Application of Six Sigma in Improving the Quality of Recyclable Polymer in Collection Centers

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Abstract

The research aims to apply Six Sigma to solve the quality problem of the collection center. It does not meet the final recycler's specification for 3% +/- 0.15% impurities in the delivered post-consumer polymer bales. By applying the first two phases of DMAIC a Cp = 0.26 and Cpk = - 4.9 was determined. After applying the last three phases, the improved indices are Cp = 1.8 and Cpk = 1.78. Therefore, it can be concluded that the post-consumer polymer collection center has an adequate and satisfactory process. With an average of 3% +/- 0.022% so it meets the impurity specifications of the final recycler.

Keywords
Six Sigma, DMAIC, Polymers, Post-consumer, Collection Centers

1. Introduction

Over the past eight years in Ecuador, the collection of post-consumer polymers by the Collection Centers (CC) has increased. This is due to the implementation of the "Law of Environmental Promotion and Optimization of State Revenues", published in the Supplement to the Official Gazette No. 583 of November 24, 2011. This is a green policy, where the Servicios de Rentas Internas del Ecuador (SRI) pays two US cents for each non-returnable plastic bottle collected by CC (Ministerio del Ambiente 2015). It is understood as a green policy to transfer the cost of environmental impact to the actors that originate it, in other words under the polluter pays principle (Perez 2016).

The definition of collection centers is the intermediation of the volume of solid waste provided by the primary recyclers to the final recyclers. The primary recyclers are responsible for collecting and prequalifying solid waste in small volumes (Albán 2019). This volume is collected in the collection center where the primary transformation of selection and compaction produce bales or bulk material of: post-consumer polymers, paper, cardboard, scrap metal among others (Organización Internacional del Trabajo 2013). While the final recyclers receive the recycled material in bales or bulk to transform into raw material conditioned for industries (Cruz 2016; Herrera et al. 2019).

The collection centers in Ecuador for their idiosyncrasy and little formal instruction from their owners. There is no development in the quality of post-consumer polymers and other materials that are sold to the final recycler. Such is the case of a collection center that has a cumulative average of 6% of impurities. The same impurities were determined by the final recycler when the bales were delivered to his facilities. This value does not comply with the impurity specification of 3 +/- 0.15% required by the final recycler. This leads to economic losses to the collection center, since the difference is not within specifications. It is discounted in the total weight of reception of the final recycler.

From this problem, the present research is born in order to comply with the specification of 3% + / - 0.15% impurity of the final recycler. In each delivery of post-consumer polymers from the collection center. For which the Six Sigma - DMAIC methodology will be applied to solve the problem. Therefore, the collection center will no longer have economic losses due to impurity discounts.

The present project determines as a strategy the application of Six Sigma DMAIC as a methodology to reduce the indicator of impurity in CC. Since it is a methodology that historically solves quality problems. Through simple tools that generate great impact in the solution of the problems (Gutiérrez and Salazar 2013). It quantitatively identifies the critical characteristics for quality (CTQ) within the processes involved. It systematically identifies causes, action plans and results follow-up (Gijo et al. 2011). Therefore, Six Sigma DMAIC improves the capacity of the process through the phases define, measure, analyze and control, which are described below.

Define is the phase where CTQ´s are identified through customer information. This can be internal if it is inside the CC and external if it is outside. The criterion that describes this phase is the identification of needs, requirements of the client or final recycler (Gupta et al. 2018). For which the voice of the client (VOC) tool is applied. It requires answers to the following questions: *Who is the client? What does the client do? What does the client say? What does the client need? What are the critical actions that the client requires?* (Kumar et al. 2006).

In the measure phase, the true extent of the problem is evaluated by quantifying the CTQ´s people involved. This phase requires collection of process data, construction of graphs and process capability indicators Cp and Cpk. This interprets the current status or performance of the CC process (Pallavi et al. 2018).

Analyzing is the phase where the effects and root causes that affect CTQ´s are identified using tools such as 6 M´s, herringbone, among others. Here the main opportunities for improvement that lead to the reduction of defects are detailed and prioritized (Rana and Kaushik 2018). In other words, it identifies possible ways to reduce the differences between the current statue and the target (Rana and Kaushik 2018; Lorente et al. 2018; Leyva et al. 2018).

In the improvement phase, the performance of CTQ´s is increased through the implementation of action plans, thereby adjusting the results of the processes. These are evaluated using control charts, outcome records and process capability indicators for continuous improvement (Saeid et al. 2018).

Finally, in the control phase, activities are determined to monitor and adjust the results. With which sustainable management is promoted within the long-term process through the beginning of the quality improvement cycle (Sharma et al. 2018).

2. Materials and Methods

The methodology that will be used to meet the 3% +/- 0.15% impurity specification for each delivery of the post-consumer polymer collection center is within the four stages of the DMAIC, which is detailed below:

a. Definition based on the final recycler.

In the first stage, the main causes of impurities will be identified for each delivery from one collection center, through the application of the customer voice tool (VOC) to a final recycler. For this, it is necessary that the final recycler will answer the following questions: *Who is the customer? What does the customer do? What does the customer say? What does the customer need? What are the critical actions that the customer requires?* At the end, the VOC matrix of the final recycler will be built.

b. Measurement of the collection center.

In the second stage, all history impurity data quantified by the final recycler (reception data from collector center) will be collected to perform the normality test. This will construct the graph and capability index of the process Cp and Cpk to determine or measure whether the operational process of the collection center is capable or not.

c. Analysis at the collection center.

The variability of the data will be analyzed through the control charts X and R. The fishbone diagram (Ishikawa) will then be applied to determine the root causes of impurities in the collection center.

d. Implementation of improvements in the collection center.

At this stage, action plans will be proposed and implemented to solve the root causes identified in the previous point. The improvement will then be validated through a control chart and the Cp - Cpk index.

e. Control of improvements in the collection center.

In this stage the improvement will be maintained by monitoring impurities detected by the final recycler. For this purpose, a control chart will be prepared where the results of the impurities versus the specification can be evaluated. In such a way that a weekly meeting with the bale production workers is planned in a disciplined way to recognize achievements or to identify opportunities for improvement.

3. Result and Discussion

The results obtained are detailed within the four stages of the DMAIC methodology, which are detailed below:

a. Definition based on the final recycler.

Table 1 presents the VOC matrix of the final post-consumer polymer recycler, consisting of the parameters identified to understand the customer's requirements.

Table 1. VOC Matrix of the final recycler of post-consumer polymers

No	Parameter	Result
1	Customer identification	Polymer final recycler Production of recycled pellets
2	Customer diagnosis	Impurities outside specification of 3% +/- 0.15% 6% average cumulative impurity
3	Key Customer Problem	3% impurities by color mixture 2% impurities by mixing polymer types 1% impurities from other materials
4	Critical customer requirements	Sort by polymer color Sort by polymer type 0% of other materials

Table 1 shows that the final recycler is dedicated to the production of recycled pellets for the plastic bottle industry. This requires high quality standards of recycled pellets, since the containers will later contain food in the market. Therefore, it is very important that the collection centers supply post-consumer polymers containing a maximum of 3% +/- 0.15% impurities. Currently the collection center does not meet the objective of impurities, which causes a risk to the manufacture of recycled pellet. The key problem is that the collection center has impurities due to: mixing of colors in 3%, mixing of polymer types in 2% and other non-polymer materials in 1%. From this, the final recycler requires the collection center to deliver material classified by type and color of polymer post-consumer, with 0% of other materials such as: water, metals, sand, wood among others.

From the breakdown and interpretation of the data in Table 1, it can be concluded how important it is for the collection center to identify its client. In order to improve the quality of its deliveries in the medium and long term, it ensures that it remains in the market of the final recycler. Therefore, it is possible for the collection center to prioritize: activities, resources and investments that in time are feasible for the economic growth of both parties.

b. Measurement of the collection center.

Figure 1 shows the proof of normality for delivered impurities from the collection center. The test was developed on a historical of eighty measurements made by the final recycler at the time of receipt of post-consumer polymers provided by the collection center.

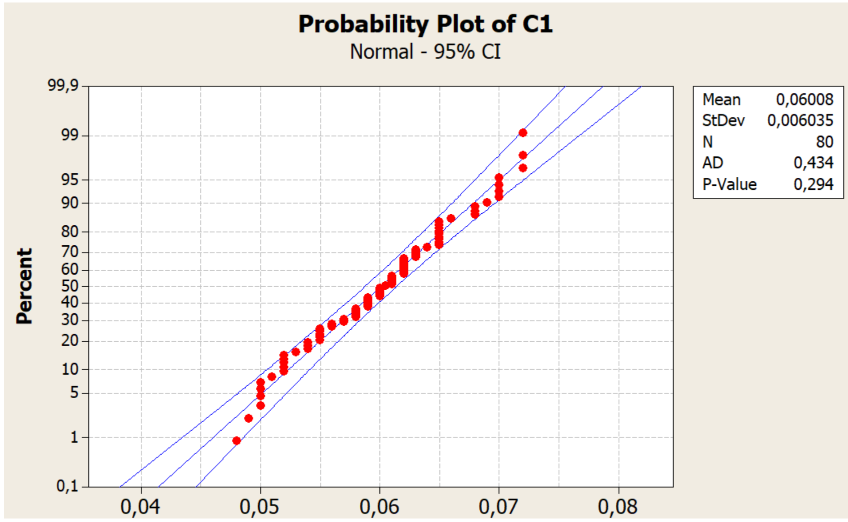

Figure 1. Normality test for impurities delivered from the collection center

From Figure 1 it can be concluded that the average of the impurities found in eighty deliveries made by the collection center to the final recycler is 6%, with a standard deviation of 0.6%. A value p > 0.01 or 0.294 which means that the impurity data respond to a normal statistical probability, with which it was possible to measure the indicators Cp and Cpk.

Figure 2 presents the capacity report of the impurity process of the deliveries made by the collection center. In this graph it is possible to highlight graphically the behavior of the impurity data with respect to the specification of 3% +/- 0.15%. The short-term capacity calculation determines the value of Cp at 0.26 and Cpk at -4.94, which makes it possible to determine the current state of the impurities.

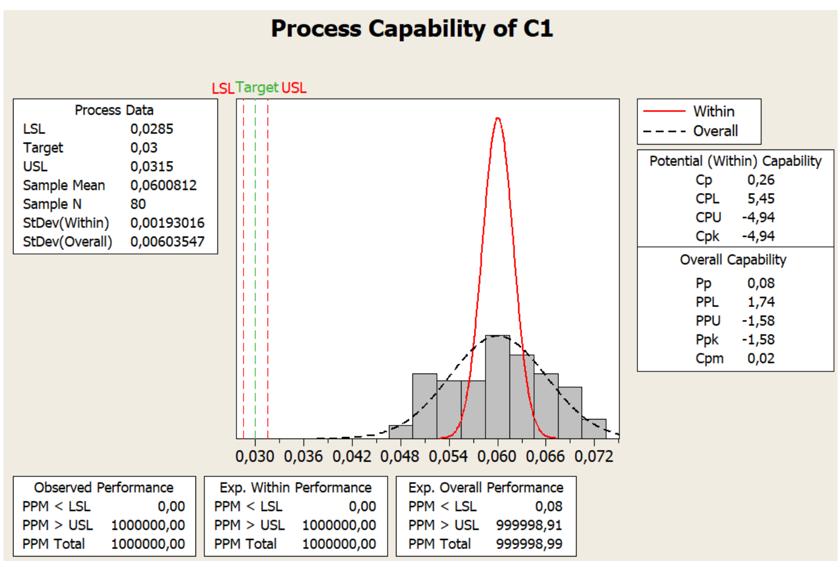

Figure 2. Capacity report of the impurity process of the collection center.

From Figure 2 it could be interpreted that Cp < 0.67 defining the current post-consumer polymer conditioning process as not adequate to meet the 3% +/- 0.15% specification. This requires deep modifications to improve the current condition of the process. On the other hand, Cpk <0 means that the average of 6% of the impurity sample is outside the specification required by the final recycler. In combination the Cpk < Cp is interpreted that the process mean is far from the center of the required specification. To conclude, it is concluded that, if the displacement of the process mean of impurities is corrected, it is possible to get into specification.

c. Analysis at the collection center.
Figure 3 presents the control graphs of the individual variable and the moving average of the impurity data found in each delivery made by the collection center. This has an average of 6% and a moving average of 0.2%. In these it is possible to observe the variability of the data with respect to its natural limits. In the case of the graph of control of individual variable it can be considered 28 points out of the limits or 28%, another interpretation is that 62% of the data are within the range of three standard deviations to the right and left of the bell.

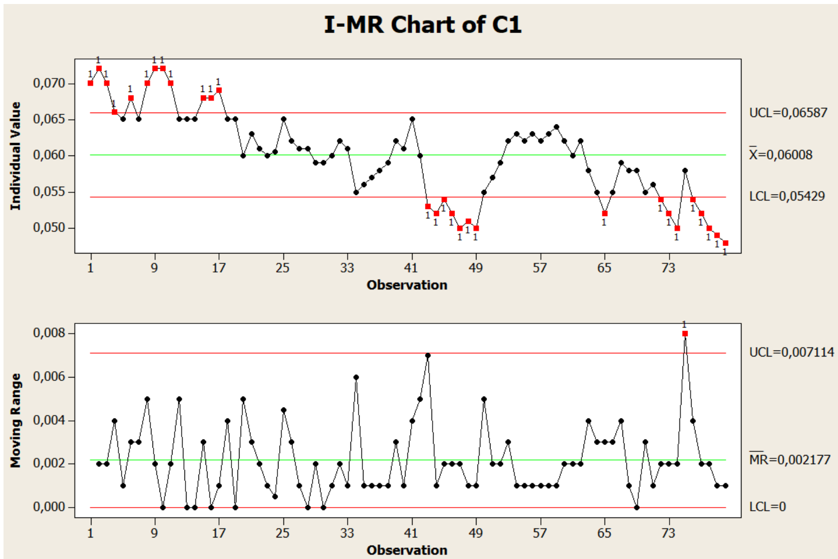

Figure 3. Impurity analysis for each delivery of the collection center.

By looking at Figure 3, it can be clearly identified that there is great variability in the data over time. Considering that two deliveries per week were made, it can be observed that the impurities behave in an irregular way. This is because the post-consumer polymer qualification process is purely manual. This consists of collecting polymers after consumption in bulk, storing in bis bags and discarding impurities on trays. It causes fatigue to the operative personnel and a lack of concentration in the activity of discarding impurities.

In figure 4, the fishbone diagram is presented for the lack of compliance with the specification of 3 % +/- 0.15% impurities for delivery made from the post-consumer polymer collection center.

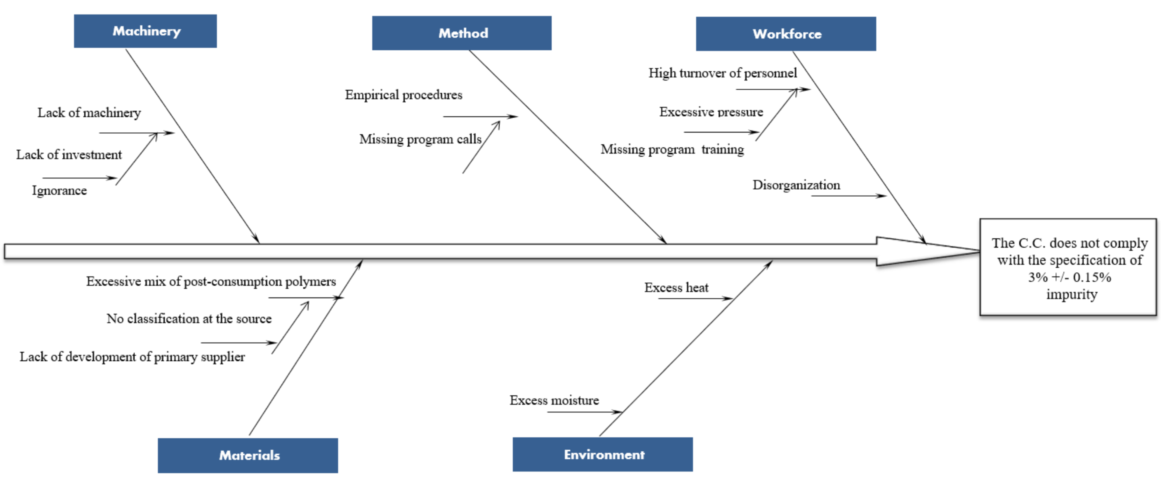

Figure 4. Fishbone diagram for non-compliance with the 3% +/- 0.15% impurity specification.

Figure 4 shows that the causes affecting compliance with the 3% +/- 0.15% impurity specification are related to the size of (i) labor in terms of lack of a training programme, (ii) machinery in terms of lack of knowledge or lack of investment conviction and (iii) materials in terms of lack of development of suppliers or primary suppliers. All were determined at level three of the diagram, however for the measurement the development of primary suppliers was not considered, as it was an external cause to the collection center.

The analysis of the lack of a training program begins with the high turnover of staff of the collection center in the areas of selection and pressing of post-consumer polymers. This was caused by excessive pressure on the personnel to comply with the specification. This pressure generates excess of errors in the activities, which consequently cause reprocessing, loss of time and poor quality. To this pressure is added the fact that the high variety of post-consumer polymers collected in the environment causes a bad classification or discard by type of polymer, which will consequently generate that the quality specification is not met in the final industries.

In machinery the Collection Centers are equipped for the operations of collection and manipulation of scrap and metals. However, as far as post-consumer polymer operations are concerned, they only have presses that generate good pressing density of this material. This implies that the critical operation of classification of polymers do not have suitable machinery to facilitate the operations of discarding impurities found in the inventory of post-consumer polymer collection center. Apparently, the owners are not convinced that the machinery can help lower the percentage of impurities. Under the idiosyncrasy that leads to the criterion that post-consumer polymers in primary collection are highly mixed with impurities, so it cannot be improved. Despite this, the final recycler began to discount impurities found in the deliveries made by the collection center. With this, the interest is born to look for possibilities that guarantee a short - medium term investment that is feasible under the context of the recycling market.

The present case of investigation determined the combination of the two causes as critical to solve in a sustainable way the problem of impurities in the collection centers. One depends on the other to ensure its improvement. Because the hand has as root causes: the lack of a training program for the wide variety of polymers post-consumption in the market and the lack of investment in appropriate machinery to help improve the activity of discarding impurities.

d. Implementation of improvements in the collection center.

Table 2 presents the matrix of action plans by root cause, which records the activities carried out to improve the current condition of the process of discarding impurities in the collection center.

Table 2. Matrix of action plans for each root cause

No	Root Cause	Action Plans
1	Lack of a training program	Develop a training program
2	Ignorance or lack of conviction of investment for machinery to discard impurities	Buy manual selection band Evaluate short-term impurity results

After the purchase and implementation of the selection band was implemented, there were favorable impacts on the income of the collection center. Since there was a 60% reduction in operating personnel in the selection area because the machinery required less labor. When implementing the training program, the lack of knowledge among the personnel at the time of identifying post-consumer polymers was evident. In addition, a policy was implemented to store material in a container in case of doubt, to be resolved by the plant supervisor. With the implementation of the two action plans, the results presented in Figures 5 and 6 are evident.

Figure 5 shows the analysis of impurities for each collection centre by means of a control chart before and after the implementation of the action plan. He then considers forty measurements of impurity that the final recycler inspected at the time of delivery of post-consumer polymers by the collection center.

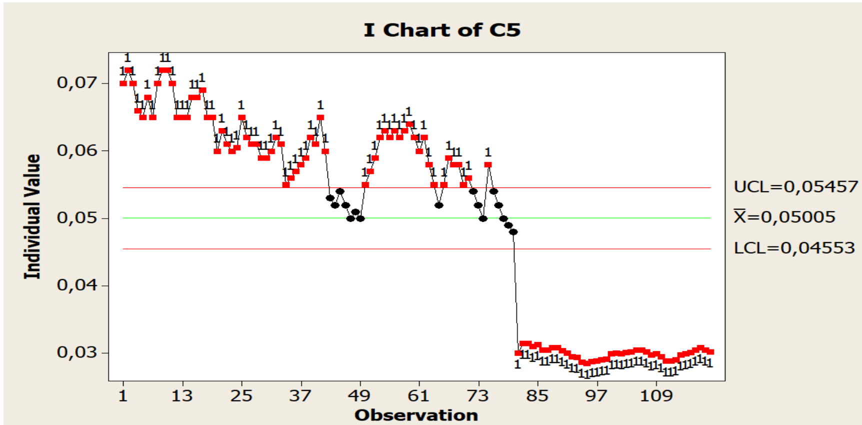

Figure 5. Impurity analysis for each delivery of the CC before and after the improvement.

From the data presented in figure No. 5, it is possible to highlight the abrupt improvement from the implementation of the action plans. The same is true of the data that are around the average of 3%. Additionally, it can be seen how the results of impurities behave with the resources of manpower and machinery necessary to provoke expected results.

Figure 6 shows the capacity report of the process of impurities found by the final recycler. In forty samples the improved mean of 3% is indicated with a short-term standard deviation of 0.022%. A short-term capacity index Cp of 1.8 and Cpk of 1.78.

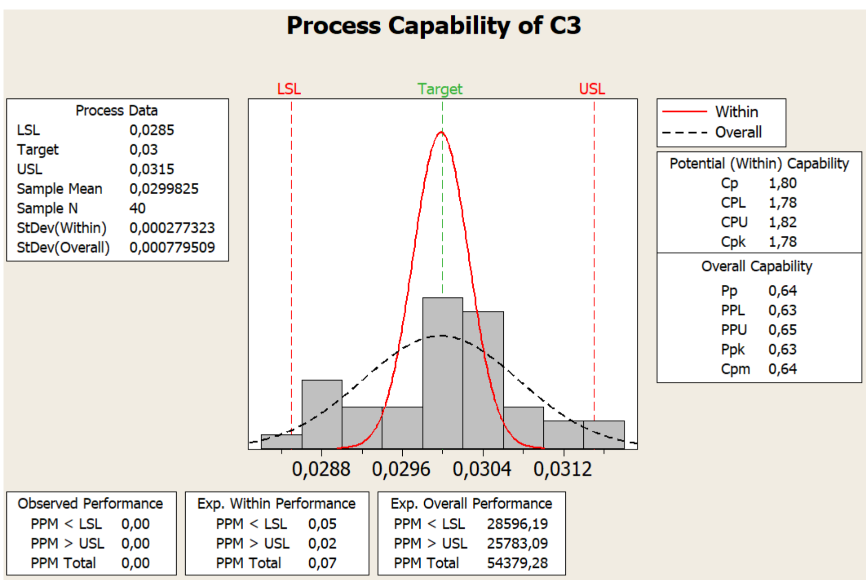

Figure 6. Process capacity report of impurities found by the final recycler.

Figure 6 can be interpreted the capacity of the process in the short term, where the Cp > 1.33 which indicates that the impurities found, or lack of quality generated in the collection center is adequate. Complementarily the index Cpk > 1,25 indicates that the collection center has a satisfactory capacity. Contrasting the Cpk index with 1, 78 with the Cp index of 1.80, it can be deduced that its proximity means that the average of the impurity results is almost at the center of the specifications of the final recycler. It can therefore be concluded that the collection center has a similar real and potential capacity for compliance with the impurity specification.

From the results obtained, it can be stated that the collection center meets the specifications of the final recycler. Where the systematic implementation of the action plans generates the results in the factors that generated high variability in the production process. They indicate the priority we must give to personnel management, the technology involved in the transformation and the timely evaluation of the results generated.

e. Control of improvements in the collection center.

Figure 7 shows the monitoring of impurities detected by the final recycler. These data are visualized in a graph of individual variable control, which is intended to track the results obtained to maintain them over time.

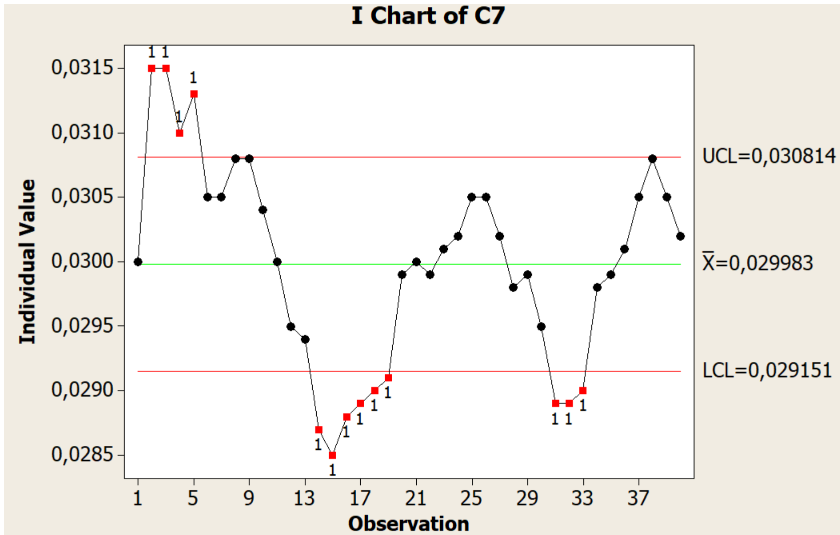

Figure 7. Monitoring of impurities found by the final recycler.

Figure 7 shows that the results are within the specification of the final recycler, so the working group was recognized at the weekly meeting. In case the impurities detected by the final recycler are out of specification. The post-consumer polymer collection center working group will define, measure, analyses and implement action plans to keep the results within the client's specifications. This initiates a cycle of continuous improvement in the process of selection and compaction of post-consumer polymers, in order to maintain the results.

In the stages of defining, measuring and analyzing the DMAIC methodology, the diagnosis of the Post-Consumer Polymer Collection Center was determined. In which it was identified that: a) They do not meet the specifications of the final recycler with a $Cp < 0.67$ and $Cpk < Cp$, b) There is no investment in technological resources to improve the condition of the process and c) Lack of training for operational personnel to improve product quality. All this is due to the cultural idiosyncrasy of the guild and the lack of formal studies that facilitate its development.

During the implementation stage, three activities were defined: 1) purchase of machinery (manual selection band) to improve the operating condition of the process, 2) elaboration and implementation of a training program to improve the elimination of impurities. From this data was obtained within the range of specifications: impurities of 3% with a standard deviation of 0.022%, $Cp > 1.78$ and $Cpk > 1.25$ which means that the capacity of the process is adequate and satisfactory. Validation of the Cp versus Cpk capability indices implies that the mean is practically at the center of the final recycler specification. All this shows that the quality capacity of post-consumer polymer bales has been improved through the application of DMAIC methodology.

Finally, in order to maintain and control the results obtained, the discipline of weekly meetings of the working group was considered. Where the results will be updated and reviewed within a control chart, to find opportunities for improvement. This activity will allow communication within the Collection Centers, as well as the interaction between: final recycler, administration of the collection center and operation of the process. This will guarantee results and promote a culture of continuous improvement in the workers.

4. Conclusions

In the Defining phase of the DMAIC methodology, the problem of the final recycler was determined using the VOC tool. This refers to a 6% average accretion of impurities in the delivery of post-consumer polymers by the CC. This is composed of: 3% for mixing colors, 2% for mixing polymers and 1% of other materials. Therefore, it is concluded that the final recycler requires the CC to enter the 3% +/- 0.15% impurity specification.

In the measuring phase, the process capacity indicators Cp = 0.26 and Cpk =-4.94 were determined. The Cp > 0,67 and Cpk < 0, determines that the capacity of the post-consumer polymer conditioning process in the A.C. is not adequate and is out of specification. The Cpk < Cp determines that the capacity of the conditioning process is out of specification. Therefore, it is concluded that the CC needs deep improvements to enter the specification of 3% +/- 0.15% impurity.

In the phase to analyze and improve the root causes that generate the variation and action plans for the adjustment of the process were determined. It is determined that the source of variability is the lack of training and machinery for the operation of the process. Through the implementation of training and selection band the process was adjusted. This generated an improvement in the capacity indexes of Cp = 1.8 and Cpk = 1.79. Therefore, it is concluded that the post-consumer polymer conditioning process is within the specification of 3% +/- 0.15%.

In order to finish in the stage to control in the CC graphs of impurity control and discipline of weekly meetings of follow-up were determined. With which the long-term sustainability of the desired results was achieved. With which it is concluded that a space is provided to elaborate new cycles of improvement DMAIC in the processes of the CC.

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References

Albán, A., Elaboración de madera plástica a partir de polímeros posconsumo. Tesis en Opción del Título de Ingeniero Industrial, Universidad Técnica del Norte, Ecuador, 2019.

Cruz, A., Mejora de la productividad del proceso de Sorema en la empresa Enkador S.A., a través de la implementación de la metodología de desarrollo de proveedores, Tesis Maestría en Ingeniería Industrial y Productividad, Universidad Politécnica Nacional, pp. 309, 2016.

Gijo, E. V., Scaria, J., and Jiju, Application of Six Sigma Methodology to Reduce Defects of a Grinding Process, *Quality and Reliability Engineering International*, pp. 1221-1234, 2011.

Gupta, V., Jain, R., Meena, M. L., and Dangayach, G. S., Six-sigma application in tire-manufacturing company: a case study, *Journal of Industrial Engineering International*, vol. 14, no. 3, pp. 511-520, 2018.

Gutiérrez, H., and Salazar, R., Control estadístico de la calidad y Seis Sigma. Mexico: Mexicana, McGraw-Hill Interamericana, 2013.

Herrera, A.R.C., Aguirre, J.P.U., and Leyva, L.L.L., Development of Post-Consumer Polymer Suppliers. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Bangkok, Thailand, March 5-7, 2019.

Kumar, M., Antony, J., Singh, R. K., Tiwari, M. K., and Perry, D., Implementing the Lean Sigma framework in an Indian SME: a case study. *Production Planning & Control: The Management of Operations*, vol. 17, no. 4, pp. 407-423, 2006.

Lorente, L., Yerovi, M., Montero, Y., Saraguro, R., Herrera, I., Machado, C., Lastre, A., and Cordoves, A., Applying lean manufacturing in the production process of rolling doors: A case study, *Journal of Engineering and Applied Sciences*, vol. 13, no. 7, pp. 1774-1781, 2018.

Leyva, L.L.L, Perugachi, E.P.C., Piarpuezan, R.V.S., Orges, C.A.M., Montenegro, E.P.O, and Burgos, G., Lean Manufacturing Application in Textile Industry, *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Paris, France, July 26-27, 2018.

Ministerio del Ambiente, Análisis de la industria y Demanda de plástico PET. Reciclaje Inclusivo y Recicladores de Base en el Ecuador, 1(1), 29-69, 2015.

Organización Inernacional del Trabajo, Políticas Públicas para la Inclusión de los Recicladores de Base al Sistema de Gestión de Residuos Municipales en Chile, 2013.

Pallavi, S., Suresh, C. M., Anshu, G., and Jha, P. C., A DMAIC Six Sigma approach to quality improvement in the anodising stage of the amplifier production process. *International Journal of Quality & Reliability Management*, vol. 35, no. 9, pp. 1868-1880, 2018.

Perez, F., Medio ambiente, bienes ambientales y métodos. Equidad y Desarrollo, 25, 2016.

Rana, P., and Kaushik, P., Manufacturing Productivity Improvement through DMAIC Methodology: A Case Study of Automotive Ancillary Unit. *International Journal of Mechanical Engineering and Technology*, vol. 8, no. 11, pp. 635-648, 2017.

Rana, P., and Kaushik, P., Six-sigma derivatives: A case study, *Management Science Letters*, vol. 8, no. 8, pp. 849-858, 2018.

Saeid, H., Seyed, M. Z., and Jafri, M. R., Application of Six-Sigma DMAIC methodology in plain yogurt production process. *International Journal of Lean Six Sigma*, vol 9, no. 4, pp. 562-578, 2017.

Sharma, G. V., Rao, P. S., and Babu, B. S., Process capability improvement through DMAIC for aluminum alloy wheel machining, *Journal of Industrial Engineering International*, vol. 14, no. 2, pp. 213-226, 2018.

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