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Analysis of Failure Modes and Effects of the Process Applied to a White Line Industry

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***Abstract*— *Increasingly, factories are forced to increase the reliability of their products and processes, since nonconformity generates poor quality and waste, interfering with competitiveness. In this way, the current scenario causes companies to seek out new methods to ensure robust process and product. One of the tools for continuous process improvement is Failure Mode Analysis and Effects (FMEA), which assists in the prior detection of failures in a given process, contributing to preventive action and problem correction in an efficient and agile way. This research intends to show the characteristics of the PFMEA in a case study, applied to the development of an assembly line of a mixed beverage machine. Finally, all analyzes and ideas addressed by a multifunctional team are presented through a standard PFMEA form, which allows the reduction of quality problems related to the product.*

Keywords*— *Quality Management, Failure Modes and Process Effects Analysis (PFMEA), White Line Industry.

I. INTRODUCTION

Faced with a scenario where competitiveness becomes a crucial element for the growth of a company, and where customers demand increasingly complex and quality products, industries are subject to innovate the way their products are manufactured. For such innovations to be applied efficiently, they must be supported by tools that, with qualitative data translated into quantitative, are able to optimize the use and maintenance of these new means of production and indirectly improve the quality of the product.

Organizations that seek excellence in the process of failure management continually seek to reduce and eliminate the flaws inherent in their products and services [1]. A very expressive tool in this area is the Failure Mode Effect Analysis (FMEA) methodology, with proactive features that allow the identification and prevention of process failures. Thus, the more effectively this tool is applied, the more benefits it will bring to an organization.

This study was motivated by the high failure rate in the implantation of a beverage machine project in a white line industry. During the five years of production of the product, it was verified that the indicator of field failures increased continuously, reaching an index of 32%, motivating the use of Process FMEA, since it helps in the search for continuous improvement, reduction of cost, elimination of failures and risks in the assembly, as well as in the increase of the reliability of the process. Thus, it is necessary to study this theme, since the previous design of the beverage machine in another manufacturing unit of the same group, had its quality indicators impacted and consequently its brand reached.

For this reason, the general objective of the research is to apply the FMEA quality tool to improve the reliability level of the beverage machine production process in a white line industry. As specific objectives, we must present concepts of quality tools, focusing on the analysis of failure modes and effects (FMEA); analyze the processes deployed, put to stand, in the production of beverage machines in a white line industry, to verify possible failures; and present needs to avoid flaws in the process.

II. THEORETICAL FOUNDATION

It is necessary to base the work focus from the existing theories on quality tools, especially in the PFMEA and its methodology, in order to base the subsequent analysis and interpretation of data collected in the field surveys, which occur specifically in the production of beverage machine in a white line industry.

2.1 QUALITY TOOLS

The industrial environment involves the production of tangible goods and, for this reason, Quality Management in this context focuses on the production process, with the objective of generating a product suitable for use. Thus, [2] lists some general characteristics of Quality Management in this environment:

Production and consumption are sharply separated;

The productive processes have precise information and are repeated several times. This makes them perfectly known, documented, and controllable. The bases for standardization and automation of many procedures are then generated;

Quality management is markedly marked by actions for improvements in the process, which involve efficiency and productivity at first, and effectiveness soon to follow. Hence, the elemental concept of quality in this environment is that of "absence of defects"; in fact, there is no way for a product to fit the intended purpose if it has some kind of defect;

The evaluation of process quality focuses on basic elements and points of control. The elements involve corrective, preventive and process consolidation procedures. The basic points are the critical situations or components of the process, well defined and characterized.

In this way, [3] argues that in modern companies, measures that promote quality constantly accompany products throughout their life cycle: the idea to serial production and delivery of products. Each phase of this process has its typical course and its sources of defects. In order to recognize these possible defects in all phases and to reduce them to a minimum, several tools were developed. Some of the main quality management tools are listed below, so that the next topic is specifically studied FMEA.

Flowcharts: according to [2], flowcharts are graphical representations of the phases that compose a process so as to simultaneously allow a global view of this process and, mainly, of the characteristics that make up each of the stages and how they relate each other. [3] explains that each step is represented as a rectangle and its subdivisions are represented as diamonds, in which the conditions of subdivision are written. Thus, [4] states that this tool also emphasizes the critical operations, which are understood here as those located at the intersection of several flows, identifying bottlenecks, in order to enable alternative schemes of action.

Pareto diagram: [5] explains that this structure migrated from the area of Economy to Quality Management by Juran. [6] clarifies that the principle says that, among many variables of influence, only few have dominant influence. I transport to quality management, which means that only a few defects cause the vast majority of defective parts (consequences of defects). In this way, [7] argues that it is more efficient to work in an organized way, allocating greater resources to elements that require them or are able to provide greater returns.

Histograms: According to [6], histograms are instruments widely used in Classical Statistics. Initially, they exemplify how a given situation can be described in a simple and efficient way; stimulate the use of images as basic elements of description of reality and induce people to use global views of processes to better understand them. In this way, its application has reflexes in the design and implementation of management processes.

Ishikawa diagram: Also known as a cause-effect diagram or a fishbone. [7] explains that its presentation scheme is similar to the spine of a fish: the main axis represents a flow of data and the spines characterize elements that converge for that fundamental flow. Thus, the main elements of the phase of the process under study and the elements that contribute to its formation are illustrated. This structure can be used to eliminate causes that negatively influence the process or to intensify elements that positively affect a set of operations.

2.2 PROCESS FAILURE MODES AND EFFECTS ANALYSIS (PFMEA)

The method of analysis and failure modes and effects (FMEA) was developed in the 1960s by NASA, United States, for aerospace projects, as explained [8]. In Germany it spread in manufacturing technology, especially in the automotive industry, in the second half of the 1980s.

The FMEA analysis is a tool that aims to avoid failures, be they process, product or design, by analyzing potential failures and by measures for improvement. Through its use, the chances of the product or process to fail during its operation diminish, increasing its reliability [9].

Although FMEA-like analyzes have always been conducted in manufacturing projects and processes, the first formal application of the FMEA was an innovation of the aerospace industry in the mid-1960s. Although initially designed to be applied to products and processes, due to its great utility, the FMEA methodology has been

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applied in several areas, such as food and safety engineering [9].

In addition, the FMEA is one of the most efficient low-risk analyzes for prevention, identification and cost-effective solutions, and also shows great effectiveness when applied in a team effort. The application of FMEA, however, can generate expenses, but when executed efficiently it can result in a significant return of quality and reliability in the process or product where applied, reducing the cost of failure [10].

The application of the FMEA is based on previously planned meetings and the formation of small groups of people, who can identify their functions, the types of failures that may occur, the causes and the effects of these failures. All the information collected is applied in a table document that allows the evaluation of the results obtained. After this evaluation, the risk assessment of each failure through indexes is made, and based on the indexes found, improvement actions are discussed to be implemented in the process, and the necessary measures are taken to reduce the risks of the faults in question, increasing the reliability of the product or process [9]. To calculate the risk, the Severity (S), Occurrence (O) and detection (D) indices are defined for each cause of fault listed, in a range of 0 to 10. After defining the indexes, the risk priority is calculated (RPN), by multiplying the other three indexes, being demonstrated by the equation RPN = SxOxD.

The FMEA method contributes to the solution of the so-called structured problems, because through the implementation of this method, you get to know better the possible errors and failures due to the high detail of the process, which may cause problems, giving security to have this control to the manager, for the most effective treatment of these problems. This makes it easy to devise a plan to correct and avoid potential failures with a broader horizon in order to maximize results and minimize company problems.

2.3 PRODUCTION PROCESS OF BEVERAGE MACHINE IN WHITE LINE INDUSTRY

According to [11], industrialization is the socioeconomic process that aims to transform an initially retrograde area of society into a source of greater wealth and profit through the introduction of machines into productions. Consequently, this implies man's role in many tasks that were previously a production process. The process of industrialization led to the demographic situation in the regions where it occurred, leading to a great increase of great advances in industrial and agricultural productivity and the rapid growth of the per capita income of the middle class and consumption pattern.

Times of industrialization are commonly divided into three and all fall into the same basic phenomenon. The eighteenth century marks the beginning of the Industrial Revolution or 1st Technological Revolution, which began in England. It was characterized by the invention of the steam engine and the consequent changes that had repercussions in the society by virtue of this new technology. Already the call The 2nd Industrial Revolution was marked by the discovery and use of electricity and use of oil as an energy source. Finally, the 3rd Industrial Revolution, also known as the Silicon Revolution, introduced the electronics and microelectronics industry into production assets.

In his work, [12] explains that large appliances such as refrigerators, freezers, stoves and washing machines belong to the white-line industrial segment. This type of industry has been present in the country since the late 1940s, a result of the policy of import substitution of durable consumer goods in force at the time. Since 1990, with the opening of the economy, changes in the Brazilian industrial structure have been taking place. In the first period, from 1990 to 1994, these changes were timid and limited to the increase in competition as a result of the entry of imported products into the market.

In the period after 1994, the stabilization of the currency and the partial recovery of the purchasing power of Brazilians stimulated more significant investments of foreign companies in the country. This phenomenon, as presented [13], is common to all national industry and represents the effects of productive globalization in Brazil, characterized by increasing foreign direct investment in the purchase of domestic companies, maneuvers known as takeover (when a foreign company takes control of a through the acquisition of its shareholding control).

Another way some national companies found to face competition was the formation of strategic alliances with international companies, essentially seeking training in new technologies as well as access to new markets.

2.3.1 Beverage Machine

According to [14], the inspiration for the creation of soft drinks came from naturally gaseous mineral waters. In the fourth century bc, the Greek Hippocrates, considered the father of medicine, already recommended baths in such sources, but apparently it never occurred to him to prescribe the liquid to drink. Carbonated water

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only began to become a popular drink around 1500, when the Belgian town of Spa gained fame for its natural sources and began to export bottles of its water to London and other capitals. The success was so great that, between the seventeenth and eighteenth centuries, several European chemists began to make attempts to recreate the product artificially. The most important step was to adopt a pump to help fix the gas in the water, a finding credited to independent studies by Englishman Joseph Priestley and Frenchman Antoine Lavoisier between 1772 and 1773. Based on this system, pharmacist Thomas Henry became the first to produce industrial carbonated water in 1782.

A few decades later, the idea of adding flavors to the product came up: ginger would have been the first in about 1820, followed by lemon in the 1830s. This process was made easier by a new technology, patented in 1819 in the United States : soda fountain (or "soda fountain", as it is now called gaseous water), a pump installed at the pharmacy counters for the liquid to be carbonated on the spot, adding different flavors to the customer's taste.

Regarding the mixed drinks machine of the study in question, it is found that it was first produced in a factory located in Joinville, in the interior of Santa Catarina, in 2013. Since then, the product has gained strength and space in the market, it is a differentiated product. In terms of process, this product does not escape the idea of the other products produced in a white line industry, being divided into receiving inputs, product assembly, quality inspection, packaging and distribution.

III. METHODS AND TOOLS

The high failure rate of products on the field for a brand is usually quite damaging. Not having customer loyalty or trust in the product can become an irreversible cost to the company, since the end consumer should always feel satisfied with their acquisition.

The original Joinville mixed drink machine project had the indicator of final consumer residency failures at around 32%, according to data from the organization. The mission of the Manaus plant is to reduce this ratio by 17 percentage points in a year. One of the tools that can be used proactively to achieve this goal is the PFMEA, since it assists in the prior detection of failures, thus increasing the reliability and robustness of the product and process.

By completing the standard PFMEA spreadsheet, you determine the severity of the failure (how bad it will be if it happens), determine the occurrence of the failure (how often it actually occurs), and determine the probability of failure detection (how easy is to realize that it occurred).

As soon as the information is collected, the Risk Priority Number (RPN) is reached. This indicator is a way of knowing which mode of failure should be prioritized. This calculation is the multiplication of the occurrence, severity and detection values.

Once this is done, the Pareto Diagram is used to analyze which assembly lines where the RPN is greater than 80, thus establishing the actions that should be determined as critical, so that they are treated as priorities.

The investigation is characterized as a case study, since a case study was carried out, analyzing the production of a beverage machine in a white line industry and the application of the Failure Modes and Process Effects Analysis tool (PFMEA).

The research has a qualitative nature, as it analyzes the activities performed by the operators during the assembly of the beverage machine, and, from this survey, critically classifies them as to the criteria of severity, occurrence and detection of failures. It is also quantitative because it translates these criteria into numerical indicators to classify them according to levels of severity and importance. Therefore, it is characterized by a qualitative-quantitative research.

As for its purpose, it is a descriptive research, since the production process of beverage machines in a white line industry is studied, analyzed and observed for later application of the PFMEA tool, involving the use of observations and video records. A bibliographical research was carried out with the study of books and articles dealing with quality tools, especially the Analysis of Failure Modes and Process Effects (PFMEA).

Observations and video recording of the operators were carried out, in order to verify the activities related to the assembly of the product, for the collection of data done "locally" directly in the place where the problems are occurring, but it can not handle the variables, conceiving them as they are. The activities observed were as follows:

Station 10: assembly of the pump carrier;

Station 20: assembly of kits 1 to 5;

Station 30: assembly of kit 7 and main board;

Post 40: immold assembly and squeezer motor;

Test Station 1: test of hypot, CO_2, H2N2 and power test;

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Test Station 2: functional test, performance test and water tightness.

Station 50: fairing and hipot assembly;

Robot station: robot test; interface board.

Test Station Flush: N2 and purge of water.

Post 60: product packaging.

IV. IMPLEMENTATION OF THE PFMEA

In the application of the selected method, all the functions related to the 10 assembly stations of the mixed drink machine were defined. They are: assembly of the pump support, assembly of kits 1 to 5, assembly of kit 7 and main plate, immold and squeezer motor assembly, hypot test, CO2, H2N2 and power test, functional test, performance test and water tightness, assembly of plastic parts and hipot, robot test; interface card, N2 and water purge and product packaging.

The data listed in figure 1 show the functions and mode of failure and effect that each causes in the process and in the final product.

	Function / System Requirements (for DVP)	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes Mechanisms of Failure	Occurrence
INDEX and/or Component, System, Process Step or Station Number/Name.	What must this design or process do? What is the purpose of this component, system, process or process step?	What could go wrong? How might the design / process / process step fail to meet the function? (Also consider potential internal/external customer complaint quotes.)	How does the failure mode effect customers, trade partners, manufacturing, the next process step, etc? What is their experience and/or reaction?		What in the design (DFMEA) or process (PFMEA) could cause the failure mode? Be specific and focus on causes within your area of influence.	
10 Product Assembly Stations	1. Lock Product on the Post	1. Do not brake	1. Pallet Beat	3	1.1 Wear	3
				3	1.2 Broken	3
	3. Passing the power cord	1. Misfit	1. Noise	3	1.1 Méthod	3
		2. Breaking Cable	1. Do not turn on	5	1.Conditions	7
		1. Break plastic lock	1. Noise	3	1. Méthod	3

Fig. 1: Failure mode and effect of each process function

After defining the steps / identification of errors, the plot of the FMEA method was elaborated, as shown in the example in figure 2 below.

Severity	Potential Causes Mechanisms of Failure	Occurrence	Current Design Controls Prevention	Current Design Controls Detection (for DVP)	Detection	RPN
	What in the design (DFMEA) or process (PFMEA) could cause the failure mode? Be specific and focus on causes within your area of influence.		What will be done (in the design or process) to prevent the cause / failure mode from occurring? Examples: Design Changes, Analysis, Mistake-Proofing, Definition of Characteristics and/or Quantitative targets (if applicable)	What verification method will be used to detect the Cause or the Failure Mode?		
3	1.Spring wear	3	1.Maintain maintenance	1. Visual Inspection	1	9
3	1.Leave lever	3	1.Maintain maintenance	1. Visual Inspection	1	9
3	1.Method	3	1.Management of project	1. Visual Inspection	1	9
5	1. Wrong mounting	7	1.Management of project 2. Reassess assembly	1. Visual Inspection	1	35

Fig. 2: FMEA plotting

It was noted that some errors are motivated by common causes and should be monitored more actively. The effects, the causes and the actions proposed aiming at correcting the flaws.

As can be seen, figure 2 indicates the main fault profiles occurring in the period from the assembly of the p10 to its exit for packaging. In the mentioned table, we tried to describe only the causes of fault profiles that indicated greater risk within each one. Those functions whose risk was considered too small and of low interference in the problems that may have an impact on the GSIR were excluded.

The results obtained allow us to see that the errors with the highest risk index (NPR) were those associated to the spinning connection stage or electrical safety tests (HIPOT), which can generate problems with consumer safety. Because of the high severity of these errors, to solve this problem, it is recommended to use poka-yokes that guarantee the correct assembly of the electrical network. It should be remembered that a problem at this stage can lead to consumer discredit and even to consumer safety processes, generating irreversible costs for the company, as well as the negative impact on the field failure indicator.

V. FINAL CONSIDERATIONS

The current scenario, focused on the fierce competitiveness between companies to offer the best products and win the consumer preference, requires not only the practice of innovation, but the supply of high quality products and value added. Therefore, in order to avoid failures in the final product and consequently the generation of a negative image for the brand, it is necessary to apply methodologies for the improvement in the manufacturing processes of products.

Methodologies such as the FMEA, presented in this research, assure that failures during the manufacturing process are detected, preventing possible errors not previously foreseen in the process development phase. Used as a quality tool to detect potential failure modes in productive processes, FMEA will provide process reliability by preventing and eliminating errors, which is why its study and application in the white line industry should be increasingly emphasized.

The present case study allowed the practical visualization of the FMEA technique employed in the development of the production process of a mixed drinks machine in a white line industry. As discussed, the initial research problem consisted of the high and increasing index of field failures in the production process of the product in another manufacturing unit of the same group, generating impact on the quality indicators, besides costs and risks in the assembly, motivating the application this methodology.

In this way, first, the bibliographic research guided the use of this tool to ensure that the implementation of the project was robust and flawless, with analyzes put in place, measuring and stratifying all activities, so that no failure goes unnoticed. This type of study provided an environment with greater reliability, thus avoiding quality problems.

Then, with the analysis of the 10 assembly stations and their respective functions, it was possible to verify the mode of failure and effect that each causes in the process and in the final product, so as to prioritize the ones that have the greatest severity and to exclude those of low risk. With the application of the tool, it was observed that the highest severity index was in the stage of connection of wiring and electrical safety tests, which can be solved with the use of poka-yokes to ensure the correct assembly of the electrical network of the product, thus avoiding failures during the use by the final consumer.

Therefore, it is concluded that the FMEA is an efficient and low-cost tool, which makes it possible to verify the problems clearly, demonstrating the qualitative data in a quantitative way, pointing out those that should be prioritized. It is recommended to continue applying this method that contributes to the continuous improvement of the quality of the mixed beverage production process in this white line industry. It is also encouraged its use in other processes, since it promotes a macro view of each step, and can be applied in other types of products and industries.

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