UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

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RESUMEN

Esta investigación tiene como objetivo realizar un análisis dentro de una empresa productora y distribuidora de pinturas y así determinar las partes del proceso que afectan a la productividad. El estudio consiste en la aplicación de la metodología DMAIC en conjunto con la aplicación de herramientas de Lean Six Sigma (LSS). El estudio se inicia con el reconocimiento de todos los procesos de la empresa y análisis de datos históricos de los datos tomados. Para comenzar se realizó un análisis de los SKU´s mediante un diagrama de Pareto y se seleccionó solamente aquellos que representan el 80% de la población, que en este caso fueron 6 tipos de productos de la línea arquitectónica. A continuación de este análisis se logra determinar que el proceso que afecta mayormente a la productividad es el área de calidad. Posteriormente se realiza un estudio de tiempos y se analiza las actividades desarrolladas dentro del proceso de control de calidad. Gracias a este análisis se logra implementar mejoras que influyen en el flujo del proceso. Como resultado principal se obtuvo que el proceso de producción se redujo en un 15% y el tiempo dentro del control de calidad se redujo en un 33%.

Palabras clave: DMAIC, productividad, industria de la pintura, Lean Six Sigma, reducción de tiempos.

ABSTRACT

The aim of this research is to perform an analysis within a paint production and distribution company to determine the parts of the process that affect productivity. The study comprises the application of the DMAIC methodology in conjunction with the Lean Six Sigma (LSS) tools. The study begins with the recognition of all the processes of the company and analysis of historical data. To begin, an analysis of the SKUs was carried out using a Pareto diagram and only those that represent 80% of the population were selected, which in this case were 6 types of products from the architectural line. Next, from this analysis, it was determined that the process that most affects productivity is the quality area. Subsequently, a time study is carried out, and the activities developed within the quality control process are analyzed. Thanks to this analysis, it was possible to implement improvements that influence the flow of the process. The major result was that the production process was reduced by 15% and the quality control time was reduced by 33%.

Key words: DMAIC, productivity, paint industry, Lean Six Sigma, time reduction.

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1. INTRODUCTION.

The paint and coating industry is in constant growth worldwide. This industry market size is projected to grow from USD 147.2 billion in 2020 to USD 179.4 billion by 2025 (Market reports, 2019). The article of the digital magazine INPRA LATINA also indicates that the consumption of coatings worldwide for the year 2017 was $172.28 billion and it is expected that until the year 2023 there will be an annual growth rate of 4.46% (Chaverra, 2018). If we look at the case of Ecuador something similar happens, the paint sector has grown from 2011 to 2017 by 166% (Chamber of Industry, 2018), likewise, the consumption of paint per capita for Ecuador is 3 liters, which means an average annual consumption of 45 million gallons (Latinpin, 2019). Thus, it is possible to see how this market has opportunities for companies that are in development and constant growth.

The case study will be implemented in an Ecuadorian company dedicated to the production and distribution of paints and complements for construction and metal mechanics. Its principal products are architectural paints, metal-mechanical paints, automotive lines, and complementary products. The company is currently in a process of growth and its main aim is to reduce the time taken in the production process and reduce the overtime. The problem they currently have is the way the production process is carried out. This means that the production process does not have a constant flow, and it is not possible to meet the customer’s requests. Thus, the purpose of the project is to analyze the AS-IS state of the company and identify the root cause. To achieve an improvement in the production process, the use of the Lean Six Sigma philosophy will be implemented. This philosophy and its concepts have become popular since they positively influence productivity, quality, and financial results, thus achieving an impact on market positioning and competitive advantages (Bakar et al., 2015). This is how in recent years its implementation has increased within the industrial world (Scheller, 2018), and several studies have been conducted that show its effectiveness. Applying LSS and its methodology Define-Measure-Analyze-Improve-Control (DMAIC) seeks to contribute to the application of its theory in companies in developing countries to see how effective and how they can influence the improvement of processes. Specifically, in paint production.

2. LITERATURE REVIEW.

2.1 DMAIC in Manufacturing Industries

The DMAIC methodology is widely used in the manufacturing industry since it allows solving different problems and needs of a company. In the case study of Smętkowska and Mrugalska this method is used to increase the quality of a production process (2018). They use various industrial engineering tools starting with brainstorming to define existing problems. Although, the SMED (Single Minute Exchange of Die) was applied in the process of using a specific machine. However, it was proposed to use this tool accompanied by other activities such as training of employees, standardization of the operations, and continuous control of the efficiency of the process to see better results. Among the benefits they made with the application of the tools exposed previously are the reduction of production costs, increased customer satisfaction, increased productivity, more production orders, and better organization and planning. (Smętkowska & Mrugalska, 2018). On the other hand, the authors of the case study of the reduction of defects in the manufacturing process of rubber gloves, propose to use this methodology in conjunction with the design of experiments (DOE) to see if the correlation between two factors is statistically significant and be able to make the best decisions that achieve your goal (Jirasukprasert et al., 2012). In addition, this research concluded that if the company acquires a culture of continuous improvement with the application of Six Sigma, many qualities problems in the processes could be solved. As a result of their study, the objective of reducing defects in the rubber glove production process was fulfilled, in addition to increasing customer satisfaction since the quality of the products improved and they achieved economic benefits. (Jirasukprasert et al., 2012). Rifqui, Zamma, Souda, and Hansali present the application of the Lean Manufacturing philosophy in conjunction with the DMAIC methodology through a case study focused on the automotive industry where its main objective is to minimize waste to increase production flow (2021). They propose the use of various Lean tools such as Kanban, Heijunka, VSM, Gemba Walking, Spaghetti Diagram, Kaizen, and Mizusumashi to achieve their proposed goal (Rifqui et al., 2021). Likewise, they propose to carry out several audits to observe that the process will adapt to the latest changes. In addition, this study proposes the realization of a quantitative study to verify that the Lean implementation with the methodology used will bring great monetary, social, and environmental benefits in this industry. After the application of all the tools, they resulted in a reduction in several aspects: in the response of time to the customer, in the work in process, in the load of the truck, and the forklift traffic. Additionally, they increased the security level of the facilities and gained storage space (Rifqui et al., 2021).

3. RESEARCH METHODOLOGY.

Previously, an extensive literary review of several case studies was carried out where the DMAIC methodology was applied, and it was observed that it can be applied in different types of manufacturing industries. That is the reason why this same methodology will be incorporated in this project to increase the productivity and efficiency of the paint and coating manufacturing process. DMAIC is the acronym for the five steps that must be followed: Define, Measure, Analyze, Implement and Control. It is a properly structured methodology where all its stages are connected to achieve the improvement process that is needed in an organization (Ocampo & Pavón, 2012). The authors: Garza, González, Rodríguez, and Hernández propose the activities carried out in each of the DMAIC phases (2016). After several visits to the production plant, in the defining stage, the main problems that the company currently has were identified, it was understood what the process of making painting is and the raw material used in it, which are its main customers and suppliers, and all other important information that helped to identify possible improvement projects (Garza et al., 2016). Then, in the measurement stage, a compilation of historical data was made that provides important information to be able to document the current efficiency of the process in addition to the choice of the main products that generate the greatest profit for the company and take time by implementing a file in excel and training of operators that allowed to carry out a value stream map (VSM) of the current production process. In the next stage, all the data previously collected were analyzed using various tools such as the Ishikawa diagram that allowed identifying the causes of the problems, the possible obstacles that may be encountered in the industry, and this also allowed clarifying and validating the objective of this study. This stage was the primary one to determine the continuous improvements required to meet the goal (Garza et al., 2016). The next stage is to implement where all the proposed improvements were carried out to eliminate the problems that prevent having a flow in the process, it is also necessary to compare the change made by taking times of the production process and in the quality area that allowed to validate that there was an improvement and increase of the efficiency and productivity of the studied process (Garza et al., 2016). Finally, in the control stage, the aspects to be controlled and the documents necessary for this were identified to verify that everything previously implemented is being met and confirm that benefits were generated within the industry (Garza et al., 2016).

4. CASE STUDY

To begin with the application of DMAIC, the main improvement points to be attacked with this case study were identified. The paint company is currently having several problems meeting customer demand. The first is represented by the activities that do not add value to the production process. This means that an adequate number of liters cannot be produced and overtime expenses have to be incurred. In this way, it is determined that the current production capacity of the plant, which is approximately 7000 liters per day, is insufficient. Thus, by applying this methodology, it seeks to implement tools that solve these problems and increase the productivity of the company.

4.1 Define

In this first stage, Define, is important to understand what the main problem within the paint and coating company is, and for this, it is necessary to understand the entire paint manufacturing process. The reason the flow chart was used was to have a schematization and a graphic representation of the paint and coating production process (Torres, 2020). This allowed us to know how the process is carried out and later make the necessary analysis and the respective improvements that can be implemented within it. Next, it will be possible to see how the products are carried out in a general way and the sub-processes that are involved. You can see the diagram in Appendix A.

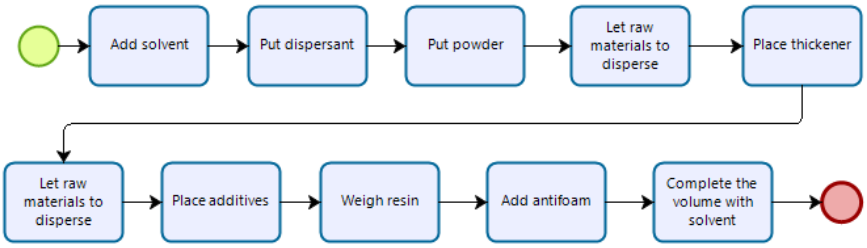

Figure 1. Flow chart of the production subprocess.

In this phase is necessary to define the most important aspects to be studied in the research, as well as the problem, the objectives, the people involved and the macro schedule of the project, so the project charter was used since it is a tool that allowed to see in an organized and in a summary way how all the investigation will be carried out.

Finally, a SIPOC diagram was used, because it allows one to visualize and identify the essential elements that are involved in the paint and coating production process and how they interact with each other to make the product (Rivera & Marín, 2015).

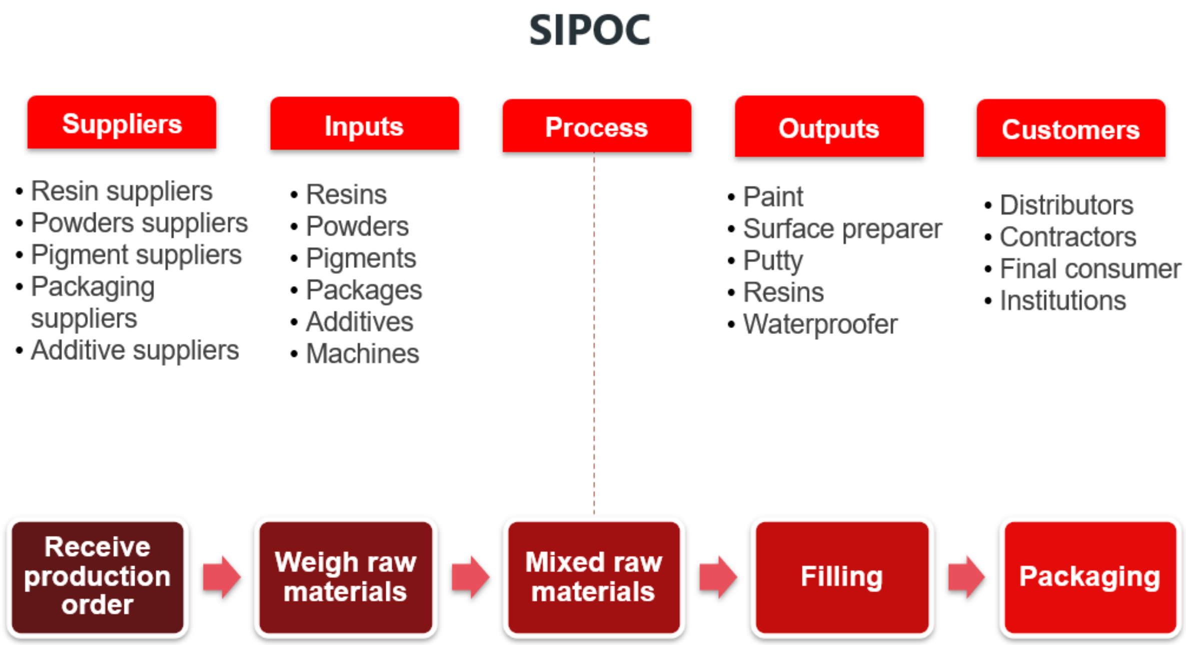

Figure 2. SIPOC of the company "Produtekn".

It is important to mention that in the inputs of this diagram, the raw materials were classified into 5 large groups that are: resins, fillers, pigments, additives, and resistance. This was done because of the large number of raw materials that are needed to make the products. To have a better knowledge about the raw materials that exist, a characterization of each one of them was made. Resins are the material that allows the paint to adhere to surfaces, fillers are all raw materials in powders that will give the paint its characteristic, pigments are the dyes that give it the color, additives are additional substances to improve properties such as resistance to bacteria and finally the containers that are the containers for paints.

4.1.1 Products selection

To identify the products that the study focused on, a classification was carried out. Paints can be grouped according to their dissolvent, their purpose, and their properties (Ortega, 2019). Based on historical sales data since 2019, Pareto diagrams were made to identify products with the highest turnover. As a first step, products were grouped based on their dissolvent. As can be seen in Figure 3 and Figure 4, approximately 80% of the demand and annual revenues fall on water-based products.

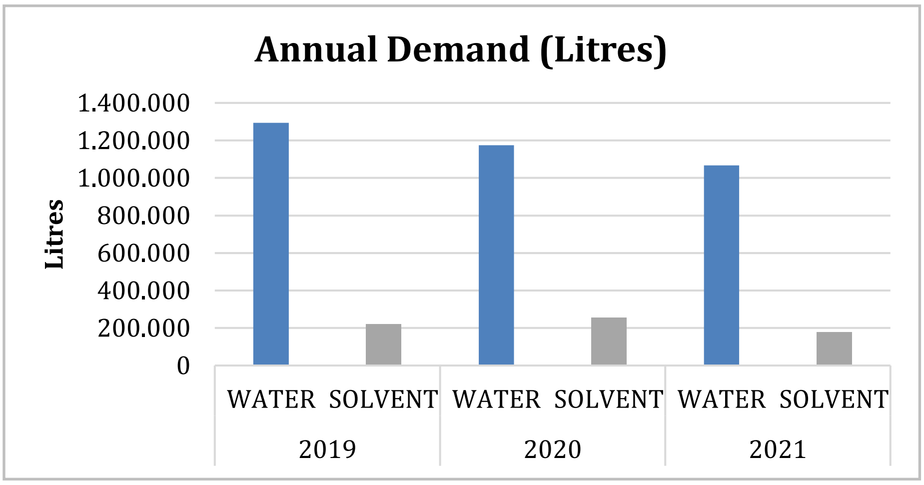

Figure 3. Annual Demand in liters.

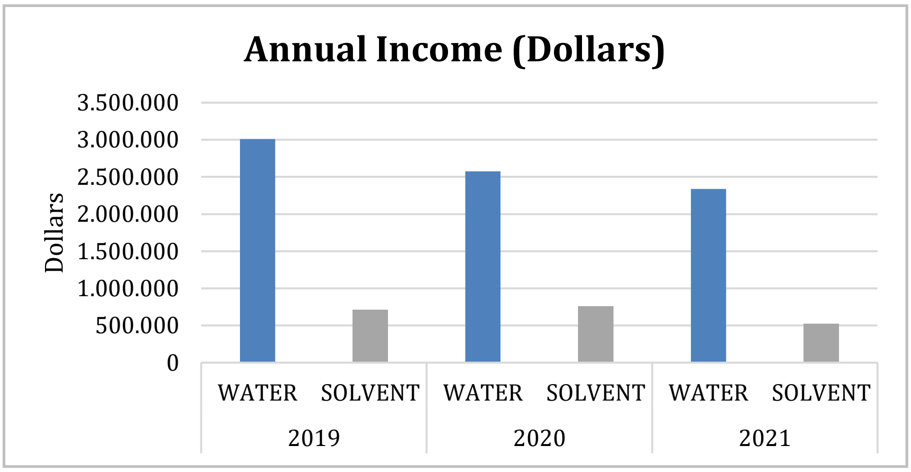

Figure 4. Annual Income in dollars.

Next, it was identified that the water-based category has twenty-two types of products. Through data analysis and new Pareto diagrams, it was defined that around 80% of the demand and annual income belong to only six types of products: Teklatex, Massivo, Satinado, Urbalatex, Acuarela, and Producril as can be seen in Figure 5 and Figure 6. For this reason, the study focused on these products. The difference between them lies in the percentages of each of the components of the paint at its production, hence its quality.

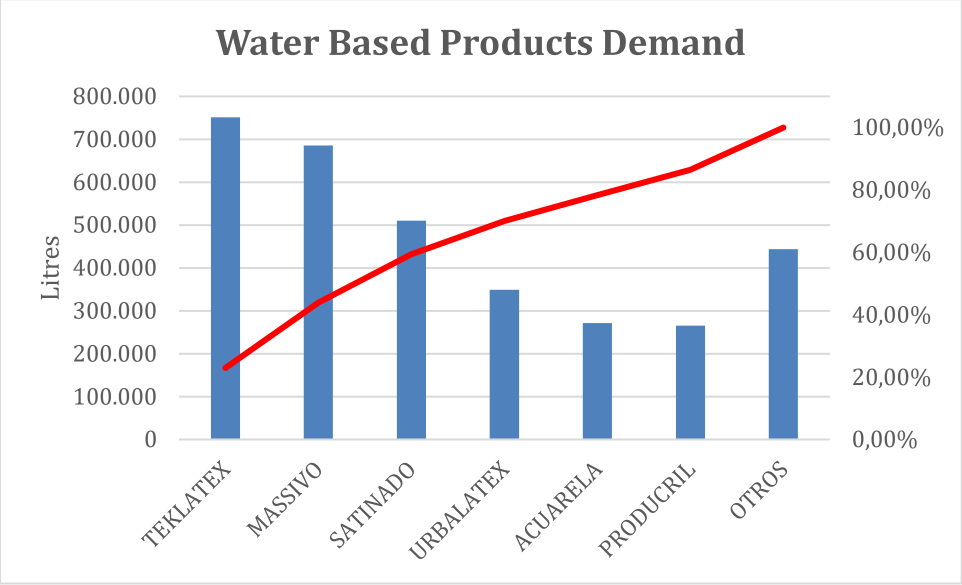

Figure 5. Annual Demand in liters.

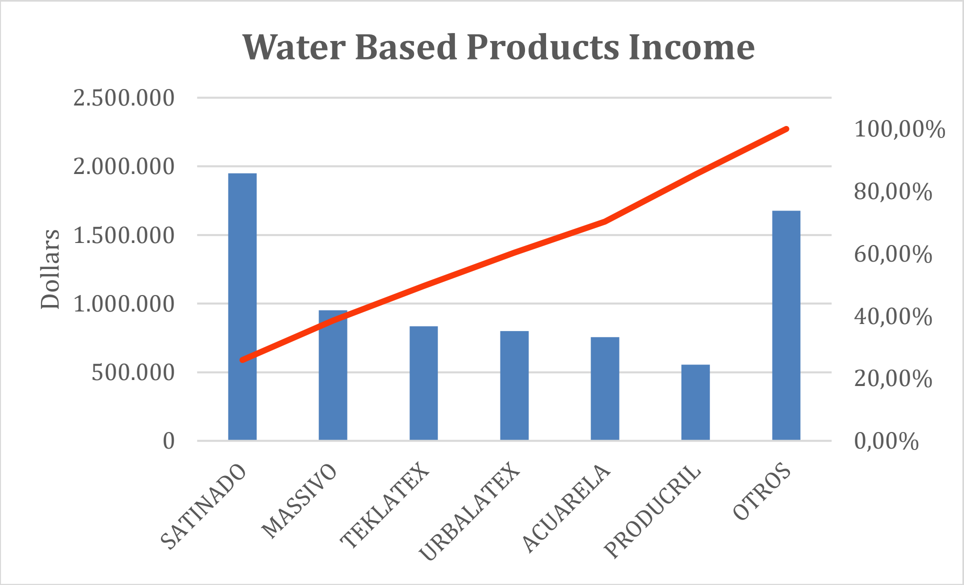

Figure 6. Annual Income in Dollars.

The authors García and Amador expose that the value stream map is a graphic representation of the current and future status of the production system, with the objective that the beneficiaries have a better understanding of the activities that do not add value to the process and should be eliminated (2019).

4.1.2 Value Stream Map (VSM)

After defining the focus lines for this project, it was identified the macro process worked. For this, the company did not have any type of historical data on the times of each of the different areas of the company, so an Excel file was implemented which contained the stage: weighing, production, filling, and packaging, the time start and end of each one of them, as we can see in Appendix B. With this, the times of two weeks were taken and then classified in those lots of interest, only of the lots that are part of the six production lines previously exposed. A sample of 36 data was obtained to perform the value stream map (VSM). With the central limit theorem, we can justify that the distribution of the sample means follows a normal distribution since it is a statistical theory that states that, given a sufficiently large random sample, greater than 30, the data follow a normal distribution (Lopez, 2018).

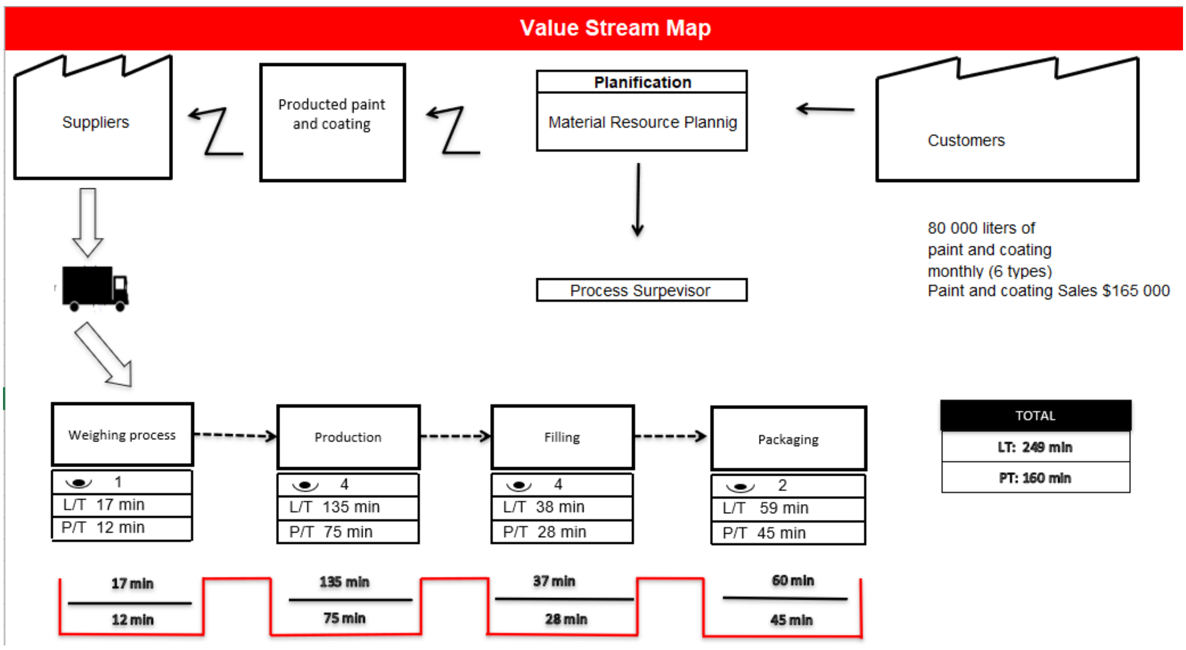

Figure 7. Value stream map of the company "Produtekn".

For a better understanding of the VSM, an analysis of the time of each one of the areas was carried out and the percentage of the activities that add value to the company was obtained. As a result, it was obtained that in the weighing area 66% of the activities do add value, in the production area only 47% add value and in the filling and packaging areas, 75% of the activities are not waste. The reason why this project focused mainly on the production area for its study and the implementation of improvements.

Within the production, the area is the quality control process, which allows making corrections and approving batches for sale. The quality area has the highest percentage of waste, as it is considered as inspection activities. For this reason, the study had a greater focus on this area. To understand this process in a more graphic way using symbols, lines, and words, also allows to know and understand the processes through the different documents, steps and areas of the company (Togra, 2015), a flowchart was made which is presented below.

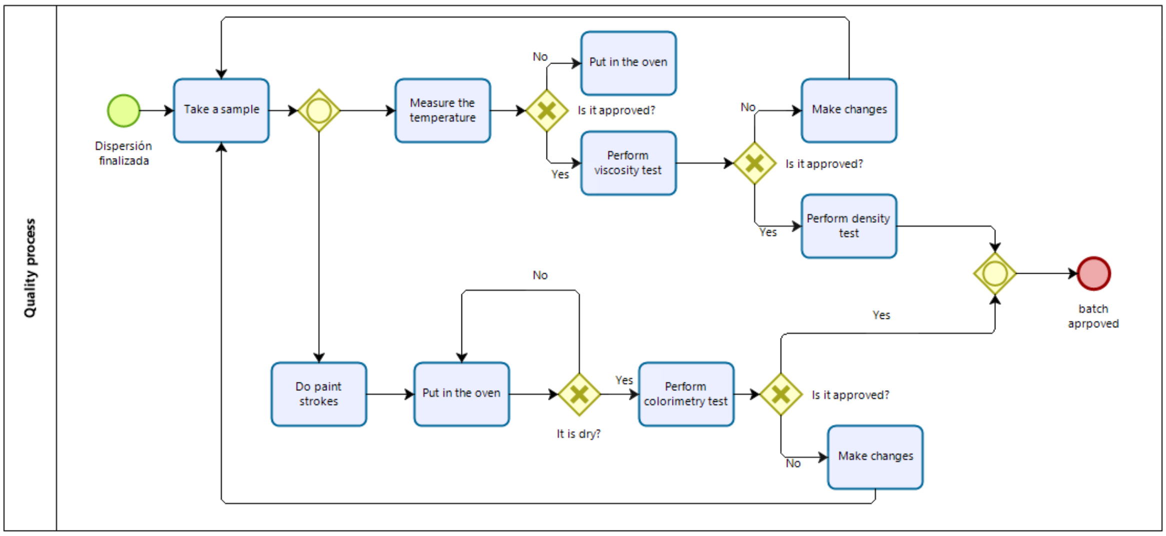

Figure 8. Quality control flow chart.

4.2 Measure

As the first step for the measuring stage, a more in-deep analysis of the quality control process is done. To better understand the actual process flow, a spaghetti diagram was constructed and is shown in Figure 9. This tool tracks the movement of the objects inside the system and is the first step to identify where the waste is coming from. As mentioned by Senderská, Mareš, and Václav (2017), this tool is used to trace the movement of products, workers, and materials around the area to determine the activities that influence the proper flow of the process. For the quality control process, the biggest problem is the number of movements the worker does. Of all the activities involved, the ones that affect the most are the search for the standard color and the collection of raw material that is used to correct the errors in the paint. During these activities, the operator must move from the upper floor to the lower floor to collect the standard color or the pigments and loads needed to pass the quality control process. Since the process is iterative, the time taken by the operator to move from one floor to the other makes the process slower and with low productivity. Thus, the focus of the analysis and improvement will be on these two activities. This allows for a current and future state comparison to determine the effectiveness of the process improvement implementations (Kanaganayagam et al., 2015).

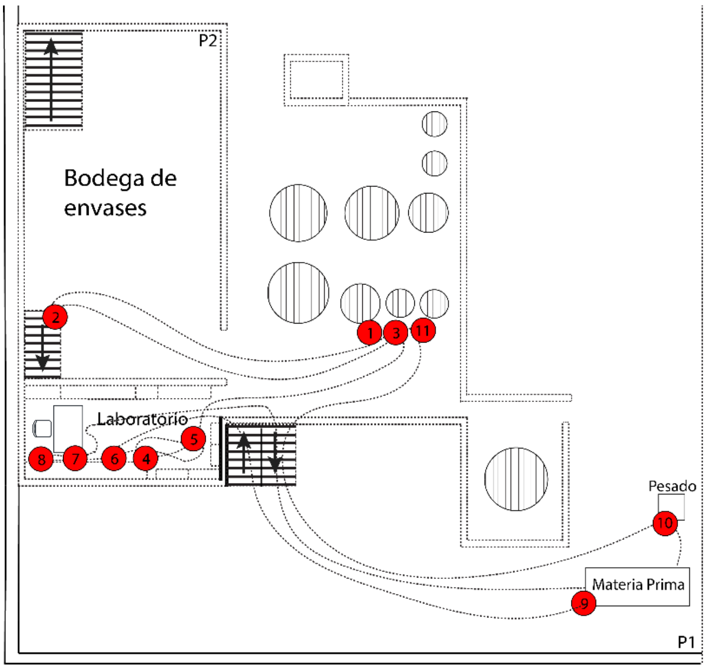

Figure 9.Spaghetti Diagram.

As part of the measuring stage, a time study is conducted within the quality control area. The time study will consider all the activities that take part in the process and will help to identify the main points for improvement. The first step in performing the time study is to determine the sample size to be measured. Thus, the table developed by General Electric

Company is considered; this table presents an approximate guide for the number of cycles to be taken based on the total process time duration (Niebel and Freivalds, 2009). Given that the average time for the quality control process is between 15-20 minutes, the sample size to be measured is 8 cycles. All the measurements were taken randomly on different days of the week. The results are shown in the Table 1.

N.	Activity	Time	Percentage
1	Take sample	0:30:00	4%
2	Take sample to laboratory	0:45:00	5%
3	Search for standard	2:36:00	19%
4	Make the trace	0:50:00	6%
5	Take temperature	0:38:00	5%
6	Put in the oven	3:40:00	26%
7	Perform viscosity test	0:13:00	2%
8	Perform density test	0:25:00	3%
9	Perform colorimetry test	0:40:00	5%
10	Correct errors	3:39:00	26%

Table 1. Quality control time study.

From the measured data, it is inferred that the activities with the longest duration are putting the trace in the oven (26%), correcting errors (26%), and searching for the standard (19%). In addition, it was determined that each iteration of the process takes approximately 14 minutes and the average of the total number of iterations per batch produced is 6. This means that the total time taken by the quality control process round up 82 minutes.

4.3 Analyze

For the analyze stage, an Ishikawa diagram was made to find the root causes of the delays (Liliana, 2016) in the quality area.

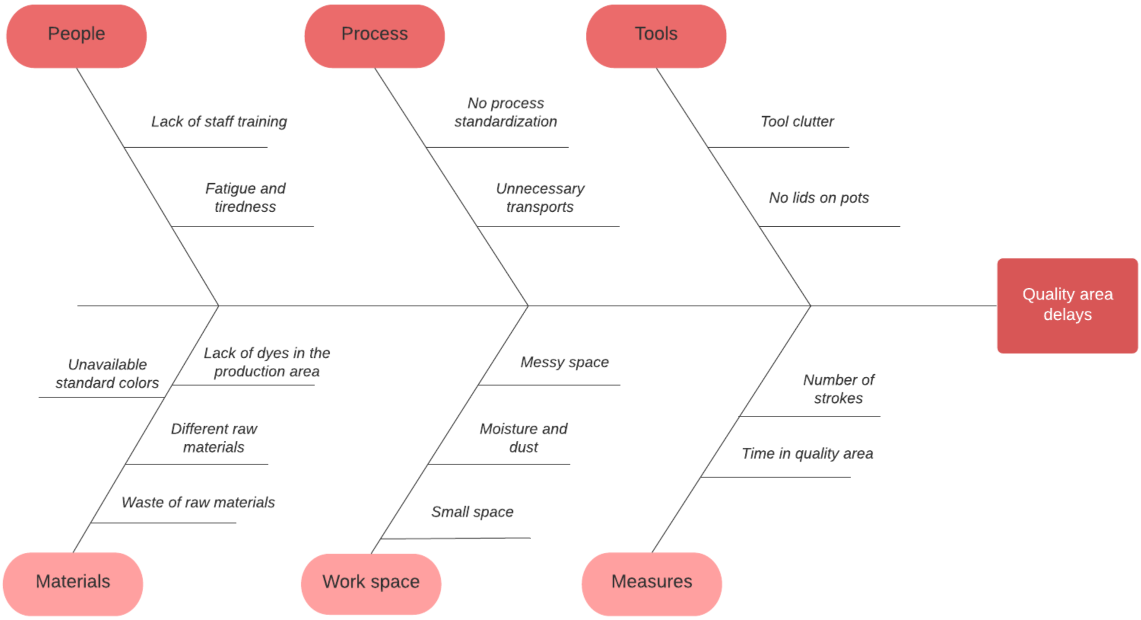

Figure 10. Ishikawa Diagram, Delays in quality control.

The most relevant causes are related to lack of training of the workforce, lack of standardization of processes, disorderly workstations, unnecessary transportation, and excessive repetitive activities that cause time of quality control increase.

4.4 Improve

4.4.1 Process standardization

Some visits were made to the plant throughout the project and inconsistencies were found in the manufacturing process of the products. And this was due to the fact that the production order sheet that was given to the operators, is very simple since it did not have the units of the quantities of each of the raw materials, nor the dispersion times. In addition, management commented that there were cases of theft of formulas because they contained the name of all the inputs necessary to make the final product, this can be seen in Appendix B.

As a solution, it was proposed to change the purchase order sheet where it is more specific. In Appendix D, we can see the different changes made. The process was separated into 3 different parts because part A and part B can be carried out simultaneously and part C is the union of the previous two. On the other hand, at the request of management, raw materials were coded, so that there was no theft of formulas. In addition, units and dispersion times were added. Finally, at the bottom of the sheet, there is a table of the quality control of the batch to record the values of the different control tests that are carried out, such as viscosity, density, color, among others.

4.4.2 5´s

The 5S methodology was implemented in the laboratory shelves where the standard colors are stored. The 5s have 5 stages (sort, set, shine, standardize, sustain) and are known for maintaining order, cleanliness, and achieving standardization of the workplace (Manzano & Gisbert, 2016). This implementation seeks to reduce the time that the operator takes to find the standard color needed to do the quality control. The changes in the area were the implementation of visual identification for each paint line and the organization of the colors by code inside the shelves. In addition, this tool will be used to keep a more detailed control of the standard colors. This means that a record of missing colors, repeated colors, and colors that are about to be finished will be kept. At the time of implementation, it was found that there were 29 missing colors and 22 repeated colors.

Figure 11.5s implementation results.

4.4.3 Reuse of lids

There was close communication with the operators in charge of the production area and they explained that there are lids for the pots that are not being used and they could not give any reason they were not using them. This caused those raw materials such as powders when pouring into the pot, a small part was wasted in the environment. In addition, another big problem was observed, it was in the activity of placing the dyes, many times it splashed into the pots that are on the sides. For this reason, standardization of this process was carried out, and the workers were informed that they must occupy it to improve the quality of the product and in such a way also help with the reduction of times when making the quality control. This reuse was also a solution so that the formulas of each paint are more precise and contribute to reducing the time of the quality area. In Figure 13, you can observe the reuse of the lids in mixers.

Figure 12. Reutilization of lids in mixers

4.4.4 Implementation of weighing and dyeing area

The spaghetti diagram showed that there are several unnecessary movements in the production process. Since, at the time of quality control, most of the time it was necessary to make corrections of both viscosity and color, for this the operators had to go down to the ground floor to get dyes and thickener and go up again and so on repeatedly until the lot is approved. To reduce these transport times, it was decided to locate a weighing, dyeing and thickener area in such a way that they only had to move through the same plant. We can see this below. In addition, each of the raw materials was labeled so that it is visually faster to find it, see Appendix E.

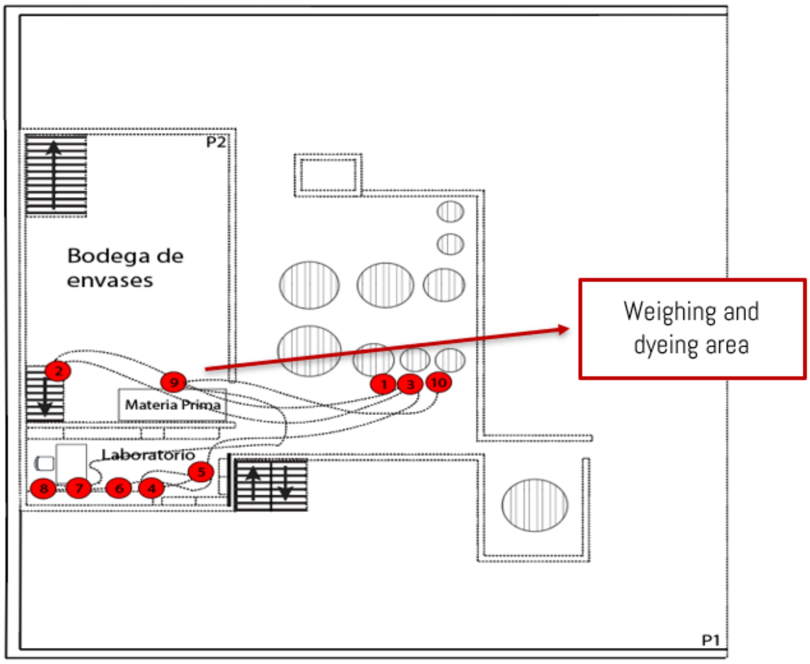

Figure 13. Implementation of weighing and dyeing area.

4.4.5 Customer Return Form Standardization

Standardization was carried out in the returns process because at the time to analyze these, the data did not give us a greater input of what was happening, since many of the times they did not have the amounts of paint being returned or the reasons the customer was returning it to the company. At the same time, this is not allowed to know the costs for returns. However, an important piece of information could be obtained, which is that there were approximately 13 returns per month. In other words, Produtekn did not have adequate control of returns. In addition to the fact that the area where the finished product is located occupies around 12 square meters of the area of the entire plant, as can be seen in Figure 14. This was the main reason why a standardization was carried out, for this it was implemented a new template that you can see in Appendix J. Here the different fields added were the reason for the claim stated, the amount to be returned and at the bottom of the sheet, a control for the review and analysis of the problem where the people in charge of the quality area will analyze whether to accept the return or not and analysis will be made of the causes for which said the problem occurred. In such a way as to create a history of data to be able to make a deep analysis of these in the future.

Figure 14. Return area of the paint and coating.

4.4.6 Improvement proposal - Plant layout

Additionally, many unnecessary transportations between the different departments were identified. In the actual layout, it can be found that similar departments are detached, and the distribution is not adequate because the flow of materials was never considered. As a possible solution, a new layout distribution model was proposed.

To improve an existing layout, the Blocplan methodology suggests creating a relationship chart between the departments of the company. This chart shows the level of importance that two departments are together. Based on this level of importance, a value can be assigned, as shown in Appendix F. These relationships can be used in mathematical models as input to the flow between the departments. The layout cost can be measured by adjacency-based objective (1) or distance-based objective. As the layout requires a multi-floor facility, the proposed layout was evaluated by the objective function suggested in the SABLE methodology (2). This methodology considers horizontal and vertical (height) distance between departments. (Tompkins, 2010).

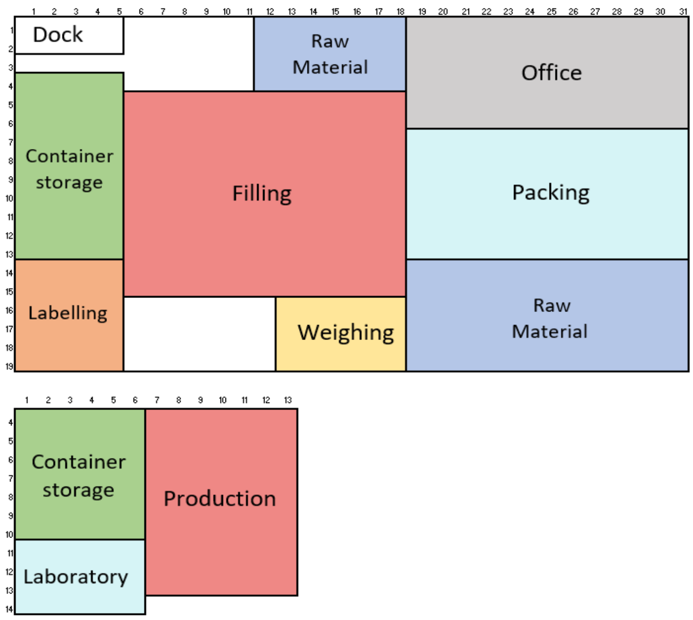

Figure 15. Actual Layout

The actual layout, shown in Figure 15, shows how similar departments are poorly distributed, such as Raw Material Storage. At the same time, departments such as Weighing and Production are not close enough even if their relationship is high. This creates a lot of unnecessary transportation.

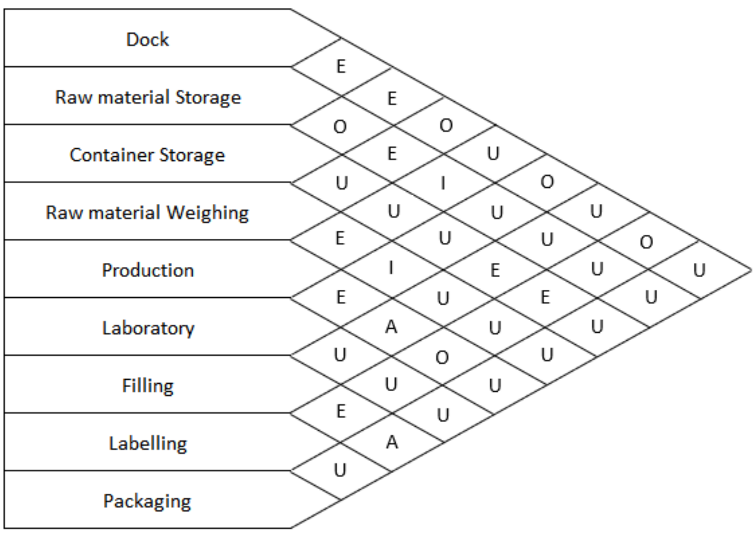

Figure 16. Relationship chart between departments.

As shown in Figure 16, departments with A (Absolutely Necessary), E (Especially Important), and I (Important) must be together to optimize the distribution of the plant.

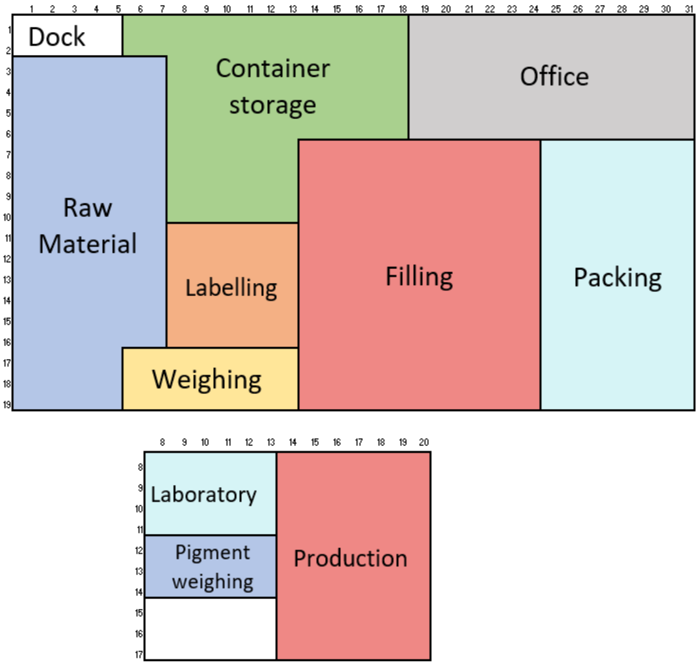

Figure 17. Proposed Layout.

Figure 17 shows the proposed distribution, it joins all similar departments it was prioritized that the departments with a high relationship are together.

$$\boldsymbol{min\ z} = \sum_{i}\sum_{j} f_{ij}\, x_{ij} \qquad (1)$$

$$\boldsymbol{min\ z} = \sum_{i}\sum_{j} (c_{ij}^{H} d_{ij}^{H} + c_{ij}^{V} d_{ij}^{V}) f_{ij} \qquad (2)$$

Current Distribution		Proposed Distribution		
Z	25	Z	**32**	(1)

Current Distribution		Proposed Distribution		
d	890	d	**612**	(2)

Table 2. Layout evaluation (1) by Adjacence and distance (2).

In Table 2, it was found that the new layout maximizes the adjacence score, meaning that departments with high relationship are now together. At the same time, the distance between the departments is minimized, which allows a considerable reduction of distances of transportation between departments.

4.5 Control

The control stage is one of the most difficult to carry out because it goes hand in hand with a change in culture within the industry (Montgomery, 2009). So, it will depend a lot on the attitude of the people who work there. However, it is considered one of the most important, since, if all the improvements made are not kept under control, the company over time may fall into the same problems that it had previously. For this reason, it is important to speak and train the operators so that they consider how important it is to make the change of culture within it.

At this stage, due to a time limitation, only a control plan was made for the company "Produtekn". A table was created where you have the aspects to be controlled and the necessary documents for each of them, as you can see below:

What will be monitored?	Documents
Number of strokes per batch.	Perform control charts, to make an analysis of assignable causes.
Production and quality area time.	Excel file implemented.
Number of returns and complaints.	Standardization of the returns form.
Production process.	Production order form.

Table 3. Control Stage Processes

This control plan will be of great help so that the company can continue to see changes over time and realize where there are possible improvements within the studied area since if it is observed that the color is exceeding a maximum limit of strokes it could enter to revision of the formula this type of batch. In addition to the control plan can be a guide for the heads of each area to implement new projects and better control their process so that the company is in a continuous improvement.

5. RESULTS

Once the changes were implemented, a new data collection was performed to show the improvements within the process. To gather this new data set, the procedure of the previous stages was used. This will help to make a comparison of the before and after state for both the production area and the quality control process. The Excel format, developed in the define stage, was used to measure production times, and two weeks of data were collected. A total of 43 production batches times were collected, which complies with the central limit theorem. The result is shown in Table 4. This reduction in time of 27 minutes represents a 15% reduction in the total time spent in the production area. To validate the veracity of the results obtained, a two-sample t-test was performed. This test is a method used to test whether the unknown population means of two groups are equal or not (JMP, 2017). For the analysis, a confidence level of 95% was used and the before and after times were compared, getting a p-value of less than 0.05, which rejects the null hypothesis, meaning that the mean of the times is different. The statistical analysis results and graphics are shown in Appendix G.

Production Process		
	Before (min)	After (min)
Lead Time L/T	159	135
Process Time P/T	75	75

Table 4. Before and after production process times.

As a second part of the analysis of results, the quality control process was studied. This process is vital since it is here where all the improvements that would help to reduce unproductive times and improve the flow of activities were developed. The sample size, as mentioned earlier, was based on the General Electric times guiding table. Thus, a sample of 8 cycles of the process was taken to develop a comparison and see the changes. The results presented in table 5 show that the average time with the implemented improvements was reduced from 14 to 11 minutes. This means that the time was reduced by 33% and the average number of traces was reduced to 5. Therefore, the total average time of the improved quality control process would last 55 minutes. Finally, a two-sample t-test was performed. A confidence level of 95% was used and the means of the times were compared. As the result, the p-value is less than 0.05, which rejects the null hypothesis, meaning that the mean of the times is different. The statistical analysis results and graphics are shown in Appendix H.

N.	Activity	Time (min)	Percentage
1	Take sample	0:33:00	5%
2	Take sample to laboratory	0:42:00	6%
3	Search for standard	1:06:00	10%
4	Make the trace	0:53:00	8%
5	Take temperature	0:36:00	5%
6	Put in the oven	3:42:00	33%
7	Perform viscosity test	0:13:00	2%
8	Perform density test	0:26:00	4%
9	Perform colorimetry test	0:42:00	6%
10	Correct errors	2:10:00	20%

Table 5. Improved time study in the quality control process.

6. CONCLUSIONS AND RECOMMENDATIOSN

The application of the DMAIC methodology is an essential tool used to improve the production processes of all companies. For the case studied, the 5 stages of the methodology were successfully implemented. With the help of the analysis tools, the main problem affecting the paint production process was identified. This process was the quality control, here several tools were applied to improve the process flow and thus reduce the downtime generated by the process activities. The major improvement obtained once the tools were implemented was the reduction of time in the quality area. This improvement reduces both, the time for quality control and the total production time of a batch of paint. As the result the quality control process was reduced in a 33% and the production process was reduced in a 15% of the total time. Therefore, the time taken to produce a batch of paint is reduced and the productivity increases. Standardize paint manufacturing process allowed a reduction in wastes such as unnecessary transportation, unnecessary movements, and reprocessing. At the same time, the quality of the product is being guaranteed. On the other hand, from now on the company will be able to measure the cost of its returns and analyze the reasons to be able to take actions to eliminate these errors and provide a better-quality product. The key for this company is to continue with the implementation of more improvement projects that will increase the paint production. It is important that the company follow a control plan like the one described above, for the operators to acquire a culture of continuous improvement and teamwork. In addition, it will allow to have more historical data for analysis and future projects within the company. This in turn will bring great benefits for Produtekn as it will allow them to continue developing and growing within the market.

In the quality area, the longest time is because of the large number of strokes made per production batch and its main cause is since the color corrections that are made are only by the experience of the worker and depends on the amount that the operator says to put each dye in the paint mixture that is being made to repeat the process and measure the color until it is approved. For this, it would be very important to invest in software such as Colibri platform (Konica, 2021), that allows giving the exact amounts of each dye to reduce the number of strokes that are currently made, as a complement, a cost-benefit analysis should be done to quantify the implementation. On the other hand, another recommendation is to incorporate control charts for the same process of color corrections, since in this way a history of the product would be kept and how many times corrections were made for each one, and if it exceeds the maximum, the assignable causes would be seen for the solutions to this problem. In addition, a third recommendation is to carry out weekly or monthly planning, since this would avoid the same colors being produced several times, overtime would be reduced and there would be a more constant production.

Furthermore, it was identified that the plant distribution is not optimal considering the importance and the flow between departments. This distribution creates excessive transport and production does not follow a continuous production line. With the proposed layout distribution, the company could decrease transportation times and make adequate use of available space. As recommendation for the long-term decisions, the company must think about a new distribution of the plant, as presented in the improvement proposal, to eliminate various activities that do not add value. In this layout, the different raw material warehouses would be unified, and the zones would be relocated to the table of relationships presented.

7. LIMITATIONS

Among the limitations that arose during the project are the lack of information on the times of the different macro-processes that the company has, which are weighing, production, filling, and packaging. Like the time it takes them to approve a production batch. This prevented having a large amount of data and being able to perform a more in-depth analysis of it, either to see if the lines are truly statistically the same or to perform a VSM with a longer data history. On the other hand, the company has daily planning of the products that must be made, which is why they have a very variable production, this affected that a change in the production level could not be measured, that is, it could not be calculated the average liters that the company managed to make after all the improvements implemented. Finally, time played an important role, since having to take data to do the analysis and other data to quantify the improvements, there was not a large amount of data to achieve a much deeper analysis. It should be emphasized that the necessary data were taken for the analysis to be adequate and correct, as justified previously with the central limit theorem. very variable production, this affected that a change in the production level could not be measured, that is, it could not be calculate the average liters that the company managed to make after all the improvements implemented. Finally, time played an important role, since having to take data to do the analysis and other data to quantify the improvements, there was not a large amount of data to achieve a much deeper anal be adequate and correct, as justified previously with the central limit theorem.

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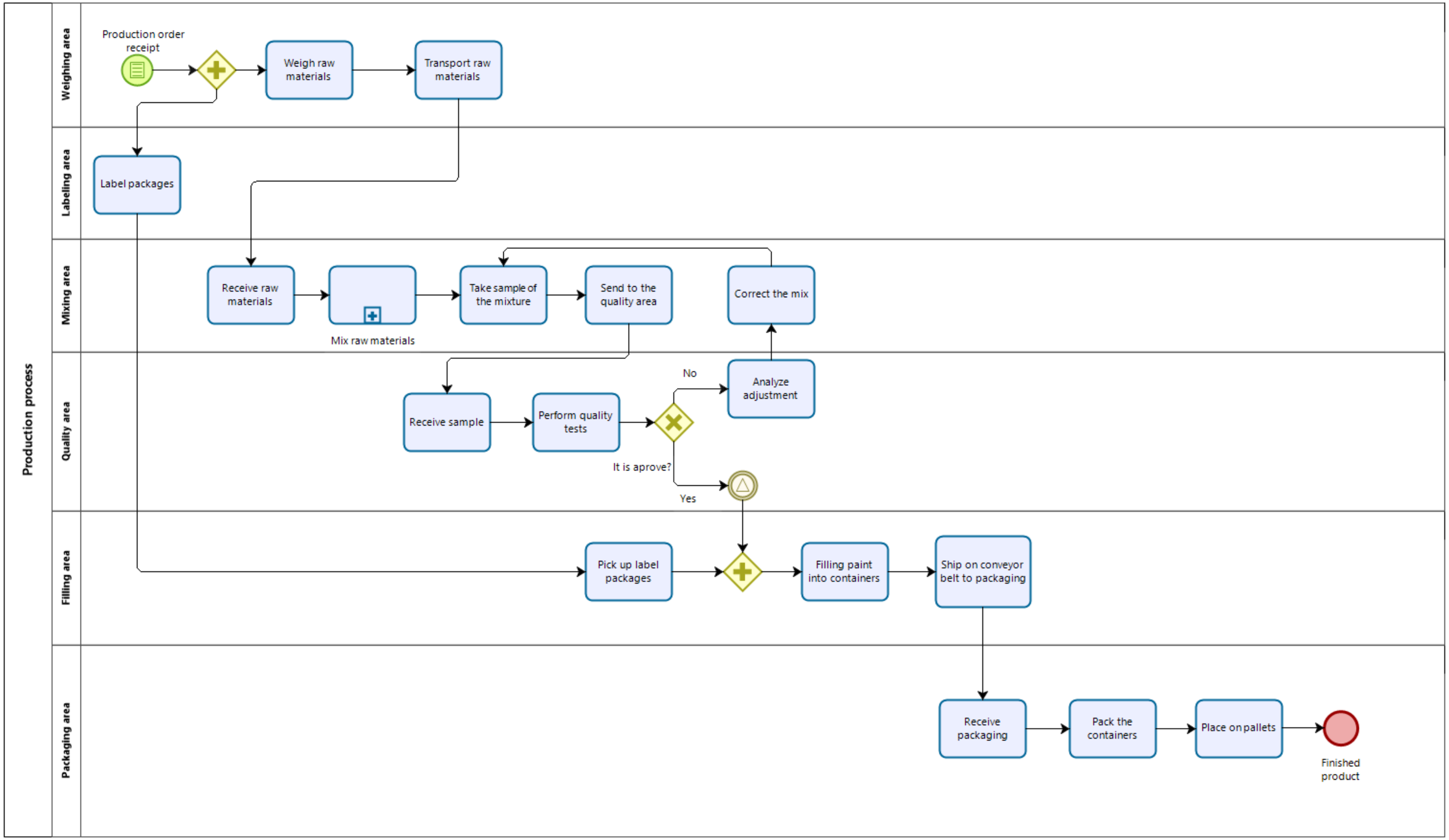
APPENDIX A: FLOW CHART OF THE PRODUCTION PROCESS



APPENDIX B: EXCEL TEMPLATE.

CONTROL DE USO DE MÁQUINAS: PRODUCCIÓN / ENVASADO

MÁQUINA:		DISPENSADOR PINTURA 4				CÓDIGO: DIS-4		
Fecha	**Producto**	**Lote #**	**Volumen**	**Etapa**	**H inicio**	**H fin**	**Operador**	**Observaciones**
				Pesado				
				Producción				
				Envasado				
				Empaquetado				
				Pesado				
				Producción				
				Envasado				
				Empaquetado				
				Pesado				
				Producción				
				Envasado				
				Empaquetado				
				Pesado				
				Producción				
				Envasado				
				Empaquetado				

APPENDIX C: PREVIOUS PRODUCTION ORDER

PINTURAS PRODUTEKN CIA LTDA

Orden de Producción 008 901225790 - 10/11/2021

Código	*Descripción*	*Cantidad*	*Lote*

Producto a Fabricar **PPPBI020L MASSIVO BLANCO HUESO EN PROCESO**

Cantidad a Producir **780,00** **Lote**________________________

Materia Prima			
MP0010	AGUA	546,000	
MP0064	TINTE AMARILLO OXIDO LATEX (OCRE)	1,435	
MP0009	TINTE NEGRO LATEX	0,017	
MP0011	DISPERSANTE HEXAMETAFOSFATO DE SODIO	0,581	
MP0012	DISPERSANTE INDOL RM	2,993	
MP0014	TERGITOL NONILFENOL 10MOLES	0,641	
MP0002	ANTIESPUMANTE	2,474	
MP0018	DIOXIDO DE TITANIO	9,604	
MP0040	CARBONATO A 10	87,807	
MP0019	CARBONATO IMPADOC	239,473	
MP0025	CAOLIN CALCINADO	83,638	
MP0029	TALCO	36,669	
MP0005	ESPESANTE	7,410	
MP0001	AMP95 REGULADOR DE PH	0,144	
MP0003	BACTERICIDA	2,487	
MP0004	FUNGICIDA	2,487	
MP0007	RESINA VINIL ACRILICA PLANTA ANDERCOL 352	69,846	
MP0013	TEXANOL	2,619	
		1.096,326	

Ruta de Producción	
Ruta	*Descripción*
1	MODIFICADO OK 2019/01/22 JAVIER C.
2	TINTES JAVIER C.

APPENDIX D: PREVIOUS PRODUCTION ORDER

PINTURAS PRODUTEKN CIA. LTDA.

FÓRMULA PATRÓN

FECHA			
PRODUCTO	MASSIVO	CÓDIGO	PBI000
COLOR	BLANCO	VOLUMEN	780
LÍNEA	ARQUITECTÓNICA	RESPONSABLE	

Orden	INSTRUCCIONES DE PROCESO	CANTIDAD, Kg	
	PARTE A		
	BOMBEAR A CALDERA ( ) LO SIGUIENTE:		
1	MP0010	250.000	AGUA
	PRENDER AGITACIÓN A 500 RPM Y ADICIONAR:		
2	MP0011	0.800	HMFS
3	MP0014	2.800	TERGITOL
4	MP0005	2.582	ANTIESPUMANTE
5	MP0021	0.400	DEG
	SE AGITA DURANTE 5 MIN , Y SE CARGA A LA OLLA LO SIGUIENTE:		
6	OXIDO AMARILLO Y-2023	34.341	
7	MP0015	436.148	CARBONATO A325
	SE DISPERSA DURANTE 30 MIN.		
	PARTE B		
	EN MQ00 SE PREPARA EN UNA CANECA, LA SIGUIENTE SOLUCIÓN: (DEJAR DISPERSAR POR 10 MIN)		
8	MP0010	30.000	AGUA
9	MP0005	7.754	ESPESANTE
	PARTE C		
10	CARGAR LA PARTE B SOBRE LA PARTE A, HOMOGENIZAR Y ADICIONAR:		
11	MP0001	0.349	AMP-95
	CONTINUAR AGITANDO DURANTE 5 MIN Y ADICIONAR:		
12	MP0003	2.667	BACTERICIDA
13	MP0004	2.667	FUNGICIDA
14	MP0007	141.312	RESINA VINIL ACRILICA
	HOMOGENIZAR UY ADICIONAR:		
15	MP0013	4.469	TEXANOL
	AJUSTAR VISCOSIDAD CON		
16	MP0010	87.558	AGUA

CONTROL DE CALIDAD PRODUCTO TERMINADO

PARÁMETRO	MÉT. TÉCNICO	ESPECIFICACIÓN	MEDICIÓN	PARÁMETRO	MÉT. TÉCNICO	ESPECIFICACIÓN	MEDICIÓN
VISCOSIDAD	NTE INEN 1013	114-118 KU		DENSIDAD	MT-04	1,2 - 1,5 Kg/l	
COLOR	MT02			BRILLO			
				CUBRIMIENTO			

Revisado por:	FECHA:

APPENDIX E: IMPLEMENTATION OF WEIGHING AND DYEING AREA.

APPENDIX F: VALUES FOR RELATIONSHIP CHART BETWEEN DEPARTMENTS.

Key	Priority	Value
A	Absolutely Necessary	4
E	Especially Important	3
I	Important	2
O	Ordinary Closeness OK	1
U	Unimportant	0
X	Undesirable	-1

APPENDIX G: TWO SAMPLE T-TEST PRODUCTION PROCESS TIME COMPARISON.

WORKSHEET 6

Two-Sample T-Test and CI: MIN; Tiempos

Method

μ_1: mean of MIN when Tiempos = T1
μ_2: mean of MIN when Tiempos = T2
Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics: MIN

Tiempos	N	Mean	StDev	SE Mean
T1	37	159,5	32,2	5,3
T2	43	134,9	60,3	9,2

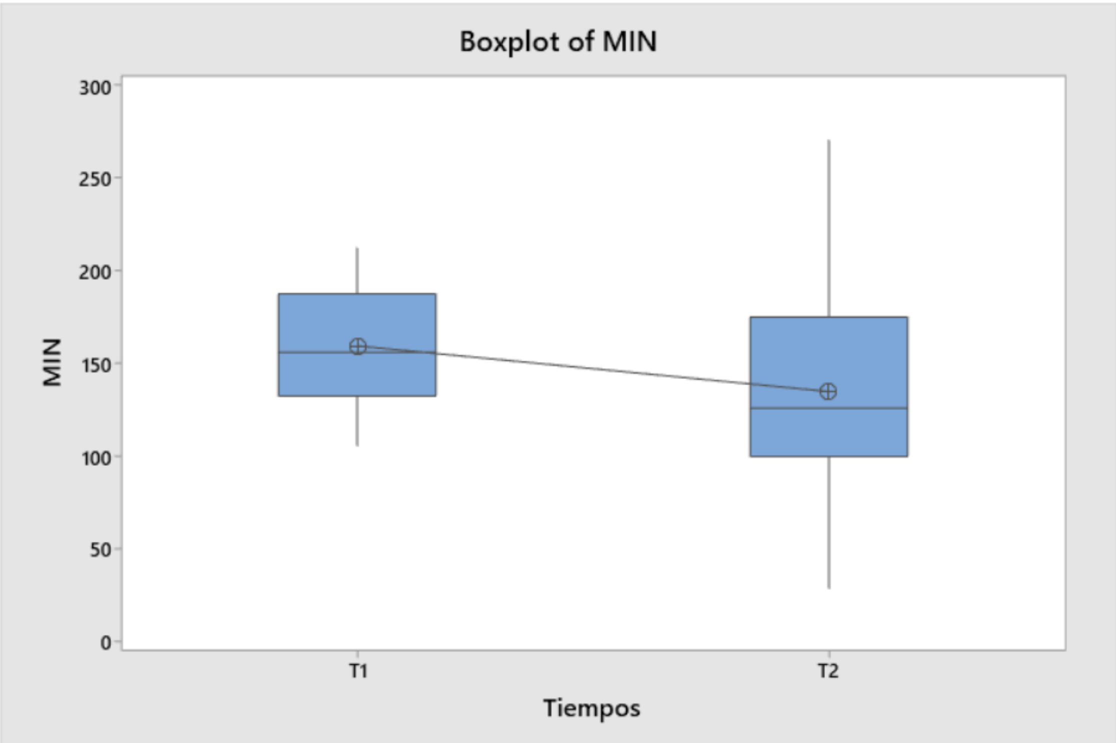
Estimation for Difference

Difference	95% CI for Difference
24,6	(3,4; 45,8)

Test

Null hypothesis	$H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis	$H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
2,32	66	0,024



APPENDIX H: TWO SAMPLE T-TEST QUALITY CONTROL PROCESS COMPARISON.

WORKSHEET 7

Two-Sample T-Test and CI: Min T; Tiempo

Method

μ_1: mean of Min T when Tiempo = T1
μ_2: mean of Min T when Tiempo = T2
Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics: Min T

Tiempo	N	Mean	StDev	SE Mean
T1	8	836,13	8,58	3,0
T2	8	663,9	15,2	5,4

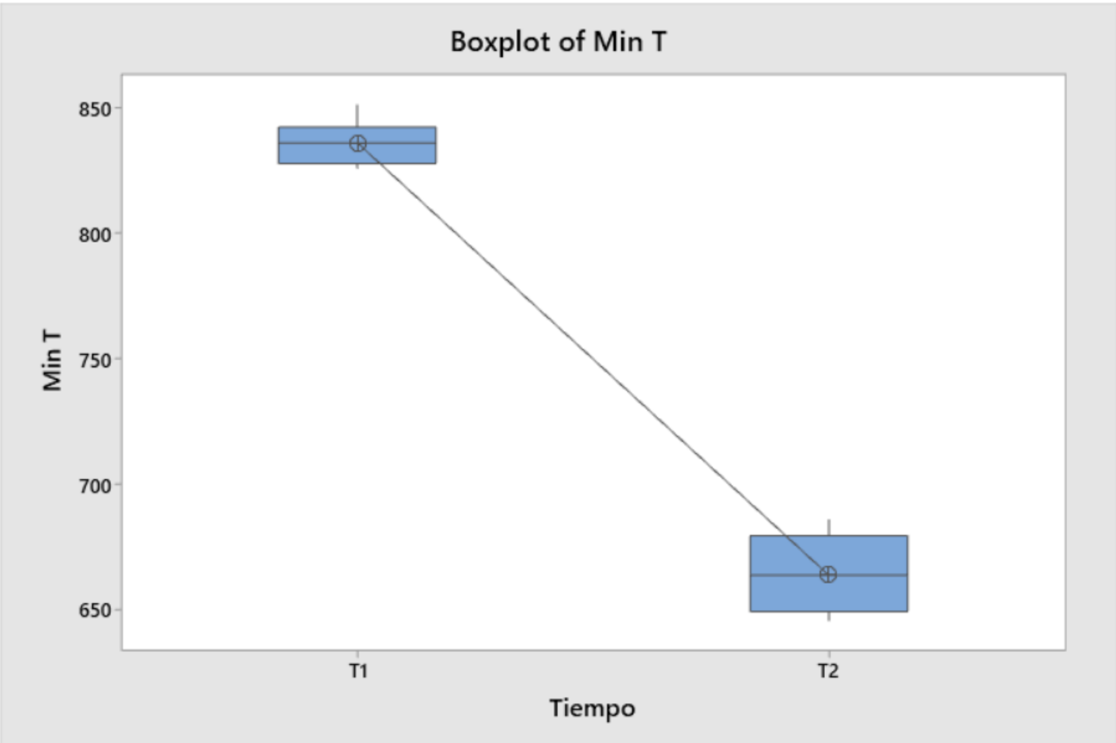
Estimation for Difference

Difference	95% CI for Difference
172,25	(158,68; 185,82)

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
27,94	11	0,000



APPENDIX I: TEMPLATE OF THE STANDARDIZATION OF THE PROCESS OF RETURNS

PINTURAS PRODUTEKN CIA. LTDA.

REGISTRO DE RECLAMOS Y DEVOLUCIONES DEL CLIENTE

CLIENTE							
I. IDENTIFICACIÓN DEL PRODUCTO							
PRODUCTO				CODIGO:		LOTE:	
FECHA FABR.				FECHA VENCIM:		FECHA RECLAMO:	
II. MOTIVO DE LA RECLAMACIÓN							
CALIDAD DE PRODUCTO		**ENVASADO Y ETIQUETADO**		**DESPACHO**		**VENTAS**	
Mal olor		Deformado		Exceso		Pedido mal tomado	
Color diferente		Roto		Faltante		Falta de pago	
Gelado		Volumen					
Brillo		Mal etiquetado					
Viscosidad							
Cubrimiento							
Contaminación							
CANTIDAD	**LT**						
	GL						
	CN						
OBSERVACIONES:							
Firma cliente:				**Firma vendedor:**			
III. REVISIÓN Y ANÁLIS DE RESULTADOS							
RESULTADO DE EVALUACIÓN LABORATORIO:							
RECLAMACIÓN ACEPTADA:				RECLAMACIÓN NEGADA:			
DEVOLUCIÓN							
ANALISIS DE CAUSAS							
ACCIONES PREVENTIVAS Y/O DE MEJORA:							