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Variability reduction in Manaus` beer process production

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Abstract

Defined as the favorite drink to celebrate good times, beer has been making the drink market one of the most competitive in the Brazilian industry. Given this scenario, brewery industries need to maintain quality standards to gain consumer preference. In the company under study, located in Manaus Industrial Pole, it was found that in the beer production process, the brewhouse stage was not satisfying the brewery wort manufacturing time requirements, which is why it became the focus of this study. This paper aims to investigate and standardize a method to reduce the variability of beer time production in the brewhouse area. The data were collected from the monitoring of the wort production process, raising each time of the equipment of that stage, both before and after the application of the method. After data collection and analysis, it was concluded that it is possible to significantly reduce the variability in the wort production process by treating critical brewhouse equipment.

Keywords: Variability; Quality; Beer;

1. Introduction

The beer market in Brazil is one of the most traditional, has a sector that is present in all cities of the country. According to the Brazilian Beer Industry Association (ABIC, 2016):

> The CervBrasil associates have 50 factories, operate a fleet of about 38 thousand vehicles and supply more than 1,2 million points of sale throughout the national territory. The sector is one of the most relevant in the Brazilian economy, with an investment close to $12 billion between 2014 and 2016.

The Brazilian beer industry mobilizes thousands of suppliers of goods and services, as well as reaching professionals from the most diverse areas of activity. Thus, it involves a contingent of people and can reach 99% of brazilian homes. CervBrasil revealed that in 2016 Brazil's beer sector keeped 2.7 million jobs and produced about 14.1 billion liters in the year.

A survey conducted in 2013 by the Strategic Management Advisory Office of the Ministry of Agriculture, Livestock and Supply (MAPA) revealed that the increase in income of the Brazilian population in recent years has led to the consumption of higher value-added foods, such as beer, which has had an increase in its sales in recent years.

In this scenario, there is the focus of the research, a case study applied in the production process of a brewery that will be called brewery M for teaching purposes, located in the state of Amazonas with a productive sector divided into three macro stages:

Brewhouse: responsible for receiving, stocking, processing, and management of feedstock (malt, aromatic hop cone, bitterness hop cone, among others). This stage produces an average of 4,000 L of wort per day that is cold for the fermenting process, and it is necessary to ensure optimal conditions that do not cause problems in the following steps;

Cellar: It is responsible for the fermentation, centrifugation, and maturation of concentrated beer. This step also manages yeast and ensures that it is used efficiently during fermentations;

Filtering: Responsible for filtering and diluting matured beer from cellars. The filtration area has a large interface with the beer bottling area, as this is the last step of the process before transportation to the fill lines.

During the stages of beer production, several variables can impact the process, leading to a change in the taste of the product. Each equipment of the brewhouse process plays a crucial role in the production of the wort, so it is necessary to have an accurate permanence time in each of them. Thus, managers at Brewery M saw the need to ensure that all production batches had the same wort time, resulting in the standardization of production batches to ensure optimum physicochemical and sensory results. However, the brewery's brewhouse was failing to achieve homogeneity in brewery wort times.

Thus, the main question of the research is "how to standardize a method to reduce the variability of wort manufacturing time located in the brewhouse area of Brewery M?"

1.1 Main objectives and relevance

Given this context, the general objective of the research is to investigate and standardize a method to reduce the variability of wort manufacturing time within the brewhouse area.

To this end, it is intended to achieve the following specific objectives:

Obj1) identify methodologies to reduce variability in related brewery production processes;

Obj2) develop and test a method to reduce the variability of wort fabrication time in the brewhouse step;

Obj3) propose suggestions for improvements to the managers of this process.

This study is relevant for the following reasons:

R1) For the company: it will add knowledge about the causes and ways of treating variability for this type of process and can be applied in other units;

R2) For customers: the consumer is the biggest beneficiary of the reduction in beer production variability, as it ensures that they are not surprised when consuming the product, as they will have the acceptable profile and characteristics;

R3) For workers: the process without high variability results in better production performance, avoiding the need for unplanned work compensation. In addition to avoiding rework in the following process steps, because when a quality problem occurs in the brewhouse process it is only corrected in the following steps of the beer process;

R4) For the academy: the theme involves a product of high world consumption, and the study will contribute to the reflection of the subject, as well as to propose new research.

1.2 Feedstock and stages of the production process

According to Ordinance No. 1/96 of January 3, 1996, of the Ministry of Agriculture, Livestock and Supply (MAPA, 1997), beer is understood to be the drink obtained by alcoholic fermentation through the yeast of the genus *Saccharomyces*, from a prepared malt wort, especially barley, where hop cone's flowers and drinking water are added. When talking about the beer production process it is crucial to start the approach from the feedstock beneficiation stage to the final filling process.

Regarding the raw material, water corresponds to 93% of the beer formulation, this water must be free of contamination and hard, ie, high in calcium and magnesium, as it serves as a nutrient for fermentative yeasts. Moreover, the water should be chlorinated and without iron.

The type of malt has a decisive influence on the characteristics of beer, its combination determines the final color, flavor, body, and aroma of beer (REINOLD, 2010). In the process, malt can be replaced by additives classified as starchy and sugary, such as rice, corn, and wheat. This practice is allowed in many countries, Brazilian legislation (MAPA, 1997) allows the partial substitution of malt by additives.

The Pilsen malt, which is used in light beers; Chocolate malt which is characterized by its toast and the strong color is widely used in dark beers; and caramel malt which is obtained from the caramelization of sugars during malting (CABRITA et al., 1985).

Another feedstock added in the wort manufacturing process is hop cone. The bitter resins and oils in the hop cone will give the beer the bitter aroma. It can be added as granulate, extract or plant itself (CABRITA et al., 1985).

In the fermentation process, yeast is added. As mentioned earlier, the yeast must be of the genus *Saccharomyces*. After fermentation, some additives may also be added, such as caramel extract that intensifies beer color and isomerized hop cone to increase beer spume stability and bitterness (CABRITA et al., 1985).

During the production of beer, there are several processes from the germination of barley to bottling of liquid. The main stages of beer processing can be divided into wort preparation, fermentation, maturation, filtration and bottling.

During the preparation of the wort happens the malt milling, which consists in the preparation of malt for mashing. According to Morado (2009), the purpose of milling is to break the grain and expose the starch contained inside. The process of mashing is considered the transformation of the feedstock into the wort, it is added water to the milled malt, where they are subjected to certain times and temperatures, resulting in a sweet solution called wort and still containing malt pomace.

Because it contains malt pomace, the wort is subjected to the filtration process, which consists of separating the pomace from the liquid wort (JUNIOR et al., 2009). This stage is very important because it gives the wort its first liquid form without malt pomace.

After filtration, wort boiling occurs which is responsible for the inactivation of enzymes, protein coagulation, and precipitation, concentration, and sterilization of the wort. Also, hop cone, caramel, and sugar, among others are added. At the end of the boiling, the wort is submitted to the decantation process, where a solid residue called trub is removed (SANTOS et al., 2005). Consequently, the wort is cooled to the correct temperature to start fermentation and in some cases, oxygen is added to favor the fermentation process (BOTELHO, 2009).

According to Morado (2009), fermentation is responsible for the transformation of fermentable sugars from wort into alcohol, carbon dioxide, and heat through chemical reactions within yeast cells. In this process, byproducts are formed which may provide pleasant or off flavors to the beer. The main compounds formed in fermentation are higher alcohols and esters, which are responsible for the fruity characteristics that some beers have.

During fermentation, another important byproduct is diacetyl, which plays an important role in the formation and elimination of off flavors, which is formed by yeast throughout the process. The high concentration of this substance develops a flavor reminiscent of rancid butter. After 7 to 12 days, the fermentation is completed, and after the yeast is removed through the decantation process. Then the beer maturation process begins, usually at the temperature below fermentation. In this phase, most sugars have already been metabolized and transformed.

After the beer has achieved the desired characteristics, a clarification is necessary to eliminate the particles that will give the beer turbidity. These particles are essentially yeast cells that have not been previously removed.

The clarification of the beer is achieved through centrifugation and the use of several types of filters, among them: the leaf, candle and press filters. According to Santos et al. (2005), the most widely used method is filtration with diatomaceous earth or diatomite. Botelho (2009) explains that the filtration stage beyond the objectives mentioned above has the function of microbiological stability.

At the end of the production process, the beer is kept under controlled conditions of pressure and temperature, to guarantee the taste and CO2 content until filling. The filling stage is a critical moment, strict oxygen level control is required to ensure that the O2 concentration is as low as possible, thus avoiding oxidation reactions as they lead to its deterioration and change of taste.

To ensure that microorganisms are not present and to extend the shelf life of the product, except for draught beer, bottled beer is subjected to the pasteurization process. Because it is a very sensitive drink, subject to rapid deterioration, it is necessary to have this process to make the beer more stable, allowing its distribution to places far from the brewery (MORADO, 2009).

The pasteurization process consists of heating the beer to approximately 60ºC and then cooling to 4ºC, generating a thermal shock in the microorganisms present in the product.

Figure 1 shows the flow of the beer process.

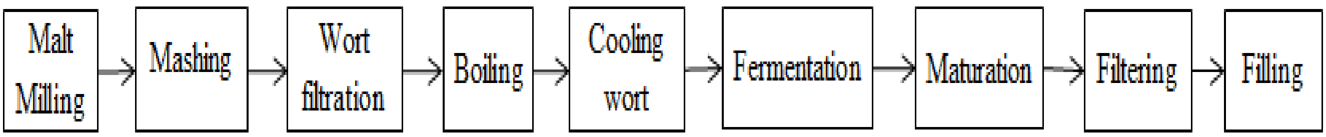

Figure 1: Beer production flow
Source: Author (2016)

1.3 Methodologies for reducing process variability

To improve the understanding of the concepts used in the problem-solving method of this article, the concept of PDCA will be approached with a presentation of its steps and tools used in each of them. Also, statistical concepts of process variability analysis will be used.

1.3.1 PDCA

The PDCA cycle is associated with the process model used by NBR ISO 9001 (ABNT, 2000) which defines the cycle as follows:

> Plan: Establish the objectives and processes required to deliver results following customer requirements and organizational policies. Do: Implement the processes. Check: Monitor and measure processes and products according to product policies, objectives, and requirements and report results. Act: Take action to continually improve process performance (NBR ISO 9001, 2000).

According to Liker (2004), this problem-solving system can also be classified as developing critical thinking, as it encourages those involved to think critically in the investigation of causes and the analysis of process phenomenons. Figure 2 summarizes the steps of this methodology.

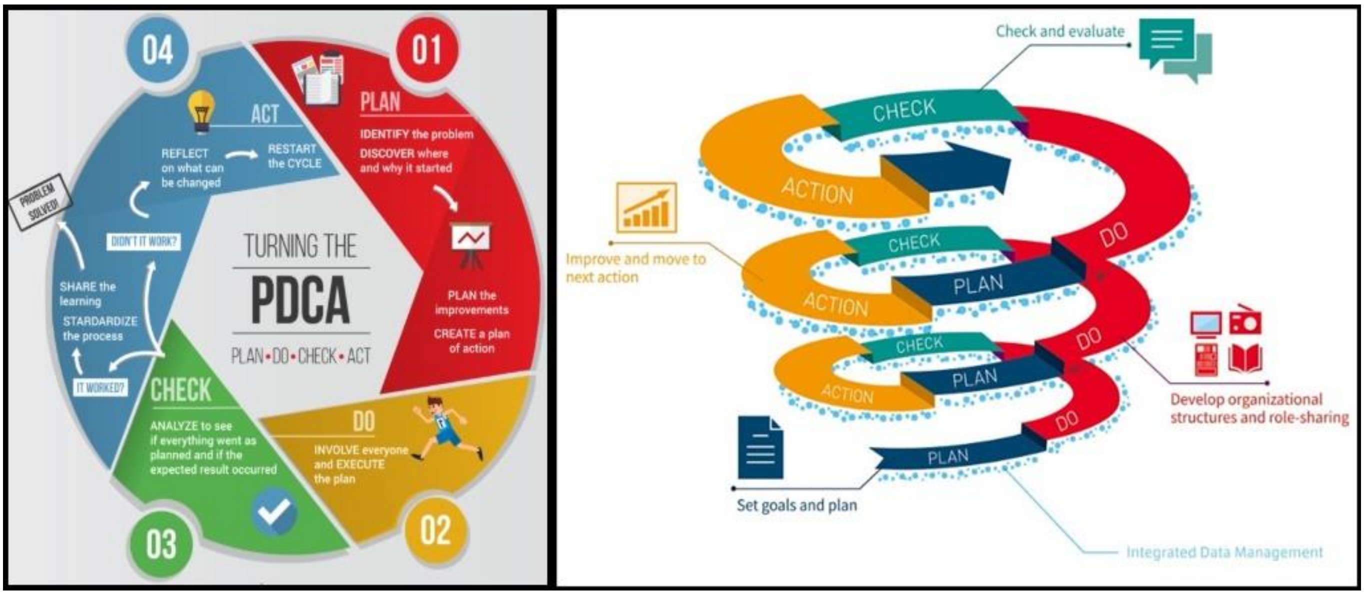

Figure 2: PDCA Cycle componentes and rotation

Sources: Siteware < https://www.siteware.com.br/en> and Asahi advertising <asakonet.co.jp>

According to Werkema (1995), PDCA is a decision-making method that seeks to ensure the achievement of the goals necessary for the survival of an organization. This method was developed by the American Shewhart but became known through Dr. Edward Deming when he went to Japan in the 1950s to teach Statistical Process Control.

The *Statistical Method from the Viewpoint of Quality Control*, published in 1939 by Dr. Walter A. Shewhart, is presented as the first publication on the PDCA. Known as a problem-solving method, it is mostly investigative and is implemented in steps.

The first step of the PDCA cycle is described by the letter P or *Plan*, it is considered the most important step as it triggers the entire subsequent cycle process. The success of applying this method to solve the problem depends on the level of criticality employed in this step, as it will provide information for the rest of the process (BADIRU et al., 1993).

According to Badiru et al. (1993), important issues for understanding the purpose should be discussed, such as: the specific objective to be achieved by the organization, the people involved in this process, the timeframe for drawing up the action plan, the resources for completing the plan, the data to be collected during the process and any issues that may result in detailed process planning to be improved.

To analyze the problem in detail, some resources are used to detail the analysis. A popular tool used to performer stratification of the problem is the Pareto chart, it informs that most of the problems happen due to a few causes. Presented in the form of a cumulative frequency diagram, it ranks occurrences from highest to lowest percent, enabling you to determine priorities that help direct efforts to tackle really important problems.

Another tool used to understand the problem is process mapping, which is nothing more than a way to systematize information throughout the processes so it can be understood by other interested people. It provides an overview of the process and enables you to identify, analyze and develop improvements for the object of study. Visually shows how inputs, outputs, and tasks are related and include key process steps. Process analysis using maps helps improve customer satisfaction by identifying actions to eliminate defects, reduce costs, eliminate non-value-added steps, and increase productivity.

The visual representation of the process mapping can be accomplished through the elaboration of flowcharts. Intended for the description of processes, it is represented through graphic symbols the sequence of steps of work to facilitate its analysis. According to Oliveira (2002), a flowchart is a form of representation that uses conventional symbols and allows a clear and precise description of the flow or sequence of a process, as well as its analysis and redesign.

It is a resource used to analyze production systems, seeks to identify opportunities to improve process efficiency (PEINADO et al, 2007). The process is the combination of equipment, people, methods and tools that generate a product or service.

The most relevant points of a flowchart, according to Oliveira (2002), are: a) standardize the representation of methods and procedures; b) faster description of the methods; c) better reading and understanding of the production system; d) facilitate the location and identification of the most important aspects within the process; e) greater flexibility; f) better degree of analysis.

The Ishikawa diagram should be used to understand the causes of the problem (Figure 3). The tool consists of a diagram with a record of the various causes from the analysis of probable origins (SOUZA, 1997).

At the end of all analysis of the planning stage, an action plan should be created to achieve the proposed problem identification objective. For Campos (1996), the action plan enables management action through delegation to all involved. During the creation of the plan, the company must consider its available resources, its characteristics and the prioritization of the causes that will suffer interference.

To ensure that the action plan achieves the expected success, actions should be developed for each priority cause elected in the previous step. There will be measures for each cause, benefiting the control of the action to be taken. The process of elaboration of the actions should be carried out through group discussions with the same people involved in the previous steps. After the action plan creation, the planning step of the PDCA cycle is completed and you can proceed to the next step called execute or *Do*.

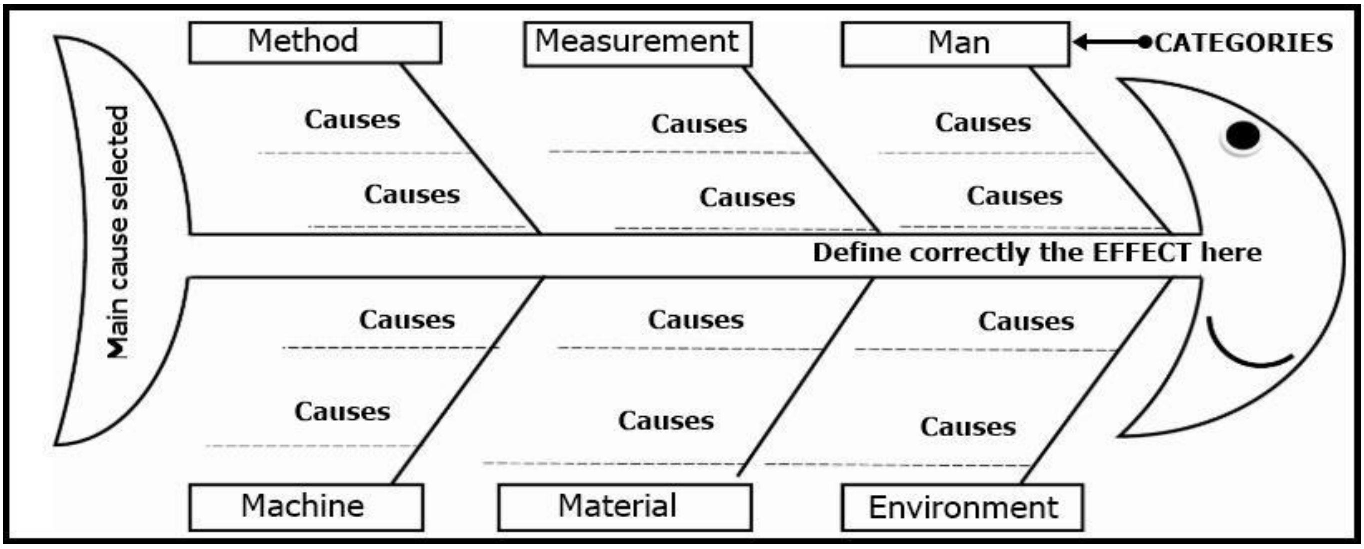

Figure 3: Cause and Effect Diagram components

Source: Author

The second step of the cycle is called execute, in this step, all actions planned in the previous step must be performed. This step will make it visible if the action plan was well structured in the plan step. It will allow the plan to be implemented in a gradual, organized manner and the measures to be taken will be more effective (BADIRU, 1993).

To achieve the desired effectiveness, Campos (2001) subdivides the process into two main steps: the knowledge stage and the action execution stage. At the knowledge stage, the organization should disclose the plan to all involved and emphasize so that it can be carried out to the best of its ability. Such disclosure should be done through participatory meetings where the tasks will be presented.

In the second stage defined by Campos (2001), after the disclosure of the plan and due understanding by all involved, the actions should be implemented. Control of the points present in the plan should be done to keep focus and eliminate any doubts that may appear during execution.

Attention should be paid to actions with good or bad results, as they serve as the information base to feed the next stage of the cycle, called *Check* (Campos, 2001).

The third step of the PDCA cycle is the verification phase of the actions performed in the previous step. This phase will verify the results of the actions coming from the planning phase. Considered the second most important part of the cycle, the phase in question, according to Clark (2001), should be emphasized by the organization to obtain a satisfactory result at the end of the cycle. “In a strong PDCA cycle, the check step is emphasized” (CLARK, 2001, p.2).

To monitor the results of actions taken from the action plan, indicators should be listed to monitor and identify the actions that have obtained the best and worst results.

To ensure a good application of the check step, Melo (2001) suggests three steps: first) compare the results; second) list the side effects; third) check the continuity of the problem.

In the first step, the data collected before and after the actions performed in the previous phase should be used to verify the effectiveness of the actions and the level of problem reduction.

In the second, there is a listing of side effects. Some actions taken in the previous step can cause positive or negative side effects to the organization. In the case of negative effects, it is up to the organization to take appropriate action.

The last step is to check the continuity of the problem. When undesirable effects continue to occur after the actions are taken, they reflect that the solutions presented were flaws. In this case, the PDCA cycle must be restarted so that the causes of the problems can be found and corrective actions can be set to block such causes. However, in the case of non-continuity of the problem, the PDCA cycle will be able to proceed to the next step, the action step.

The last step of the PDCA cycle is responsible for standardizing the actions taken that have yielded satisfactory results throughout the cycle to ensure that problems do not return over time. Such standardization process, according to Melo (2001), consists in modifying existing standards or, failing that, elaborating a new standard.

After standards are drafted or modified, they must be disclosed in the company. The disclosure process should be accompanied by training of all employees involved in changing standards. According to Melo (2001), training should preferably be carried out at the workplace with adequate resources. These standards should be regularly monitored to verify their compliance correctly. For Melo (2001), the company must ensure that a problem solved does not reappear due to the lack of compliance with the standards.

With the completion of this step, the cycle comes to an end.

1.3.2 DMAIC

This methodology is a specific model for continuous improvement by reducing variability with proper control of the production process. Similar to the PDCA cycle, DMAIC is a set of steps that lead to the solution of a given problem through the use of methods that guarantee the reduction of the failure rate in products, processes or services.

Penczkoski et al (2008), conceptualizes DMAIC as follows:

> A methodology that aims at continuous improvement based on process optimization and control, seeking to identify and analyze undesirable results prioritizing the resolution of problems, for this the work team should count from people with technical knowledge to people who only perform the operationalization of the processes tasks.

As mentioned earlier, this cycle is structured in steps. These steps are represented by the letters that complete the name of the methodology, as follows: define, measure, analyze, improve and control. This method was developed at Motorola following as an evolution of the PDCA cycle (SLACK, 2002).

The first step of this method is to define, similar to the first step of the PDCA cycle as it is also necessary to clearly define the problem that will be solved. Considering various factors that may influence the decision and especially the wishes of customers. For Knowles et al (2005) this definition process can be done by answering some questions, such as: What are the client requirements? How is the work currently being done? and what are the benefits of an improvement?

In the next step, the cause of the problem is founded. Called measure, this step is to analyze the process through the use of quality and statistical tools. With this it is possible to situate the company in the scenario it is in and then outline the strategies to reach the desired level of perfection.

After measuring the scenario that the company is in, it is possible to go to the next step, called analyze. The goal of this step is to determine the root cause of problems and look for opportunities for improvement. Using the Pareto diagram, it is possible to prioritize the most relevant causes in the problem and then treat the others further (KNOWLES et al, 2005).

The next step is called improve, this is a step of both designing and implementing ideas that will solve the problem. The most appropriate technique for this type of approach is brainstorm or benchmark in other companies or units of the same company to identify opportunities for implementing a process or product improvements (KNOWLES et al, 2005).

Similar to the PDCA cycle, the DMAIC cycle method also has a step to estimate and control the quality achieved with anomaly treatment. Calling step control, in addition to the mentioned goals allows you to identify new deviations and open gaps for new corrective actions. In reaching a sustainable outcome, we proceed to the standardization of procedures.

1.3.3 Capability study

Process capability study aims to identify if the process is capable of producing to specification and under control. For Montgomery (2004) there are three essential techniques for the analysis of process capacity: histogram, control graphs, and planned experiments. For this, data must be reliably estimated, Montgomery (1997) recommends to have at least 100 observations for the histogram to be moderately stable to obtain a reliable estimate of the process' capacity. The figure 4 shows an example of a histogram for analyzing the capability of a process.

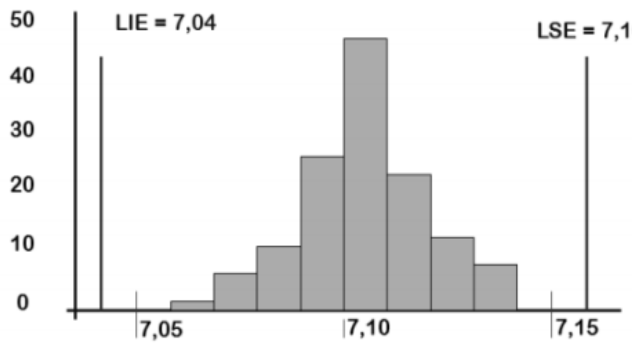

Figure 4: Process Capability

Source: Werkema (1995)

Capacity indices assess whether a process is capable of satisfying defined specifications. To use the indices, the process must be under statistical control and the variable of interest has a distribution close to normal. According to Montgomery (2004) and Deleryd (1999), there are four capacity indices for normally distributed data. These indices are Cp, Cpk, Cpm, and Cpmk.

The Cpk index is a variant of the Cp index, it is defined as the smallest between lower bound Cp and upper bound Cp. Thus, this index indicates the position of the curve relative to the target. Cp, called the process potential capacity index, considers that the process is centered on the nominal value of the specification. The higher the Cp value, the greater the process's ability to reach specifications, provided the average is centered on the nominal value.

A rule of thumb, according to Montgomery (2004) for analyzing this index is to define three reference ranges, shown in Table 1.

Table 1: Analysis Reference

Cp	Nonconforming Items	Interpretation
Cp < 1	Above 2700	Unable Process
1 <= Cp <= 1.33	64 to 2700	Acceptable process
Cp > = 1.33	Below 64	Potentially capable process

Source: Montgomery (2004)

2. Methodology

The research has an applied nature since it will contribute in a practical way to the improvement of one of the brewery's production processes M.

As for the objectives, the study is descriptive with a quantitative approach. Regarding the procedures, it used bibliographic research about beer and methodologies to reduce variability.

Also, the research is a case study conducted between 2016 and 2017 with the following phases:

Phase 1) Study of brewing processes: In September 2016, it was studied the beer production processes in a practical and theoretical way to understand all the necessary steps to the brewing process;

Phase 2) Literature review: In October 2016, methodologies aimed at reducing variety in production processes were identified;

Phase 3) Development of a method to reduce variability: In November 2016, the method to reduce the variability of the brewhouse process was developed.

To apply this method the following steps were performed:

Step 1) Goal context: In the first week of November 2016, the data collected from the wort manufacturing times in the brewhouse stage was analyzed and compared the values obtained with the desired by the company, so the goal for the search was chosen.

Step 2) Process Mapping: In the second week of November 2016, a flowchart was elaborated with all the stages of brewhouse production.

Step 3) Time and variability analysis: In the third week of November 2016, the individual times of each stage of the production process were calculated with their respective capability indices.

Step 4) Definition of IV: Still in November 2016, by choosing critical steps, check items were chosen to monitor the effectiveness of the treatment of the problems.

Step 5) Cause analysis: At the end of November 2016, based on the data analyzed in the previous step, a process of investigation of the causes that led to the anomalies found was initiated.

Step 6) Definition of the action plan: During the cause analysis, corrective and preventive actions were defined to ensure that the problems did not happen again.

Stage 7) Treatment of anomalies: at the beginning of December 2016, corrective actions were performed and follow-up of preventive actions was carried out.

Step 8) IR verification: In January 2017, the data about December 2016 and the first half of January 2017 were collected to check the evolution of the verification items.

Stage 9) Standardization: During the second half of January 2017, the stage of standardization of positive practices during the implementation of improvement actions was initiated.

Regarding data collection, it was performed in November 2016 during the development of the variability reduction method and in January 2017 after the application of the method. Data were collected through time records of each stage of the brewhouse process, tabulated using spreadsheets, histograms, and calculations of capability indices obtained by Minitab version 17.1, a statistical software available for use in the studied company.

The analysis and discussion of the results were taken in February 2017 from the analysis of three variables: the total wort manufacturing time, the equipment capability indices.

3. Discussion

The discussion of the results will be made with the following topics: diagnosis of the production time variation in the brewhouse, analysis of the time variability after the application of the method and comparison of the obtained results.

3.1 Diagnosis of the variation in wort production time

To diagnose the variation in wort production time, data from 100 production batches were used with the appropriate removal of out-of-curve values, called "outliers", as they represent sporadic events.

First, the variation in the total wort manufacturing time was identified through the out-of-range percentage analysis according to the following calculation:

% batches out-of-range = (batch off time / total batch number) x 100

Calculating out-of-range batches it was identified that 71% of the production batches had total wort production time outside the specification time. Thus, the goal of reducing the out-of-range percentage to 40% by December 2017 was set.

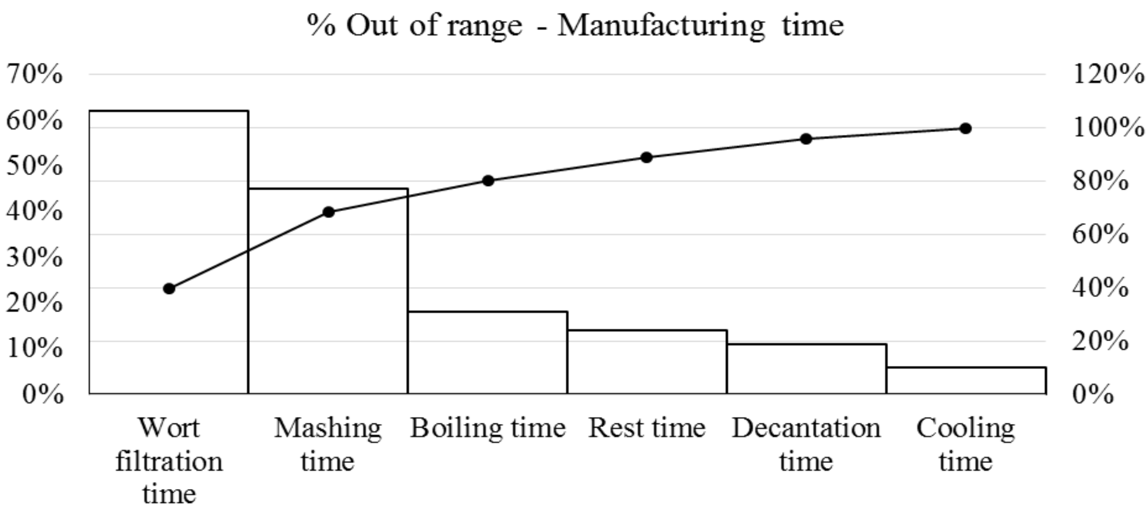

Figure 5: Variation analysis in brewhouse

Source: Author (2016)

The first analysis of the steps that most impacted the total manufacturing time was through the elaboration of a Pareto graph (Figure 5), which can identify the steps with the highest out-of-range percentages of the total manufacturing time steps.

To analyze all the stages involved in the must production, a diagnosis of the critical points of variability was carried out utilizing the capability analysis of each process point. Capability is represented by indices that show how much the process is capable of reaching the desired specifications. In the study, two indices were used: the Cp which is the potential capacity index and the Cpk which is the capacity index relative to the location.

For this analysis, Minitab version 17.1.0 (a statistical software) was used to calculate the Cp and Cpk indices and to construct histograms, as shown in Table 2.

Table 2: Cp e Cpk before problem resolution

Stage	**Cp**	**Cpk**
Mashing time (min)	0.34	0.25
Wort filtration time (min)	1.15	-0.19
Rest time (min)	1.82	1.76
Boiling time (min)	1.61	1.47
Decantation time (min)	1.4	1.19
Cooling time (min)	1.57	1.51

Source : Author (2016)

Comparing the statistical indices it is concluded that the equipment with the greatest variability in the wort production was the mashing and the filtration. According to Juran and Gryna (1980), the ideal index recommendations are Cp = 1.67 and Cpk = 1.33.

Showing the worst index in terms of variability, the mashing step had a potential capacity index Cp = 0,34 and a relative capacity index Cpk = 0.25. Showing that this step negatively influenced meeting the total time specifications.

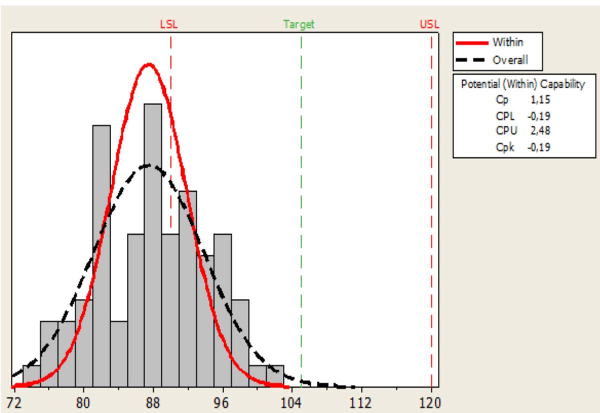

Figure 6: Histogram of wort filtration time before

Source: Author (2016)

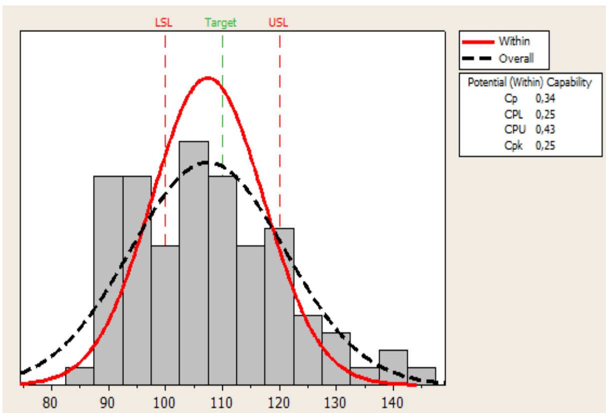

Figure 7: Histogram of mashing time before

Source: Author (2016)

The wort filtration step had a Cp = 1.15 index, but its Cpk = - 0.19 index was very low, leading to the conclusion that the data are positioned at the lower limit of the specification, which reflects filtration time suboptimal, hampering the following stages of wort production, and not satisfactorily answering the time specified in the technical production standard. Figures 6 and 7 show the histogram of the residence time in mashing and filtration.

To monitor the result of interference in the production process, two verification items were defined.

Based on the information, a cause and effect diagram was prepared through the participation of those involved in the production process to identify the causes of the anomalies. The main causes found were: communication problem between the collaborators during the wort dispatch to the fermentation stage, delay in the opening and closing of valves transfer between one equipment and another by mechanical locking and the fast wort filtration due to the failure of the filtration collectors.

3.2 Time variability analysis after method application

From the proposed method, an action plan was elaborated to eliminate the causes found for each anomaly. The main actions were:

For Cause 1) To solve the problem of communication between the collaborators, a checklist was elaborated so that the operators of the brewhouse stage made sure that the ready wort could be sent for fermentation;

For cause 2) regarding valve locking, a defective valve treatment plan was prepared and an operator training was conducted to perform maintenance;

For Cause 3) To reduce the fast wort filtration, the company's automation team performed an adjustment on the modulating valve of the wort filtration manifold.

Table 3: Cp e Cpk for critical equipment

Stage	Cp	Cpk
Mashing time (min)	0.54	0.28
Wort filtration time (min)	1.55	1.40

Source: Author (2017)

After discussing the problems, the percentage of out-of-specification batches of total work manufacturing time increased to 31%. With this improvement, the capability indices Cp and Cpk of the mashing and filtration steps were changed. The results show that the best-impacted stage was the filtration because it was the closest to the ideal proposed by Juran and Fryna (1980), as shown in the Table 3.

To visually analyze the change in mashing and filtration results, the respective histograms were elaborated using the Minitab statistical software. In the histograms, it is possible to see that the filtration times are mostly located in the center of the graph.

This reflects the correction of the capacity index Cpk that corresponds to the actual values concerning the center of the ideal specification range. Below are the images of the two histograms with results after the interventions.

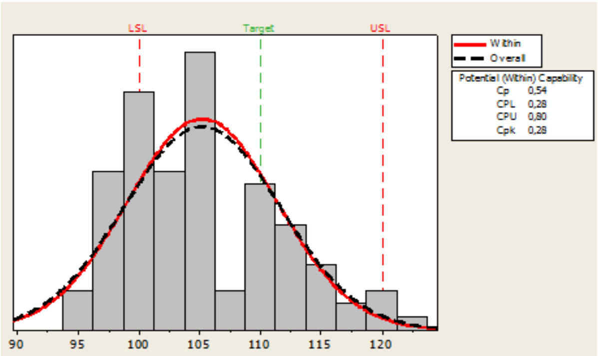

Figure 8: Histogram of wort filtration time after
Source: Author (2017)

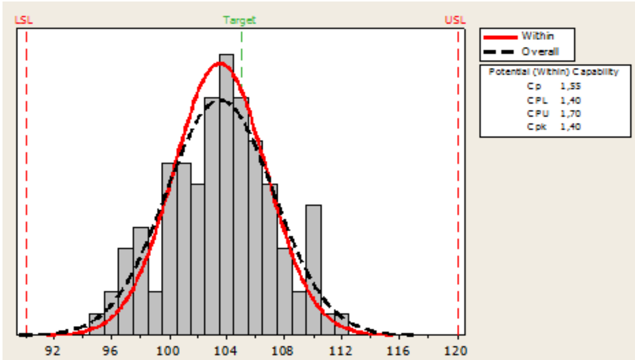

Figure 9: Histogram of mashing time after
Source: Author (2017)

3.3 Comparison of Results

With the application of the method improvements were obtained in all the variables analyzed in the proposed study, the total wort manufacturing time decreased from 71% of out of range batches to 31% of out of range times.

Figure 10 shows the comparison between before and after the out-of-range percentage for each step of the production process, where it is possible to perceive improvement in all steps individually.

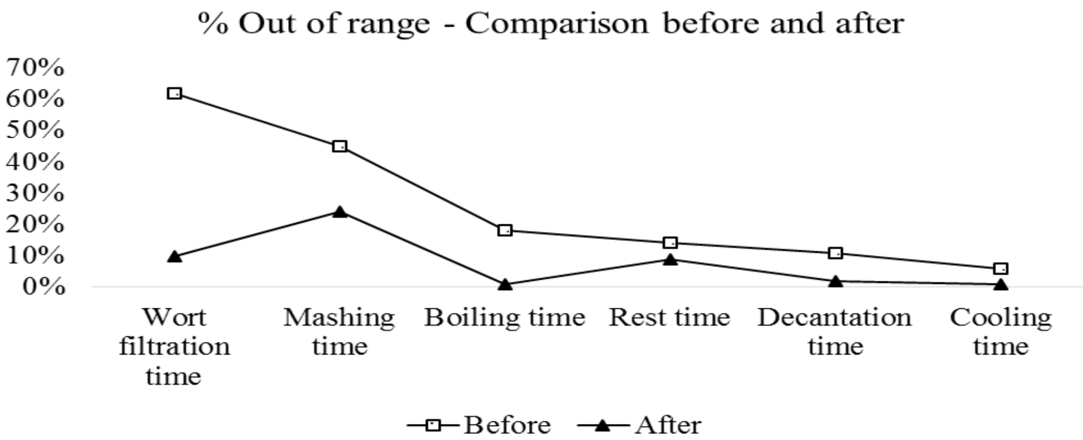

Figure 10 - Comparison before and after – Brewhouse stages
Source: Author (2017)

To compare the capacity index results of the mashing and filtration steps, below there is a comparative table of the results obtained at the beginning of the study and after the corrective actions.

Table 5 - Comparison between Cp and Cpk

Índex	**Before**	**After**
Cp of mashing	0.34	0.54
Cp of wort filtration	1.15	1.55
Cpk of mashing	0.25	0.28
Cpk of wort filtration	-0,19	1,40

Source: Author (2017)

The evolution of Cp from 0.34 to 0.54 and Cpk from 0.25 to 0.28 of mashing means that there was an improvement in its ability to produce to specification, although it was minimal and not close to recommended as ideal for the index. Since the evolution of the filtration indices was much more significant, the Cpk from -0.19 went to 1.40 meaning that the values of the filtration time left the lower margin of the desired limit and moved towards the center, besides being close to the recommended Cpk value for companies by Juran and Fryna (1980) which is Cpk equal to 1.33. Another significant result of this step was the Cp which was 1.15 and became 1.55.

4. Conclusions

The study aimed to investigate and standardize a method to reduce the variability of brewing wort manufacturing time. Data collection and analysis were performed in the brewhouse process of a brewery at the Manaus Industrial Pole in 2016 and early 2017. It was found that this production process had variability in almost all stages, and was necessary to classify the most critical to starting the problem treatment process.

Regarding the identification in the literature of methodologies aimed at reducing variability in brewery processes, a lack of this theme was identified for this type of application. The materials found aimed at reducing the variability of production processes in several branches of the industrial area, except in beer. Besides, scientific and literature materials for brewing processes are related to manufacturing methods with biochemical rather than control analyzes.

Regarding the improvement and testing of a method for reducing the variability of wort manufacturing time, the method based on the PDCA and DMAIC cycle coupled with the use of a statistical tool was satisfactory due to its simplicity and objectivity in each step. Thus, the problem-solving process was fast and accurate. In addition to being effective, since the variability in the total wort manufacturing time was reduced from 71% to 31%, it achieved satisfactory results with the positive evolution of the indices of the two critical stages of the process.

Nevertheless, proposals were made to improve the process based on investigating the causes and ideas resulting from *Brainstorming* performed with the team involved. Thus, the proposals were also present in the action plan for the treatment of the problem.

The main learning obtained was regarding the flexibility of the PDCA cycle in the application in work to reduce variability, not using the DMAIC method that is commonly used for this type of application.

The limitations of the research are related to the disclosure of the reference parameters for the limits of the production stages, factors restricted due to the organization's confidentiality policy.

For the managers of the organization are suggested to disseminate the model used in this article to other units of the company to assist the process of treating variability within the production process of the brewhouse.

For the academy, it is suggested to analyze the relationship between the variability problems of this process and the possible defects present in the beer sensory and to identify which flavor changes happen according to the variation in the equipment used to perform the brewhouse process.

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6. References

[1] ABNT (Associação Brasileira de Normas Técnicas). ISO 9001:2000 - Sistemas de Gestão da Qualidade – Requisitos.

[2] ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DA CERVEJA. Anuário 2016. Disponível em: <http://www.cervbrasil.org.br/arquivos/ANUARIO_CB_2016_WEB.pdf>. Acesso em: 15 de janeiro de 2017.

[3] BADIRU, A. B. AYENI, B. J. Practitioner's guide to quality and process improvement. London: Chapman & Hall, 1993. 353p.

[4] BOTELHO, B. G. B. Perfil e teores de aminas bioativas e características físico-químicas em cervejas. Faculdade de Farmácia, UFMG, Belo Horizonte, MG, 2009.

[5] CABRITA, J., G., M., Leão, J., M., M., & M., M. (1985). Curso de Produção de Cerveja. Leça do Balio, Portugal: Unicer, E.P.

[6] CAMPOS, V. F. Gerenciamento da rotina do trabalho do dia-a-dia. Belo Horizonte: Editora Fundação Christiano Ottoni, 1996.

[7] CAMPOS, M. S. Em busca do padrão Seis Sigma. Revista Exame, 1999.

[8] CAMPOS, V. F. Gerenciamento da rotina do trabalho do dia-a-dia. 7. ed. Belo Horizonte: Editora de Desenvolvimento Gerencial, 2001.

[9] CLARK, A. B. How managers can use de Shewhart PDCA Cycle to get better results. Houston: Jesse H. Jones Scholl of Business – Texas Southern University, 2001

[10] DELERYD, M. *The effect of Skewness on estimates of some process capability indices*. International Journal of Applied Quality Management, v. 2, n. 2, p. 153-186, 1999.

[11] JUNIOR, A. A. D.; VIEIRA, A. G.; FERREIRA, T. P. Processo de produção de cerveja. Revista Processos químicos. Faculdade de Tecnologia Senai Roberto Mange, Anápolis-GO, jul\dez de 2009.

[12] JURAN, J. M.; GRYNA J., FRANK, M. Quality planning and analysis. New York: McGraw-Hill,1980.

[13] KNOWLES, G., L. WHICKER, J. HERALDEZ, E F. CANALEST. "A conceptual model for the application of Six Sigma methodologies to supply chain improvement." International Journal of Logistics: Research and Applications, 1 de Março de 2005: 51-65.

[14] LIKER, J.K. The Toyota Way. New York: McGraw-Hill, 2004.

[15] MAPA, Decreto nº 2.314, de setembro de 1997. Disponível em: <http://sistemasweb.agricultura.gov.br/sislegis/action/detalhaAto.do?method=consultarLegislacaoFederal>. Acesso em: 23 out. 2016.

[16] MELO, C. P. CARAMORI, E. J. PDCA Método de melhorias para empresas de manufatura - versão 2.0. Belo Horizonte: Fundação de Desenvolvimento Gerencial, 2001

[17] MONTGOMERY, D. C. Introdução ao Controle Estatístico da Qualidade. São Paulo: 4. ed. Editora LTC, 2004.

[18] MORADO, R.. Larousse da cerveja. São Paulo: Larousse do Brasil, 2009.

[19] OLIVEIRA, D. P. R. Sistemas. Organização & Métodos: O&M - uma abordagem gerencial. 13.ed. Sao Paulo: Atlas, 2002.

[20] PEINADO, J.; GRAEML, A. R. Administração da produção: operações industriais e de serviços. Curitiba : UnicenP, 2007.

[21] PENCZKOSKI, D.; PEDROSO, B.; PILATTI, L. Dificuldades da implantação do programa Seis Sigma. In: Encontro de Engenharia e Tecnologia dos Campos Gerais, 4., 2008, Campos Gerais. Anais eletrônicos. Disponível em: http://www.4eetcg.uepg.br/oral/70_1.pdf. Acesso em: 20 out. 2016.

[22] REINOLD, Mathias. Reações enzimáticas e físico-químicas que ocorrem durante a malteação da cevada. Veículo: Revista Indústria de Bebidas– ano 9 – nº 55. Edição: 2010.

[23] SANTOS, M. S, DOS; RIBEIRO, F. M. DE. Cervejas e refrigerantes. São Paulo: CETESB, 2005. Disponível em: http://www.cetesb.sp.gov.br. Acesso em: 25 out. 2016.

[24] SLACK, Nigel et al. Administração da Produção. São Paulo: Atlas, 2002.

[25] SOUZA, R. Metodologia para desenvolvimento e implantação de sistemas de gestão da qualidade em empresas construtoras de pequeno e médio porte. 1997. 187 f. Tese (Doutorado) – Escola Politécnica, Universidade de São Paulo, São Paulo, 1997.

[26] WERKEMA. M. C. C. Ferramentas estatísticas básicas para o gerenciamento de processos. Belo Horizonte: Fundação Cristiano Ottoni, 1995.