variable (quantitative and qualitative) and will be related to customer specifications (specified in point a), within a relationship matrix.

The critical variables will be selected through the relationship table, using numerical weights, where the degree of relationship between them will be determined. The weights are given from zero (0) to five (5), five representing the highest degree of relationship and zero has no relation whatsoever. To select each of these variables, the area manager, team leaders and process operators will be surveyed. With which, the variables that directly affect the final characteristics of plastic wood will be determined. Next, with the working group, the method of qualitative variables control will be defined, this being the process cards as the most optimal method that shows step by step how to follow a procedure and thus be able to standardize it.

On the other hand, for the quantitative variables the control method is selected from the revision of the state of the art, having as reference 20 investigations as shown in table 1.

Table 1. Bibliographic review of control methods for quantitative variables.

Methodology	Research	Percentage
Statistical Control Charts	15	58%
Ishikawa diagram	3	12%
Statistical processes control	2	8%
Normality test	1	4%
Descriptive Analysis	1	4%
Control Diagrams	1	4%
Six Sigma	1	4%
Acceptance Sampling	1	4%
Histograms	1	4%

After carrying out the respective tabulation of the data we have that, of 20 quality control investigations 15 have been resolved through control graphs, representing 58% of the other methods. Therefore, control charts will be used to evaluate quantitative variables. The calculation of the sample will be carried out for the construction of the control charts of quantitative variables. The production lot has 4 sheets of recycled plastic wood per shift (Pozo, 2019), that is 5 lots per week. With which the sample is calculated using the following formula:

$$n = \frac{N\sigma^2 z^2}{e^2\,(N-1)+\sigma^2 z^2} \tag{1}$$

Where:

Z = The 95% confidence value indicates a constant value of 1.96
N = 20 represents the study population.
σ = 0.5 a constant value because the standard deviation of the population is unknown.
e = 0.05 corresponds to the sample error.
A confidence level of 95% and a sample error of 5% were considered.

Replacing values, we have:

$$n = \frac{20(0.5)^2(1.96)^2}{(0.05)^2\,(20-1)+(0.5)^2(1.96)^2}$$

$$n = 19{,}308$$

From this it is determined as a sample 20 sheets of recycled plastic wood in 5 batches of weekly production. This means that for this case study, the total production is equal to the defined sample. This is because the simulation laboratory produces small batches.
Then the amount of data indicated by the sample will be collected and the average, range and standard deviation will be calculated, as well as a normality test, which will facilitate the preparation of the control chart in the computer tool.

c. Implementation of statistical quality control.

For qualitative variables, a check list of the steps defined in the process files will be executed. While for the quantitative variables a sheet will be implemented, where the operational staff will build and analyze control charts.

3. Result and Discussion

a. Diagnosis of the production process of recycled plastic wood.

In Table 2, the SIPOC matrix of the recycled plastic wood production process is presented, where five subprocesses can be observed. These are: reception of raw material, selection, crushing, mixing and molding. It should be noted that currently the production activities of plastic wood are defined empirically, without evaluation methods for product quality.

Table 2. SIPOC matrix of the recycled plastic wood production process.

Supplier	Entrances	Process	Out	Customer
Storage	*Recycled polymer *Vegetable fiber	Select recycled polymers and vegetable fiber	*Polymer type *Vegetable fiber selected	Crushed
Selection	*Polymer type *Vegetable fiber selected	Triturate polymers and vegetable fiber	*Polymer falke *Powdered vegetable fiber	Formulation
Crushed	*Polymer falke *Powdered vegetable fiber	Mix polymer flake and powdered vegetable fiber	*Composite material	Modeling
Formulation	*Composite material	Foundry composite material	*Molten composite material	Compacted
Modeling	*Molten composite material	Compact molten composite material	Recycled plastic wood	End customer

Table 3 shows the Check List for quality control in the production of recycled plastic wood. Which presents 6 questions and answers that define if the current process complies with some method of statistical control of the quality of the finished product.

Table 3. Check List for quality control in the production of recycled plastic wood.

Subprocesses	Is a procedure followed?	Are the teams fund calibrated?	Is machinery maintenance performed	Are standardized measures established?	Are there quality control points?	Is the final product compliant?
Raw material classification	no	no	no	no	no	yes
Crushed polymers	no	no	no	no	no	no
Spraying of vegetable fibers	no	no	no	no	no	no
Mixture	no	no	no	yes	no	yes
Molded	no	no	no	no	no	yes

Pressing	no	no	no	no	no	no
Compliance (%)	0%	0%	0%	16.6%	0%	49,8%

After having carried out the check list of the statistical quality control in the production of plastic wood, it was determined that the process does not have procedures. The equipment is not calibrated and is not performed maintaining. In addition, there are no quality control points in any area of each thread. The percentage of compliance with standardized measures only represent 16.6%. And the compliant outputs of the process represent 49.8% compliance with the 6 threads. By knowing the shortcomings of the plastic wood process, the wood specification is determined by (VOC), as shown in table 4.

Table 4. Wood customer specifications.

Wood properties	Physical properties	*Resistance *Density *Thickness *Durability
	Technological properties	*Color *Size

After a bibliographical investigation, it was possible to determine that in both plastic and conventional wood, the client searches the market for the following properties of: resistance, density, thickness, size and how the color is finished. It should be considered that these are the properties that customers want to consider a quality product.

b. Identification of the quantitative and qualitative variables of recycled plastic wood.

To enter the analysis of variables, a matrix was made that shows the relationships that the process variables have with the properties of plastic wood. Table 5 shows the summary of the relationship between wood properties and the variables (quantitative-qualitative) of the process. Here, each variable to be evaluated is shown to meet the customer's specification.

Table 5. Matrix of relationships between specification and critical variables.

Specifications	Selection	Crushed	Sprayed	Mixture	Molded	Compact
Resistance	**Polymer type**			**Mixing percentage**	* *Molding time* **Temperature*	**Pressure* * *Pressing time*
Density	**Polymer type** **Vegetable fiber**			**Mixing percentage**		* *Pressed time* **Pressure*
Espesor Thickness		*Flake size*	*Flake size*	**Mixing percentage**		*Pressed time* **Pressure*
Color	**Polymer type**			**Mixing percentage**	*Molding time*	
Durability				**Mixing percentage**		

* **Bold**: Qualitative variables
* Italic: Quantitative variables

From table 5 it is determined that the main variables that affect the quality of the product in each subprocess are: qualitative such as the type of polymer, type of vegetable fiber and type of mold. As quantitative variables, the percentage of mixing, pressing time, pressure, flake size and molding time. Having the study variables ready, each one is measured in their respective areas or subprocesses. Table 6 shows an example of a control for the qualitative polymer type variable, in the format of the process sheet that includes the mission, inputs, steps, outputs and the name of the control variable. By complying with this sheet, compliance with standard activities is guaranteed.

Table 6. Process control sheet of the polymer type variable selection area.

Plastic Wood	**Process Sheet: Classification of the type of polymer in the selection area**	**Code:**	
		Pages:	
Process Mission			
Perform the correct classification of polymers in the area of raw material selection to guarantee the strength of the final product.			
Procedure			
Entrances	Steps	out	
Packaging of different materials	1.Remove the labels from each plastic container to be able to visualize the identification symbol. 2. Find in each container the triangle with numbering 2 that indicates the high-density polyethylene. 3. Place the selected containers in a container. 4.Label the selected container container with the name "PEHD high density polymer selected"	* High density polyethylene classified and labeled	
Containers			
Tags			
Control Variable:	Type of polymer selection area		

In the same way, the control form for the quantitative variables as shown: defective flake quantity, pressure and temperature.

Control of the quantitative variable quantity of defective flake in the crushing area: as I had mentioned for the control of the quantitative variables, the control graphs are used, which are constructed from data collected by a sample size 5 lots, and with this the normality test is carried out as shown in Figure 1.

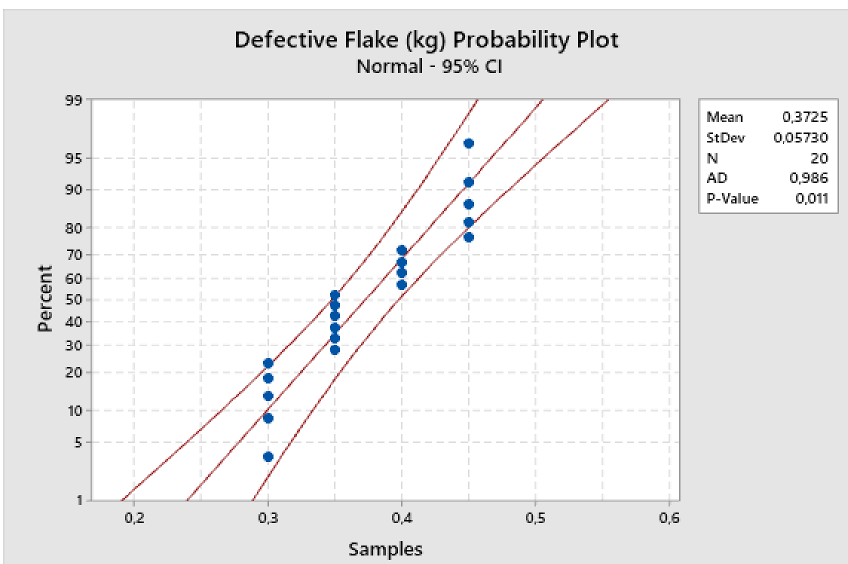

Figure 1. Normality test for the quantitative variable defective flake percentage.

If the data is non-normal, a greater number of false alarms can be observed, since less than 2% of the points are outside the control limits in graph I. The normality test is not necessary. (Minitab, 2016). According to our probability graph, we propose two hypothesis tests that will help to take actions, thus having:

H0: The data follow a normal distribution.

P> α value: The data follow a normal distribution.

H1: The data does not follow a normal distribution.

P value ≤ α: The data does not follow a normal distribution

$$H1: p \leq \alpha: 0{,}01 \leq 0.05$$

Therefore, H1 is accepted and H 0 is rejected.

We verify that the data is not normal but since they do not represent more than 2% of points outside the limits, we proceed to make our control chart by variables. Type I-MR (Individual data and mobile ranges) that monitors the average and variation of a process. Figure 2 shows the behavior of the defective flake quantity variable for each kg of flake analyzed.

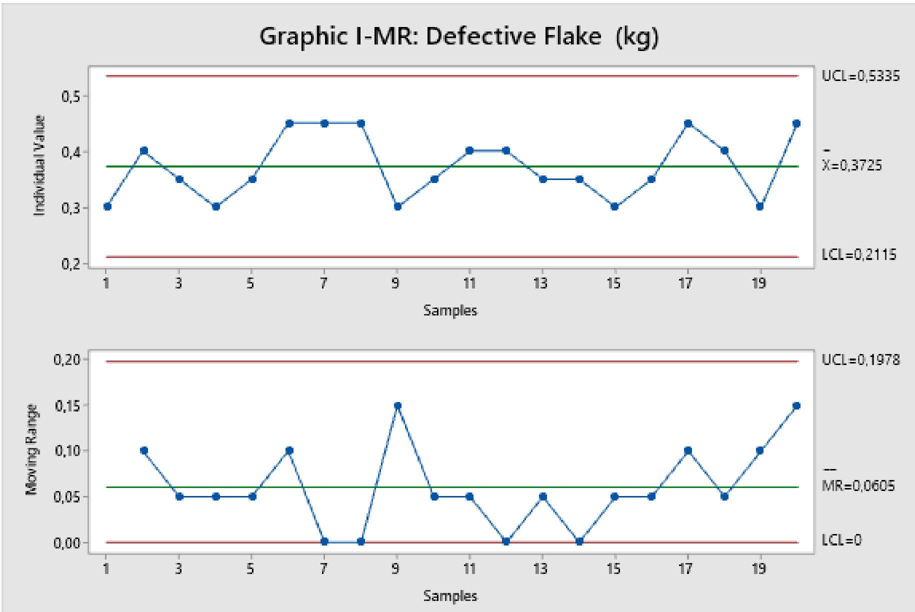

Figure 2. Control chart - Variable quantity (kg) of defective flake.

From figure 2 it can be determined that the process is stable and there is no point out of control. We conclude: that there is stability since the average - variation of the process are stable and have no points out of control in any graph. In addition, we can standardize the amount of defective flake that may exist for each kilogram evaluated, this being 0.53 kg as the maximum value. If this value is exceeded, the process must be stopped, and the source of the fault must be sought, and corrective actions taken.

Control of the quantitative temperature variable in the molding area: the sample size will be the same for all quantitative variables. Therefore, 20 measurements were taken since the mold enters the oven and the temperature reaches 110 º C. With the data we proceed to make the control graph in the software, as shown in Figure 3. It is convenient to indicate that the same program calculates the average and the control limits, so that no calculation will be necessary.

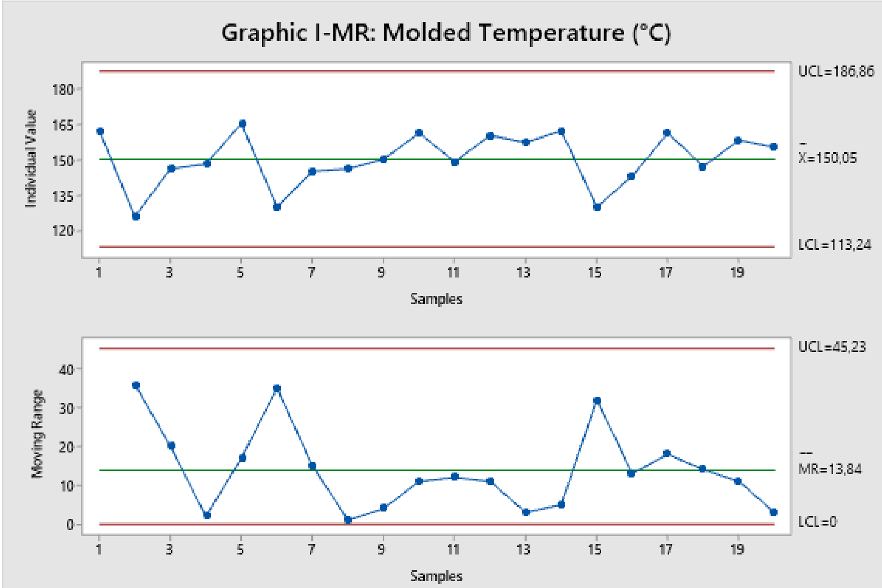

Figure 3. Control graph for the temperature variable in the molded area.

Figure 3 shows no instability in terms of the temperature variable in the molding area. We can conclude that the set of data taken at the temperature variable is normal since no point is exceeding the control limits. In addition, the molding activity is stable as the average indicates. Therefore, the standard values in this area are given by an upper limit of 186.86 º C, in other words, if it exceeds this limit, there will be failures in the resistance specification of the final product, in the same way if the temperature is very low. For this reason, it is recommended to work with the value of the nominal average temperature that is 150ºC.

Control of the quantitative pressure variable in the pressing area: In the same way, the sample size data is collected and the software for the construction of the control graph of the pressure variable is entered, as shown in Figure 4.

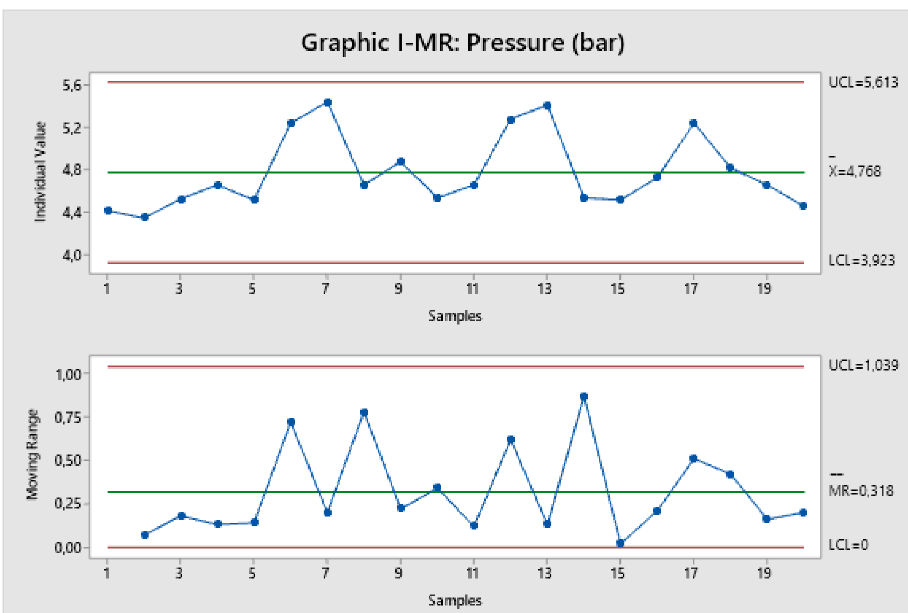

Figure 4. Control chart for the pressure variable in the compact area.

The points analyzed were the normality of the data, the stability of the process and the control limits, for which we have that a normality test is not necessary since no value that represents 2% of the total data is outside the limits , this guarantees that the process is stable with respect to the average. In addition, we can define a standard value of 4.76 bars to obtain a correct press that guarantees hardness and density of plastic wood. Table 6 shows a summary of the standard values obtained from the construction of these graphs.

Table 6. Summary of standard values for quantitative variables

Var	Standard Value
Defective flake	0.37 Kg
Temperature	150º C
Pressure	4.76 bar
Molding time	36 min
Pressing time	26 min

c. Implementation of statistical quality control

For qualitative variables there is a process sheet in each area which must be read and applied step by step to ensure adequate control compliance with the qualitative variable. For each step completed, the person in charge of the process must mark with a nod (√) that this step has been completed and therefore the variable has been controlled. Table 7 shows an example of the check list for the control of the qualitative variable type of vegetable fiber.

Table 7. Check List for control of the qualitative variable type of vegetable fiber.

<table>
<tr><th colspan="2">Items</th><th>Yes</th><th>No</th></tr>
<tr><td colspan="2">1. Visually identify that the fibers introduced to the laboratory are mixed or contain impurities</td><td></td><td></td></tr>
<tr><td colspan="2">2. If the fibers are in a container and comply with the previous step proceed to label with the name of the fiber Example: "Selected Rose Vegetable Fibers"</td><td></td><td></td></tr>
<tr><td colspan="2">3.If the fibers do not have any container, go to the reception area of raw material and look for one that is empty and does not contain any labels.</td><td></td><td></td></tr>
<tr><td colspan="2">4. Label the container with vegetable fibers with the name of the fiber Example: "Selected Rose Vegetable Fibers"</td><td></td><td></td></tr>
<tr><td colspan="4">Observations:</td></tr>
<tr><td>Responsable</td><td>Date</td><td colspan="2">Firm</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
</table>

On the other hand, table 8 shows the format for controlling quantitative variables such as the amount of defective flake measured in kg in the crushing area, temperature and pressure. For the time variables of the molding and pressing threads, the person responsible for the process must control the standardized time, represented in table 6.

Table 8. Control sheet of the quantitative variable.

<table>
<tr><th colspan="6">Types of Quantitative Variables</th></tr>
<tr><td>Flake size</td><td></td><td>Pressure</td><td></td><td>Temperature</td><td></td></tr>
<tr><td>Objective:</td><td colspan="5">Control quantitative variables using a control chart in plan</td></tr>
<tr><td rowspan="5">Construction steps</td><td colspan="5">1. Take samples of the variable to be controlled</td></tr>
<tr><td colspan="5">2. Record the data in the attached table</td></tr>
<tr><td colspan="5">3. Locate the data collected on the graph (X, Y)</td></tr>
<tr><td colspan="5">4. Join with a continuous line all the data in the control chart.</td></tr>
<tr><td colspan="5">5. Observe if the points remain within the range of the upper and lower limits, if this happens continue, otherwise stop the process and look for the causes of the error.</td></tr>
<tr><td>No. Samples</td><td>Unit of measurement ( )</td><td colspan="4">Control chart of the quantitative variable</td></tr>
<tr><td>1</td><td></td><td colspan="4" rowspan="10"></td></tr>
<tr><td>2</td><td></td></tr>
<tr><td>3</td><td></td></tr>
<tr><td>4</td><td></td></tr>
<tr><td>5</td><td></td></tr>
<tr><td>6</td><td></td></tr>
<tr><td>7</td><td></td></tr>
<tr><td>8</td><td></td></tr>
<tr><td>9</td><td></td></tr>
<tr><td>10</td><td></td></tr>
<tr><td colspan="6">Observations:</td></tr>
<tr><td colspan="2">Responsable</td><td colspan="2">Date</td><td colspan="2">Firm</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

The implementation of the statistical control of the quality of the production process of recycled plastic wood resulted in a controlled process, which correctly guarantees the performance of each subprocess of the production area, thus ensuring the quality of the final product. The evaluation of the results of the recycled plastic wood was carried out through the analysis of the tensile strength, in table 9 the comparison of the properties before and after the implementation is indicated.

Table 9. Comparison of the properties of plastic wood before and after

Properties of plastic wood	**Before**	**After**
Force Max. (N)	605,42	751,03
Elongation at max. force (%)	3,05	3,68
Breaking force (N)	445,06	316,51
Elongation at break (%)	3,39	3,87
Density (g / cm3)	1,76	1,71
Coefficient of variation (%)	51,38	7,26

Looking at the values in table 9 we can show an improvement in the properties of plastic wood, such as the maximum force applied that has increased by 24% of the initial value, where no quality control was performed. As for the elongation force, that is, when the material begins its deformation, the percentage of improvement is 17.11%. The breaking force decreased by 28.88% since the greater the maximum force, the lower the elongation of the material.

By maintaining the same formulation for the specimens before and after implementing statistical quality control, the density did not vary greatly, thus decreasing only 0.05 kg, that is, the material remains light. In addition, we can observe that the coefficient of variation has totally decreased from 51.38% to 7.26%, due to the fact that there are now control points in each area of the process that allow the qualitative and quantitative variables in the production of production to be kept under control. plastic wood.

4. Conclusions

The initial diagnosis was determined, each of the subprocesses that make up the plastic wood production process were defined, as well as to identify the quantitative and qualitative variables present in each area and in this way designate the strategic places that needed a control point that guarantee the quality of the product, which were: the raw material reception area, crushing, molding and pressing area, which now have a quality control tool.

It was identified that the production of recycled plastic wood is a process whose production volume is low, for this reason, for the control of quantitative variables, the individual graphs of mobile ranges (I-MR) were implemented that allowed to detect the variability and stability of the process. On the other hand, since the qualitative variables are difficult to quantify, a control tool (process sheets) was designed that allows activities to be carried out in an orderly manner and thereby guarantee a standardized procedure.

As for the strength of the material, plastic wood is produced with a maximum resistance value of 751.03 N and with 316.51 N of breaking strength. It was also possible to standardize the time variable in the molding and pressing area, being these 36 and 26 minutes respectively, the temperature in the molding area could be standardized with a value of 150 º C and in the pressing area the correct pressure for guarantee the hardness of plastic wood sheets is 4.76 bars.

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.

Aliverdi, R., Naeni, L.M., and Salehipour, A., Monitoring project duration and cost in a construction project by applying statistical quality control charts. *International Journal of Project Management*, vol 31, no. 3 411-423, 2013.

Besterfield, D., Control de la Calidad. México: PEARSON, 2009.

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.

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.

Herrera, A.R.C., Benavides, E.P., Aguirre, J.P.U., and Leyva, L.L.L., Application of Six Sigma in Improving the Quality of Recyclable Polymer in Collection Centers. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Pilsen, Czech Republic, July 23-26, 2019a.

Herrera, A.R.C., Aguirre, J.P.U., and Leyva, L.L.L., Improvement Production Capacity of Recycled Plastic Wood through Six Sigma DMAIC. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Pilsen, Czech Republic, July 23-26, 2019b.

Hernández, C., and Da Silva, F., Aplicación del control estadístico de procesos (CEP) en el control de su calidad, Tecnología Química, vol XXXVI, pp. 130-145, 2016.

Joekes, S., Herramientas de monitoreo y control estadístico de atributos en procesos de alta calidad: estudio de resultados, implementación computacional y aplicación práctica. Tesis Doctorado en Ciencias de la Ingeniería, Universidad Nacional de Córdoba, Argentina, 2016.

Krajewsky, L., Ritzman, L., y Malhotra, M., *Administración de Operaciones. Producción y Cadena de Valor*, 8va Edición, Pearson Education, México DF, 2008.

Milo, M.W., Roan, M., and Harris, B., A new statistical approach to automated quality control in manufacturing processes. *Journal of Manufacturing Systems*, vol. 36, pp. 159-167, 2015.

Mendoza, E., Propuesta metodológica para estandarizar procesos en pequeñas empresas Metal-Básicas. Tesis para obtener grado académico de Maestría, Universidad Nacional Autónoma de México, 2011.

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.

Pozo, E., Implementación de la metodología DMAIC para la mejora de capacidad de producción en la elaboración de prototipos de madera plástica. Tesis en Opción del Título de Ingeniero Industrial, Universidad Técnica del Norte, Ecuador, 2019.

Quintana, A., Pisani, M., and Casal, R., Desempeño de cartas de control estadístico con límites bilaterales de probabilidad para monitorear procesos Weibull en mantenimiento. *International Journal of Quality & Reliability Management*, vol. 35, no. 9, pp. 1868-1880, 2018. *Ingeniería, Investigación y Tecnología, v*ol. 16, no. 1, pp. 143-156, 2015.

Biographies

Andrés R. Cruz Herrera is a Researcher Professor of the Industrial Engineering Career, at the Universidad Técnica del Norte, Ibarra, Ecuador. Electronic Engineer and Master's in Industrial Engineering and Productivity from the National Polytechnic School (Cum Laude), Quito Ecuador. Specialist in Industrial production and Sustainable technology, Recycling and Process Optimization.

Lupe P. Taimal Cuasapud is Industrial Engineering at the Faculty of Engineering in Applied Sciences of the Universidad Técnica del Norte, Ibarra, Ecuador.

Jeanette del P. Ureña Aguirre is a Researcher Professor of the Industrial Engineering Career, at the Universidad Técnica del Norte, Ibarra, Ecuador. Industrial Engineering degree and a Master in Cleaner Production and Master in Industrial and Environmental Safety and Hygiene degree from Universidad Técnica der Ambato, in Ecuador. Specialist in cleaner production. She is member of the FOCAPRO and GePRO research groups. She has participated in projects in the field of industrial and environmental safety, as well as energy efficiency.

Santiago M. Vacas Palacios is Agroindustrial Engineer and Master of Business Administration. Productivity and Quality Management Specialist, with participation in the Development and Implementation of Several Industrial Projects and the Assembly of Dairy, Flour and Coffee Processing Plants. Investigator Professor of the Industrial Engineering Career, at the Universidad Técnica del Norte, Ibarra, Ecuador.

Leandro L. Lorente Leyva is a researcher/professor of the Industrial Engineering Career, at the Universidad Técnica del Norte, Ibarra, Ecuador. Holds a Mechanical Engineering degree and a Master of Computer Aided Design and Manufacturing (CAD/CAM) degree from Universidad de Holguín, in Cuba. Specialist in computer-assisted design, planning and manufacturing. He is member of the SDAS research group. Has participated in numerous projects and completed research in several areas.