UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

QUALITY IN THE ECUADORIAN PLASTICS INDUSTRY: ADOPTION OF LEAN METHODOLOGIES FOR THE REDUCTION OF DEFECTIVE PRODUCTS IN PLASTIFLAN

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RESUMEN

La industria de plásticos ha tenido un gran crecimiento en los últimos años. La creciente necesidad de entregar productos de calidad se ha convertido en un desafío importante para las empresas dedicadas a la manufactura de productos plásticos. La calidad de un producto depende de varios factores que se involucran directamente en su producción: la materia prima, la maquinaria utilizada, los operadores y el proceso de manufactura en sí mismo. Dentro de este contexto, se estudia el caso de una empresa ecuatoriana de manufactura de plásticos que presenta problemas con la calidad de sus productos debido a una cantidad excesiva de unidades defectuosas. Se propone la aplicación de herramientas Lean Six Sigma para la optimización de los procesos productivos y la reducción de cantidad de unidades defectuosas. Esto requiere en primer lugar un control sobre el proceso más minucioso, un entrenamiento constante a los operadores, implementación de reprocesos en línea, reestructuración de responsabilidades y coordinación de tareas dentro del área de control de calidad para finalmente obtener una estructura en la planta que permita prevenir unidades defectuosas e identificar y arreglar fallas rápidamente.

Palabras Clave: control de calidad, unidades defectuosas, optimización, criterio de operadores, Lean Six Sigma, reprocesos, calidad.

ABSTRACT

The plastics industry has seen significant growth in recent years. For businesses devoted to the production of plastic products, the growing demand for high-quality products has become a significant challenge. The quality of a product is influenced by a number of variables that are directly involved in its production, including the raw material, the machinery used, the operators, and the manufacturing process itself. In this context, the case of an Ecuadorian plastics manufacturing company is examined. This company experiences issues with the quality of its products as a result of an excessive number of defective units. It is suggested that Lean Six Sigma tools be used to improve production processes and decrease the number of defective units. To finally achieve a structure in the plant that enables preventing defective units and quickly identifying and correcting errors, it is necessary to control the most minute process, provide continuous operator training, implement on-line processes, restructure responsibility, and coordinate tasks within the area of quality control.

Keywords: quality control, defective units, optimization, operator´s criteria, Lean Six Sigma, reprocess, quality.

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INTRODUCTION

In the past years, one of the main focuses within small and medium enterprises around the world has been quality improvement and standardization. Industries are aiming to improve customer satisfaction, cost, quality, and processes to be more efficient and profitable (Nandakumar, Saleeshya & Harikumar, 2020). Ecuadorian society has been growing in population and economy, meaning that more plastic is being manufactured. According to the National Finance Corporation (2021), the production of plastic has reached around 350 million tons per year. In 2021, in Ecuador, this industry made up about 0,51% of the GPD.

We developed our study in Plastiflan SA, an Ecuadorian plastic production company founded in 1986 with a portfolio of more than 200 SKUs of plastic containers and caps. Plastiflan is one of the primary suppliers for several industries such as food, beverages, pharmaceuticals, cosmetics, chemistry, among others. A quality department ensures the company delivers a high-quality product. Its production can be schematized in two main processes: blow molding and injection molding. Blow molding is the formation of a hollow object by blowing a molten thermoplastic tube called a parison (Chaciński and Sutowski, 2021). The blow molding process is simple, first the raw material is inserted in the machine, it goes through the screw and melts. Then the plastic is given a hose shape which is filled with air to adapt to the mold. The mold is die cut with blades and finally the leaks are controlled.

Our purpose was to reduce the number of internal quarantines regarding best-selling products which are containers and gallons, accounting for more than 80% of total production of blow molding products. Molding product family represents 83% of the total production. The company defines internal quarantines as products that do not comply with the defined technical standards. Following the success of several companies that used Six Sigma, we defined DMAIC as the approach to use (Tsarouhas, 2021). In order to optimize the productive processes, we implemented different tools, such as: Lean Strategies, Control Charts, R&R Analysis, Pareto, and Ishikawa Diagrams in order to standardize the quality control and avoid operators' biases.

LITERARY REVIEW

In order to apply quality control strategies and optimize the production process, different methods or approaches can be used. Seaman et al. (1993) considered the problem with quality control from a feedback perspective; hence, they developed and implemented an algorithm that iteratively solved the multi-objective optimization problem in-line. This algorithm changed the role of the operator from monitoring and operating the process to monitoring and improving quality, which in turn reduced the defects in line.

On the other hand, more recent studies on plastic production like Setyabudhi, Sanusi and Sipahutar (2019) concluded that the causes for bad quality were the operators or the operators' interpretations of the machine. Implementing a six-sigma approach that trained new employees, improved attitude, and controlled the general environment of the process would improve the sigma level of the company and correct this error. Additionally, Fuentes (2014) deduced that the biggest problem with quality in a production line in a plastics industry is the fact that criteria between operators varies extensively, for which the solution is to clearly define the critical variables for quality in each product and reduce the disagreements of the operators when inspecting the raw materials and finished products by standardizing production and process parameters. Alternatively, Loy (2016) reckons that implementing a Quality Control Method through Statistical Process Control (SPC) dwindles the number of defective products and controls the parameters at the source (the machine), henceforth controlling the variations of the process.

Likewise, Saputra et al. (2019) concluded that implementing SPC improves process capability and decreases the malfunctioning variables which reduce defects. Finally, Kandris et al. (2005) exposes that designing a system structure controlled by a programmable logic controller that can detect defects in-line is the most effective, reliable, accurate and fast solution for the overall operation.

METHODOLOGY

Six Sigma is a business methodology that enables companies to achieve effectiveness and uphold quality standards, claim Harry and Schroeder (2000). It is also well-known as a technique that boosts output and productivity by cutting waste (Linderman. et al, 2002). The DMAIC method is used to address issues such as poor customer satisfaction, excessive expenses, and inefficient operations (Bhargava, 2017). We used the Six Sigma DMAIC technique for the current investigation. Define, Measure, Analyze, Implement, and Control is also known as DMAIC.

The problem and its needs must be determined during the ‘Define’ phase (Tsarouhas, 2021). As a result, we started by comprehending the business, characterizing, and identifying the issues Plastiflan S.A. was facing. We also established our goals and measurement limitations. According to Tsarouhas (2021), data must be gathered in the subsequent phase in order to confirm and quantify the current situation. In the "Measure" stage, internal quarantines, waste, reprocessing, allowable limits for each product, machine accuracy, and other product qualities were considered. We concentrated on the metrics that improved the process and eliminated the ones that were time and labor intensive and did not add value to the current study. Based on the information provided by the company and the agreed data collection plan, historical data and newly acquired data were gathered. For the "Analysis" phase, this data was used. This phase is anticipated to identify the underlying causes, fully comprehend the procedure, and consider the influencing components (Tsarouhas, 2021). We looked at the data gathered, the indications, the control sheets, the outcomes of the tools used, and the primary root causes. Tsarouhas (2021) stipulates that instruments that tighter performance adjustments and improve procedures need to be devised and used during the "Implementation" phase.

As a result, we introduced Lean tools that were compatible with ISO 9001 certification and also standardized product quality assessment. For this, we standardized the majority of the criteria that the operators used to assess each sample they took. In addition, the process structure was tightened to make it clearer and simpler to understand. Managing process modifications and making durable improvements are required during the "Control" phase (Tsarouhas, 2021). In order to ensure the operators were consistently practicing their abilities for item testing, we developed a training schedule for them. We also scheduled monthly reviews for after the implementation to control tool performance and monitor the adoption of improvements to the existing procedures. Finally, in order to regularly analyze and follow up on the adjustments made and improvements put into place, we developed a training plan that the quality manager could share with operators and analysts.

QUALITY AND DEFECT DETECTION IN PLASTIFLAN

Defining Quality Problems

Lean manufacturing and Six Sigma are methodologies for improving quality and productivity that have been widely used in many businesses (Jiménez, 2014). We chose this methodology so that we could break our project into five basic steps: Define, Measure, Analyze, Implement, and Control. The DMAIC method in six sigma is frequently used for problem solving (De Mast, 2012).

The historical data was revised in order to better identify the issue, and it was discovered that while 3% of orders can be rejected in a given week, on average there were 6% rejected orders over the previous months, with some weeks having as much as 14%. Data from an earlier collection was obtained to assess the best course of action and the underlying causes for the quarantined items when quality issues were discovered with the amount of rejected orders. To determine the plastics manufacturing process to be analyzed, a pie chart was drawn up. From this, we obtained that the blow molding process produced 82,5% of the overall production (Figure 1).

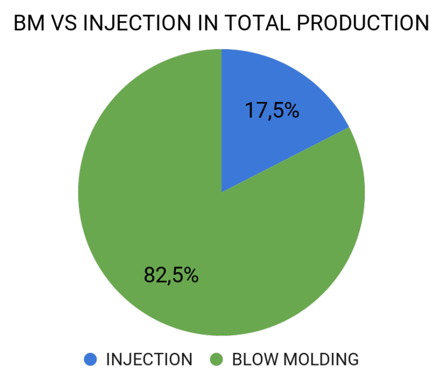

Figure 1: Blow Molding vs Injection Analysis

After narrowing down the process in which our study was going to be focused, the family of products were analyzed to determine the bulk of main products that are manufactured in the blow molding machines. A Pareto chart was used to decide which product had a higher recurrence in this procedure (Figure 2).

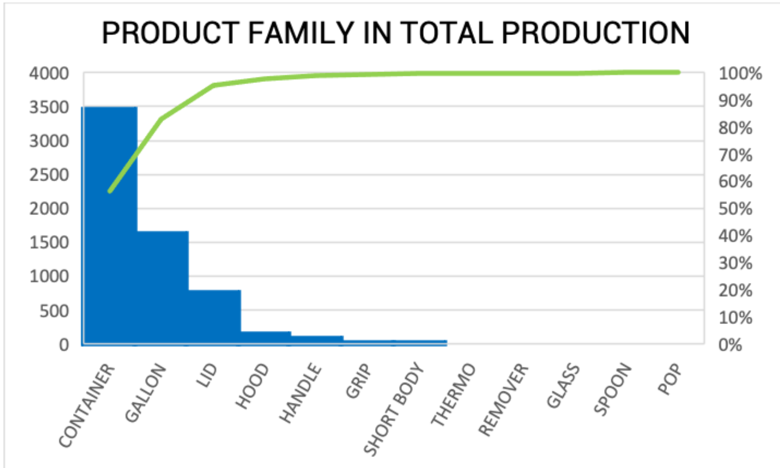

Figure 2: Pareto diagram for product families

It was determined that more than 80% of the total production is made up of containers and gallons. An additional investigation was conducted to identify the machinery that was utilized most frequently, contributing most of the total production for blow molding and the source of the majority of the orders that were quarantined (Exhibit A). A Pareto chart was used to determine the machines that were going to be analyzed, using a weighted score strategy to score the number of working hours, percentage of usage, total production, and total number of orders. It was clear that the machines in which analysis and measurements were going to take place were blow molder one and blow molder four (Figure 3).

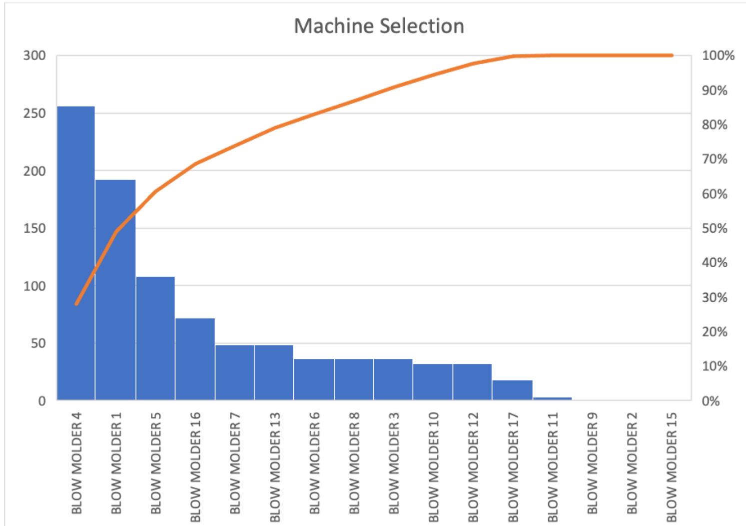

Figure 3: Pareto diagram for Machine Selection

Analyzing Quality and Defect Detection in Plastiflan

The primary goal was to minimize internal quarantines. Employees of Plastiflan classified them as rejections of goods that fall short of criteria. To further focus our project's objectives, we will only consider those variables that can be influenced and changed. When the primary issue of too many internal orders being refused was broken down into its primary causes, it was found that concerns with operators, machines, process/method, and measurements were the main focus. We explored potential causes for various issues in order to direct the project's future actions. It was also made clearer which particular factors needed urgent consideration and how they affected the issue. First, the production line's identification of defective units was examined to see whether it was in or out of control (Figures 4 and 5).

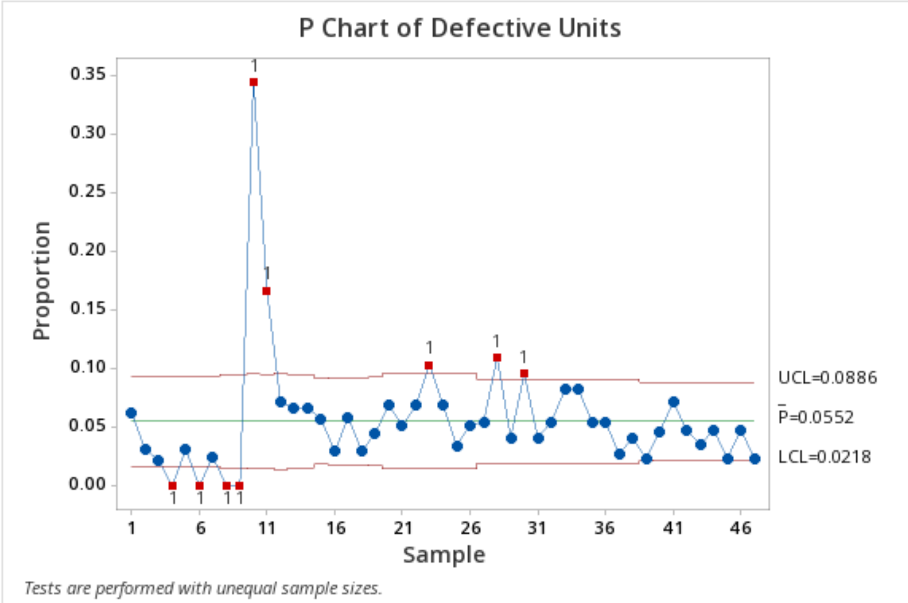

Figure 4: Control Chart Blow Molder 1

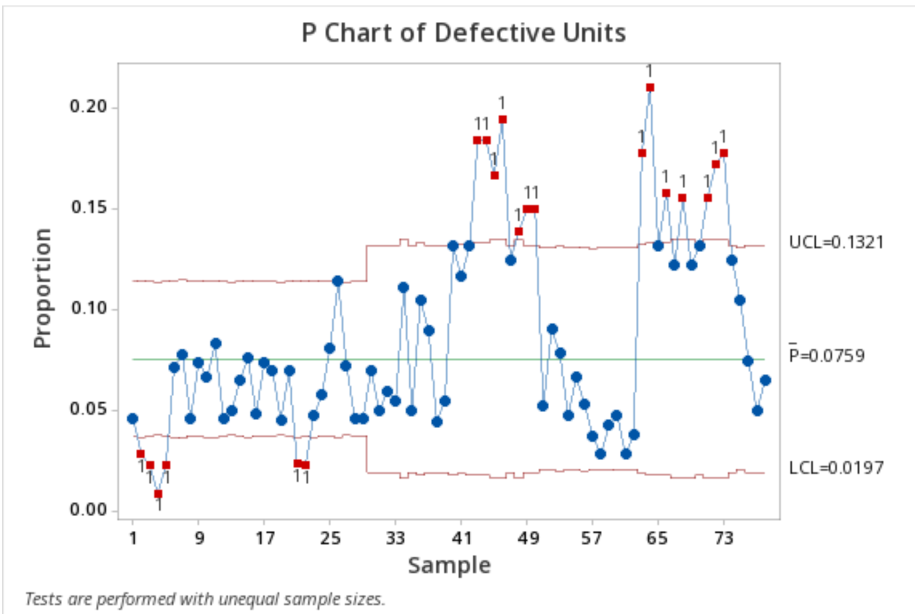

Figure 5: Control Chart Blow Molder 4

After a thorough analysis of the process flow, the way the operators work and the defective units were analyzed, it was found that visual attributes are challenging to quantify, that operators lack criteria for identifying defective units, and that there is no systematic approach to look for defective units in line. Defective units might also result from variations in the supplier's material quality, unanticipated machine damage, and unpredictable environmental reasons. Since the process was out of control, and there were no assignable causes that explained why it was out of control, further analysis was required.

An R&R study was conducted to ascertain whether all operators were qualified to approve or reject a product, because the operator criteria was found to be deficient. The studies of Repeatability and Reproducibility (R&R) are created to determine whether or not the work performed by inspectors is efficient and consistently performed. That is, if the inspection job detects production process flaws before the goods are received to the subsequent operations (Romero & Romero, 2011). The R&R was developed to compare the criteria of two operators and two analysts to the standard criteria set by the manager of the quality department. It is advised that 10 samples from at least three distinct products be reviewed twice or three times by a minimum of three persons in an R&R, according to a study from Dubois and Courtois (2019). In order to assess the levels of association between each appraiser and the standard for the R&R performed in Plastiflan, four individuals were examined, and three products were analyzed. Each product provided 10 samples, and each sample was examined twice using two different codes. The results are displayed in Table 1.

GAGE EVALUATION					
	Source	StdDev (SD)	Study Var (6 * SD)	% Study Var (%SV)
	Total Gage R&R	0.246157	1.47694	70.91
	Repeatability	0.162475	0.97485	46.80
	Reproducibility	0.184920	1.10952	53.27
	Part-to-Part	0.244767	1.46860	70.51
	Total Variation	0.347137	2.08282	100
ASSESSMENT AGREEMENT WITH STANDARD				
	# Units Inspected	# Units Matched	Percent	95% CI
	30	6	20	(7.71, 38.57)

Table 1: First R&R Results

It was evident that neither the analysts' nor the operators' criteria matched the accepted level or the standard criteria since the values were well below 70%. Only 47% of the process can be duplicated, showing that this analysis's process cannot be easily repeated. In a similar way, the reproducibility is just 53%, demonstrating that neither analysts nor operators can evaluate the same sample in the same way or get to the same conclusion for the same sample. Finally, it may be said that this analytical procedure is unreliable because the percentage of overall variability is not noticeably different from the Part-to-Part variability. Since the criteria differs among appraisers and there is only a 20% agreement with the standard, it was concluded that the operators did not understand how to apply the criteria since they are untrained or unspecialized. In order to improve and standardize the criteria used to decide whether or not a product was defective and, subsequently, whether it needed to be quarantined, a quality training program (Exhibit B) was devised. The four videos that made up the quality training demonstrated how to follow a quality procedure, which attributes to control and how to do so, as well as the new standardized measures for two of the attributes.

We developed a sampling plan for machines 1 and 4. (Exhibit C and D). The entire population had to be examined because there were only a small number of orders that were rejected each week (Montgomery & Runger, 2011). The historical data from each machine was chosen at random to determine the population size. The population size was then calculated using the number of orders from that week. There were fifteen orders for each machine that needed to be examined. It was decided that a sample would be taken during each shift of each machine for fourteen days in order to have thirty random samples of each machine and conduct a thorough analysis of attributes and measures. In contrast to blow molder four that has an autonomous fault detection system and doesn't require an operator to interact with the process, blow molder one needs the operator to physically cut the extra material. Therefore, it became intriguing to examine both machines and the types of issues that arise regarding the goods in each one and whether they are the same.

In order to perform the analysis, a binomial approximation to normal variables validation was performed because the data obtained were a binary response variable. Montgomery and Runger (2011) propose three rules (Table 2) that our data has to follow in order to be able to accomplish this. The calculations and validation for these rules according to our data are shown in Exhibit E.

Rule	Description
n>30	The sample size has to be greater than 30
n*p>5	The sample size times the proportion of defective units has to be greater than 5
n*q>5	The sample size times the proportion of good units has to be greater than 5

Table 2: Rules for Binomial Approximation

After corroborating that the data effectively complies with the established rules, we moved on to proportion testing for the two machines and the two shifts we worked with while collecting the data. The first shift's defective unit percentage was compared to the second shift's defective unit percentage. Blow molder one's (manual) defective unit percentage and blow molder four's defective unit percentage were both examined (automatic). Although there was a variation in the percentage of defective units between the morning and night shifts, there was no statistical difference (Figure 6).

Test

Null hypothesis $H_0: p_1 - p_2 = 0$
Alternative hypothesis $H_1: p_1 - p_2 \neq 0$

Method	Z-Value	P-Value
Normal approximation	-1.13	0.259
Fisher's exact		0.462

Figure 6: Results Proportion Tests Shifts

The same scenario happened to the proportion tests for the different machines (Figure 7).

Test

Null hypothesis	H_0: $p_1 - p_2 = 0$
Alternative hypothesis	H_1: $p_1 - p_2 \neq 0$

Method	Z-Value	P-Value
Normal approximation	-0.93	0.355
Fisher's exact		0.465

Figure 7: Results Proportion Tests Machines

Since there is no statistical difference across shifts, machines, and the defective units inside them, we looked at process flaws. Rebates, material failure, deformation, color failure, and black spots/color spots are the five most common visual faults. A thorough study revealed that all defects are treated the same, which means that regardless of which defect is found, the entire batch is quarantined, even though there are five different kinds of faults that are reprocessed in various ways. As a result, the workload of the operators has decreased, but the quality department is having problems because of the excessive quarantine items (Plastiflan, 2022).

Following a thorough investigation, we were able to determine that the company had a quality problem, and when defective units were found, the entire lot was quarantined. But at the time of examination, the OEE showed an almost perfect quality score. The calculations produced by the corporation were found to be deceptive after validating the formula employed and the data supplied for computing the OEE. The results for overall equipment availability, performance, efficiency, and quality were acquired, and although it appeared that the company's average was nearly great, investigation revealed that their estimates ranged from below zero to well over one, which is logically impossible (Hedman et al, 2016). Setup and reprocess times were not being taken into consideration and the number of defective units were not registered correctly, so they were not used for the estimation (Exhibit F).

Improving Quality and Defect Detection in Plastiflan

The first action taken was to standardize the criteria used to evaluate the product attributes before starting the implementations. To be able to assess each product, with the head of quality, we chose products randomly from blow molder one and four in order to calculate the permissible limits for each flaw when analyzing the products. This led to the creation of standards for the different types of defects. The standard stated that there could not be even the tiniest rebate in the mouth. The tolerated maximum for rebates in the body and handle of the product was 0.3 millimeters.

Once the tolerable limits for rebates was standardized, a visual sheet of attributes was developed (Exhibit G), in order to place this sheet in the production folders so that operators can visualize how the defects look and what their standardizations are. In addition, to implement this sheet, a training was carried out consisting of 4 videos with an evaluation consisting of 28 questions. Operators, analysts, and supervisors had to do the training and obtain a minimum score of 8 points out of 10 in order to approve the training and obtain the certificate, however, the average obtained by the workers was 7.8. So, a new training plan was recommended to the quality department head.

Also, as previously mentioned, defects were divided into critical and non-critical and for this, it was standardized that non-critical defects are rebates, as a reprocess can be made on the production line. This is considered as an improvement, as it allows reducing internal quarantines in addition to having a more efficient process that allows reducing reprocessing. Additionally, to this classification, a control sheet was implemented that must be filled every hour in order to control the quantity of defective units and the total production from each machine (Exhibit H). On this sheet operators must fill in the number defective units, number produced units and check the correct functioning of the automatic defect detection system by the hour. In addition, the sheet must be signed every hour by the analyst in order to verify that the required data is being registered. This sheet will allow the company to have a record of how the process is working and also perform control graphs. If the process is out of control, assignable causes must be found and eliminated to ensure that the process is under control. This tool allows a constant evaluation of how the process is and motivates operators and supervisors to take immediate action to prevent defective units. Once this tool was already in use in the company, new control graphs were constructed. Assignable causes were easy to find, and the process is now under control as can be seen in Figures 8 and 9.

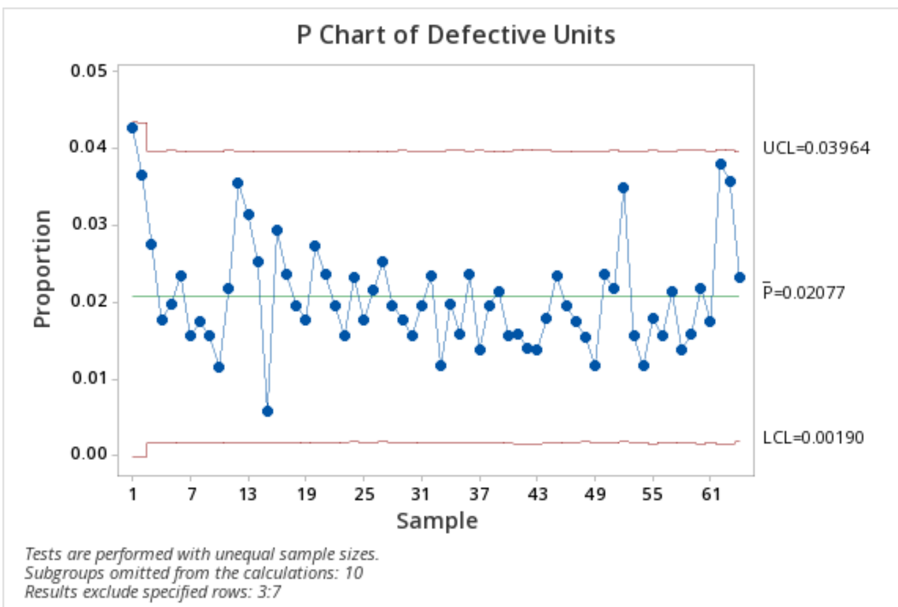

Figure 8: Control Chart Blow Molder 1

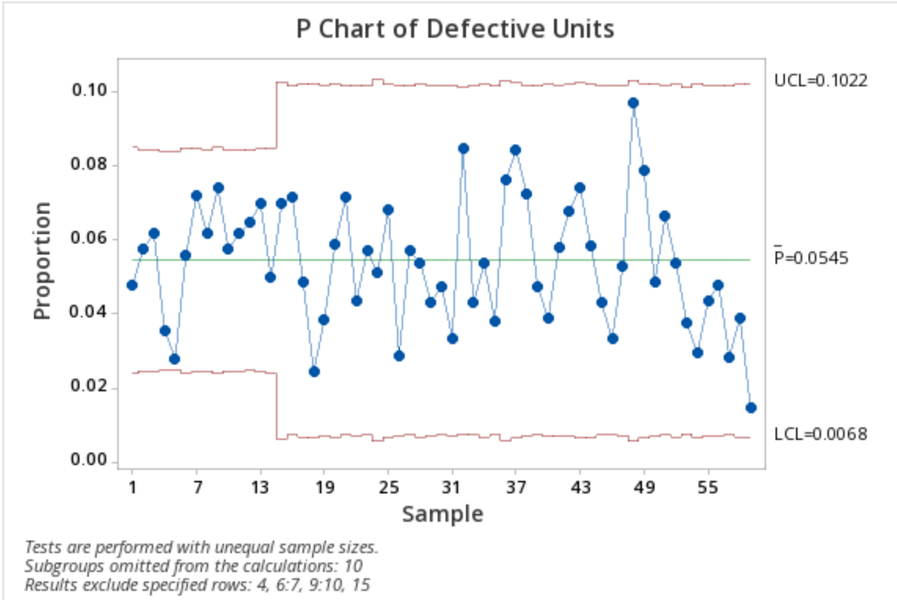

Figure 9: Control Chart Blow Molder 4

Additionally, a Kaizen event, a technique for continuous improvement which consists of acts taken by a work team with the goal of improving a process (Manos, 2007), took place in order to engage employees in all implementations made. Due to the employees' availability, only one kaizen event—which lasted around 30 minutes—was held and only two operators and two analysts were able to attend the event. A brief presentation was given in the situation, outlining the issues encountered and the solutions to be used. The tools' definitions, goals, and outcomes were presented, along with examples on how to use each one. The purpose of this event was to include the staff in the ongoing progress. The event's outcomes were positive since participants were more motivated to work together, to use the tools and conduct a much more in-depth analysis of the units in order to properly appraise and avoid incorrectly quarantining lots.

The Toyota Grade Classification Worker plan was another tool used to create a quality training program based on the analyst's knowledge and experience. You can assign each employee's expertise level in three levels that are indicated by circles. A whole black circle indicates that the worker needs training, a circle that is half black and half empty indicates that the employee is in training, and an empty circle denotes that the employee has completed their training. Key activities and employees who will participate in the quality processes must be determined before each circle can be assigned. Then, each employee is given a circle according to their role, level of training and involvement in the process (Moon, 2013). This tool was implemented in conjunction with the quality manager since she assigned the corresponding circles to each employee. A template for this tool is shown in Figure 10.

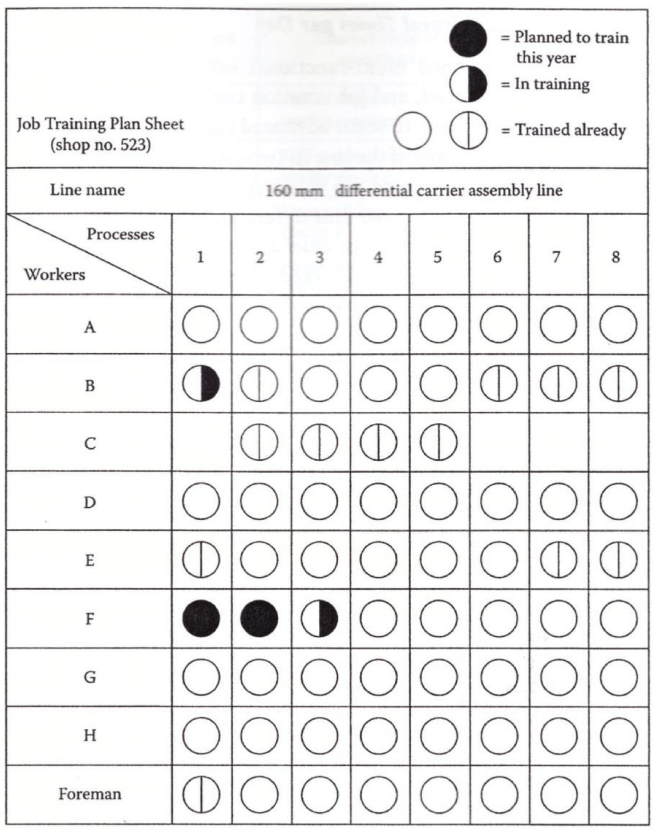

Figure 10: Toyota Grade Workers Classification Matrix

On the other hand, the RACI tool was implemented as a strategy for daily quality management. According to Smith (2005) this tool allows workers to be separated into groups and assigned roles to follow up activities that are carried out on a daily basis. Finally, a second R&R study was conducted following the same parameters from Dubois and Courtois (2019). In order to assess the levels of association between each appraiser and the standard for the R&R performed in Plastiflan, four individuals were examined, and three products were analyzed. Each product provided 10 samples, and each sample was examined twice using two different codes. The results are displayed in Table 3.

GAGE EVALUATION				
	Source	**StdDev (SD)**	**Study Var (6 * SD)**	**% Study Var (%SV)**
	Total Gage R&R	0.294577	1.76746	76.91
	Repeatability	0.184630	1.10778	48.21
	Reproducibility	0.229537	1.37722	59.93
	Part-to-Part	0.244767	1.46860	63.51
	Total Variation	0.382997	2.29798	100
ASSESSMENT AGREEMENT WITH STANDARD				
	# Units Inspected	**# Units Matched**	**Percent**	**95% CI**
	30	10	33.33	(17.29, 52.81)

Table 3: Second R&R Results

With a 49% in repeatability and a 60% in reproducibility there is a small improvement. It may also be stated that the analytical procedure is more reliable than before because the percentage of overall variability is not noticeably different than the Part-to-Part variability. Agreement between the appraisers and the standard criteria also improved to 34%.

Finally, in order to improve quality management a new OEE calculation is proposed that considers set up times, reprocess times, number of defective units and standard parameters given by the machine instead of ideal calculations in order to have accurate data. With this proposal, values are now in the correct range (between 0 and 1) and the company can have real values that clearly display their problems instead of misleading information that doesn't portray the real situation (Exhibit I)

RESULTS

After standardization, quality testing, training, attributes, visual control, and hourly control checking, a new R&R was created, and we got good results showing how effective the tools are. It was possible to increase the operators' criteria in comparison to the standard by 14%, as well as the reproducibility and repeatability by 7% and 2%, respectively (Table 4). As a result, operators, managers, and analysts have a far better criteria to determine whether the product has to be placed under internal quarantine.

	Previous R&R	**New R&R**	**Results**
Total	70.91%	76.91%	Increased by 6%
Repeatability	46.80%	48.21%	Increased by 1.41%
Reproducibility	53%	59.93%	Increased by 6.93%
Part - to - part	70.51%	63.51%	Decreased by 7%
Agreement with standard	20.00%	33.34%	Increased by 13.4%

Table 4: R&R Comparison

When assignable causes were uncovered during data collection, as previously shown in figures 8 and 9, it was revealed that there was an issue with the company's cold hose, which at specific periods caused damage to the equipment. The process of identifying defective units is now under control. As a result of the units being damaged, these points could be omitted outside the boundaries of the graph.

Furthermore, after RACI (Exhibit J) and Toyota Grade Workers (Exhibit K) were implemented, we were able to establish the quality department and assign roles so that all operations and day-to-day duties could be kept an eye on and enhanced. Thus, the procedure might continue to improve steadily, maintaining control and lowering the number of orders for quarantine.

Finally, the average number of quarantined orders decreased by 2%, which allowed us to achieve our initial goal and was the most significant and practical result we were able to achieve. It is crucial to stress that there has been a decline in the number of orders that have been quarantined, a trend that we want to continue by using the more thorough control sheet, which makes it possible to track defective units in comparison to manufactured units. It is anticipated that this trend and the proportion of orders can be stabilized by continual improvement and the control plan (Table 5), allowing the company's set limit to be maintained.

Activity	**Responsible**	**Time Range**
Quality Training	Head of Quality Department	Every Quarter
Skill evaluation (RACI & Toyota)	Head of Quality Department	Every Quarter
Processes checkups (Control Graphs)	Head of Production Department	Weekly
Standardization of processes	Quality and Production Department	Each Semester

Table 5: Control Plan

CONCLUSIONS

Finally, it was possible to categorize the types of defects in two categories. They could be categorized into critical defects and non-critical defects. Critical defects are the black spots, deformations, material failure, and color failure. Since these kinds of flaws cannot be fixed on the production line, a more thorough analysis must be carried out to determine whether the material can be used again or if it needs to be discarded. On the other hand, the rebates can be defined as non-critical defects since this type of flaw can be fixed by adding a new activity that can be carried out within the production line in which the defective products are reprocessed, reducing internal orders, and achieving the study's main goal. Additionally, it was determined that the second level sigma analysis should be performed on both the production line and the quarantined orders to perform a more thorough analysis that will allow for the reduction of errors as well as the control of the number of rejected orders.

Finally, we draw the conclusion that the OEE calculation method is ineffective for the organization since it ignores crucial data needed for accurate findings and instead provides them with a false impression of how their process is operating. Because of this, we recommend that the OEE be calculated weekly or monthly rather than in the current order.

LIMITATIONS

The company's lack of cooperation in data collection and the provision of historical data was one of the project's constraints. Additionally, the operations were restricted by the lack of collaboration when visiting the plant. This is why, despite the fact that they were given a preliminary notion, they were unable to proceed with the implementation of the previously planned Hoshin Kanri tool. On the other hand, Plastiflan's documentation is inefficient since, at the time the data was gathered, it was impossible to link the manufacturing order to the quality area's records.

Furthermore, there were other external variables that we were powerless to control, which led to high employee turnover inside the company, which caused high variability in the proportion testing. In addition, the company did not view the repeat processes of molecularly altering the products as an inconvenience, which limited the accuracy of the information provided by them because it was an unconsidered fact. Assuming the foregoing, it is also crucial to note that working with binary variables made it difficult to apply all statistical models to the analysis, necessitating the analysis of the machines and turns separately.

REFERENCES

Behnam Neyestani. (2017). Seven Basic Tools of Quality Control: The Appropriate Quality Techniques for Solving Quality Problems in the Organizations. *Zenodo*. https://doi.org/10.5281/zenodo.400832

Bhargava, V. (2017). Six Sigma Techniques in Plastics. *Robust Plastic Product Design: A Holistic Approach*, 267-288. https://doi.org/10.3139/9781569905814.008

Chaciński, T. and Sutowski, P. (2021) Common defects in injection molding of plastic products and their influence on product quality. *Journal of Mechanical and Energy Engineering*, 5(1), pp. 7-14. doi: 10.30464/10.30464/jmee.2021.5.1.7.

de Mast, J., & Lokkerbol, J. (2012). An analysis of the Six Sigma DMAIC method from the perspective of problem solving. *International Journal Of Production Economics*, *139*(2), 604-614. https://doi.org/10.1016/j.ijpe.2012.05.035

Dubois, C., & Courtois, P. (2019). Choice of parameters for an R&R study and its impact on the measurement capability. *19th International Congress of Metrology (CIM2019)*. https://doi.org/10.1051/metrology/201912001

Felizzola Jiménez, Heriberto, & Luna Amaya, Carmenza (2014). Lean Six Sigma en pequeñas y medianas empresas: un enfoque metodológico. *Ingeniare*. Revista Chilena de Ingeniería, 22(2),263-277. ISSN: 0718-3291. https://www.redalyc.org/articulo.oa?id=77231016012

Fuentes, S. (2014). Diseño para la implementación de calidad Seis Sigma en el área de molino de la empresa Tecnoplast del Ecuador CIA LTDA. (Engineer Graduate). *Universidad de Guayaquil.* Ecuador

Harry, M. and Schroeder, R. (2000) Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations. *Doubleday*, New York.

Hedman, R., Subramaniyan, M., & Almström, P. (2016). Analysis of critical factors for automatic measurement of OEE. *Procedia Cirp*, *57*, 128-133

Kandris, D., Papadimitriou, N., Pantazis, N., Fais, R., Psaros, G., Pantouvakis, G., & Spyrpoulos, S. (2005). Design and Development of an Industrial Quality Control System for the Detection of Defective Plastic Receptacles. *Technological Educational Institution (T.E.I.) of Athens.* Greece.

National Finance Corporation (2022). Fabricación de Productos de Plásticos. https://www.cfn.fin.ec/wp-content/uploads/downloads/biblioteca/2022/fichas-sectoriales-1-trimestre/Ficha-Sectorial-Fabricacion-de-Productos-de-Plastico.pdf

Linderman, K., Schroeder, R., Zaheer, S., & Choo, A. (2002). Six Sigma: a goal-theoretic perspective. *Journal Of Operations Management*, *21*(2), 193-203. https://doi.org/10.1016/s0272-6963(02)00087-6

Loy, Z. (2016). Método para implementar un plan de mejora en el sistema de aseguramiento de la calidad en la pequeña y mediana industria de empaques flexibles - Plásticos. (Engineer Graduate). *Universidad de Guayaquil.* Ecuador

Manos, A. (2007). The benefits of Kaizen and Kaizen events. *Quality progress*, *40*(2), 47.

Montgomery, D. and Runger, G., 2011. *Applied statistics and probability for engineers*. Hoboken, N.J.: J. Wiley & Sons.

Moon, I. (2013). Machine Layout, Multi-Functional Workers, and Job Rotation Help Realize Flexible Workshops. Seoul National University. 1 - 38. https://ocw.snu.ac.kr/sites/default/files/NOTE/7645.pdf

Nandakumar, N., Saleeshya, P., & Harikumar, P. (2020). Bottleneck Identification And Process Improvement By Lean Six Sigma DMAIC Methodology. *Materials Today: Proceedings*, *24*, 1217-1224. https://doi.org/10.1016/j.matpr.2020.04.436

Romero, L., & Romero, D. (2011). Attribute Gauge R&R in an inspection process in the automotive industry. *Produção Em Foco*, *1*(1), 171-194.

Saputra, T., Hernadewita, H., Prawira Saputra, A. Y., Kusumah, L., & ST, H. (2019). Quality improvement of molding machine through statistical process control in plastic industry.

Journal of Applied Research on Industrial Engineering, *6*(2), 87-96. doi: 10.22105/jarie.2019.163584.1068

Seaman, C., Desrochers, A., & List, G. (1993). A multiobjective optimization approach to quality control with application to plastic injection molding. *IEEE Transactions On Systems, Man, And Cybernetics*, *23*(2), 414-426. https://doi.org/10.1109/21.229454

Setyabudhi, A., Sanusi, & Sipahutar, I. (2019). Application Of Six Sigma Methodology To Improve the Product Quality Of Moldings Plastic (Case Study: PT Mega Technology Batam). *IOP Conference Series: Materials Science And Engineering*, *505*(1), 012067. https://doi.org/10.1088/1757-899x/505/1/012067

Smith, M. L., Erwin, J., & Diaferio, S. (2005). Role & responsibility charting (RACI). In *Project Management Forum (PMForum)* (Vol. 5).

Tsarouhas, P. (2021). Reliability, availability, and maintainability analysis of an industrial plant based on Six Sigma approach. *The Handbook Of Reliability, Maintenance, And System Safety Through Mathematical Modeling*, 1-17. https://doi.org/10.1016/b978-0-12-819582-6.00001-0

EXHIBITS

Exhibit A: Blow Molder Machines Analysis

MACHINE	NUMBER OF PRODUCTION ORDERS	SCORE	WORKING HOURS	SCORE	REAL PRODUCTION	SCORE	USAGE	SCORE	OVERALL SCORE
BLOW MOLDER 9	9	0	98	0	10700	0	0.14	0	0
BLOW MOLDER 2	32	0	377	0	58475	0	0.64	3	0
BLOW MOLDER 11	71	1	716.5	1	156400	1	0.79	3	3
BLOW MOLDER 15	22	0	257.5	0	160200	1	0.21	1	0
BLOW MOLDER 6	158	3	1531.5	3	171810	1	1.00	4	36
BLOW MOLDER 8	137	3	1404.75	3	171936	1	0.86	4	36
BLOW MOLDER 3	159	3	1519	3	204802	1	1.00	4	36
BLOW MOLDER 7	168	4	1628.25	3	217542	1	1.00	4	48
BLOW MOLDER 10	109	2	1154.75	2	257620	2	0.86	4	32
BLOW MOLDER 12	105	2	1118	2	259600	2	0.86	4	32
BLOW MOLDER 13	109	2	1279	3	264500	2	1.00	4	48
BLOW MOLDER 17	83	1	976.5	2	350300	3	0.71	3	18
BLOW MOLDER 16	135	3	1481	2	358400	3	1.00	4	72
BLOW MOLDER 1	207	4	1978.25	4	394963	3	1.00	4	192
BLOW MOLDER 4	202	4	2101.25	4	474035	4	1.00	4	256
BLOW MOLDER 5	150	3	1547.75	3	551676	4	0.64	3	108

Range	Score	Range	Score	Range	Score	Range	Score
0-42	0	1-421	0	0-110335	0	0-0.2	0
43-83	1	422-842	1	110336-220671	1	0.21-0.4	1
84-125	2	843-1263	2	220672-331006	2	0.41-0.6	2
126-166	3	1264-1684	3	331007-441341	3	0.61-0.8	3
167-207	4	1685-2105	4	441342-551676	4	0.81-1	4

Exhibit B: Quality Training

Videos:

Link 1: https://youtu.be/a4SNF2Wf0jk

Link 2: https://youtu.be/erejRaSPogw

Link 3: https://youtu.be/du2JwNqUd2E

Link 4: https://youtu.be/wm5ost76vnA

Questionnaire: https://forms.gle/CZosSH2nFz8bFzZKA

Exhibit C: Sampling Strategy Blow Molder 1

BLOW MOLDER 1

JUNE 2022-SEPTEMBER 2022

% USAGE	100%

ORDERS PER WEEK

23	2
24	12
25	15
26	8
27	13
28	16
29	14
30	19
31	24
32	18
33	17
34	18
35	20
36	11

WORKING HOURS PER WEEK

23	4,5
24	103
25	126
26	33,5
27	100,75
28	82
29	91
30	117,5
31	118,5
32	119,5
33	109,5
34	112
35	102
36	74,5

STOPS PER WEEK (HOURS CONSUMED)

	BLACK SPOTS	PROBLEMS WITH GRINDING	PROBLEMS WITH RM	CALIBRATION	QUALITY APROVAL	COLOR CHANGE	MOLD DAMAGE	MACHINE DAMAGE
23	0	0	0	0	0	0	0	0
24	1,5	0	0	0	0	0	0	0
25	2,5	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	5	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0

SAMPLING SIZE CALCULATION

Random Week	23	
Population size	15	
Time	7	days
Samples Per day	2	

Exhibit D: Sampling Strategy Blow Molder 4

BLOW MOLDER 4

JUNE 2022-SEPTEMBER 2022

% USAGE	100%

ORDERS PER WEEK

23	9
24	12
25	14
26	15
27	14
28	17
29	17
30	17
31	18
32	14
33	15
34	16
35	15
36	9

WORKING HOURS PER WEEK

23	92
24	145,75
25	92
26	98
27	106,5
28	114
29	137
30	145,5
31	123
32	127,5
33	138,5
34	129,5
35	150
36	92

STOPS PER WEEK (HOURS CONSUMED)

	BLACK SPOTS	PROBLEMS WITH GRINDING	PROBLEMS WITH RM	CALIBRATION	QUALITY APROVAL	COLOR CHANGE	MOLD DAMAGE	MACHINE DAMAGE
23	0	0	0	0	0	0	0	0
24	0	0	0	6	1	0	1	0
25	7	0	0	15,5	0	0	0	0
26	12	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0

SAMPLING SIZE CALCULATION

Random Week	33	
Population size	15	
Time	7	days
Samples Per day	2	

Exhibit E: Rules for binomial approximation to normal

Data		Rules	Values	Rule Fulfilled?
Data For Machine 1				
sample size machine 1 (nm1)	30,000	nm1>30	30,000	True
proportion defectives machine 1 (pm1)	0,474	nm1*pm1>5	14,211	True
proportion goods machine 1 (qm1)	0,526	nm1*qm1>5	15,789	True
Data For Machine 4				
sample size machine 4 (nm4)	30,000	nm4>30	30,000	True
proportion defectives machine 4 (pm4)	0,545	nm4*pm4>5	16,364	True
proportion goods machine 4 (qm4)	0,455	nm4*qm4>5	13,636	True
Data For Shift 1				
sample size shift 1 (ns1)	30,000	ns1>30	30,000	True
proportion defectives shift 1 (ps1)	0,633	ns1*ps1>5	19,000	True
proportion goods shift 1 (qs1)	0,367	ns1*qs1>5	11,000	True
Data For Shift 2				
sample size shift 2 (ns2)	30,000	ns2>30	30,000	True
proportion defectives shift 2 (ps2)	0,367	ns2*ps2>5	11,000	True
proportion goods shift 2 (qs2)	0,633	ns2*qs2>5	19,000	True

Exhibit F: OEE calculation Plastiflan

OEE= Availability * Performance * Quality

Availability= Operation Time / Time assigned for operation
Performance= Ideal Cycle / (Operation Time / Expected Production)
Efficiency= Good Quality Products / Expected Production
Quality= Good Quality Products / Actual Production

	Availability	Efficiency	Performanc	Quality
Max Value	1,0000	1,3333	8,0000	1,0047
Min Value	-2,0000	0,0000	-0,1881	0,0000
Average per Order	0,9783	0,8170	0,8356	0,9994

Exhibit G: Visual Attributes Control Sheet

Plastiflan
plásticos, promocionales y amenities

Control Visual de Atributos

DEFORMACIONES

Piel de Naranja

Imperfecciones en la Rosca

Ojo de Pescado

Orificios por Manga Incompleta

Imperfecciones por Mal llenado de Molde

ORIFICIOS POR CORTE

MATERIAL EXTRAÑO

COLOR O TONO

UNIFORMIDAD DEL ENVASE

Plastiflan
plásticos, promocionales y amenities

Control Visual de Atributos

RECHUPES

REBABAS

<u>Rebabas en el Cuerpo</u>
Menos de 0.3 milímetros

<u>Rebabas en la Boca</u>
No puede haber ni las mas mínima

<u>Rebabas en el Asa</u>
Menos de 0.3 milímetros

PUNTOS NEGROS

Son puntos de cualquier color diferente al color o tono del envase o que resalten

Un solo punto en el envase que esté ubicado en el cuerpo del artículo y que mida menos de 0.3 milímetros

Exhibit H: Hourly Control Sheet

MAQUINA

Fecha	Hora	Unidades Producidas.	Unidades Defectuosas	Sistema Deteccion de Defectos Automatico	Analista	Firma
01/11/22	12:00 am - 1:00 am	430	20	✓	Juan Chafla	
01/11/22	1:00 am - 2:00 am	440	22	✓	Juan Chafla	
01/11/22	2:00 am - 3:00 am	430	28	✓	Juan Chafla	
01/11/22	3:00 am - 4:00 am	420	32	✓	Juan Chafla	
01/11/22	4:00 am - 5:00 am	430	21	✓	Juan Chafla	
01/11/22	5:00 am - 6:00 am	430	32	✓	Juan Chafla	
01/11/22	6:00 am - 7:00 am	430	30	✓	Juan Chafla	
01/11/22	7:00 am - 8:00 am	440	20	✓	Alejandro Alean	
01/11/22	8:00 am - 9:00 am	420	30	✓	Alejandro Alean	
01/11/22	9:00 am - 10:00 am	440	20	✓	Alejandro Alean	
01/11/22	10:00 am - 11:00 am	430	30	✓	Alejandro Alean	
01/11/22	11:00 am - 12:00 pm	420	10	✓	Alejandro A	
01/11/22	12:00 pm - 1:00 pm	430	10	✓	Alejandro A	
01/11/22	1:00 pm - 2:00 pm	420	20	✓	Alejandro A	
01/11/22	2:00 pm - 3:00 pm	430	25	✓	Alejandro A	
01/11/22	3:00 pm - 4:00 pm	430	35	✓	Alejandro A	
01/11/22	4:00 pm - 5:00 pm	420	48	✓	Alejandro A.	
01/11/22	5:00 pm - 6:00 pm	440	32	✓	Alejandro A	
01/11/22	6:00 pm - 7:00 pm	430	20	✓	Alejandro Alean	
01/11/22	7:00 pm - 8:00 pm	MONTAJE			Juan Chafla	
01/11/22	8:00 pm - 9:00 pm				Juan Chafla	
01/11/22	9:00 pm - 10:00 pm	200	14	✓	Juan Chafla	
01/11/22	10:00 pm - 11:00 pm	200	10	✓	Juan Chafla	
01/11/22	11:00 pm - 12:00 am	200	12	✓	Juan Chafla	

Exhibit I: OEE calculation Our Proposal

OEE= Availability * Efficiency * Quality

Availability= Operation Time / Total Available Time
Efficiency= Actual Production / (Operation Time * Units per Hour)
Quality= (Actual Production - Defective Units) / Actual Production

	Availability	Efficiency	Quality
Max Value	1,0000	1,0000	0,9848
Min Value	0,0417	0,0000	0,3750
Average per Order	0,8375	0,7849	0,8064

Exhibit J: RACI Matrix Implemented

RACI Matrix

Tarea o acción	Paola Pujota	Evelin Cruz	Alejandro Álvarez	Juan Carlos Chafla	Cristobal Matango	Manuel Amaya	Supervisor de Turno	Operador de Turno
ROLES	Departamento de Calidad					Departamento Produccion		
Actividades Control de Calidad en el Proceso								
Tomas de medición en la Tablet con la información completa	A	R	R	R	R	I		C
Reemplazo de muestras aprobadas (deben estar etiquetadas	C	R	R	R	R			
Recoger fichas técnicas y muestras de cada máquina al finalizar la producción.	A	R	R	R	R		I	C
Registros Físico y digitales Nefrocontrol (medidas y control de fugas).	A		C	R		I		
Registros Físico y digitales Marcseal y James Brown	A		C	R		I		
Recoger y organizar las muestras de retención de cada turno (guardar por un mes).	I	R	R	R	R		C	
Revisión de registros de control de calidad	A	R	C	C	C	I	I	C
Para clientes críticos realizar la revisión y control de parámetros mayores	A		C		R		C	
Recepción e inspección de materias primas, masterbatch y material de embalaje	R							
Generación y revisión de control de medidas diario	I		R		R	C		C
Revisión de producto no conforme, devoluciones y cuarentena (etiquetado y evaluación de producto).	A	R	R	R	R			
Evaluación de muestras en desarrollo.	C	A	A	A	A			
Bodega de Despacho								
Revisión y aprobación de PT en bodega.	I	R	A	A	A			

R	Responsible	Persona encargada de completar la tarea
A	Accountable	Persona que evalúa si la tarea está completa
C	Consulted	Persona que cumple el rol de consejero y da recomendaciones sobre la tarea asiganda
I	Informed	Persona que debe ser informada después de una decisión o acción

RACI Matrix

Tarea o acción	Paola Pujota	Evelin Cruz	Alejandro Álvarez	Juan Carlos Chafla	Cristobal Matango	Manuel Amaya	Supervisor de Turno	Operador de Turno
ROLES	Departamento de Calidad					Departamento Produccion		
Documentación								
Recoger y firmar registros de calidad (No se aceptarán registros sin firma).	A	R	R	R	R	I	C	
Llenado de matriz de Evaluación de desempeño		R						
Llenar registro de balanzas	A	R	R	R	R	A	C	
Emisión y actualización de fichas técnicas	I		R		R			
Archivo y gestión documental del área de calidad.	I	R	C	C	C			
Revisión, transcripción y corrección de los registros físicos y digitales de Nefrocontrol, Marcseal y James Brown.	A	R	C	C	C			
Gestión administrativa de calidad.	R							
Emisión de Certificados								
Emisión de etiquetas para ambos turnos	I	R	R	R	R			
Actualización y creación de las etiquetas con código SAP (nuevo formato)	I	R	R	R	R			
Emisión de certificados de calidad	C	R	R	R	R			
Limpieza de la planta								
Verificación de limpieza de planta y llenado de registro de limpieza	A	R	C	C	C		I	
Impresión, verificación y seguimiento de registros de limpieza de baños y lavado de manos (cuarto limpio).	A		R	C	C		I	

R	Responsible	Persona encargada de completar la tarea
A	Accountable	Persona que evalúa si la tarea está completa
C	Consulted	Persona que cumple el rol de consejero y da recomendaciones sobre la tarea asiganda
I	Informed	Persona que debe ser informada después de una decisión o acción

Exhibit K: Toyota Grade Workers Matrix Implemented

Necesita Entrenamiento	Está en Entrenamiento	Entrenado
●	◑	○

Nombre del Área: Control de Calidad

		PROCESO								
		1.RECEPCIÓN MATERIA PRIMA (ANÁLISIS VISUAL)	2. CONTROL EN PROCESO DE PRODUCCIÓN	3. EMISIÓN DE CERTIFICADOS DE CALIDAD	4. ANÁLISIS DE PRODUCTO ENCUARENTENADO	5. INSPECCIÓN CON MILITARY STANDARD	6. LLENADO DE REGISTROS	7. CONTROLES DE LIMPIEZA DE PLANTA	8. CONTROL DE BPM	9. CONTROL DE DESPACHOS DE BODEGA
EMPLEADO	Alejandro Álvarez	◑	◑	○	○	◑	◑	○	●	◑
	Cristobal Matango	○	◑	○	◑	◑	●	◑	●	●
	Evelin Cruz	●	●	◑	●	◑	◑	◑	○	●
	Juan Carlos Chafla	●	●	●	●	●	◑	◑	●	●
	PAOLA PUJOTA	○	○	○	○	○	○	○	○	○