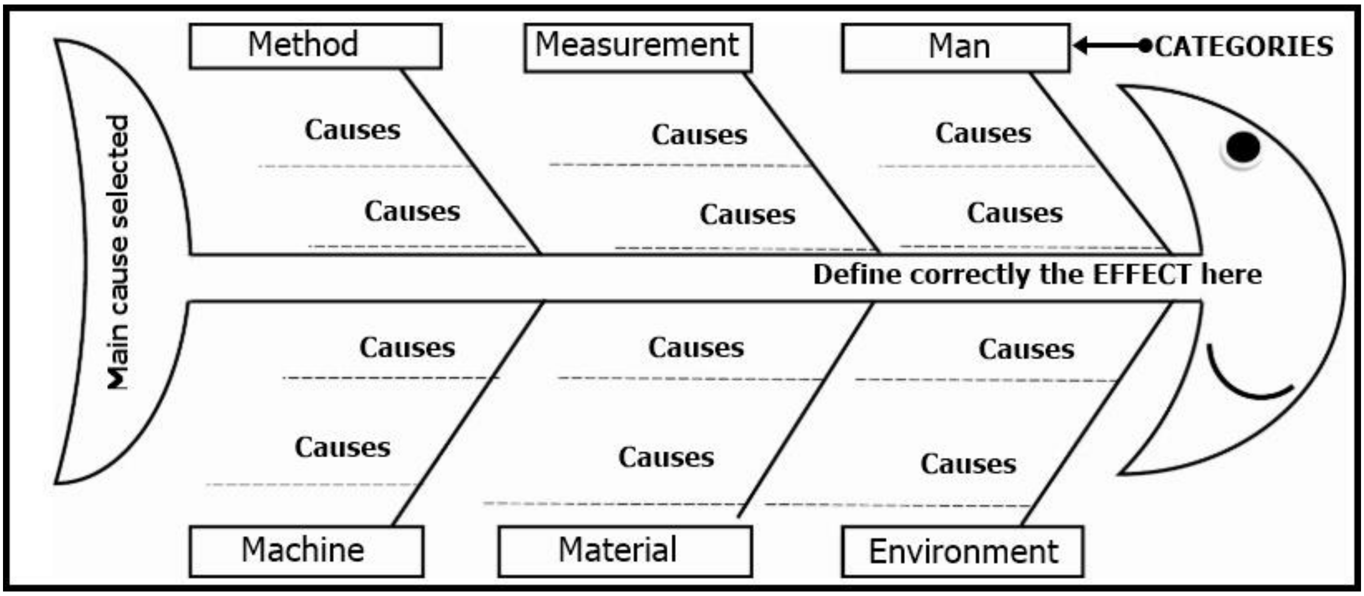


Figure 9 – Three main Ishikawa diagram elements (Effect, Categories and Causes)
Source: Author made improvements from Datavisiononline picture

2.5.3 Ishikawa Diagram

The Ishikawa Diagram or Cause and Effect Diagram are composed of three elements, the effect, the categories and the causes (Figure 9), created in 1943 at the University of Tokyo (Japan) by Dr. Kaoru Ishikawa. It is a widely used tool. It is known but unexplored in its potential, as it is most often used to identify some causes of problems. In Japan, in addition to exploring as many causes as possible when trying to see the relationship with the "problem" effect, the tool is also widely used to identify causes to prevent a particular event (Figure 10), in order to not to necessary to take corrective action. In addition to this approach, it is also possible to identify the causes of an event (system, project, goal, process, or good management practice) that has been successful over time (Figure 11).

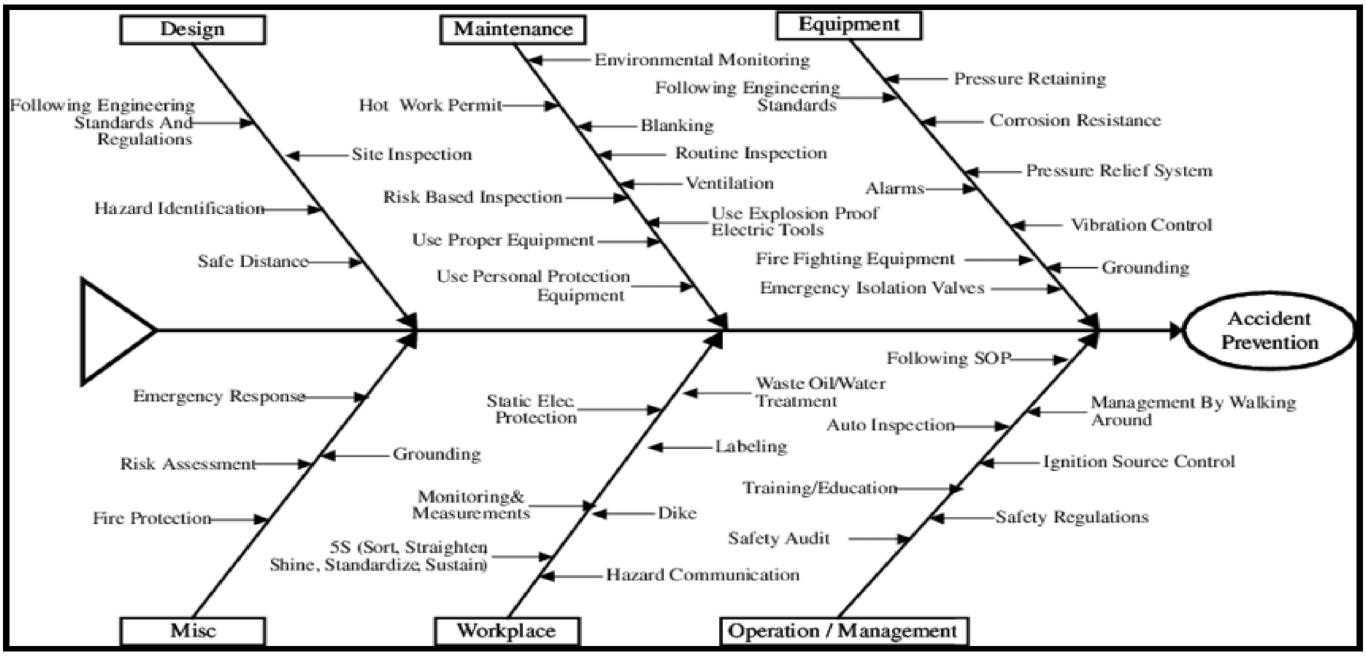


Figure 10 – Fishbone diagram to prevent accident
Source: Chang and Lin (2006 p. 55)

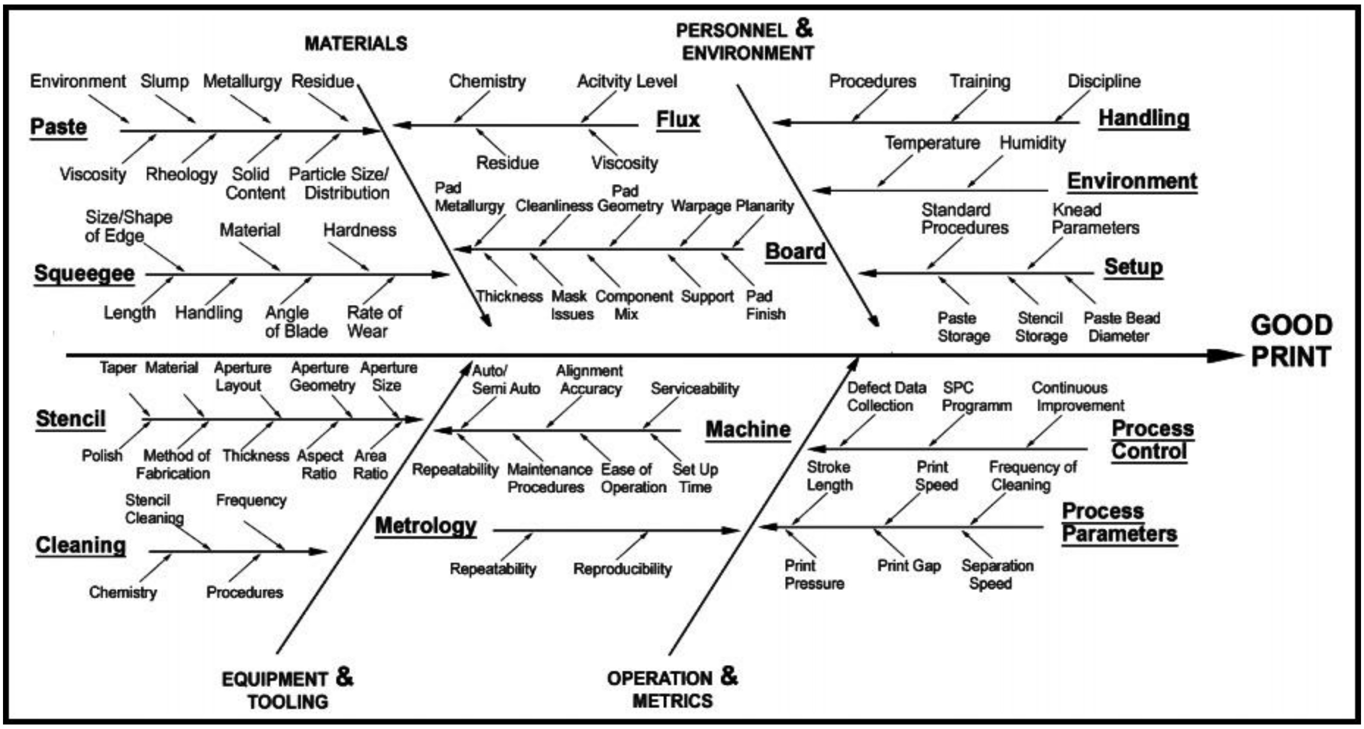


Figure 11 – Causes that contribute for good stencil printing process
Source: Fleck and Chouta (2003 p. 25)

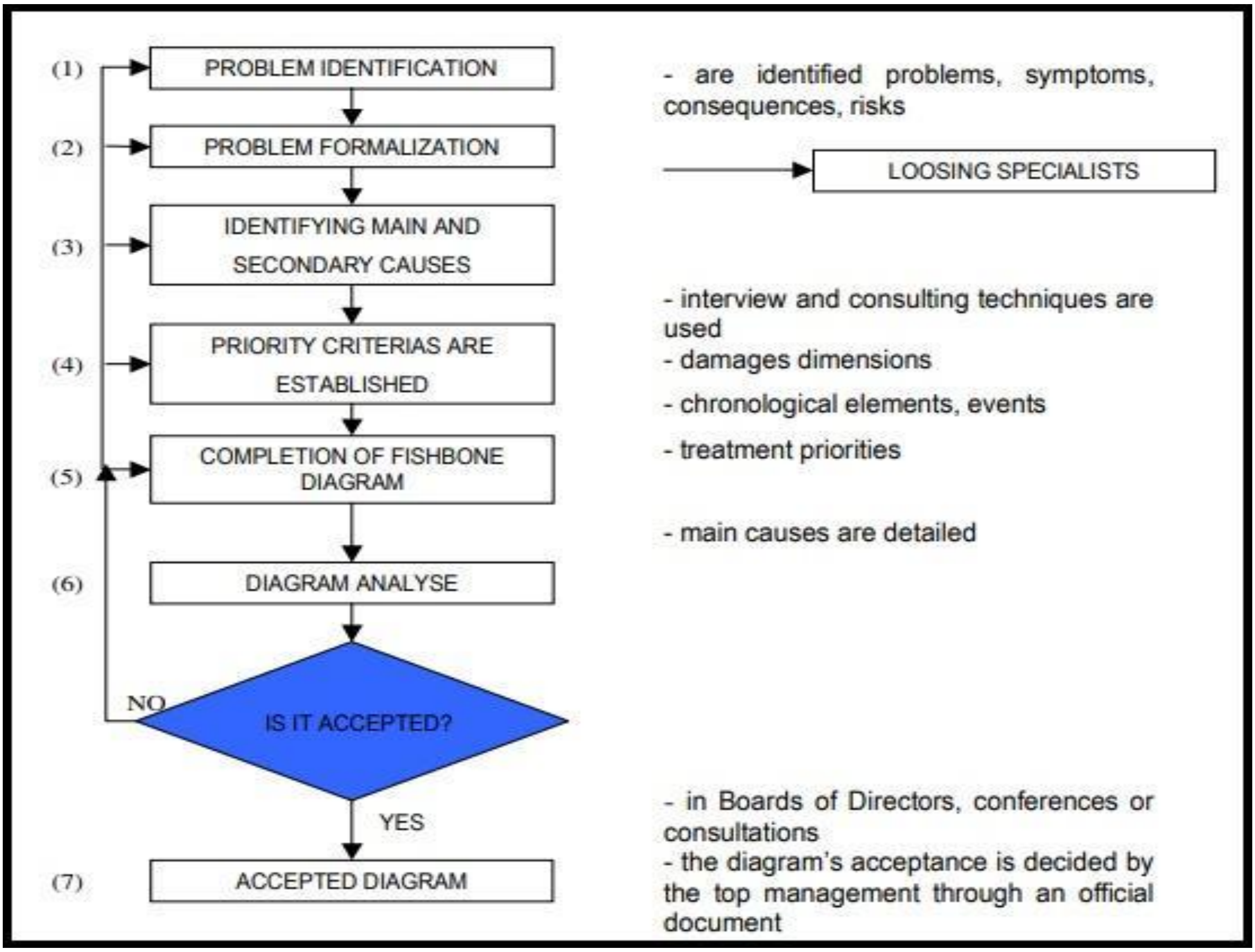


Figure 12 – Logic Scheme of Fishbone Diagram Implementation
Source: Ilie and Ciocoiu (2010 p. 2)

Basically this diagram is constructed as follows:
a) Identify the effect to be analyzed by writing it to the right of the diagram. The accurate identification of the effect is very important so as not to spend time on the next steps;
b) The survey of possible causes is usually done through brainstorming (WERKEMA, 2006), using the six Ms (materials, methods, machines, workmanship, measurement, and mother nature) to guide the discussion;
c) Put the main causes in the branches (fishbone) to the right of the diagram;
d) Repeat the process for the sub causes until the team realizes that the diagram is complete.
The Figure 12 presents a plan for implementing the Ishikawa Diagram that was developed by Ilie and Ciocoiu (2009 and 2010), with seven steps to study a problem and get manager approval: (1) Correct problem identification; (2) Formalization of the problem; (3) Identification of major and secondary causes; (4) Establishment of priority criteria; (5) Partial completion of Ishikawa Diagram; (6) Critical analysis of the diagram; (7) Decision and (8) Acceptance of managers.
Ilie and Ciocoiu (2010) conducted a study applying the diagram to determine the risk of a multi-cause event (Loosing Specialists). It would be interesting if the methodology could be used with adaptations also to analyze causes to prevent events or to analyze the causes that contributed to the success of an event.

3. Methodology

The research is applied since the knowledge generated will be used by Company X. Regarding the objectives, the research is descriptive, since it will describe through the comparison between variables involved in the performance of two inspection tests. Data were collected and analyzed using a combined (qualitative and quantitative) approach through the case study, bibliographic research, chrono-analysis and the use of PDCA with quality tools (brainstorming, GUT, Ishikawa Diagram and Vertical Flowchart) to verify the performance of the efficiency test considered standard and the experimental test.

The research started in the first semester but was formalized and improved in the UFAM Production Engineering Course in the second semester of 2016, as described in Chart 2.

STEPS	JUNE	JULY	AUGUST	SEPTEMBER
Article Template Presentation	X			
Theme presentation		X		
Introduction: contextualization, problem, justification, objectives, and proposal of the topics for the literature review.		X		
Development: Presentation and discussion of the Bibliographic Review			X	
Data collection and analysis			X	
Discussion of Results				X
Final Considerations and advisor analysis				X
Essay and review of the article				X
Improvement and delivery the final version				X
Article defense				X

Chart 2 – Research Methodology Schedule

Source: Author (2016)

Regarding the data collection and analysis, performed in August 2016, the data were collected by the study of time, using the timer, of each test operation, both the standard method and also the new method.

Then, the data were digitized and graphed for discussion of results and construction of the article that was defended for an examining board of the Production Engineering course of UFAM's Faculty of Technology.

4. Case study and Results

The case study took place in the Quality Assurance sector and focused on the reliability test performed to verify the efficiency of the TVs produced by Company X.

In July 2015, senior management decided to automate the energy efficiency inspection test to improve performance after identifying that the standard test was unable to achieve the increased production volume of new television models to be inspected.

To assist in identifying the possible causes of the “Failure to Meet the Increased Volume of New TV Models” problem, brainstorming sessions were conducted to identify potential causes through the use of the Ishikawa Diagram (Figure 12).

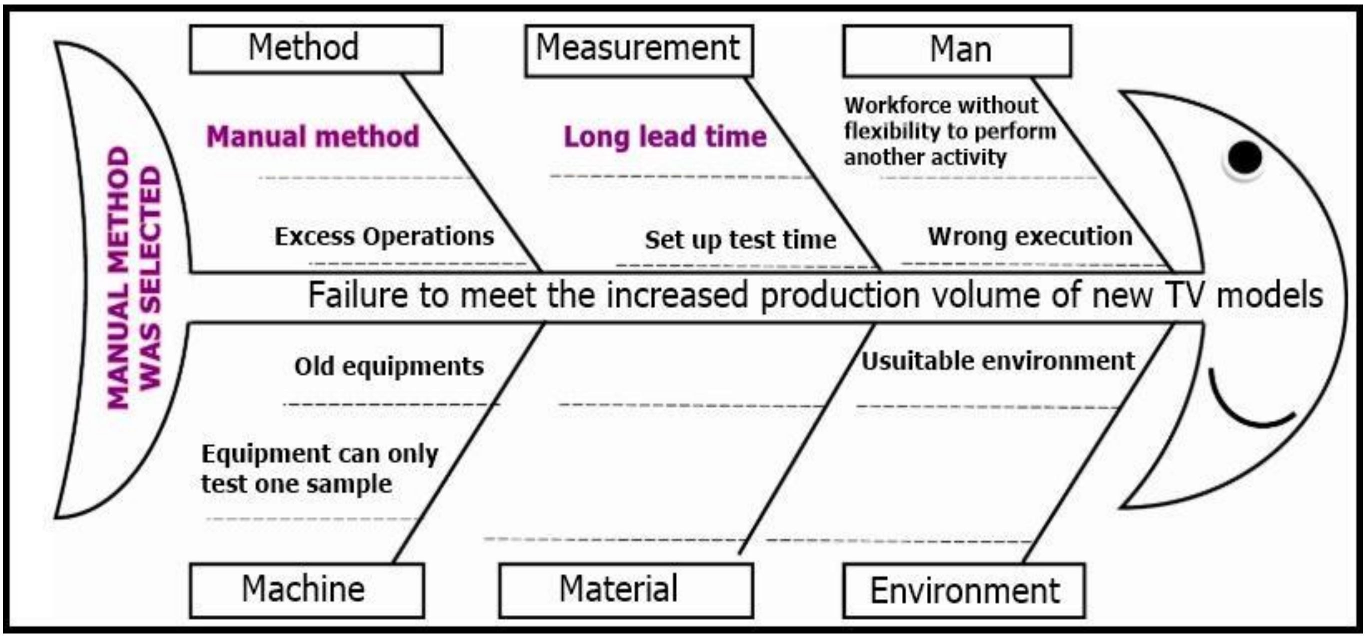


Figure 12 – Causes that contributes for the standard test to failure to meet increased production of TV

Source: Company X

EFFECT ANALYZED: Standard test failure to meet increased production volume of new TV models						
CATEGORIES	CAUSES	GRAVITY	URGENCY	TREND	SCORE	PRIORITY
METHOD	Manual method	5	5	5	125	First
MEASUREMENT	Test long lead time	5	5	5	125	First
MEASUREMENT	Set up test time	4	4	4	64	Second
METHOD	Excess of operation	4	4	4	64	Second
MACHINE	Equipment can only test one sample	3	4	4	48	Third
MAN	Wrong execution	4	3	3	36	Fourth
MACHINE	Old equipments	3	3	3	27	Fifth
MAN	Workforce without flexibility to perform another activity	2	2	2	8	Sixth
ENVIRONMENT	Unsuitable environment	2	2	2	8	Seventh

Chart 3 – Priorization of the nine causes through GUT Matrix analysis

Source: Author

Figure 12 points out 9 possible causes of the problem, after applying the GUT Matrix (Chart 3) the priority would be to attack two causes "Manual method" and "Test long lead time", and it was chosen to attack "Manual method".

Then an action plan was prepared for the implementation of the new (experimental) inspection test developed in partnership with the parent company. The plan was prepared based on the PDCA methodology, containing about ten actions performed as can be seen in Figure 13.

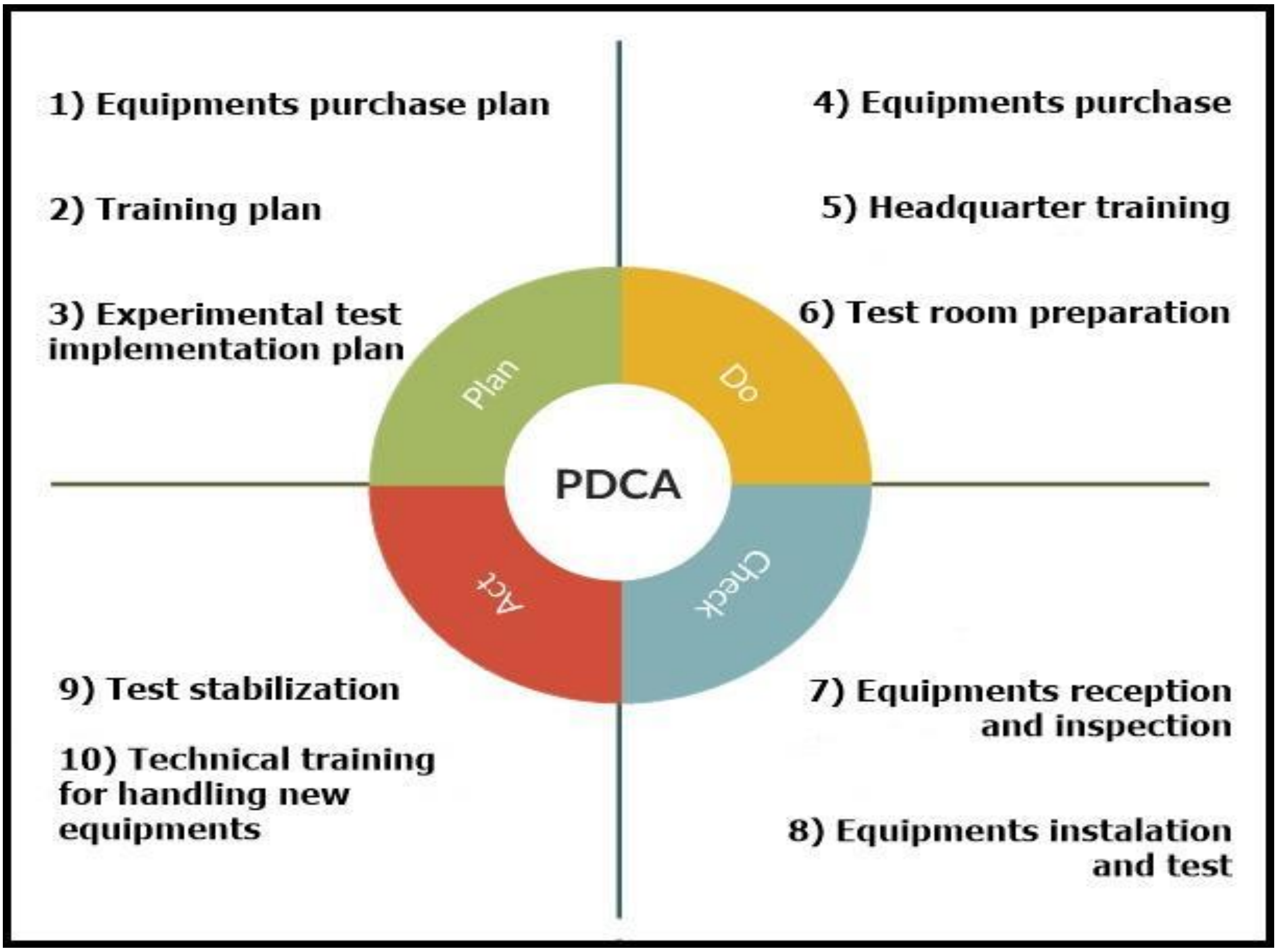


Figure 13 – The implementation of experimental test by using PDCA cycle
Source: Author

After concluding the PDCA rotation (Figure 13), the study of the experimental test performance was started, in order to verify the efficiency of the new test method, comparing it with the previous one.

The energy efficiency inspection test on televisions consists of inspecting the energy consumption values reported on the energy efficiency label on televisions from 13" (minimum inch) to 65" (maximum inch). When a new TV model is introduced, it will pass all reliability tests, one of them being the energy efficiency inspection test (within the specified inches), where only one sample per model will be required to perform of the test.

The energy efficiency test is performed as follows: 1) Sound stabilization; 2) Power measurement (KW / h) in static mode; 3)Power measurement (KW / h) in dynamic mode; 4) Power measurement (KW / h) in standby mode; 5) Measurement of TV screen area (diagonal measurement); 6) Model rating (From "A" to "E").

Results were discussed between August and September 2016, based on the analysis of two variables: v1) inspection time; v2) the number of operations performed during the test.

Then, comparisons were made between the performance of the standard method and the experimental method of execution, using vertical flow charts to visualize the operations, the arithmetic mean and the lead time (total time in hours to execute the whole process).

The discussion of the results was made with the following topics: 3.1) to diagnostic the performance of the standard inspection test; 3.2) to diagnostic the performance of experimental inspection test; 3.3) to analyse the positive points acquired with the new inspection test; 3.4) to compare the 2 tests.

VERTICAL FLOWCHART					Lead Time (in hour):	06:29:03	
Main symbol	Operation	Total	6	03:17:33	50,78%	Company:	X
	Transfer of material		0	0	0,00%	Type of process:	Standard / New
	Decision or Measure		5	3:11:30	49,22%	Process`name:	Energy efficiency inspection test
	Documentation		0	0	0,00%	Department:	Quality Assurance
	Storage		0	0	0,00%	Data:	September 17th 2016

Steps	Symbols	X Time	Accum.	% Accu	Description
1	Operation	00:31:22	00:31:22	8,1%	To prepare the sample, connecting the cables and set up the equipment
2	Operation	01:00:40	01:32:02	23,7%	To put the sample into off mode and disconnected
3	Operation	01:03:07	02:35:09	39,9%	To put the sample into on mode
4	Operation	00:35:26	03:10:35	49,0%	To prepare sound and image adjustment
5	Decision or Measure	00:52:02	04:02:37	62,4%	To measure power in static mode
6	Decision or Measure	00:13:09	04:15:46	69,8%	To measure power in dynamic mode
7	Decision or Measure	00:15:51	04:31:37	69,8%	To measure the screen area
8	Decision or Measure	01:04:38	05:36:15	86,4%	To measure power in stand by mode
9	Decision or Measure	00:45:50	06:22:05	98,2%	To measure the visible diagonal
10	Operation	00:00:41	06:22:46	98,4%	To set up the sample for the factory mode
11	Operation	00:06:17	06:29:03	100,0%	To pack the sample

Chart 4 – Lead time of standard inspection of a TV energy efficiency test

Source: Author

4.1 Diagnostic Performance of Standard Inspection Test

The standard inspection test is performed manually using only one television sample, following 11 execution steps as described in Chart 4.

To diagnose the standard inspection test, 20 timed test cycles were first performed to determine the X Time in an hour of each step performed. From the completion of the 20 cycles, it can be seen that the lead time was 6h29min03 with almost 51% of the time devoted to performing operations and 49% of the time to measure.

After analyzing, specifically the operations where the measurements take place, you can diagnose the standard inspection test from the following points:

- Set up time: Because it is performed manually, to proceed from one operation to another, it is necessary to configure the measuring equipment and to connect the equipment cables to the television;
- Measurement of visible screen diagonal: When a sample is equal to or above 60 ”inches, one more person must be available to support the measurement;

● Fault Detection: If any cables are badly connected or equipment is misconfigured, or any other error goes unnoticed during the test, it is necessary to start the operation again, and if the error goes unnoticed by the end of the test, This may have a direct impact on the final result, and sometimes it is necessary to repeat the entire inspection test.

● Inadequate environment: The ambient temperature is a factor that influences the test measurements and should be stabilized at 23 ° C ± 5 ° C. As there is no control of the ambient temperature, it was noted that this is one of the factors that hinder the measurement operations, as it causes variation in the values, besides generating discomfort for those who perform the test. In addition to not having a suitable ambient temperature for the test, the environment also does not have good acoustics, and due to this factor, it was noted that the sound structure hinders the operation of sound adjustment of the TV, which must stabilize in the 80 dB (decibel) level.

All of the points cited with their specific signs are related to the main causes that affect standard test productivity.

4.2 Diagnostic Performance of Experimental Test

The experimental test, called Energy System Measurement, was developed in partnership with Headquarter's R&D team, which communicates between the new measurement equipment and the TV. While the standard inspection test was fully manual, the experimental test performs 15 steps, of which 67% are performed automatically and 43% manually, as can be seen from Chart 5.

Twenty timed cycles were again performed to determine the average times (X Time) of each step performed to verify the performance of the new inspection test.

In 20 timed test cycles, it can be verified that the lead time was 04h14min34, this represents 65.4% of the standard test lead time which means a 33.5% reduction in time to perform the new test.

The creation of the Energy System Measurement seeks to eliminate the problems detected in diagnosis (Figure 12 and Chart 3) by eliminating their symptoms, or otherwise, they would develop in the future.

The main updates were:

● The setup times that occurred from one operation to another in the standard inspection test are not required in the new inspection test, from the connection between the measuring equipment and the television, the *Energy System Measurement* sends commands to the equipment proceeding to the next operation without manual intervention;

● Measurements of the visible diagonal of the screen have been automated through to the *Energy System Measurement*, which has a database with every possible inch of TVs with their proper tolerances. The system identifies the screen diagonal measurement based on the data entered into the system in the initial setup, where the size is placed based on the specification of the television;

● Automation of inspection testing has not only improved runtime and method of execution but has also reduced the risks of performing operations incorrectly. The usual method performed before required the execution of many processes, and if wrongly performed, it was necessary to restart the test, resulting in late delivery of the result. Optimizing operations, the risk of incorrect execution has been reduced, so that if there is any wrong execution, either from faulty cable connection or initial setup error, the Energy System Measurement can identify and send alerts to correct the error and proceed the test.

- To avoid ambient temperature influences in the test, the temperature was controlled after the air conditioners installation, reducing the variation in the measured values;
- In addition to having temperature control, the environment also underwent acoustic treatment, being installed acoustic dampers and carpet generating better sound performance.

VERTICAL FLOWCHART									Lead Time (in hour):		04:14:34
Main symbol	■	Operation			Total	10	02:14:24	52,80%	Company:	X	
	➡	Transfer of material				0	0	0,00%	Type of process:	Standard	New
	◆	Decision or Measure				5	2:00:10	47,20%	Process` name:	Energy System Measurement	
	■	Documentation				0	0	0,00%	Department:	Quality Assurance	
	▼	Storage				0	0	0,00%	Data:	September 17th 2016	
Steps	Symbols					X Time	Accum.	% Accu	Type of operation and description		
1	□	⇨	◇	▭	▽	00:04:00	00:04:00	1,6%	Manual: to prepare the sample and connecting the cables		
2	□	⇨	◇	▭	▽	00:00:15	00:04:15	1,7%	Manual: open the Energy System Measurement		
3	□	⇨	◇	▭	▽	00:01:44	00:05:59	2,4%	Manual: to insert sample data		
4	□	⇨	◇	▭	▽	00:00:01	00:06:00	2,4%	Manual: to start the test by clicking START		
5	□	⇨	◇	▭	▽	00:01:52	00:07:52	3,1%	Automatic: to stabilize sound and adjust image		
6	□	⇨	◇	▭	▽	01:00:00	01:07:52	42,4%	Automatic: to put the sample in Standby mode		
7	□	⇨	◇	▭	▽	00:40:00	01:47:52	42,4%	Automatic: to measure the power in static mode		
8	□	⇨	◇	▭	▽	00:10:00	01:57:52	46,3%	Automatic: to measure the power in dynamic mode		
9	□	⇨	◇	▭	▽	00:10:00	02:07:52	50,2%	Automatic: to measure the power in internet mode		
10	□	⇨	◇	▭	▽	00:00:05	02:07:57	50,3%	Automatic: to set up the sample for the factory mode		
11	□	⇨	◇	▭	▽	01:00:00	03:07:57	73,8%	Automatic: to put the sample in Standby mode		
12	□	⇨	◇	▭	▽	01:00:00	04:07:57	97,40%	Automatic: to measure the power in Standby mode		
13	□	⇨	◇	▭	▽	00:00:10	04:08:07	97,47%	Automatic: to measure the area and the screen visible diagnonal		
14	□	⇨	◇	▭	▽	00:00:10	04:08:17	97,53%	Automatic: to generate the report		
15	□	⇨	◇	▭	▽	00:06:17	04:14:34	100,00%	Manual: to pack the sample		

Chart 5 – Experimental test called Energy System Measurement

Source: Author

4.3) Comparison between the two tests.

Despite having more steps, the experimental test is faster and has almost 53% of the steps performed in operation and 47% as measurement, values very close to the standard test.

According to Chat 6, there was a reduction from 6h29min03 to 4h14min34 in lead-time, which means about 2h14min29 time savings.

The major reductions occurred in the sound stabilization and image adjustment step following the area and diagonal measurement step.

Figures 14 and 15 show the times of each test, it is possible to notice less variability and considerable gain with the experimental test, since the standard test only perform testing on 5 samples per week, now the experimental can test 15 samples per week at least.

VERTICAL FLOWCHART				Lead Time (in hour):	06:29:03
Main symbol: Operation	Total	6	03:17:33	50,78%	Company: X
Transfer of material		0	0	0,00%	Type of process: Standard / New
Decision or Measure		5	3:11:30	49,22%	Process' name: Energy efficiency inspection test
Documentation		0	0	0,00%	Department: Quality Assurance
Storage		0	0	0,00%	Data: September 17th 2016

Steps	Symbols	X Time	Accum.	% Accu	Description
1	□ ⇨ ◇ ▢ ▽	00:31:22	00:31:22	8,1%	To prepare the sample, connecting the cables and set up the equipment
2	□ ⇨ ◇ ▢ ▽	01:00:40	01:32:02	23,7%	To put the sample into off mode and disconnected
3	□ ⇨ ◇ ▢ ▽	01:03:07	02:35:09	39,9%	To put the sample into on mode
4	□ ⇨ ◇ ▢ ▽	00:35:26	03:10:35	49,0%	To prepare sound and image adjustment
5	□ ⇨ ◇ ▢ ▽	00:52:02	04:02:37	62,4%	To measure power in static mode
6	□ ⇨ ◇ ▢ ▽	00:13:09	04:15:46	69,8%	To measure power in dynamic mode
7	□ ⇨ ◇ ▢ ▽	00:15:51	04:31:37	69,8%	To measure the screen area
8	□ ⇨ ◇ ▢ ▽	01:04:38	05:36:15	86,4%	To measure power in stand by mode
9	□ ⇨ ◇ ▢ ▽	00:45:50	06:22:05	98,2%	To measure the visible diagonal
10	□ ⇨ ◇ ▢ ▽	00:00:41	06:22:46	98,4%	To set up the sample for the factory mode
11	□ ⇨ ◇ ▢ ▽	00:06:17	06:29:03	100,0%	To pack the sample

VERTICAL FLOWCHART				Lead Time (in hour):	04:14:34
Main symbol: Operation	Total	10	02:14:24	52,80%	Company: X
Transfer of material		0	0	0,00%	Type of process: Standard / New
Decision or Measure		5	2:00:10	47,20%	Process' name: Energy System Measurement
Documentation		0	0	0,00%	Department: Quality Assurance
Storage		0	0	0,00%	Data: September 17th 2016

Steps	Symbols	X Time	Accum.	% Accu	Type of operation and description
1	□ ⇨ ◇ ▢ ▽	00:04:00	00:04:00	1,6%	Manual: to prepare the sample and connecting the cables
2	□ ⇨ ◇ ▢ ▽	00:00:15	00:04:15	1,7%	Manual: open the Energy System Measurement
3	□ ⇨ ◇ ▢ ▽	00:01:44	00:05:59	2,4%	Manual: to insert sample data
4	□ ⇨ ◇ ▢ ▽	00:00:01	00:06:00	2,4%	Manual: to start the test by clicking START
5	□ ⇨ ◇ ▢ ▽	00:01:52	00:07:52	3,1%	Automatic: to stabilize sound and adjust image
6	□ ⇨ ◇ ▢ ▽	01:00:00	01:07:52	42,4%	Automatic: to put the sample in Standby mode
7	□ ⇨ ◇ ▢ ▽	00:40:00	01:47:52	42,4%	Automatic: to measure the power in static mode
8	□ ⇨ ◇ ▢ ▽	00:10:00	01:57:52	46,3%	Automatic: to measure the power in dynamic mode
9	□ ⇨ ◇ ▢ ▽	00:10:00	02:07:52	50,2%	Automatic: to measure the power in internet mode
10	□ ⇨ ◇ ▢ ▽	00:00:05	02:07:57	50,3%	Automatic: to set up the sample for the factory mode
11	□ ⇨ ◇ ▢ ▽	01:00:00	03:07:57	73,8%	Automatic: to put the sample in Standby mode
12	□ ⇨ ◇ ▢ ▽	01:00:00	04:07:57	97,40%	Automatic: to measure the power in Standby mode
13	□ ⇨ ◇ ▢ ▽	00:00:10	04:08:07	97,47%	Automatic: to measure the area and the screen visible diagonal
14	□ ⇨ ◇ ▢ ▽	00:00:10	04:08:17	97,53%	Automatic: to generate the report
15	□ ⇨ ◇ ▢ ▽	00:06:17	04:14:34	100,00%	Manual: to pack the sample

Chart 6 – The comparative performance of two tests

Source: Author

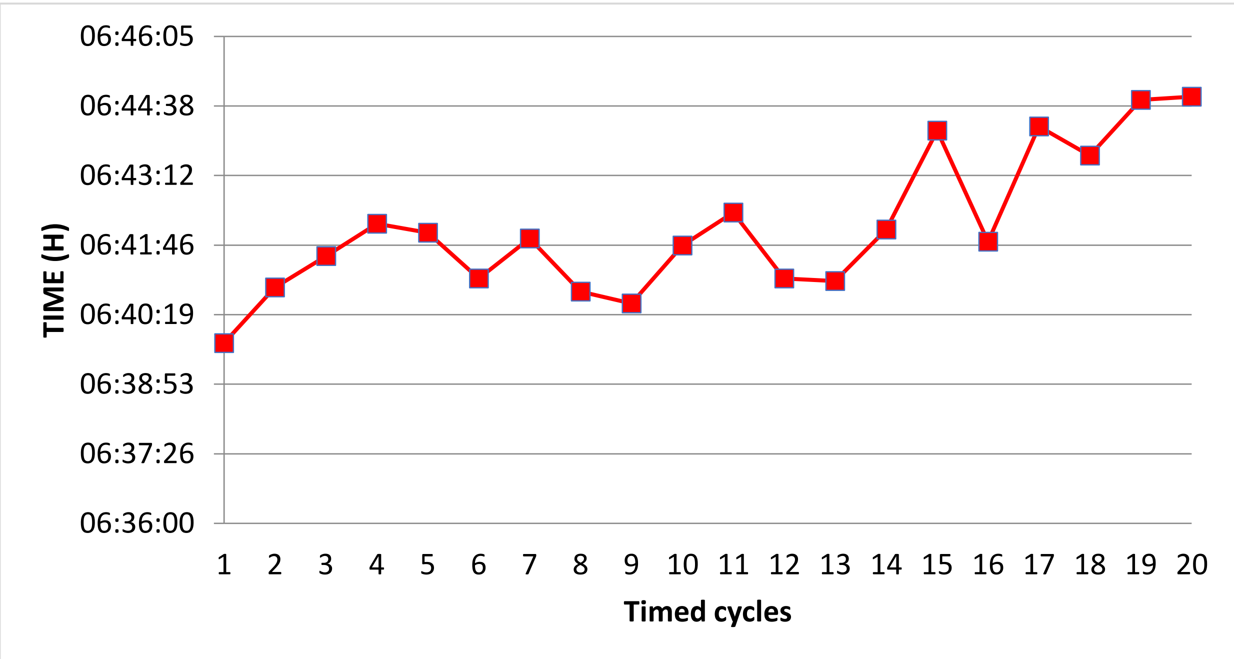


Figure 14 – Test standard lead times in 20 cycles of measurement

Source: Author (2016).

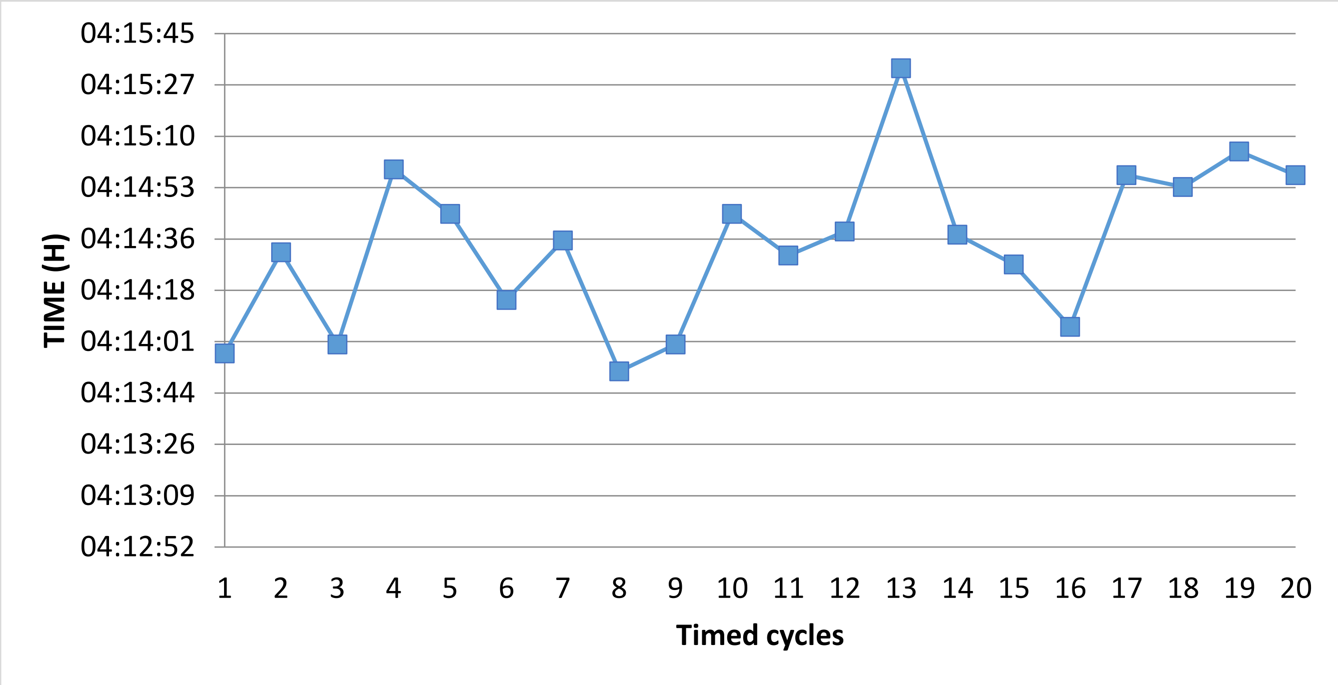


Figure 15 – Experimental test lead times in 20 cycles of measurement
Source: Author (2016).

With the introduction of the new automatic method for conducting the inspection test, there was no improvement only in the main points affecting the test, but the following positive points were also obtained:

a) Automatic report creation

One of the most important optimizations made by the Energy System Measurement is the report creation. Previously, after completing the test, it was necessary to compile all the measurement values manually, and most of the time, the report was only generated the next day. With optimization, the test result report is generated seconds after the test is completed.

b) Increased sample quantity for inspection

The equipment used in the standard test could test only one sample per day and it was not possible to analyze or compare the measurement result of a particular television model if there were any abnormalities. After automation, the inspection test is performed with up to three samples at the same time and samples of the same TV model or different TV models. With test automation, testing can be performed on up to six samples during normal working hours.

c) Workmanship Flexibility

In the previous scenario, the standard inspection test, due to the long duration and also the number of operations, required only one person responsible for performing the inspection test and not having the flexibility to perform other industry activities.

With the implementation of the new inspection test, where major operations have been automated, there is no longer a need for a person responsible for performing the inspection test alone. The same workforce now has the flexibility to perform other industry activities beyond energy efficiency inspection testing.

5. Conclusions

The article aimed to answer the question "how to analyze the efficiency of a new inspection test method aimed to reach the increase in TV set production volume?".

To this end, it was set a general objective (to compare the performance of the standard method and the new method of performing the energy efficiency inspection test) and three specific ones, the data collection and made with Company X's quality assurance sector data reached the following conclusions:

First) Standard inspection test performance diagnosis was performed 100% manually, its average lead-time was 6h29min03, performed in 11 steps with risks of set-up time problems, visible screen diagonal measurement, fault detection and because of the inadequate environment;

Second) The performance analysis of the experimental inspection test has 67% of its steps performed automatically and 43% manually, its average lead-time was 4h14min34, a gain of 33.5% in the total time required to perform the test. Among the positive points obtained are: a) the automatic generation of the test report; b) increase in the number of daily samples that can be tested as the new method; c) error reduction; d) improvement of labor flexibility to perform other activities in parallel;

Third) The analysis of the new inspection test used to attend the TV production volume can be done by applying Brainstorming, Ishikawa Diagram, GUT Matrix, PDCA (with feasibility study, equipment acquisition, training, etc.), Vertical Flowchart together with the chrono-analysis of the production steps. However, it is worth highlighting the importance of the support of senior management for each of these tools to be used creatively by the employees involved in the project.

To further research, a study of the problems inherent in the experimental test is suggested, since there was not enough time to identify them, to analyze their causes and to propose improvements to the managers of Company X.

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