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APPLICATION OF FMEA FOR IMPROVEMENT IN THE MANUFACTURING PROCESS OF MOBILE PHONES IN A FACTORY OF THE INDUSTRIAL POLE OF MANAUS

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Abstract: *The objective of this paper is to analyze the excess of failures in a mobile phone line production in order to make process improvements in a factory of the industrial pole of Manaus (PIM) by using FMEA methodology (Failure Mode, effect analysis). The excess of failures was an extremely influential aggravating factor by its customer, since the increase of the productive capacity in the company would be determined by the reduction of the percentage of failures or increase of YIELD from the conception of the product until the final phase of its life. Tracing the root causes is an important step in improving manufacturing processes for reducing failures. The impact of this is the reduction in industrial costs and an increase in the quality index of the product, ensuring customer satisfaction in having to produce its product in a factory that operates under condition the EMS (Electronic Manufacturing Services).*

Keywords: *FMEA; Process; Quality management.*

1. Introduction

In the first two months of 2017, the Industrial Pole of Manaus (PIM) earned R $ 11.82 billion, representing a growth of 12.19% over the same period last year (R $ 10.54 billion). In dollar terms, revenues for the two months were US $ 3.81 billion, a significant increase of 45.01% compared to January and February latest year (US $ 2.62 billion), according to Suframa(2017).

A significant increase in production in the first two months of 2017, in comparison to the same period of the previous year, the LCD monitor for computer use (1285.75%) stands out. Home theater (328.80%), electronic concierge (447.31%), air conditioners split system (94.74%), microwave oven (88.35%), television with LCD screen (30.77%), tablet PC (25.79%), Blu-ray DVD (24.21%), portable microcomputer (21.43%), television signal receiver (17.21%) and cell phone (13.26%).

The companies that are responsible for the production of the 13.26% of cellular telephones and the other items that compose the slice of the electronics sector in the industrial hub of Manaus (PIM) suffer from high rates of process and product failures caused by the inefficiency of manufacturing processes and insufficient training to employees working on the production lines. Thus, the index of discarded products, or that have failures awaiting analysis and repair by the technical team, grows according to the increase of production, generating high costs with areas for repairs and highly qualified workforce to carry out diagnostic services, repairs and maintenance of assets in stock awaiting technical analysis.

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The approach using the FMEA methodology in these industries, and in particular in the studied company, to determine the failure modes and their effects, is of paramount importance for tracking the possible root causes of the problems generated in the production environment. Knowing how they behave is crucial to determine the prevention and elaboration of the best proposals for improvement, adopting predictive maintenance and subsequently productivity improvement determined by the YIELD (index that determines the total produced according to the number of failures generated). The production or manufacture of consumer goods is based on how companies organize the items that make up the assembly processes in the production lines and how the defects that occur will be solved.

The speed in solving the problems and the improvements generated in the processes to mitigate the emergence of the same, will determine in short, if a company is able to produce a certain product efficiently or not. Producing a product efficiently means that the quality criteria demanded by customers are put first, and the reduction of industry costs are the result of well-defined process designs aligned with the quality policies of the corporation. These have been the premises discussed by different researchers in the last decades, from competitive advantages and costs (Soares, 2014), quality and performance (Ribeiro, 2016) and reliability (Rosa, 2016; Ming *et. al*, 2015).

Methodologies for process improvement, seeking to increase efficiency and quality levels, have been a constant pursuit within organizations. In this line, organizations seek to advance their controls to the organizational level, not just within the factory floor. Corroborating this strategy, Barbosa et al. (2018) propose to align the various integrated management systems of the organization, namely those of quality, environment and safety, with the business strategy adopted by it. Different authors also share the importance of FMEA application, where its application provides the reduction of process problems, increasing its reliability, reducing waste and other associated with poor process performance, thus increasing its level of quality.

The general objective of this article is the application of the FMEA tool to identify the causes of failures in testers in production lines with the purpose of proposing actions for their reduction and/or elimination. These modes may arise in the process of producing new products of the company under study, particularly in NPI (New Product Introduction) projects, as well as in current products, affecting the quality, cost and reliability of the process. In particular, the work tries to answer to the following question:

RQ1. Given the various manufacturing problems, what methods or tools would the engineering team have to adopt to eliminate or reduce failures, so that the company would not fail to deliver the orders to their respective customers in a timely manner?

2. Theoretical Background

In 1949, the military procedure US MIL-P 1629 entitled Procedures for Performing a Failure Mode Effects and Criticality Analysis was created by the US Army to identify the effects of failures in systems and equipment, and classification according to their impact on the success of the mission, and the safety conditions relating to personnel and equipment (Soares, 2014).

The FMEA was first developed as a formal design methodology in 1960 by the aerospace industry, seeking to excel in its reliability and safety requirements (Rosa, 2016).

This section intends to present, in a summarized way, the concept of the FMEA tool, its derivations and applications.

2.1. FMEA conceptualization

FMEA is an approach that helps identify and prioritize potential failures in equipment, systems or processes, becoming a logical system that prioritizes potential failures and provides recommendations for preventive actions (Kardec et al., 2002). Thurnes et al. (2015) corroborate defining the FMEA as the most established tool for risk analysis and prevention of various engineering failures.

In addition, the FMEA allows identifying and prioritizing potential failures in equipment, systems or processes, aiming to anticipate known or potential failure modes and recommend corrective actions to eliminate or compensate for the effects of failures (Lafraia, 2001).

Failures in the manufacturing process occur when the process does not meet the specifications established for the manufacture of the product. This may be due to: (1) defects in the raw material or components used in the manufacture of the product; (2) failures in the manufacturing process; (3) Mounting errors (Stamatis, 1995). The FMEA tool is also used in products that are already in operation. In this case, it is sought to find the root cause of system failures to propose improvement solutions. Thus, unlike the FMEA carried out in the project phase, it is not necessary to predict possible failures, since it works with failures that are already occurring in the system (Mesquita, 2014).

According to Palady (1997), a team person (the engineer) usually has the most knowledge about the subject matter; however, as an individual, that person cannot clearly see and understand all aspects of the project, process, or service. Still according to the author, the process FMEA (PFMEA) should start as soon as possible (after the concept of the project and the concept of the process).

FMEA is a tool that is widely adopted in several companies and processes around the world, that has transposed the limits of the industrial barrier, with applications in service environments in general, offices, among others, as attested to the wide bibliographic production available (Bian et al., 2015; Miguel & Pedrosa, 2014; Pedrosa, 2014; Braaksma et al., 2013; Chen, 2013; Braaksma et al., 2012; Zied et al., 2011; Estorilio & Posso, 2010; Niu et al., 2010; Mahto & Kumar, 2008; Miguel & Segismundo, 2008; Jardine et al., 2006; QS-9000 (SAE J-1739), 2002).

2.2. Types of FMEA

The FMEA can be applied in the development of a new product / process or also in existing products and processes. The steps and the way of accomplishment are the same; however, the difference lies in your goal, according to Soares (2014).

In relation to the type of FMEA, there is no unanimous number, where some authors defend the existence of four types (system, product, process and service) and others advocate the existence of three (product, process and service).

The types of FMEA can be classified, according to their application, as pointed out by Stamatis (1995):

a) Systems FMEA: used to analyze systems at the beginning of design and project stage;
b) Project FMEA: used to analyze projects before they are products. The focus is on failure modes caused by design deficiencies;
c) Process FMEA: used to analyze the production processes;
d) Service FMEA: used to analyze services before reaching the consumer.

In this sense, FMEA is a reliability analysis method intended to identify failures that alter the functioning of systems and enable priorities for actions to be defined (Braaksma et al., 2013).

There is a major impact on development costs and time when FMEA is carried out at the design stage and the application of this aid in identifying and solving problems. In addition, it maintains product and process knowledge throughout the organization and is always an important tool for identifying potential failures, according to Stamatis (1995).

The purpose of the process FMEA is to be able to identify, evaluate and obtain possible solutions to potential failures in the production and assembly processes so that all product compliance requirements are met. Multidisciplinary teams (the FMEA teams) perform the analysis. Multidisciplinary teams perform the analysis, where they are called to compose a team of FMEA employees from different areas of the company, with varied technical knowledge. Then, upon convocation, the team meets to determine all possible potential failure modes, the effects and causes of each failure mode on product performance, to assess risks and to specify improvement actions, susntais Laurenti et *al.* (2012).

FMEA aims to:

i. recognize and evaluate potential failures that may arise in a product or process,
ii. identify actions that may eliminate or reduce the chance of such failures, and
iii. document the study, creating a technical framework that can assist in future reviews or developments of the project or process.

According to Moubray (1997), failure modes can be classified into three categories: (1) when capacity falls below desired performance, (2) when desired performance rises above initial capacity and (3) when asset is not capable to make the desired start.

Also according to the author, FMEA is an important part of reliability-centered maintenance, defined as a process used to determine what must be done to ensure that any physical asset continues to do what its users want to do in the present operational context.

Failure is understood as the inability of a system, subsystem, component or task to perform the required function.

By effect, it is understood as being the generated characteristic of an action in some probabilistic scenario. Among the definitions present in an FMEA, severity, likelihood of occurrence and risk of non-detection are estimated and used to assess the risk associated with each failure mode. That is, the combination of these indicators gives us the parameter called priority number of risk. The higher its value, the greater the risk of a system failure occurring.

3. Methodology

Problems with excess manufacturing failures caused the company to take some steps so that in new projects the same process defects would not affect production.

Thus, the nature of the research is of the applied type, since its objective was to generate knowledge for practical application directed to the solution of specific problems, involving local truths and interests.

The research is exploratory, since the design of the study is related to the application of the FMEA tool. Thus, it is intended to gradually introduce theoretical concepts that lead to practical results.

The scope of the research focuses on understanding the reality of the process for applying the required methods for tool insertion and obtaining previous results to reduce the impacts of future failures on new processes.

The approach is of the qualitative type, since it aims at the practical application of the FMEA tool in the manufacturing processes of cellular phones in a PIM company.

In this context, it has a quantitative approach because the research is based on data processed statistically from the events collected from the company's production lines. The research procedure consists of a case study.

Regarding the production process, the stages consisted of data collection of failures, analysis and grouping of failures in spreadsheet, identification of major failures, selection of the most critical processes and failures associated with them, root cause study, proposed action plan, implementation of the action plan and evaluation of results.

4. Case study

In the following study, the excess of failures in the production process resulted in measures that caused the company to take action so that the reduction and / or elimination of these did not result in quality problems in the process.

Furthermore, these measures reached the prevention of failures in the field or for the consumer, influencing cost and production, as well as to delineate the process with a view to preventing functional failures in new projects.

The manufacturing process of cellular phones in the studied company takes place in five productive stages (Figure 1).

- Board Assembly (BA): stage for the automated assembly of the boards with the electronic components listed in the BOM (Bill of materials) of the project;
- In Line (IFLASH): stage where the already assembled boards go through the first programming stage, known as Factory Mode (Factory Mode);
- PHASING: stage where some basic tests are performed (Self-test) and calibration of RF (Radio Frequency) in the electronic board;
- Radio Test: stage designed to completely assemble the product and perform all functional tests (display tests, proximity sensor, gyroscope, digital sensor, microphones, speakers, etc.);
- CFC: the final part of the phone's assembly, and where the Customer mode software will be inserted and tested.

For each production step, manufacturing failures, occurring in the process is recorded in an automated system hosted on the company's intranet called Governance for future or real-time evaluation of productivity and quality indexes of production lines. This web page application is accessible to all company sites in Brazil and worldwide to track production. These records can be downloaded according to the date, as well as the start and end times of occurrences.

The period for data collection included May (01/05/2018) until the end of July (07/31/2018). The data collected were given in the production environment and correspond to all the manufacturing processes, as shown in Figure 1.

Figure 1. Line Production Structure.

The compilation of the information was based on the defect codes entered into the system by process technicians, the description of the failures in the automated testers, the codes related to each failure, the type of product, the sector where the failures occurred and the type of process of test.

Some data were collected through interviews with each professional about the types of failures and where they specifically occur.

This type of collection is important because process FMEA relies heavily on empirical information about the ways in which each type of process is manufactured.

Professionals involved in the task of monitoring and controlling quality and productivity indices have some knowledge of the product, and this generates a range of additional and important knowledge for proper FMEA management.

In order to determine the type of process where the failures occurred, the respective faults codes registered in the company's governance systems were separated and grouped by each type: board assembly (SMD), material, machine and assembly. Thus, all data related to the number of failures by sectors in the periods from May to July 2018 (Figure 2).

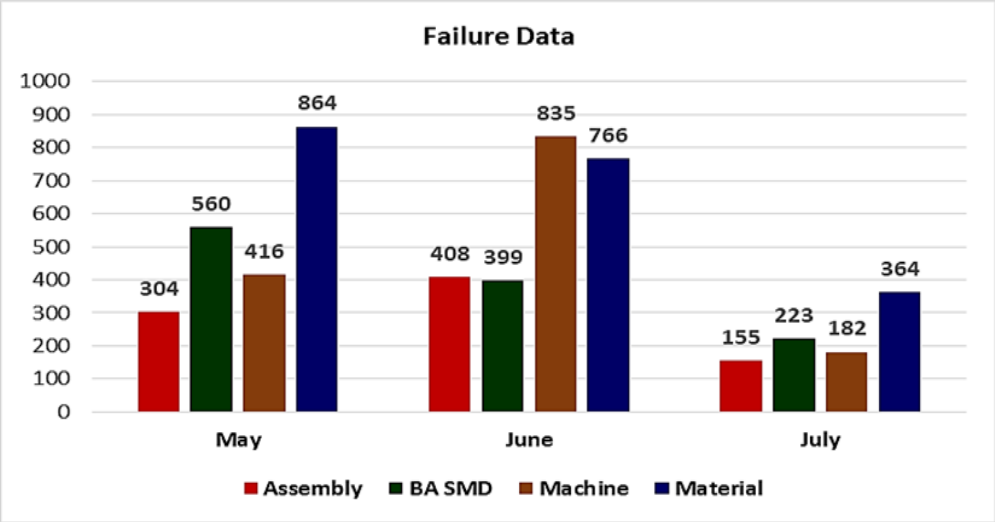

Figure 2. Total number of failures by type of process (May to July 2018).

The processes that originate the faults are described in this way, as they were where they occurred.

Thus, they are described as: a) Board assembly: place where automated machines of various types assemble the boards together with the bill of material (BOM) components of the project; b) Material: location related to quality problems with the supplier; c) Machine: place where programming, calibration and functional tests of phones take place; d) Mounting: place where assembly steps of the device by trained persons occur.

Prior analysis of data collected by intranet logs is important, as there are no previous logs related to failure analysis and its effects, and the product is new, many defects are unknown in the process and tend to behave in unpredictable ways.

For a more accurate stratification of total failures by production lines of the company, analyzes were performed using the Pareto chart for the period under study. Production lines are identified as Middle End, Front End (FE01, FE02, FE03), Back End (BE01, BE02, BE03), CFC1, CFC2, CFC3. The values collected during the period of May and July (Figure 3 and Figure 4).

According to the data shown in the figures, it can be seen that the most impacted production line for all types of processes where failures occur is MIDDLE END. Based on the analyzed data, the FMEA of processes was mapped, to document and to point out the failure modes, as well as the root causes related to BA (SMD), machine, assembly and material.

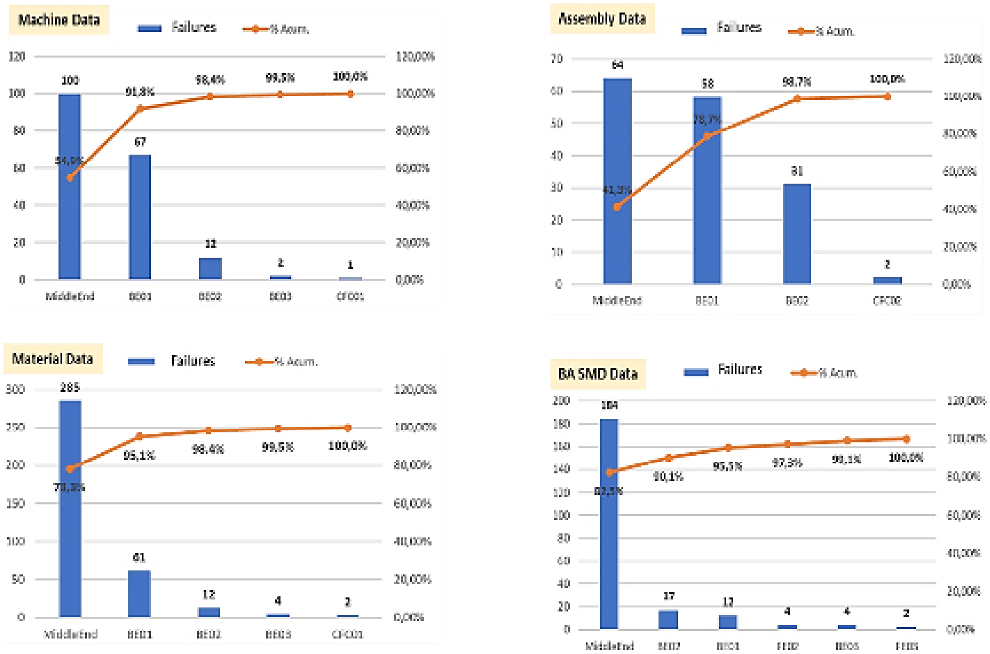

Figure 3. Total number of failures by type line production (May 2018)

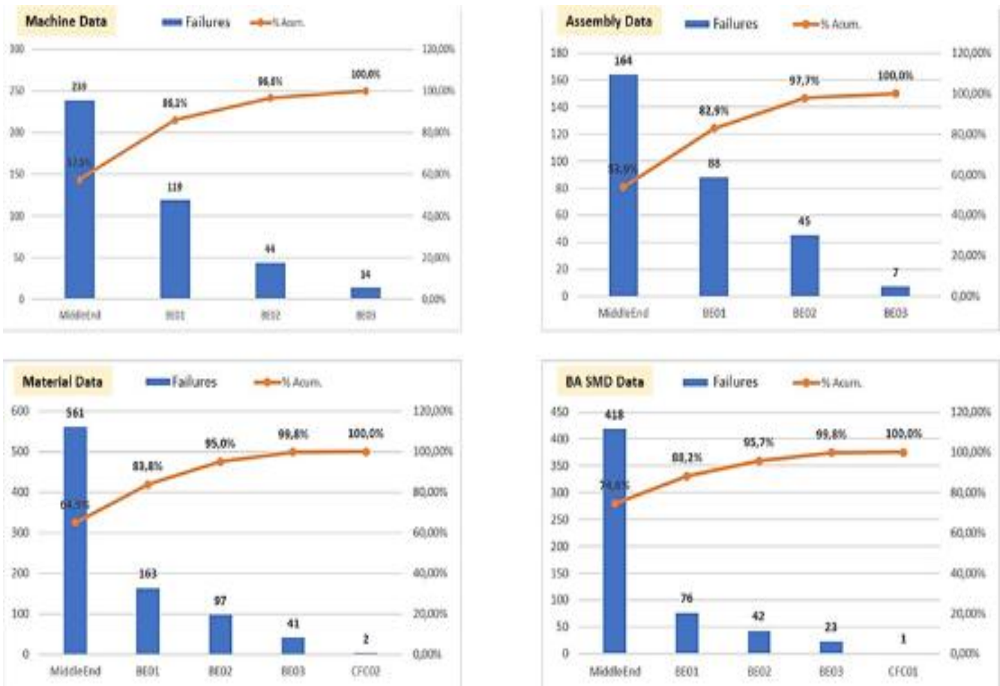

Figure 4. Total number of failures by type line production (July 2018)

Using, as reference, the failure data from May and those related to machines, we verified that the MIDDLE END line was the one that got most impact. The stratification of machine failures allowed an association with the possible causes: NT (false fault), S2 (erase), RA (recalibrated), ENG (engineering), RC (recalibration), FTDS (FTDS). In this way, the data were stratified and compiled (Figure 5), showingYIELD in the studied period in the productive process were NT and S2, respectively. For the NT fault, a process FMEA was performed, to map the possible causes and effects in the automatic functional test step.

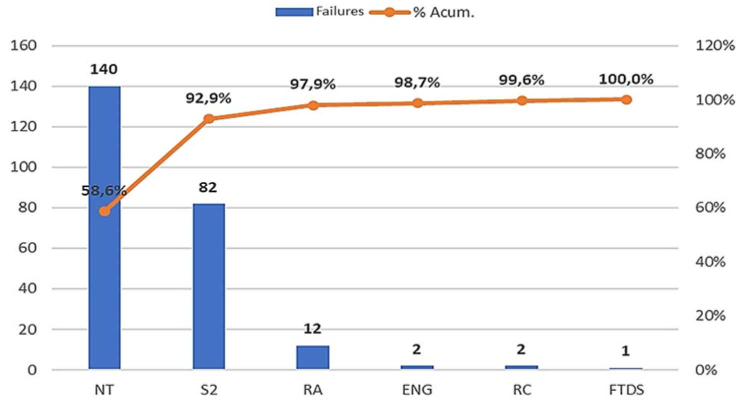

Figure 5. MIDDLE END Total failure mapping (machines)

The analysis shows that the main offenders that impacted YIELD in May in the process were NT, with 140 and S2 with 82 failures respectively. For NT fault, process FMEA was performed and all possible causes and effects in the automatic functional test process that are related in the same way were mapped.

For the construction of the FMEA, the name of the item to be studied, the mode of failure, the cause of the failure, the severity classification, the occurrence classification, the type of control, the detection index, the NPR, were identified the S x O index, the type of action that should be taken to mitigate failure mode, timeframe, action taken, and action completion date.

All of this data was logically gathered in an FMEA form and classified according to the effects of the causes of NT failure mode.

The risk priority number (NPR) index was calculated by multiplying the corresponding indices of the severity, occurrence and detection scales. The S x O index was obtained by multiplying the severity factors and the occurrence of NT failure mode causes. In the process mapping, there were 27 causes related to NT failure mode, however, as the number of causes were many, it was necessary to analyze the main causes using the Pareto graph.

The number of causes related to NT failure mode is reduced from 27 to 16, as it was considered the basic rule of the Pareto diagram that says: to solve 80% of the total problems, you must attack the 20% biggest causes. that occurred during the evaluated production process. The same rule was applied for obtaining the S x O versus CAUSES, but the number was reduced from 27 to 21, a much smaller number of causes compared to previous data.

For the preparation of the FMEA form, the NPR ratio was chosen, since the reduced amount went from 27 to 16, the latter being the actual number of causes (basic causes) that should be addressed in the FMEA. The adoption of this measure was due to the relatively large number of possible causes indicated in the "Brainstoming" meetings by the company's FMEA team. Thus, it was decided to reduce the number of causes and highlight the causes that would actually impact more effective preventive measures and proposals for more robust improvements.

According to a study, it can be noted that NT failure mode would have been reduced to acceptable levels if test engineering looked for possible failures that could result from incompatibility in testing due to non-upgrading of test software.

Thus, there was a need for improvement in the trial versions of all production lines.

It should be noted that on the MIDDLE END line, the failure modes that appear most in the Pareto diagrams should be worked out carefully, as the effects of this mode could result in significant impacts on future NPIs, and the proposals will be based on modes that occur in assembly, material, and board assembly (BA) processes.

The analysis shows the results in the FMEA developed for this study (Table 1).

Table 1. FMEA: Number of Priority Risk (NPR) Result.

Cause	NPR	Accumulated (%)
10 MHz cable damaged	420	8%
RF coaxial cable damage	360	15%
RF relay broken	360	22%
Test SW updating	336	29%
CMW out of calibration	324	36%
AC/DC supply out of calibration	324	42%
Meter out of calibration	324	48%
Setup poorly done	240	53%
Light sensors unbalanced	210	57%
SIM DOOR worn out	192	61%
10 MHz generator turned off	180	65%
Operational error	144	68%
Test nails dirty	144	71%
Key test out of position	144	73%
Warm environment	126	76%
Shield box cover in loop	126	78%
RF connectors with impurities	126	81%
Client server and machine out of sync	126	83%
Coupling sensor unbalanced	126	86%
RF connector broken	120	88%
Lack of energy	120	91%
Connection error with network	108	93%
Test nails broken	108	95%
Shield box open	84	97%
Guide pin worn out or broken	60	98%
Board mismatch in the tester	48	99%
USB connections worn out	36	100%

5. Discussion

The mapping of processes by some kind of qualitative and/or quantitative tool is of fundamental importance for the manufacturing process, since they are the ones that show the indicators of the line and show the possible defects that occur in the day to day of the factory. FMEA is a tool that, if used correctly, aims to prevent failure modes in processes, products, projects and services.

The various failure modes that appeared during the NPI period of the company studied were predicted in previous FMEA's.

One of the causes of NT failure mode prevention that most impacted the process was the upgrade of the test software version to the automatic testers on the production lines.

The various failures that occurred in the testers were predicted at the FMEA drafting brainstorming meetings. However, due attention was not given by the test engineering team to their occurrence, they did not give due importance to the failures that could occur. With this, the first failures that occurred were analyzed and apparently, the product technicians and engineers found no problem with the assembled phone.

Over the days, the number of unresolved failures accumulated and mingled with actual assembly problems and other process-related causes. However, this accumulation has reached an uncontrollable level of "defective" products standing still awaiting engineering analysis to take some action.

In a palliative and emergency manner, the management authorized the dismantling process of the stopped devices and the return of parts and plates to be reassembled at the beginning of the line. This drastically reduced the build-up of mounted devices, but it did not solve the problem of false faults occurring at a high frequency, as no actions were found that discovered the root cause of the failures. Some devices approved to be retested, but others did not. Those who did not approve at all failed near the upper or lower limit in the testing steps.

According to the data analyzed, it appears that the number of failures that occur in the factory is relatively high and, consequently, the Yield very low. The RADIOTST (JOT) column shows the percentages and hourly quantities of YIELD, NTF (not trouble found), and DPHU (defects produced per hour) (Figure 6). In line BE01, the percentage of NT false failures, which are called in the NTF matrix, averages 4.71% (52 NT failures) of the total produced. In line BE02, the percentage reaches 7.22% (48 NT failures), and the actual percentage is much higher, because the data that is collected in the matrix is what process technicians (debug) can insert into the system as possible causes of the defects caught hour by hour.

The managerial decision to disassemble the handsets as a way of disposing of the stopped parts generated large amounts of scraps because the phones were disassembled without due attention from process engineering. Through this whole problem, there was a need to address the root cause of most defects that were classified as false. However, they could not pass when retested on the test machines, as failures occurred at the upper and lower limits of the test steps. These failures were considered intermittent, because when the devices approved when retested, the response values for that test step were close to the failing thresholds.

Thus, great efforts were required to construct the FMEA of processes only to determine and organize the problems that occurred in the production lines. Experts do not advise this type of palliative process, since the methodology is always used in a way to treat preventively the ways that will happen. Reduction of the failure rate in the process steps, component losses, machine downtime and corrective actions in the process, increase of process reliability and reduction of rework with defective boards were objectives achieved with this project, from the application of this tool, confirming its potential.

The failure modes that appear with greater quantity in the Pareto diagrams should be carefully considered, as the effects of these modes may result in significant impacts on future NPIs (New Product Introduction), and the proposals will be based on modes that occur in assembly, material and BA (board assembly).

The various failures in the testers were foreseen in the brainstorming meetings of the FMEA, but were not taken into account by the test engineering team. As a result, the first glitches that occurred were analyzed and apparently, technicians and product engineers did not find any problems with the phone mounted.

However, due analyze performed by process technicians, it was noticed that there were no problems identified and the phones were approved after second pass in the tester, called false failure

The elaboration of the FMEA of processes resulted in the treatment of data to reduce one of the main offenders that occurred in the assembly process of cellular phones, which were false failures. This analysis resulted in the company's need to upgrade the test software version used in MIDDLE END, BACK END and CFC line machines.

So, upgrading the test software version in the automatic testers of the production. This change was basically made by changing the upper and lower limits of each step throughout the programming, that is, the test rangers were increased so that the devices that failed with marginal faults could approve.

The engineering team adjusted the upper and lower limits of the steps, thus enabling the most effective approval of the failures that were related to the NT failure mode and no longer requiring them to be dismantled. After updating the version of the test software, it was waited one month to verify the performance of the tester's equipment's and it was verified the substantial reduction of the false faults (NT). The quality results in the process is collected in the BEO1 machines are shown (Figure 6).

Before

BE01			RADIOTST (JOT)						RADIOTST			ASHLEY_LATAM_BE01			CAR_IN
Time			P. YIELD		P. NTF		P. DPHU		YIELD	NTF	DPHU		Failure	Action	3%
15:00:00	-	15:59:59	77,78%	116	8,64%	8	15,38%	18	77,78%	8,64%	15,38%	TOP #1	SUSPEND_1	Maintenance of Dummy USB.	WMS_BE
16:00:00	-	16:59:59	83,73%	151	1,81%	3	14,46%	24	83,73%	1,81%	14,46%				
17:00:00	-	17:59:59	78,26%	157	6,21%	10	15,53%	25	78,26%	6,21%	15,53%				
18:00:00	-	18:59:59	81,88%	161	2,50%	4	15,63%	25	81,88%	2,50%	15,63%	TOP #2	GET_SIM2_Card_PRESENT_STATE	DUMMY SIMCARD short-circuit alignment and removal.	SMT
19:00:00	-	19:59:59	78,29%	124	3,88%	5	17,83%	23	78,29%	3,88%	17,83%				
20:00:00	-	20:59:59	71,21%	125	9,85%	13	18,94%	25	71,21%	9,85%	18,94%				
21:00:00	-	21:59:59	75,89%	100	5,36%	6	18,75%	21	75,89%	5,36%	18,75%	TOP #3	MIC_A_LEVEL_SPEC_01750	Audio Calibration with Golden Phone	TEST
22:00:00	-	22:59:59	72,91%	76	4,05%	3	22,97%	17	72,91%	4,05%	22,97%				
	-			0		0		0	0,00%	0,00%	0,00%				
TOTAL			78,02%	1010	4,71%	52	16,73%	178	78,02%	4,71%	16,73%		GOAL YELD: 93%	GOAL NTF: 3% GOAL DPHU: 4%	GOAL CAR IN: 2%

After

BE01			RADIOTST (JOT)						RADIOTST			ASHLEY_LATAM_BE01			CAR_IN
Time			P. YIELD		P. NTF		P. DPHU		YIELD	NTF	DPHU		Failure	Action	3%
07:00:00	-	08:00:00	86,09%	148	1,74%	2	12,17%	14	86,09%	1,74%	12,17%	TOP #1	AUDIO_OUTPUT_ALERT_THD_02800 - 18 falhas de DPHU	03 cell phones failed. They have been retested and approved. Cause under review.	WMS_BE
08:00:00	-	09:00:00	91,86%	185	1,16%	2	6,98%	12	91,86%	1,16%	6,98%				
09:00:00	-	10:00:00	89,68%	149	0,65%	1	9,68%	15	89,68%	0,65%	9,68%				
10:00:00	-	11:00:00	89,13%	177	2,17%	4	8,70%	16	89,13%	2,17%	8,70%	TOP #2	GPS_CARRIER_TO_NOISE - 10 Falhas de DPHU	Component without weld. (U3705 and U3706) Reoccurring failure..	SMT
11:00:00	-	12:00:00	84,11%	106	4,67%	5	11,21%	12	84,11%	4,67%	11,21%				
12:00:00	-	13:00:00	77,88%	87	0,96%	1	21,15%	22	77,88%	0,96%	21,15%				
13:00:00	-	14:00:00	86,71%	168	2,31%	4	10,98%	19	86,71%	2,31%	10,98%	TOP #3	SUSPEND_1 - 6 Falhas (5 de DPHU e 1 de NTF)	02 cell phones failed. They have been retested and approved. Cause under review.	TEST
14:00:00	-	14:50:00	72,83%	84	4,35%	4	22,83%	21	72,83%	4,35%	22,83%				
	-			0		0		0	0,00%	0,00%	0,00%				
TOTAL			86,40%	1104	1,96%	23	11,10%	131	86,40%	1,96%	11,10%		GOAL YELD: 93%	GOAL NTF: 3% GOAL DPHU: 4%	GOAL CAR IN: 2%

Figure 6. Process failure matrix for line BE01 (before and after implemented actions)

The elaboration of the FMEA process resulted in the processing of data to reduce one of the main offenders that occurred in the process of assembling cell phones, which were false failures. This analysis resulted in the company having to update the version of the test software used on the MIDDLE END, BACK END and CFC line machines. This modification was basically done by changing the upper and lower limits of each step throughout the programming, ie the test rangers were increased so that the devices that failed marginal faults could pass.

The engineering team adjusted the upper and lower limits of the steps, thus enabling more effective approval of faults that were related to NT fault mode and no longer requiring disassembly. After updating the test software version, it took a month to verify the test performance and found a substantial reduction in false failures.

The design of the FMEA was decisive in the design of the NT failure mode, because through the methodology used to carry out the design, the engineering was able to guide and make better decisions to prevent future process failures. The reduction in the failure rate linked to marginal failures represented 2.41% in line BE01 and 1.81% in BE02.

In summary, the improvement of the company's quality and productivity indices were effective, as shown in Figure 7.

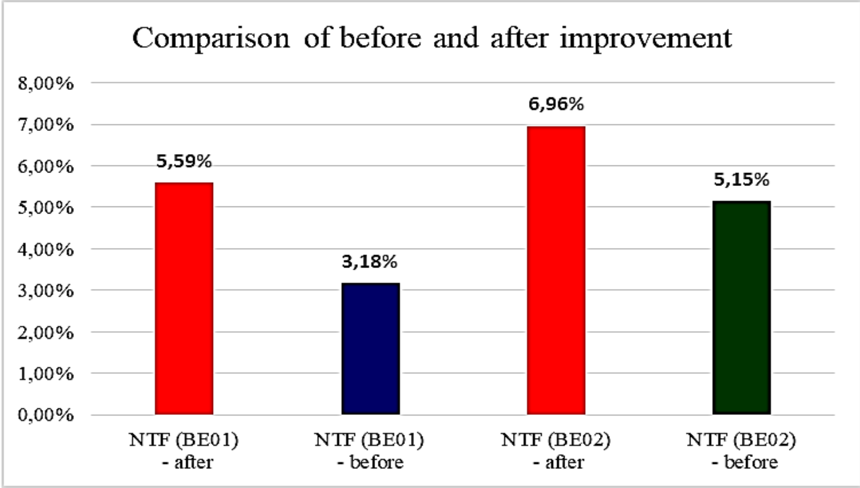

Figure 7. Result: Production Lines

6. Conclusions

Process mapping by some kind of qualitative or quantitative tool is of fundamental importance to the manufacturing process, as they show the current state of the process and allow evaluating the line indicators, and identifying the potential risks that occur daily in a factory.

FMEA is a tool that, if used correctly, allows us to prevent failure modes in processes, products, projects and services. Proper project planning, even before it becomes a final product, is of paramount importance for the proper development of FMEA. If there are any unforeseen events that are not noticed during project planning, one of the tools that can be used to mitigate possible failure modes and their effects is FMEA.

The correct collection of systemic information, either manually or through the empirical knowledge of the people working directly in the production process, is crucial for effective cause mapping, and possible ways to be resolved in time, even before they occur of a failure.

The practical knowledge of the team that will develop the FMEA project has to be balanced at branstorming meetings, along with the data collected systemically or manually so that the team can come to a clear understanding of the failures and the actions to be taken.

The way the tools are used is of paramount importance for efficient line performance monitoring. Moreover, this is most necessary when the company does not have automated information systems to record the anomalies that occur daily.

Reduction in the failure rate of process steps, component losses, machine downtime and corrective actions, reduction of rework with repair, were objectives achieved with this project, by applying this risk analysis tool, ratifying its potentiality and resulting in increased process reliability.

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References:

Braaksma, A. J. J., Klingenberg, W., & Veldman, J. (2013). Failure mode and effect analysis in asset maintenance: A multiple case study in the process industry. *International Journal of Production Research*, *51*(4), 1055-1071. https://doi.org/10.1080/00207543.2012.674648.

Braaksma, A. J. J., Meesters, A. J., Klingenberg, W., & Hicks, C. (2012). A quantitative method for Failure Mode and Effects Analysis. *International Journal of Production Research*, *50*(23), 6904-6917. https://doi.org/10.1080/00207543.2011.632386.

Barbosa, L. C. F. M., Oliveira, O. J. & Santos, G. (2018). Proposition for the alignment of the integrated management system (Quality, Environment and Safety) with the business strategy. *International Journal of Quality Research*, *12*(4), 925-940. https://doi.org/10.18421/IJQR12.04-09.

Bian, J., Sun, X., & Yang, J. (2015). Failure Mode and Effect Analysis of Power Transformer Based on Cloud Model of Weight. *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, *13*(3), 776. https://doi.org/10.12928/telkomnika.v13i3.1804.

Chen, C. C. (2013). A developed autonomous preventive maintenance programme using RCA and FMEA. *International Journal of Production Research*, *51*(18), 5404-5412. https://doi.org/10.1080/00207543.2013.775521.

Estorilio, C., & Posso, R. K. (2010). The reduction of irregularities in the use of “process FMEA.” *International Journal of Quality and Reliability Management*, *27*(6), 721-733. https://doi.org/10.1108/02656711011054579

Jardine, A. K. S., Lin, D., & Banjevic, D. (2006). A review on machinery diagnostics and prognostics implementing condition-based maintenance. *Mechanical Systems and Signal Processing*, *20*(7), 1483-1510. https://doi.org/10.1016/j.ymssp.2005.09.012.

Kardec, A., Nascif, J. & Baroni, T. (2002). *Manutenção: Gestão Estratégica e Técnicas Preditivas.* Rio de Janeiro: Qualitymark Editora: ABRAMAN, 160 p.

Lafraia, J. R. B. (2001). M*anual de confiabilidade, mantenabilidade e disponibilidade.* Rio de Janeiro: Qualitymark Editora: Petrobrás, 388p.

Laurenti, R., Rozenfeld, H. & Franieck, E. K. (2012). Avaliação da aplicação dos métodos FMEA e DRBFM no processo de desenvolvimento de produtos em uma empresa de autopeças. *Gestão & Produção*, *19*(4), 841-855. https://dx.doi.org/10.1590/S0104-530X2012000400013.

Mahto, D., & Kumar, A. (2008). Application of root cause analysis in improvement of product quality and productivity. *Journal of Industrial Engineering and Management*, *1*(2), 16-53. https://doi.org/10.3926/jiem.2008.v1n2.p16-53.

Mesquita, W. G. (2014). *Redução dos custos da má qualidade através da metodologia FMEA: um estudo de caso na montadora Alfa.* Programa de Pós-graduação em Gestão Organizacional Mestrado Profissional em Gestão Organizacional (RC). Retrieved from http://repositorio.bc.ufg.br/tede/handle/tede/4424.

Miguel, B., & Pedrosa, M. (2014). *Análise dos Modos de Falha e seus Efeitos (FMEA) aplicada a um Secador Industrial.* Retrieved from http://repositorio.ipl.pt/bitstream/10400.21/4151/1/Dissertação.pdf.

Miguel, P. C., & Segismundo, A. (2008). O papel do FMEA no processo de tomada de decisão em desenvolvimento de novos produtos: Estudo em uma Empresa Automotiva. *Produto & Produção, 9,* 106-119. Retrieved from http://seer.ufrgs.br/index.php/ProdutoProducao/article/viewArticle/5011.

Ming, W. J., Min, H., Jun, Y., & Jun, L. X. (2015). The Study of Process Reliability of Aircraft Engine. *Procedia Engineering, 99,* 835-839.

Moubray, J. (1997). *Reliability-Centred Maintenance*, 2nd ed. New York, NY: Industrial Press Inc.

Niu, G., Yang, B. S., & Pecht, M. (2010). Development of an optimized condition-based maintenance system by data fusion and reliability-centered maintenance. Reliability Engineering and System Safety, 95(7), 786–796. https://doi.org/10.1016/j.ress.2010.02.016.

Norma QS-9000 (SAE J-1739), (2002). *Análise de modo e efeitos de falha potencial (FMEA): Manual de referência*, Segunda Edição. São Paulo: IQA - Instituto da Qualidade Automotiva, 85p.

Palady, P. (1997). *FMEA: Análise dos Modos de Falha e Efeitos: prevendo e prevenindo problemas antes que ocorram.* São Paulo: Instituto IMAM, 270p.

Pedrosa, B. M. M. (2014). *Análise dos Modos de Falha e seus Efeitos (FMEA) aplicada a um secador industrial.* Tese de Mestrado, Instituto Superior de Engenharia de Lisboa - Portugal, 98p.

Ribeiro, J. F. M. (2016). *Indicadores de qualidade em campo para o gerenciamento de melhorias no processo de celular*. Tese de Mestrado. Universidade Federal do Pará. Retrieved from http://ppgep.propesp.ufpa.br/ARQUIVOS/dissertacoes/Dissertacao2016-PPGEP-MP-JoseFlavioMatosRibeiro.pdf.

Rosa, R. N. (2016). *Aplicação da manutenção centrada em confiabilidade em um processo da indústria automobilística*. Universidade Federal do Rio Grande do Sul. Escola de Engenharia. Programa de Pós-Graduação em Engenharia de Produção. Retrieved from https://lume.ufrgs.br/handle/10183/163902.

Soares, T. M. C. Q. (2014). *Análise da eficácia da aplicação da Metodologia FMEA do Processo: Caso de estudo numa empresa certificada*. Tese de Doutorado. Repositório Científico do Instituto Politécnico do Porto ISEP - Instituto Superior de Engenharia do Porto. ISEP - Dissertações de Mestrado. ISEP - DM – Engenharia Electrotécnica e de Computadores. Retrieved from http://hdl.handle.net/10400.22/6592.

Stamatis, D. H. (1995). *Failure Mode and Effect Analysis: FMEA from theory to execution*, 2nd. ed. ASQC, Milwaukee: Quality Press, 2003. 494p.

Superintendência da Zona Franca de Manaus. Faturamento do PIM cresce no primeiro bimestre de 2017. Retrieved from http://site.suframa.gov.br/noticias/pim-fatura-mais-de-r-81-bilhoes-em-2017. Accessed at: 07 set 2018.

Thurnes, C. M., Zeihsel, F., Visnepolschi, S., & Hallfell, F. (2015). Using TRIZ to invent failures–concept and application to go beyond traditional FMEA. *Procedia Engineering*, *131*, 426-450.

Zied, H., Sofiene, D., & Nidhal, R. (2011). Optimal integrated maintenance/production policy for randomly failing systems with variable failure rate. *International Journal of Production Research*, *49*(19), 5695-5712. https://doi.org/10.1080/00207543.2010.528063.

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