UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

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Yuvinne Nicolay Guerrero Segovia
Carlos Francisco Herrera Jarrín
Rommel Alexis Trujillo Pérez

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Nombre del profesor, Título académico **Pablo Sebastián Burneo Arteaga, MEM**

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Nombres y apellidos: Yuvinne Nicolay Guerrero Segovia

Código: 00201420

Cédula de identidad: 1724603970

Nombres y apellidos: Carlos Francisco Herrera Jarrín

Código: 00200619

Cédula de identidad: 1722595806

Nombres y apellidos: Rommel Alexis Trujillo Pérez

Código: 00137366

Cédula de identidad: 1724766413

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RESUMEN

Ecuador produce aproxiamdamente 6.6 millones de litros de leche a diario, de los cuales el 31% se encuentra destinado a la producción de quesos. Uno de los principales productores de queso en Ecuador cuenta con líneas de producción automatizadas en un 90%; sin embargo, experimenta problemas de no conformidad con el peso neto de sus diferentes presentaciones de queso. Este estudio describe la aplicación de la filosofía Lean Six Sigma para reducir la variabilidad del peso neto de los quesos mediante la aplicación de la metodología circular DMAIC propuesta por Villacis y Burneo (2020). Esta aplicación consiste en ciclos continuos dentro del proceso DMAIC lo que aumenta el número de "quick wins" obtenidos en un corto periodo de tiempo. A través de la recolección de datos, el análisis estadístico y la aplicación de herramientas lean, fue posible reducir la variabilidad del proceso de moldeo del queso en un 83%, lo que se reflejó en un aumento de capacidad, pasando de un Cpk de 0.37 a 1.12.

Palabras clave: Industria Láctea, DMAIC, Kaizen, Lean, Lean Six Sigma, Mejora de Procesos, Control estadístico de calidad, Six Sigma.

ABSTRACT

Ecuador produces about 6.6 million liters of milk a day, of which 31% is destined for cheese production. One of the main cheese producers in Ecuador has 90% automated production lines; however, it presents problems of non-conformity with the weight of its different cheese presentations. This study describes the application of the Lean Six Sigma philosophy to reduce the variability of the net weight of cheeses through the application of the Circular DMAIC methodology proposed by Villacis and Burneo (2020). This application consists in continuous cycles within the DMAIC process. The number of quick wins obtained increase and improvements are obtained in a shorter time frame. Through data collection, statistical analysis, and application of lean tools, it was possible to reduce the variability of the cheese molding process by 83%, which was reflected in a capacity increase with a Cpk racing from 0.37 to 1.12.

Key words: Dairy Industry, DMAIC, Kaizen, Lean, Lean Six Sigma, Process Improvement, Statistical Quality Control, Six Sigma.

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INTRODUCTION

Globalization has provided enormous business opportunities in several countries, which in turn has promoted market competition (Chiu Y. et al., 2020). A company, whether manufacturing or services, survives the competition only if it can respond to the market requirements through the added value offered in its products (Medeiros et al., 2020). In this context, the main objective of every manufacturing industry is to meet the customers' needs by delivering a quality product on time and reasonably priced (Palange & Dhatrak, 2021). In this way, those industries maintain operational, managerial, and engineering activities focus on achieving and maintaining the desired levels of perceived quality characteristics (Critical to Quality, CTQ's) (Montgomery, 2013).

Current competitiveness means that customers expect superior quality products, so organizations must look for ways to improve their functional performance (Rathi et al., 2016). There are several techniques used by professionals to achieve the proposed quality goals and increase the productivity of a company. According to Ikumapayi et al. (2020) two methods traditionally used with this approach are the Six Sigma method and the Lean Manufacturing philosophy. Six Sigma consists of several statistical techniques and tools focused to improve processes variability and quality (Kaswan & Rathi, 2019); whereas Lean Manufacturing is an effective philosophy to tackle non valued activities and wastes (Nandakumar et al., 2020). Ikumapayi et al. (2020) argues that the combination of these methods produces the best and most effective tools a company can possess to increase its overall productivity.

Lean and Six Sigma (LSS) were integrated on the 2000s; since then, both the productive and service sectors have put this philosophy into practice to eliminate all non-value-added activities and reduce variability in production processes (Yadav and Desai, 2006). LSS is a philosophy focused on continuous improvement which seeks to improve performance, competitiveness, and values defect prevention over defect detection (Kubiak and Benbow, 2016). It also aims to achieve fast flexible flow of products and services whilst systematically eradicating any issues that could adversely affect the quality of that product or service: variation, waste, and cycle time (Thomas et al., 2016).

LSS has been satisfactorily applied on manufacturing industry with plenty of benefits that have been demonstrated through the years. However, the number of literary reviews focused on the application of LSS in dairy industry is limited since there is no clear and defined context about the areas involved (Costa et al., 2018). Food industry managers such as Scott, Wilcock and Kanetkar (2009) have shown special interest in high-impact projects that appeal to continuous improvement by applying the LSS philosophy. However, the challenge arises as these programs become more complex due to the nature of the industry.

In Ecuador, agricultural production is considered one of the essential economic activities for the development of the country (Alvarado, 2016). Real (2013) states that each Ecuadorian consumes about 100 liters of milk a year, 30 liters below the minimum consumption recommendation made by the World Health Organization. According to INEC data, the country's dairy industry produces approximately 5 million liters of milk daily; 75% of it is destined for the elaboration of cheese, milk in carton and milk in cover (Ramírez, 2017). The national dairy industry is mostly based on small and medium-sized producers. Given the nature of companies, the application of the DMAIC methodology for the management of continuous improvement projects turns out to be an appropriate approach.

According to Ecuador's Ministry of Agriculture, around 6.6 million liters of milk are currently produced every day, creating approximately 1 million jobs along the entire supply chain. In this context, 31% of dairy production is destined to cheese production processes (CIL, 2021).

However, despite the prosperity of the industry, it presents several constraints that affect its optimal performance. Overproduction, low productivity, non-agile mechanisms, and ineffectiveness have led producers to offer their products in informal markets (CIL, 2021). According to the Center of the country's dairy industry, those problems has generated losses of more than 50 million dollars a year for this productive sector (CIL, 2021).

PREVIOUS STUDIES

Although the number of studies within the food industry are limited, those that have been published show the positive impact that has been achieved throughout the integration of Lean Manufacturing and Six Sigma (Costa *et al.*, 2018). However, the same author affirms that, until 2018, the application of these in the dairy industry has been limited because there is no clear and defined context about the areas involved. Among the few studies that have been carried out, the one of Dora and Gellynck (2015) stands out. This research demonstrates the successful application of LSS to reduce overfilling and reprocessing in a gingerbread production line.

In relation to the application of LSS in the dairy industry, in 2017 Powell carried out the application of LSS in a milk producing company. In this way, the methodology was fundamental to reduce milk waste and increase environmental sustainability. Similarly, in 2018 a study was conducted by Serrano and Ruiz in a small dairy company. In this industry, the cheeses produced did not meet the specifications required by the consumer and their percentage of yield was low. By using Lean and Six Sigma tools such as DOE, Kaizen Events and Poka Yoke it was possible to reduce the variability of the process, obtaining benefits of more than $580 per week and an increase in cheese yield by 2.9% and 3.7% for butters.

METHODOLOGY

DMAIC is a methodology that is implemented during a Six Sigma project to achieve the continuous improvement of a specific process (Villafuerte, 2019). It seeks to solve issues and eliminate non-value-added steps through a cycle composed of five stages: define, measure, analyze, improve and control (Hakimi et al, 2018). The most common problems include waste, reprocessing, increased operating costs, among others. (Villafuerte, 2019). As Yahira et.al (2011) explains, the application of the DMAIC methodology is recommended when the cause of the problem is not clear, the possible savings are significant and the time in which the project can be carried out is between 4 to 6 months.

De Mast & Lokkerbol (2012) state that the DMAIC methodology serves as a general guide and is therefore adaptable to the characteristics of each project. However, it is essential that all stages of the cycle are completed; in this way, is more likely to achieve the objectives of the project (Linderman et al., 2006). Pande et al. (2002) state that data collection is a fundamental activity throughout the entire DMAIC cycle, from setting objectives in the defining phase to inspecting improvements in the control stage. In this way, Gošnik et al. (2014) affirm that it is necessary to make the DMAIC cycle more flexible for its application in Six Sigma projects.

In 2020, Villacís and Burneo proposed an adaptation of the DMAIC focused on the creation of cycles within each step of the methodology. Later in 2021, Chávez and Burneo merged the problem-solving process with the DMAIC to promote understanding of the framework. The methodology used in this project can be visualized in **Table 1**. DMAIC methodology as a cyclical framework.

Table 1. *DMAIC methodology as a cyclical framework*

Problem Solving Process	DMAIC Methodology	DMAIC Activities Required	Deliverable
Problem	Define	Define Measure Analyze	- Project Charter - SIPOC diagram - Process flowcharts - CTQ definition - Historical data analysis
	Measure	Measure Analyze	- Baseline control charts - Capability analysis - Assignable causes analysis
Cause	Analyze	Analyze Measure	- Pareto analysis - Cause and effect diagram - 2-sample t test - Brainstorming
Solution	Improvement	Improvement Measure Analyze (re)Define	- Kaizen event - Andon - Design of experiments - Operating principle - Function principle - Center line - Receipts automatization - Competency matrix - Capability analysis
	Control	Measure Analyze (re)Define	- Standardization - Process monitoring plan

For the application of the methodology, the study framework presented by Machfud (2020) was used. In the defining phase, the scope of the project, the production processes and risks associated with the problem of interest were determined through observation. At this stage, the tools recommended by Obergfell (2020) were used, among which project charter, SIPOC diagram, Process flowcharts, CTQ definition and historical data analysis stand out. At the measurement stage, the baseline of the process of interest was established through the construction and analysis of control charts and capacity analysis. From this stage the phases of analysis and implementation were applied simultaneously. The iterative process began with the diagnosis of a root cause, then the analysis of that cause and ended with the implementation improvements known as "quick wins" (Rodrigues et al., 2019). Within the improvement stage, a new cycle was proposed in which the impact of the improvements implemented was measured, their impact on the problem of interest was analyzed and procedures were standardized. Once the data on the impact of the implemented improvements was collected and analyzed, a control plan was created focused on guaranteeing the permanence over time of the changes made.

PRELIMINARY STUDY OF THE COMPANY

The company under study is a dairy company specialized in the production of cheese with more than 30 years of experience. It has several production processes that begin from the reception of the raw material and culminates with the dispatch of the packaged product. The company has a production capacity of one hundred thousand tons of milk that is distributed to produce various cheese presentations (Alves, 2021). **Figure 1** shows the production frequency of each cheese type offered by the company; it also evidence that the main cheese type is mozzarella which represents 60% of the total production. For this reason and regarding to the explicit request of the company, this research will focus on this product.

Currently, 90% of the production lines are automated; this strategy has allowed the company to become the best dairy supplier of a local retailer. Nevertheless, this same automatization has also generated problems that require innovative solutions. Within the production line of mozzarella cheeses, it has been identified that the various presentations that are made have a net weight above the specification limit. The weights tolerance has been established in a range of ±10 grams. This directly affects the amount of product that is delivered to customers or distributors, resulting in annual monetary losses estimated at $800.000 dollars.

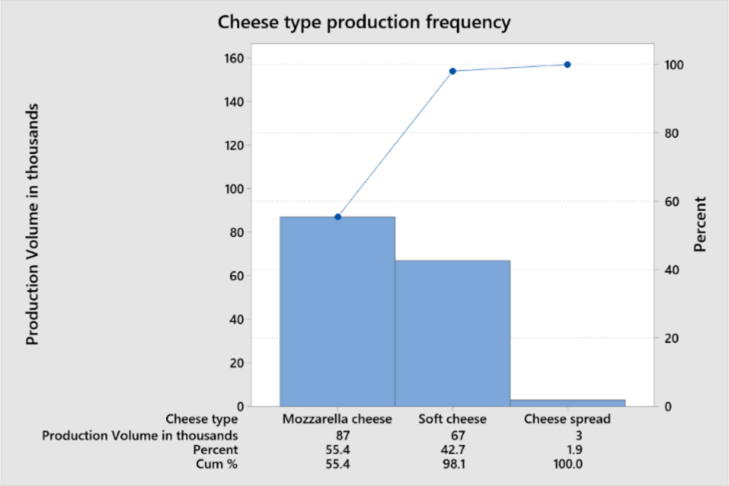


Figure 1. *Pareto diagram frequency production*

Additionally, a series of problems have been identified which directly affects the company. Inside the packaging area, the extruder and packing machines suffer breakdowns which causes both processes to be paralyzed for an indeterminate period, delaying shipments. Cheeses that present non-conformities (unwanted weight and deformed geometry) are stored in the packaging area causing storage problems.

Due to the sensitivity of this problem and impact on company performance the following research question was formulated: How to control the net weight of mozzarella cheese in its various presentations? From this question, more specific ones are derived such as:

- Which activity contributes with the greatest amount of variability to the net weight of cheese?
- How to minimize the amount of reprocessed product?
- What monetary benefit will the reduction in variability have?

The objective of this paper is to reduce variability and waste in the production process of mozzarella cheese, through the application of the Lean Six Sigma philosophy to meet the net weight of each product. To support the main objective the following specific objectives were proposed:

- Establish the baseline of the process.
- Evaluate the benefit of applying the LSS philosophy in monetary terms.
- Reduce the amount of product to be reprocessed.
- Establish adequate measurement systems to control the outputs of each production line.

ANALYSIS AND EVALUATION PROCESS

To achieve the objectives set, it is necessary to thoroughly understand the operation of the production plant of the company under study. In this context, going and seeing what is happening in the plant by using the senses to understand problems and processes that employees develop daily will provide a better understanding of the environment, this process is known as a Gemba Walk (Womack, 2009). This activity was carried out frequently. In this context, it is important to note that the knowledge of the internal processes allowed to obtain a better perspective of the machinery operations and the technical specifications that the cheeses must have to be part of the production process and comply with the requirements dictated by the control bodies.

Until then, inside the production plant there were no scales that allowed to control the net weight of each presentation of cheese for each production line. A considerable amount of the production batches only had the initial calibration, but the control process was omitted due to the lack of balances in fixed positions. Additionally, there was no rigorous control by the operators, so at that specific time the process was not standardized. By following a cyclical DMAIC methodology, the first quick win of the Gemba Walk was the implementation of balances on each production line to ensure that there is control over the production batch.

Based on the observations made, Obergfell recommends constructing a high-level diagram (SIPOC), shown in **Figure 2** level to identify the inputs and outputs of the mozzarella cheese production process (2020). Through this diagram it was determined that the limits of the system begin with the reception of milk and end with the palletizing of the finished product. All internal processes within the established limits are considered within scope. Likewise, it was determined that the quality critic for the project is the net weight of the cheeses, an indicator that will represent our dependent variable (Y). The observation determined that the possible critical processes in relation to the net weight of cheeses are molding and brining.

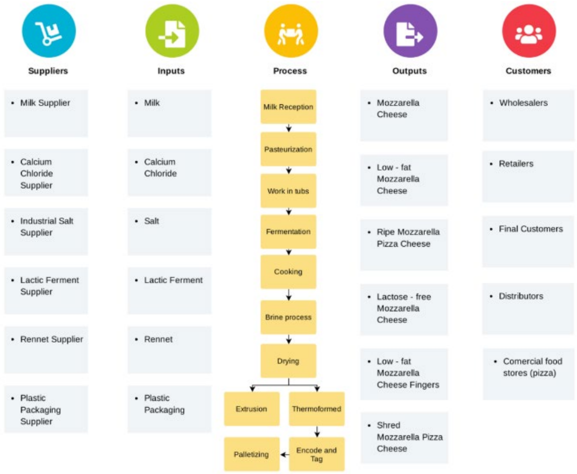


Figure 2. SIPOC diagram

As mentioned before, one of the critical processes is molding. For the execution of this stage, the intervention of two machines is necessary, the steam spinning and the molding machine. The first is responsible for receiving the cheese from the fermentation vats. Inside, the cheese is cooked until a malleable consistency is obtained. The molding machine is responsible for receiving the cheese in the host hopper. Here, the extrusion screw pushes the dough into each mold. It is possible to set screw rotation speed, disc rotation speed and hammer height.

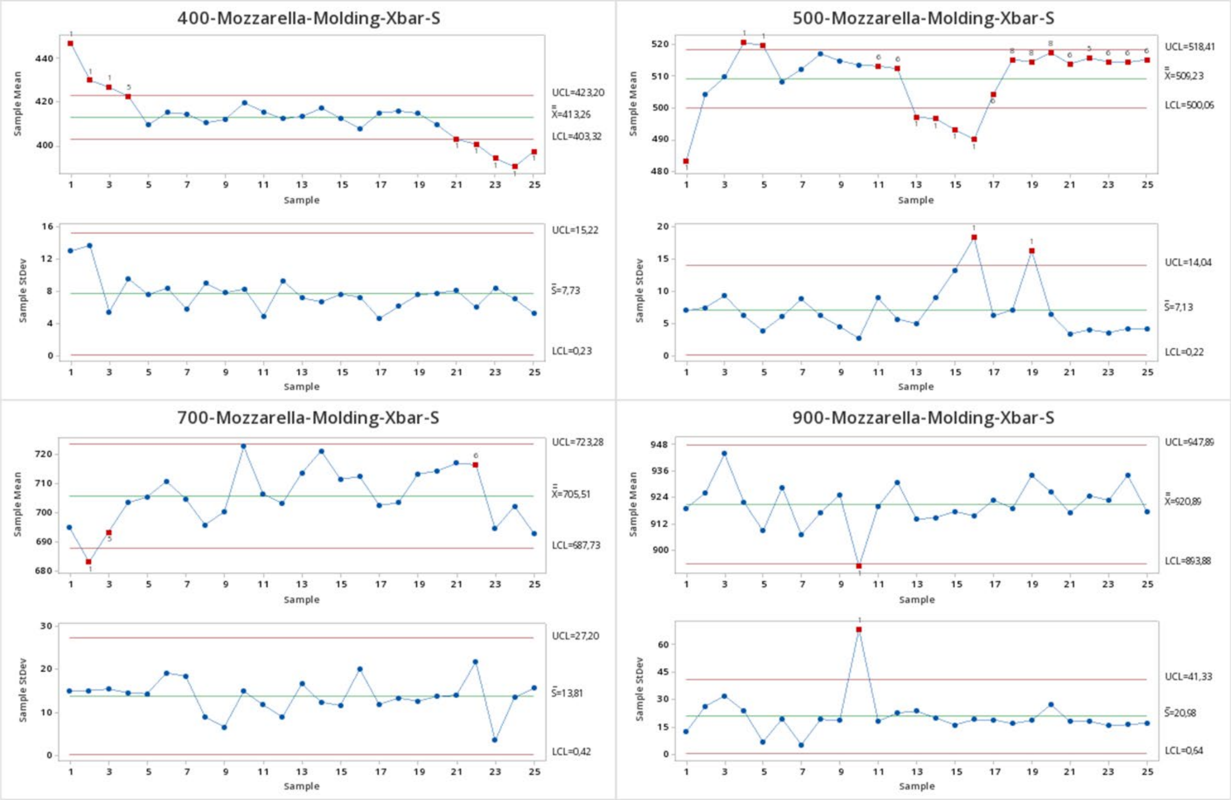
To evaluate the impact of these processes on the net weight of cheeses, a sampling plan was created focused on the creation of control charts. The variable of interest is quantitative and continuous. In pursuance of establishing the baseline of the process Montgomery (2013) recommends that a subgroup size of 4 to 6 is robust for normality deviations in the data. Likewise, it will be necessary to take 20 to 25 samples. Given the high frequency of mozzarella cheese production, 25 samples were taken with 6 observations for each presentation obtaining a total of 150 observations. In addition, a systematic sampling was used to guarantee maximum variability between subgroups, minimum within the subgroups and analyze an entire batch (Montgomery, 2020). The measurements taken were made in several shifts to observe the different operators perform their rutinary functions.

Based on this, control charts were created for six mozzarella cheese presentations (200g, 300g, 400g, 500g, 700g and 900g) in each critical process (molding and packaging). Control charts are shown in **Figure 3**. The software package to analyze the data was Minitab.

The 400g mozzarella cheese has a rectangular geometry. As can be seen in **Figure 3** the process is out of control. At the same time, it was decided to run a test for special causes to determine the observations that need to be investigated and identify specific patterns in the data.

Assignable causes were found through observation of the production process and a literature review by various authors such as Montgomery and the Western Electric Company.

However, the graph shows problems to maintain the average over time, this is mainly due to the amount of cheese in the host hopper decreases, causing the speed of the molding disc to also decrease. The result of this out-of-control process is compact cheeses, with a better geometry but with a lower weight established by the tolerance limits (± 10 grams). This same analysis was performed for all six presentations.


400-Mozzarella-Molding-Xbar-S

500-Mozzarella-Molding-Xbar-S

700-Mozzarella-Molding-Xbar-S

900-Mozzarella-Molding-Xbar-S

Figure 3. Baseline Control Charts

To corroborate this, as shown in **Figure 4**, a pareto diagram was constructed to identify the frequency of assignable causes for all cheese presentations within the production process. It is clearly noted that assignable causes are not dealt by the company. It is evident that there is no standardization and therefore the net weight is affected as production time goes on. There are excessive initial calibrations which influences the number of cheeses produced outside the specification limits. The change in procedure refers to new cooks in the spinning machine. Finally, the process step not completed refers when the amount of cheese in the hopper is zero, the machine must be operated manually causing the rotational speed to decrease. Remarkably, the process step not completed, and procedure change are both assignable causes that are related.

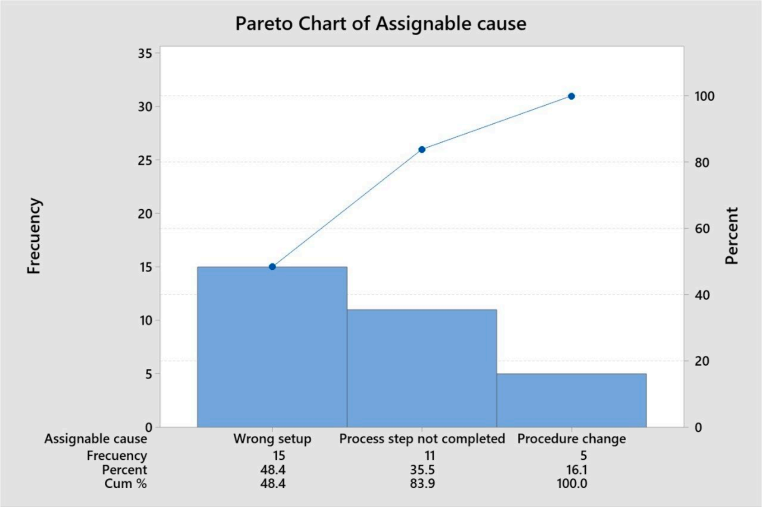


Figure 4. Pareto diagram assignable causes frequency

As the investigation deepened, and based on the assignable causes found, the following question was formulated: What is the impact of the amount of cheese in the hopper on the net weight? To statistically argue the impact of the hopper running out of cheese, a correlation analysis between production time and average net weight was performed. A negative correlation (-0.8) indicates that as time increases, the weight decreases, which corroborates the theory proposed. Several studies in the food industry conclude their statistical analyses at a significance level of 5%. The correlation found is indeed significant as seen in **Figure 5**.

Using the data collected, it was found that the number of cheeses that exceeded the upper specification limit varies according to the presentation. All the presentations have an excess of weight but the ones that stand out are 400g, 500g and 900g, as seen in **Figure 6**. It is important to note that these three presentations have different geometries and therefore it cannot be ruled out that one of the possible problems that affects the weight is the variability of the molds. It can be observed that the number of cheeses above the upper specification limit varies before and after the brine process. There is enough evidence to conclude that there is a considerable difference in weight.

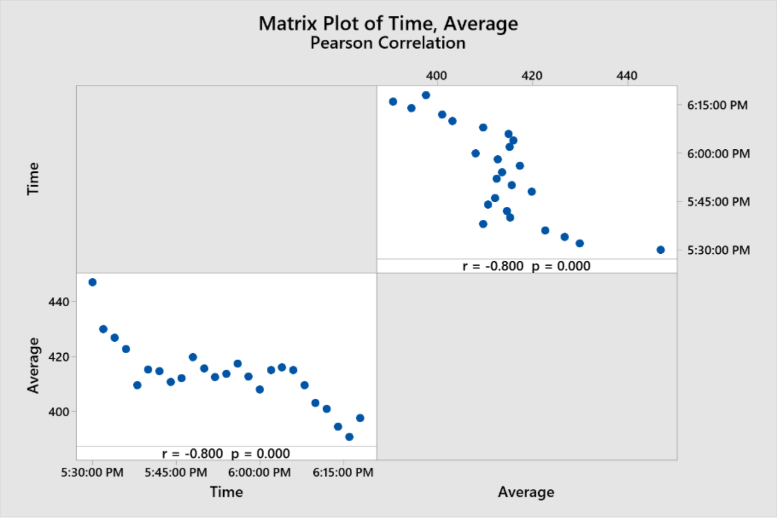


Figure 5. *Correlation Time vs Net Weight*

At this point a new question arose. Is there a significant difference in net weight before and after brine? Montgomery and Minitab (2020) recommend using a t-test given the nature of the data and the situation. Likewise, several simple comparative studies carried out in the food industry conclude their results at a significance level of 5%. 150 samples were collected before salting and 150 after salting. With this sample size the t-test had a power of 0.99, higher than the values of 0.8

or 0.9 commonly used in these studies. A first approach yielded results where the comparisons showed atypical data. Not removing this type of data increases the chances of presenting a type I or type II error and therefore it is possible not to detect the effects and conclude erroneously (Minitab, 2021). In this case the atypical data were withdrawn since they refer to the assignable causes previously found.

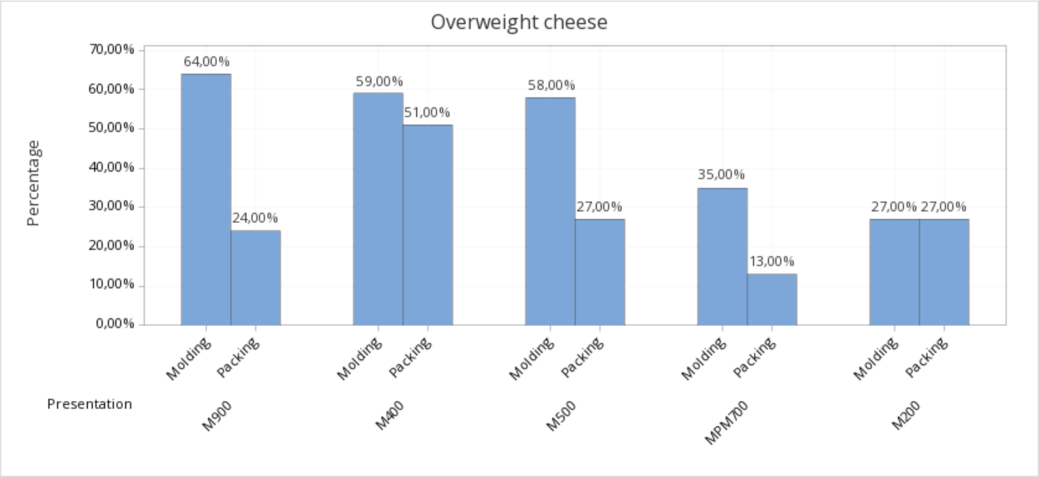


Figure 6. *Overweight in cheese by presentation*

For presentations of 400g, 500g, 700g and 900g the p value < 0.00, which indicates that the brine process clearly has a significant effect on the net weight of the cheeses. However, for the presentation of 200g the p value > 0.05 indicating that there is no significant effect on the weight. This is mainly caused by the effect of molds and machine configuration. It is necessary to emphasize the importance of the amount of cheese that enters to the interior of the molds. Having a cheese of lower weight does not need a long time to conform in a better way; in this way the cheese absorbs a smaller amount of water, and the brine process does not affect the net weight. Results are shown in **Table 2.**

Table 2. *2 sample t-test results for brine process*

Presentation	200	300	400	500	700	900
Atypical data removed?	Yes	Yes	Yes	Yes	Yes	Yes
p - value	0.85	-	0.03	< 0.00	< 0.00	< 0.00
Significant effect?	No	-	Yes	Yes	Yes	Yes

The brine process is critical to the production process of mozzarella cheese. Its main function is to absorb most of the fat in cheese. In this way, the net weight is directly affected and therefore it is necessary to find a way to quantify the weight reduction. As previously mentioned, only four presentations suffer a significant weight reduction due to the action of brine. When performing the t-tests, Minitab software threw confidence intervals at 95% resulting in a lower limit that represents the minimum weight that the cheese loses and an upper limit as the maximum amount of weight it loses as part of this process. The average reduction percentage for the presentation of the 400g is approximately 1% of its weight. This means that when leaving the brine, the cheese loses 1% of the weight it had at the time of being molded. This analysis was carried out for the other presentations where the results can be visualized in **Table 3**.

Table 3. *Weight loss quantification by effect of the brine process*

Presentation	400	500	700	900
Lower limit [g]	0.27	1.91	9.33	23.95
Lower limit [g]	5.03	6.09	16.48	32.33
% average reduction	1%	1%	2%	3%

Up to this point, the existence of non-conformity in the net weight of cheeses has been justified. However, based on these preliminary analyses, extremely important insights were found that are possible causes of the main problem. As a first point it is highlighted that there are many setups for the molding machine. This causes that approximately the first forty cheeses do not have the appropriate weight, generating non-conforming product. This is complemented by the lack of an optimal configuration of the molding machine for each cheese presentation. The lack of standardization was an important fact, calibration procedures have not been established for the acquired balances and for the spinning and molding machines.

Through observation it was verified that in the hopper there must be a minimum amount of cheese so that production is not interrupted. This is strongly related to the lack of maintenance of machinery, especially molds. Over time, the material has worn out resulting in increased variability. When analyzing the production process in different shifts, it was observed that within the molding process the speed of rotation of the disc is extremely high. This generates that the cheeses come out deformed, increasing the amount of product to be reprocessed, directly affecting inventory space. One of the most important findings is related to the empirical operation of workers. In the absence of constant training to operate the machines, operators rely on their experience to get the job done.

With the purpose of reducing the impact of these problems, a kaizen event was held where those involved were operators, managers and production coordinators, analysts, and maintenance personnel. For a week we sought to implement quick wins to control the net weight of the cheeses. The event was divided into nine stages, each stage had a goal to be met that allows to continue with the next. The main advantage of this Lean Manufacturing tool is that it’s an iterative process (Avilés, 2021). Whenever necessary, the event can be rerun again.

As the first activity of the event, an opening session was held where the possible causes of the problem and possible opportunities for improvement were analyzed. This conversation space made it possible to evaluate the perspectives of each operator. To do this, each operator created opportunity cards in post it notes. The red card represented the problem, and the green card represented the possible solutions. The execution of this activity was fruitful since it was carried out for each of the different shifts. As a result of this, an opportunities matrix was built where they were classified according to their impact and time horizon required for execution. It was clear that high-impact opportunities must be implemented. It is worth mentioning that due to the execution time of the project, these opportunities were implemented in a period not exceeding one week.

Opportunities were categorized as following. For process standardization, firstly it was necessary to establish the principle of operation of the machines involved in critical processes. By creating this document, a structural diagram of the machine can be visualized. To provide support, it was necessary to generate an ideal sequence of operation along with the ideal conditions. Once this document was created, the next step was to train operators so that they know the inner workings of the machine and can operate it. Following this, the next step was contacting the supplier of the machinery to automate the recipes of the cheeses to work under the same standard and minimize variability. Finally, to close this standardization process, it is essential to have a centerline for the molding machine. Centerlining is a concept belonging to Lean Manufacturing whose primary objective is to find a range of optimal configurations to minimize waste, set up times and improve product quality (Cardozo, 2010).

Additionally, the following opportunities for improvement were proposed that must be worked on together with the company and direct involvement of the operators.

- Maintenance: TPM plan, periodic calibration, and molding disc correction.
- Measurement tools: Balance acquisition.
- Training: Awareness of the procedure to follow (for each operator).
- Repowering: Molding disc and layout redesign.

The analyses showed that standardization of recipes is necessary to reduce the disturbing factor of the difference between masses. In conjunction with the company and CMT representative at the national level, it was possible to automate the recipes to 95%. The remaining 5% requires a special configuration where only CMT has access.

Once the recipes were standardized, the next stage of the process was initiated. As evidenced in the correlation analysis and the assignable causes, the amount of cheese in the hopper indirectly affects the net weight of the cheeses. Therefore, a time analysis was performed to find the minimum amount of cheese in the hopper necessary to maintain a constant rotational speed of the disc. For this, a takeover of the cycle time of the molding disc was made for a production batch under normal and stable conditions. shows the application of this analysis.

The analysis allowed to verify that evidently when there is 5% of cheese remaining in the hopper, the cycle time of the molding disc begins to increase until it doubles. This is mainly caused because the extrusion screw does not have enough cheese to push it towards the molds. Consequently, molded cheeses have fewer deformities; however, net weight is affected. To mitigate the impact of this action, a visual indicator was placed on the outside of the hopper (**Figure 7**). Through the implementation of this type of visual indicators, the generation of a safer workspace can be enhanced; so that continuous monitoring does not require supervision and training. There is a wide variety of types of visuals; however, the fundamental characteristic of them lies in their easy understanding and that especially the colors have an immediate visual impact (Brady Worldwide Inc., 2012). The main impact of this tool is summarized in providing and guaranteeing organization and control in the mozzarella cheese production process.

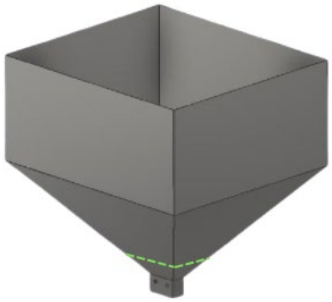
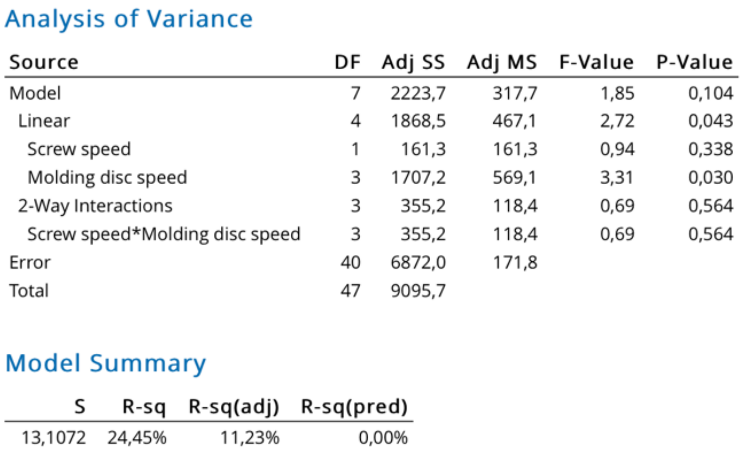


Figure 7. *Visual indicator on the hopper*

As a complement and to guarantee the continuity of the production process without interruptions, an operating principle focused on four pillars (Guarantee, Synchronize, Stop and Release) was created. Each pillar has a specific function, where each one is linked to the previous one. As first pillar, the amount of cheese needed in the hopper must be guaranteed. Then the times that the cheese is cooked in the spinning machine must be synchronized, in this way it is avoided that at some point the hopper runs out of cheese. In case of not having the minimum amount of cheese, production must be stopped and the cheeses that are still in the molds must be released. In this way, the number of products to be reprocessed decreases thanks to the existence of a continuous procedure to deal with the problem.

Once this opportunity for improvement was closed, it was decided to move to the molding disc approach. With the purpose of determining the optimal configuration of the model disc, several experimental designs were created. Experimental design methods have found broad applications in diverse disciplines, it is considered as a critical important tool in the scientific and engineering world to achieve improvements in production processes (Montgomery, 2013).

As previously mentioned, the molding machine can be configured in different ways. In this way, the factors that can be modified are the rotational speed of the molding disc and the extrusion screw. In model number 1, visualized in **Figure 8**, there is evidence of a poor fit of the model to the data and without predictive capacity because the greatest amount of variability comes from error. At a significance level of 5% it would be concluded that the only significant factor on the net weight of the cheeses is the speed rotation of the molding disc. However, this model cannot be accepted given its high error which indicates that some term that completes the built model is being omitted. This means that there is a disturbing factor that contributes with variability to the process.



Analysis of Variance

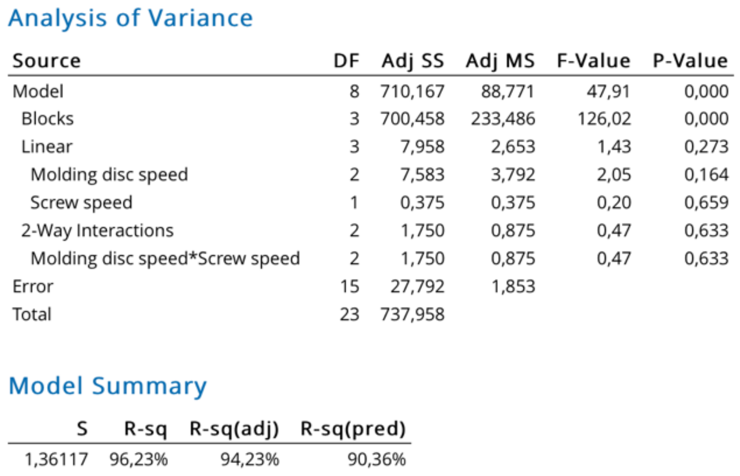
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	2223,7	317,7	1,85	0,104
Linear	4	1868,5	467,1	2,72	0,043
Screw speed	1	161,3	161,3	0,94	0,338
Molding disc speed	3	1707,2	569,1	3,31	0,030
2-Way Interactions	3	355,2	118,4	0,69	0,564
Screw speed*Molding disc speed	3	355,2	118,4	0,69	0,564
Error	40	6872,0	171,8		
Total	47	9095,7			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
13,1072	24,45%	11,23%	0,00%

Figure 8. *General full factorial design without blocks*

After several days of process observation, it was found that the disturbing factor was the cleats belonging to each division of the molding disc. In this way, a new model was built again where this new factor was added; however, as it was a factor that was possibly contributing with variability to the model, it was blocked. **Figure 9** shows the new experimental model. It is a more robust model since it has a great capacity to predict future values and the greatest amount of variability comes from the blocks, which means that the main cause of the non-conformity cheese weight are the molds and cleats. At a significance level of 5%, it was concluded that the blockage of this factor was significant. However, in constructing this model, no principal factor turned out to have a significant effect on the response variable.



Analysis of Variance

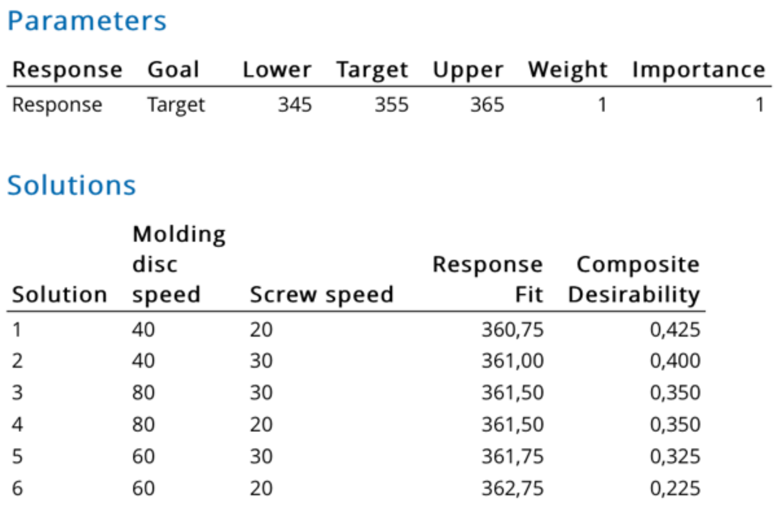
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	8	710,167	88,771	47,91	0,000
Blocks	3	700,458	233,486	126,02	0,000
Linear	3	7,958	2,653	1,43	0,273
Molding disc speed	2	7,583	3,792	2,05	0,164
Screw speed	1	0,375	0,375	0,20	0,659
2-Way Interactions	2	1,750	0,875	0,47	0,633
Molding disc speed*Screw speed	2	1,750	0,875	0,47	0,633
Error	15	27,792	1,853		
Total	23	737,958			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1,36117	96,23%	94,23%	90,36%

Figure 9. *General full factorial design with blocks*

For this experimental design, four replicates were made, obtaining a total of 24 experimental runs. In this sense, the test power was 0.99 allowing to detect small effects. To find an optimal configuration for the molding process, Minitab software's response optimizer was used. Since a cheese presentation of 355 grams was analyzed, the lower specification limit was set at 345 and the upper specification limit at 365. In **Figure 10** the output of the optimizer shows the results, giving an optimal configuration of a molding disk speed of 40% and a screw speed of 20%. Thus, it was concluded that the operating standards of the company are correct but present problems with the cleats. However, setting the molding disk speed to values less than 60% will result in less defective product.



Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Response	Target	345	355	365	1	1

Solutions

Solution	Molding disc speed	Screw speed	Response Fit	Composite Desirability
1	40	20	360,75	0,425
2	40	30	361,00	0,400
3	80	30	361,50	0,350
4	80	20	361,50	0,350
5	60	30	361,75	0,325
6	60	20	362,75	0,225

Figure 10. *Response optimizer*

The standards established for the correct operation of the molding disc (Centerline) can be seen in **Table 4.** Molding disc centerline. These values were obtained in a joint management work with the maintenance area. The statistical analysis previously carried out validates the values presented. Once this Centerline was created, the operators were informed and trained to configure the machine according to the different presentations of mozzarella cheese that are produced.

Table 4. *Molding disc centerline*

Presentation	**200**	**300**	**400**	**500**	**700**	**900**
Hammer height [cm]	21.55-21.6	21.65-21.75	21.35-21.45	21.75-21.85	28.55-28.65	31.3-31.5
Screw speed [%]	17-19	17-19	17-19	17-19	19-21	19-21
Rotational speed [%]	69-71	59-61	59-61	59-61	79-81	79-81

The next step of this research was to standardize the molding disc to decrease the variability in the net weight of the cheeses. To do this, a new methodology (ACLR) was developed based on four pillars: assign, codify, level and replicate. The first pillar refers to assigning a cleat to a specific mold considering that external dimension of the cleats must be measured (height, width, and depth) and assign it to a similar mold. Following this, each mold and cleat must be encoded with both a number and letter per division. **Figure 11** evidence the coding that was carried out. As a third pillar, the height of the cleats within each division must be leveled. In this way it will be controlled that the amount of cheese that enters the molds will be the same and therefore the variability will be reduced. Finally, this procedure must be replicated for each disk within the production process (square, rectangular and circular). Due to the limited execution time of this research, the ACLR methodology could only be applied to the square molding disc.

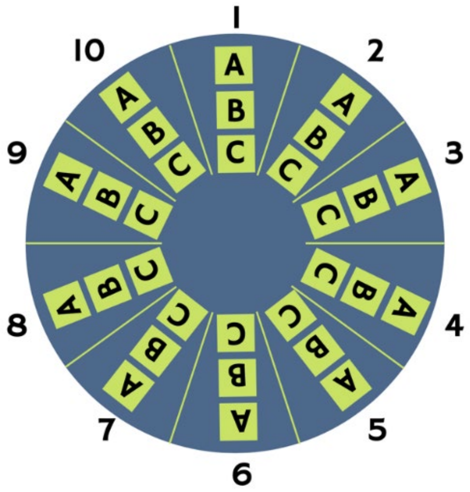
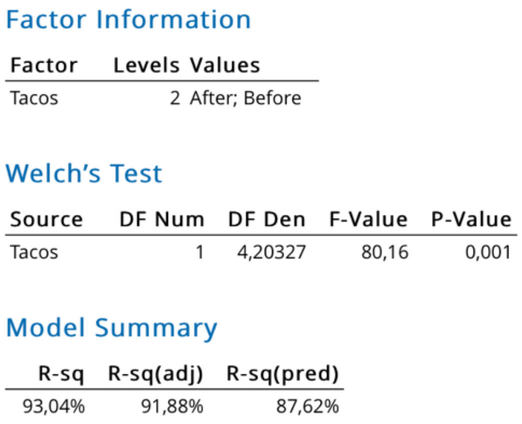


Figure 11. *Molding disc standardization*

In this way, data was collected again once the improvement opportunities were implemented demonstrating a positive impact on the reduction of variability for the molding process. A Welch's test (**Figure 12**) was conducted in which the means of the variances of the collected data were compared. Unlike the single-factor ANOVA procedure, the Welch test does not assume that all populations have equal variances (Minitab, 2021). Since the samples do not have equal variances, at a significance level of 5%, it can be concluded that the mean of the variance before and after the improvements are significantly different. Thus, there was a reduction within each division of the disc of 83% and 11% between each division. These results showed the effectiveness of performing a standardization process.



Factor Information

Factor	Levels	Values
Tacos	2	After; Before

Welch's Test

Source	DF Num	DF Den	F-Value	P-Value
Tacos	1	4,20327	80,16	0,001

Model Summary

R-sq	R-sq(adj)	R-sq(pred)
93,04%	91,88%	87,62%

Figure 12. *Molding disc variability reduction*

Based on all previous improvements that were implemented, a new data collection was carried out (25 samples with 6 observations) so that a control chart was built again for the molding process of the mozzarella cheese of 355 gr. As shown in **Figure 13**, the process is under control and has no problems maintaining the mean and its variability is stable. By having better control over the assignable causes found in the process baseline, it is observed that only at the beginning of the process there is a pattern due to initial calibration activities. However, with current process conditions, no significant improvement can be implemented.

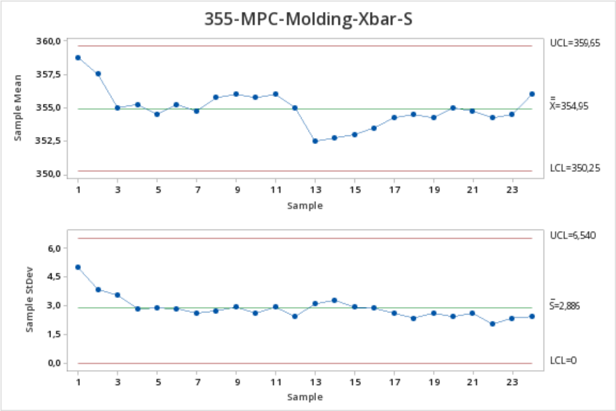


Figure 13. *Control Chart after improvements*

Having a process under control, the next step was to perform a capability analysis (**Figure 14**) to verify if indeed cheeses meet the specifications limits. Several capability ratios have been developed to summarize how well the process yields measurements within the specification's limits (NCSS Statistical Software, 2021). Comparing the data taken at the baseline and the data after improvements it is observed that the process capacity indicator increased from 0.37 to 1.12; this indicates that the process can meet specifications but can be improved. A deeper analysis shows that for every million cheeses produced, only 583 will be defective. In this context, the repowering of molds is an option that must be considered.

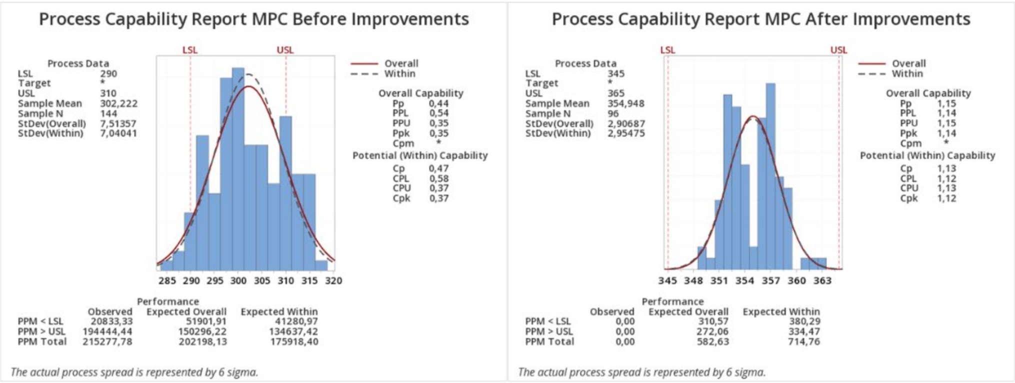


Figure 14. *Process Capability Analysis comparison*

Guaranteeing quality is necessary and mandatory to ensure the correct execution of operations. In this area, quality control becomes the primary objective since it implies a wide traceability of all the processes involved in the elaboration of a specific product. In this way, finally to meet the standards from now on, a quality control plan has been developed, based on five main activities. Through this tool, both the features and established methods that affect the conditions of the product can be monitored and controlled. **Table 5** shows the quality control plan.

Table 5. *Quality control plan*

Machine	CMT spinning machine	Molding machine
Operation description	Cook cheese under specific recipe (Principle of operation)	Mold the cheese according to the presentation and recipe (Principle of operation)
Process characteristics	Working under automation (Centerline)	Disc rotational speed, screw, and hammer height (Centerline)
Sampling plan	N/A	20 samples with 4 observations
Control method	Standard Worksheet	Standard worksheet, control chart and process capability analysis
Reaction plan	Competency matrix and manual operation of the spinning machine	Stop production and manual operation of the molding machine

LIMITATIONS

The case study presented was carried out in a dairy industry of great impact in Ecuador. Due to the size of the industry, its prevalence in the market, its level of automation and the collaboration of operators, coordinators, and management the six-sigma project had favorable results. However, there were limitations that delayed data collection due to external audits, factory cleaning and production planning. In this same context, the application of lean tools was satisfactory from the point of view of "quick wins" and recommendations for improvement;

however, the industry had an explicit request to expose only opportunities for improvement and action plans in order the responsible department to implement what was found. This represents a limitation because on certain occasions the action plan was not carried out as recommended, which could cause failures in the process. Finally, the team's lack of experience led to mistakes that delayed the delivery of results; however, these errors served as an experience and promoted academic training.

The confidentiality requested by the company represented a limitation to achieve one of the objectives of the proposed project. The monetary impact of overweight cheese production was quantified at USD 800,000; however, the effect of lean tools and six sigma analyses could not be quantified due to the lack of financial information and confidentiality of it. In this sense, percentages of reduction of the cheeses weight variability were presented to the industry in order that the financial department can carry out the relevant analyses.

CONCLUSIONS

In conclusion, we achieved improvements in the mozzarella cheese production process and obtained benefits of efficiency, effectiveness, reduction of waste, among others. The set ups that arise during the entire production were reduced, this generated a smaller amount of defective product, therefore a reduction in the percentage of reprocessed product was obtained. In the same way, the variability of the product was stabilized, with this we refer to the variability of the product that remains within the allowed limits when it leaves the molding machine. We also managed to implement scales in each production line. This was implemented thanks to the Gemba Walk, since a problem about weight control could be identified, for this reason we had considered that there must be a feasibility to achieve better control of the net weight.

On the other hand, we managed to generate a standardization of the processes that includes the operators, operation, and an adaptation of the center line. All this falls on the spinning and molding machines because the activities carried out on these machines generated the greatest variability in the net weight of mozzarella cheeses. In the same way, a training plan was generated for the operators to maintain the ideals of standardization, which was developed and implemented by the company. All these findings and improvements made the automation of the molding machine increase to 95%. Finally, even though a Cpk of 1.12 has been obtained that defines that the specifications were met, there are opportunities for improvement that can still be applied to increase the quality of the process.

RECOMMENDATIONS

It is recommended that the company continues with the control plan, because the improvements will last, and the performance achieved in the mozzarella cheese manufacturing process will be maintained. It is also recommended that a device or sensor be included in the center line of the hopper to achieve that production stops automatically, and this can preserve the standardization ranges that were created. In the same way, it can be suggested to implement a production planning according to demand forecasts, because this can reduce the changes of formats of the different mozzarella cheese items and the times that the machinery is not in operation, which could define as increased productivity and effectiveness.

On the other hand, the increase of fermentation vats can be recommended so that there is an increase in operating capacity. This could also interfere in the redesign of the layout because the space where these tubs are located is very limited, directly affecting the movement and handling of products. Likewise, it is recommended to repower or create transport rails for the tubs, because the wheels show very high wear, which affects their handling and in a long term could cause bodily harm to the operators. Finally, the creation of an inventory management system is suggested. This system can help to have a traceability of products and their perishability. Similarly, this system could generate storage spaces which can be identified as lower inventory costs.

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