Improvement Production Capacity of Recycled Plastic Wood through Six Sigma DMAIC

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Abstract

This research aims to increase production capacity of wood plastic through Six Sigma DMAIC implementation, within the simulation laboratory of production of recycled plastic wood sheets of the Universidad Técnica del Norte, Ecuador. Where they simulated the conditions of the current problem, which reflects the lack of strategies to improve production capacity, and three steps were determined as project methodology based on DIMAC (define, measure, implement and control). First, the current diagnosis was carried out where it was identified that the final client has excessive waiting times for the product. With which they measured and calculated: production time in 214.3 minutes + / - 15.7, Cp=0.91 and Cpk = 0.49. Combined these results mean that production times are not suitable for the job and are off-center to the upper limit. Second, improvements were implemented from root cause analysis, which determined the lack of: maintenance, work method, training and design / construction of larger capacity molds. Third, the results were evaluated after the improvements, where a production time of 173.4 minutes was obtained, that is, an improvement of 19%, Cp=1.09 and Cpk = 0.99. These indicators mean that the production times are capable for the job and is slightly displaced to the upper limit.

Keywords
Six Sigma, DMAIC, Improvement, Capacity, Production, Recycled Plastic Wood

1. Introduction

Ecuador currently generates 4.1 million tons per year of solid waste, 25% of which is potentially recyclable (Ministerio del Ambiente, 2015) The urban area is characterized by 58% organic waste and 42% inorganic waste. Of the latter, one of potentially recyclable solid wastes is plastic with 10.7% (INEC 2017). This waste has led to the development of new industries that mitigate the environmental impact and generate new products. Within which recycled plastic wood provides a range of opportunities and possibilities. Because its physical and mechanical properties offer numerous advantages over climatic conditions, maintenance and pest attack (Moya et al. 2012).

During the last decade growing environmental awareness, social responsibility and government regulations have led to the development of new industries that mitigate environmental impact, generating new products (Vahdat and Vahdatzad 2017). Within which recycled plastic wood offers a range of opportunities and possibilities. Since this product complies with the two fundamental sections of an ecological design and these are: environmentally conscious design and product life cycle assessment (Vahdat et al. 2018). Because its physical and mechanical properties favor climatic conditions, maintenance and pest attack (Moya et al. 2012). Ecuador currently generates 4.1 million tons per year of solid waste, 25% of which is potentially recyclable (Ministry of Environment, 2015). The urban area is characterized by 58% organic waste and 42% inorganic waste. The potentially recyclable solid wastes is plastic with 10.7% (INEC 2017).

The companies producing plastic wood in Ecuador are in the main cities, Quito, Guayaquil and Cuenca. These, generally under mechanical and thermal processes produce floors, pallets, enclosures among others. However, it has been identified that they do not have strategies to improve production capacity. Therefore, in the simulation laboratory of production of prototypes of plastic wood of the Universidad Técnica del Norte. The current conditions of the companies were simulated in order to improve production capacity using Six Sigma DMAIC methodology.

The literature defines Six Sigma DMAIC as a sequence of steps that seek to establish the source or origin of variation in the process. This methodology is composed of five phases and these are: 1) Define, 2) Measure, 3) Analyze, 4) Improve and 5) Control (Gupta et al. 2018). Below is a brief definition of each one and the tools to be used in each phase.

Define: is the first step to implement this methodology. It consists of approaching the determination of the processes. To gather information on the requirements and needs of its clients, with the purpose of identifying possible improvement opportunities (Ocampo and Pavón 2013).

Deployment of the client's voice: it is a tool that seeks to satisfy the client's demands under qualitative research techniques. Its objective is not to identify a complete set of improvements, but a complete range of attributes that satisfy the client. (Mazur 2012)

Measure: at this stage, the metrics that will determine the current performance of the process must be identified and validated. For this it is necessary to identify what the requirements and/or characteristics are in the process or product. That the client perceives as key, and that parameters (input variables) are those that affect this performance (Gijo et al. 2011).

Process capacity: a study of actual process data over a considerable period of time. With which the real performance of the process will be obtained (Chase and Jacobs 2014; Lorente et al. 2018; Leyva et al. 2018).

Potential capability index: symbolized by Cp', is the result of dividing the tolerated variation width by the amplitude of the natural variation of a process. That is, it compares the width of specifications tolerated in the process with the amplitude of the real variation of the process (Suwanich and Chutima 2017).

Cpl, Cpu, and Cpk indices: the indices of upper capacity and lower capacity (Cpl and Cpu). They are calculated through formulas that consider the centering of the process and the results represent the variation tolerated for each side of the mean. And the real capability index (Cpk) is equal to the lowest between Cpl and Cpu. This means that it is considered as a corrected version of the Cp since this indicator considers the centering of the process (Purnama et al. 2018).

Interpretation of the Cp index: in order to determine whether a process is potentially capable of meeting specifications, it is necessary that the actual variation is always less than that tolerated. If the Cp index is greater than one is evidence that the process meets the specifications, and if the process is less than one is interpreted as a process that does not meet the specifications (Rana and Kaushik 2017).

There is a definition of the Cp index that is independent of the distribution quality characteristic and is the technical report of ISO 12783. It defines *Cp* as: $\frac{\mathrm{ES-EI}}{\mathrm{P}_{0.99865}-\mathrm{P}_{0.00135}}$ where $\mathrm{P}_{0.99865}$ is the 99.865 percentile of the quality characteristic distribution and $\mathrm{P}_{0,00135}$ is the 0.135 percentile. Thus, whatever the distribution will be found in 99.73% of the quality characteristic values (Gutierrez and Salazar 2013). The values of *Cp* and their interpretation are presented in Table 1 below.

Table 1. *Cp* values and their interpretation

Index value *Cp*	Process type or category	Decision (if the process is focused)
$\mathbf{Cp \geq 2}$	World class	You have Six Sigma quality
$\mathbf{Cp > 1.33}$	1	Adequate
$\mathbf{1 < Cp < 1.33}$	2	Partially adequate, requires strict control
$\mathbf{0.67 < Cp < 1}$	3	Not suitable for the job. An analysis of the process is necessary. Requires serious modifications to achieve satisfactory quality.
$\mathbf{Cp < 0.67}$	4	Not suitable for the job. Requires modifications.

Analyze: The purpose of this phase is to analyze previously obtained data and determine significant variables. In addition, the root causes of the defects are identified. For this purpose, analysis tools are selected and applied to the data collected in the Measure stage. In this way, we structure a plan of potential improvements to be applied in the next step (Rana and Kaushik 2018).

5 Why?: is a tool where it is required to ask "why" at least five times specifically in order to determine the root cause of the problem. (Besterfield 2009)

Cause-effect diagram: a tool that identifies the characteristic variation in a process or operation with an effect or consequence of multiple causes. As its name implies, the cause-effect diagram determines an exhaustive analysis and complete investigation. In order to identify the main root causes of the problem (Matute 2017).

Improve: in this phase it is defined that "if in the analysis phase it was determined that a process is not capable, it will have to be optimized to reduce its variation". To meet this objective, potential solutions are developed and quantified. They will lead us to improve and optimize the process, and then evaluate and verify the final solution (Pellero 2015).

Brainstorming: also known as brainstorming, is a creative tool that integrates members of a group to develop their ingenuity. This is done by brainstorming on a issue or problem. All this in order to generate more ideas and if possible, contribute to the improvement of proposals. Because, based on what has been said, it allows reflection and dialogue in terms of equality (Cruz 2016; Herrera et al. 2019).

Control: this phase of the project seeks to incorporate and standardize the changes made previously. In other words, once the solution has been found to improve the performance of the system, it is necessary to ensure that the solution is maintained over a period (Saeid et al. 2017).

Control chart: it is a graphical tool whose function is to visualize indicators of a process or certain quality characteristic that is in stable condition (Gutiérrez and Salazar 2013).

2. Materials and Methods

The project was developed within the simulation laboratory of recycled plastic wood production of the Universidad Técnica del Norte. The following production conditions were considered: lack of processes, lack of specification of the product and lack of calculation of production time. The following methodology was defined:

a. Initial diagnosis of the production process of recycled plastic wood

In the first stage of this study, the first two phases of the DMAIC methodology are developed:

Identification of the problem: in order to execute the first phase of the methodology, the voice of the client (VOC) tool will be applied to the addressees of the final product. For this, it will be necessary to conduct interviews with those involved, and thus be able to give answers to the following questions: Who is the client? What does the client do? What does the client say? What does the client need? and What are the critical actions that the client requires? At the end, a VOC matrix will be constructed with the information obtained to identify the problem.

Then, the process will be characterized through the SIPOC matrix with the working group made up of operators, production leaders and area managers. Where to identify: activities, inputs and outputs of the process. This will diagnose the number of operators and production lot of the recycled plastic wood process. Finally, the production time will be defined by means of a Gantt diagram. As a result, the standard time for processing recycled plastic wood will be obtained. And it will be analyzed the quantity of lots that can be elaborated in each activity of the process within a production shift.

Measurement of the capacity of the process: first the size of the sample will be determined. In this case, as it is a simulation laboratory, Gutierrez and Salazar (2013) criteria will be considered. It considers a sample of 50 products for a slow process that produces few products per day. Then data will be collected to calculate the capacity indices: *Cp, Cpk, Cpl, Cpu, Pp, Ppk*. All will be calculated by the Minitab tool, to ensure the reliability of the calculation.

b. Improved production capacity of the recycled plastic wood process

In the second stage, the next two phases of the DMAIC methodology will be developed:
Root cause analysis: in this phase, tool 5 Why? will be used, which will be carried out with the help of the working group that in this case is made up of: team leaders and those responsible for the process. This will consider key questions that help identify the root cause of the problem. In addition to this, a cause-effect diagram will be constructed with the working group, where the root causes of the elements of the process will be identified. At the end, a matrix will be constructed with the root causes identified in the 5 Why? and cause and effect diagram versus the defined action plans.

Implementation of the improvements: in this phase it is defined how and when the proposed improvements will be carried out. For this, the planning matrix will be elaborated, which will record: action plans, execution time and those responsible for compliance. After this, the defined planning will be executed in order to evaluate the results.

c. Analysis and evaluation of the results obtained in the production process of recycled plastic wood

In the third stage, the results will be evident after the implementation of the improvement and the last phase of the DMAIC methodology will be applied.

Control of improvements: in this last stage a new study of production time will be developed to calculate the standardized time of the process after the improvements. After this a new analysis of production capacity will be made after the improvement considering the indicators in phase two. Finally, the results will be followed up with control charts ($\bar{X}$-R). With this, the fulfillment of the production time will be evidenced or adjustments to the process will be defined and implemented if necessary.

3. Result

Next, the development of the DMAIC methodology is presented according to the objectives set to improve the capacity of the wood plastic production process:

a. Initial diagnosis of the production process of recycled plastic wood

Identification of the problem: Table 2 presents the VOC matrix of the recycled plastic wood production process, in which the customer's requirements are detailed.

Table 2. VOC Matrix of the recycled plastic wood production process

No	Parameter	Result

1	Customer identification	Recipients of the products
2	Diagnostic of the client	Few final products are made per day
3	Key problem of the client	Excessive waiting times for the final product
4	Critical customer requirement	Redduce waiting times for the product Increase production capacy

From Table 2 it can be indicated that the problem is excessive waiting times for the final product. Because the wood plastic manufacturing process produces very few products per day. So, the customer requests, reduce waiting times and increase production capacity.

The number of operators in the process is 8, these are distributed as follows: 2 operators are responsible for the activity of raw material selection, 4 operators perform the crushing of raw material and 2 operators are responsible for the last three activities mixing, molding and compacting. The production batch is a sheet of plastic wood, which is systematically transformed in each activity of the process, where the production time was determined.

Production time: Figure 1 shows the sequence of standardized times for each activity of the production process, by means of a Gantt diagram.

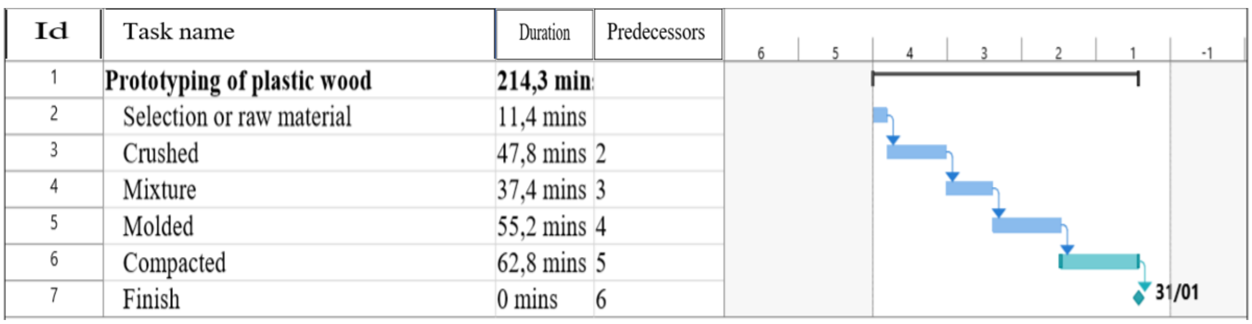

Figure 1. Sequence of standardized times by activities of the elaboration process.

From Figure 2, all the activities and their predecessors can be observed, with the standard time calculated for each of them. As a result, a production time of 214.3 minutes is obtained to produce a wood plastic sheet. The production time consists of: 11.1 min. for raw material selection (post-consumer polymers and vegetable fiber), 47.8 min. for crushing, 37.4 min. for mixing elements, 55.2 min. to mold the mixture, and to finish 62.8 minutes for compacting the melt. Based on the above, it can be concluded that the selection and crushing process processes process 8.14≈8 lots with a sheet of plastic wood for one shift/day. While: mixing, molding and compacting can only process 3,08≈3 batches with a wood plastic sheet for one shift/day.

Measurement of process capacity: Table 3 presents the capacity indicators (standard time variable) of the recycled plastic wood production process.

Table 3. Capacity indicators of the recycled plastic wood production process

Current capacity of the process	
Time variable	
Indicator	Value
Cp	0,91
Cpk	0,49
Cpu	0,49
Cpl	1,31

Table 4 shows the result obtained for the potential capability index and the actual capability index <1, based on Table 1 the process is defined as class 3. This means that it is not suitable for the job and an analysis is necessary, as the process requires serious modifications to reach a satisfactory capacity. The capability index for the upper specification *Cpu<0,49*. This represents that there are problems in the upper part (there are excessive times to what is tolerated) and it is necessary to make modifications. Regarding the lower specification index (*Cpl*) it is important to point out that there are no problems, since *Cpl >1,33*. It is therefore considered that the process meets the minimum production time. Figure 2 presents the capacity report of the recycled plastic wood process that consists of distribution graph and capacity analysis.

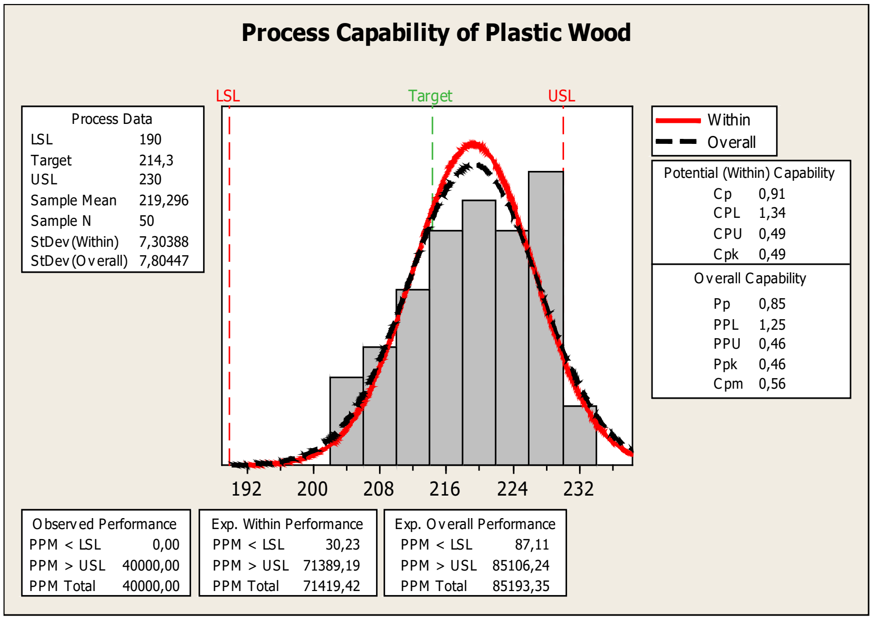

Figure 2. Recycled plastic wood process capacity report.

Figure 2 shows that the process is not able to operate within the defined time limits. This is because there are data that are not within the tolerated limits. The process has a general capacity *Pp<1*. This indicates that the process is not meeting the production time specification. The potential capacity within the process *Ppk <1*, which indicates that eventually data will be obtained outside the standard process time specification.

b. Improved production capacity of the recycled wood plastic process

Phase 3, root cause analysis: Table 4 presents the development of 5 Why? in the production process of recycled plastic wood.

Table 4. Development of 5 Why? in the production process of recycled plastic wood.

No	5 Why?	Answer
1	Why does the standard time of the process have high variability in the upper limit?	Because, the mixed, molded and compacted activities are not able to respond to the capacity of the raw material selection and crushing activities.
2	Why does the mixing, molding and compaction activities have low response capacity?	Because there is a mold not suitable for the last three activities.
3	Why is there a mold not suitable for the last three activities?	Because there is not an adequate number of molds, with high reception capacity.
4	Why do not we have an adequate number of molds, with high reception capacity?	Because the standard design and quantity of the process is maintained
5	Why is the standard design and quantity of the process maintained?	Because there is a lack of redesign and construction of suitable molds.

Table 4 shows the identification of the main root cause of the production process of recycled plastic wood by means of 5 Why? Therefore, the standard time of the process has high variability in the upper limit *Cpu=0,46*. Defining as root cause the lack of redesign and construction of adequate molds. This cause will be combined with the root causes identified in the cause-effect diagram.

Cause-effect diagram: Figure 3 shows the cause-effect diagram of the wood plastic production process. Where the main causes that cause high production, times are presented. And they generate a *Cpu = 0.49* with respect to the standard time resulting from Phase 2.

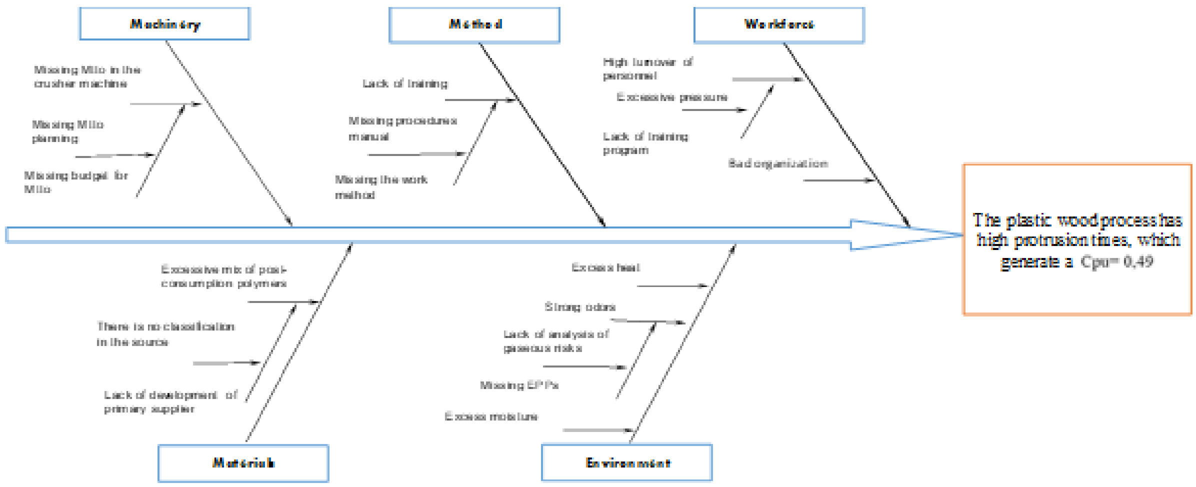

Figure 3. Cause - effect diagram of the wood plastic production process.

Figure 3 shows the main causes that generate variability, therefore, they do not comply with the production time calculated in Phase 2. Of the root causes identified, in the variability of materials we have the lack of development of primary or base suppliers. This will not be resolved in the project, since it is outside the borders of the organization. We therefore suggest supplier development projects to mitigate it. The other root causes including that of exercise 5 Why, with their respective action plans is presented in Table 5.

Table 5. Root causes vs. action plans of the recycled plastic wood process.

No	Root Causes	Action Plans
1	Missing budget for Maintenance	Assign budget for maintenance Implement maintenance
2	Missing work method	Elaborate procedure
3	Lack of training	Instruct procedure
4	Missing EPPs	Buy and provide EPPs
5	Lack of redesign and construction of suitable molds.	Design and build new molds

Phase 4, implementation of improvements: Table 6 presents the planning matrix for the implementation of the improvements. Which is defined within three months where those involved executed the relevant action plans.

Table 6. Planning matrix for the implementation of improvements.

No	Action plans	Month 1	Month 2	Month 3	Accountable
1	Assign budget for maintenance	X			Plant manager
2	Implement maintenance	X	X		Maintenance manager
3	Elaborate procedure		X		Group leader
4	Instruct procedure			X	Group leader

5	Buy EPPs	X			Plant manager
6	Provide EPPs		X		Group leader
7	Design of new molds	X			Maintenance manager
8	Construction of new molds		X		Maintenance manager

Table 6 shows that the proposed action plans were complied with. Maintenance was implemented in the wet mill to improve its efficiency in post-consumer polymer grinding. The procedure was elaborated and instructed to everyone involved in the production area. Appropriate EPPs was provided for molding and compacting activities. To finish, more moulds were designed and built based on the maximum tolerated capacity of the moulding furnace. As a result, the raw material reception capacity was improved four times with respect to the previous mold.

c. Analysis and evaluation of the results obtained in the production process of recycled plastic wood.

Phase 5, control of improvements: Figure 4 shows the production time after implementation of the improvements. In the sequence of standardized times by activities of the elaboration process, by means of a Gantt diagram.

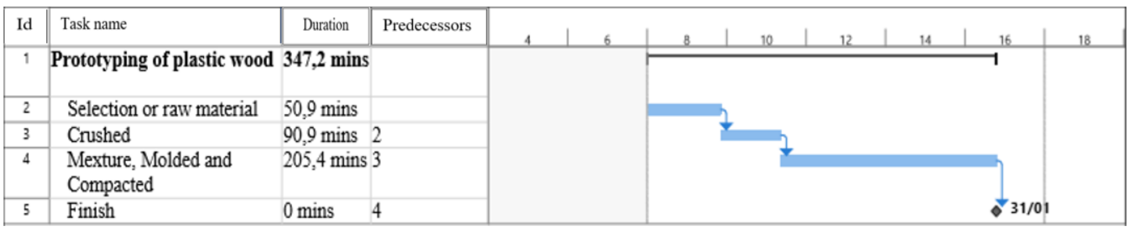

Figure 4. Sequence of standardized times by activities of the elaboration process after the improvements.

Figure 4 shows the new production time of the process in 347.2 minutes to produce two sheets of wood plastic. This new time consists of: 50.9 min. for raw material selection, 99.9 min. for crushing and 205.4 min. for mixing, molding and compacting. In the latter, the improvement is eradicated, since having more moulds reduces the waiting time. And the last three activities sequentially produce two sheets of plastic wood, 63% larger than the previous one. This translates into a 19% improvement in production time of wood plastic sheets. Based on the new production times it can be said that the process selects and shreddes 3,38≈3 production batches with 2 sheets of wood plastic for a shift / day. While the following three activities; mixing, molding and compacting process 2,33≈2 production batches with 2 wood plastic sheets per shift/day.

Improved process capacity: Table 7 shows the indicators of production capacity after the improvement. These represent the behaviour of the process in the short term, after the implementation of the action plans.

Table 7. Indicators of production capacity after improvement

Current process capability	
Time variable	
Indicator	Value
Cp	1,09
Cpk	0,99
Cps	0,99
Cpi	1,20

Table 7 shows that the result obtained in *Cp>1* and based on Table 1 it is determined that the *Cp* of the process is now class 2. This means that it is partially adequate to meet the production time specifications. In addition to this it requires a strict control to maintain the improvements. The *Cpk<1* defining the centering of the process as class 3. What is interpreted as not adequate and requires serious modifications to improve this indicator. *Cps* improved, however, is still <1. This means that problems still occur in the upper part (there are excessive times to what is tolerated). Regarding *Cpl*, it is important to point out that there are no problems since *Cpl <1* and the process is considered adequate and meets the minimum production time.

Next, in Figure 5, the capacity report of the wood plastic process (improved), the graph corresponding to the capacity analysis is shown.

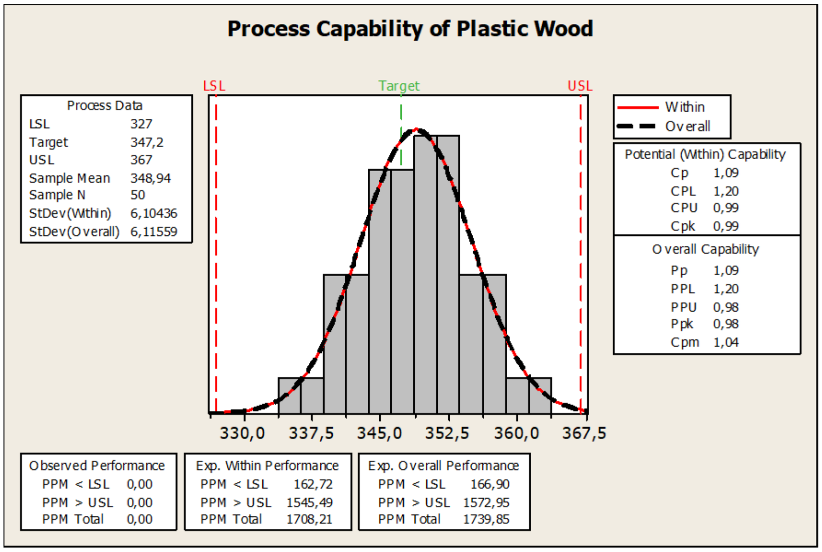

Figure 5. Capacity Report of the Wood Plastic Process (improved)

From Figure 5 it is determined that the process is not capable since there are data that are not within the specification limits. In addition, it indicates that the process now has an overall capacity (*Pp*) of 1.09 which has been improved. However, it is still below 1.33 which indicates that the specifications are not being met. In addition, the result of the potential capacity within the process (*Ppk*) is 0.98 which is < 1 and indicates that eventually data will be obtained outside the process specifications.

Control of the improvements: in order to maintain the improvements implemented, monitoring is applied to the process every month and according to the results obtained, possible opportunities for improvement will be identified. Next, Figure 6 presents Graph X_R of the recycled plastic wood production process. Through this tool the process will be monitored by the working group to identify and adjust possible variations in production time.

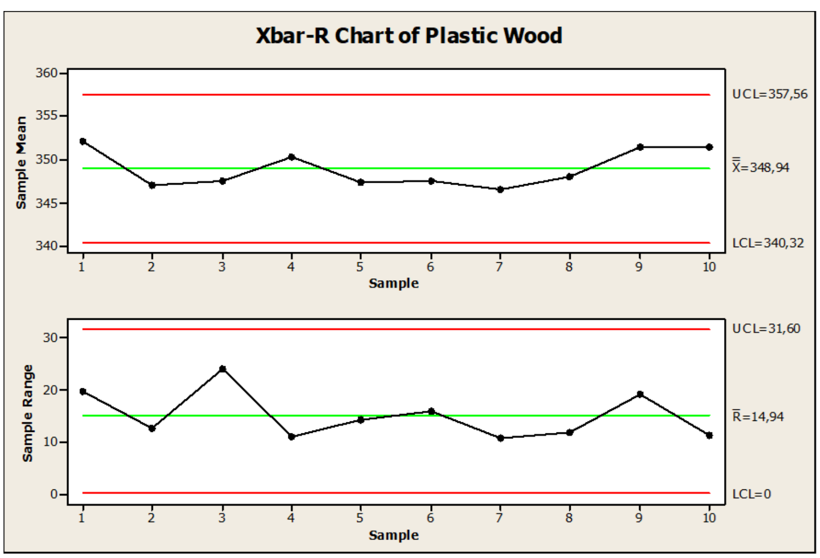

Figure 6. Graph X_R of the production process of recycled plastic wood.

Figure 6 shows the data obtained after the improvements, and it can be observed that the production time is within *UCL=357,59*; *LCL=340,29* with an average of 348,94. This means that production times remain relatively similar with the stated objective of 347.2, thus the process average is stable. If these parameters vary, the use of this tool will make it possible to identify when and why changes were generated in the process.

4. Discussion

The discussion will be based on comparative tables before and after the implementation of the DMAIC methodology. Table 8 indicates the factors before and after the improvements in the wood plastic production process.

Table 8. Factors of the before and after improvements in the wood plastic production process.

Factors	Before	After
Production time (min)	214,3	173,6
Units / Lot	1	2 (63% larger)
Production / Shift	3	4
Mold	1	2 (63% larger)
Lack of maintenance	-	Maintenance carried out
Lack of procedures	-	Defined procedures
Lack of training	-	Training
Missing EPPs	-	Provision of EPPs

From the above table it can be concluded that the results after the implementation of improvements and these are: the production time decreased from 214.3 min to 173.4 min. The production lot is now composed of two units. The production capacity during a shift/day went from 3 to 4 sheets of recycled plastic wood with a size of 63% larger than the previous one. Maintenance was performed on the shredder, now the procedures of the process are defined and complies with the training to those involved. With respect to the capacity indexes of the process, Table 9 presents the summary of before and after indicators of the improvements.

Table 9. Total summary of before and after indicators

Capacity of the process before the improvements		**Process capacity after improvements**	
Time Variable		Time Variable	
Indicator	Value	Indicator	Value
$\boldsymbol{Cp}$	0,91	Cp	1,09
$\boldsymbol{Cpk}$	0,49	Cpk	0,99
$\boldsymbol{Cps}$	0,49	Cps	0,99
$\boldsymbol{Cpi}$	1,34	Cpi	1,20

With respect to Table 9 it can be indicated that thanks to the application of the Six Sigma DMAIC methodology the potential capacity index (*Cp*) increased by 0.18 and now this indicator has a value >1. It determines that the process is now capable of carrying out its production in the established production time. However, in order to achieve this, a strict control is required since there is still variability in the data obtained. With respect to the *Cpk* index there is also an improvement since it increased 0.50 which indicates that the focus of the process has improved. The result of the capability index for the upper specification (*Cps*) is still < 1. However, it is important to mention that this indicator went from 0,49 to 0,99 which indicates that the variability in the upper specification limit decreased considerably. The lower specification index (*Cpi*) despite having decreased is still maintained >1 which indicates that the process meets the minimum production time.

5. Conclusions

With the elaboration of the process that intervenes in transformation of recycled polymers into prototypes of plastic wood, the times required in each activity of the process were determined, resulting in a production time of 214,3 minutes to make a sheet of plastic wood. By implementing DMAIC the production time is 347.2 minutes to make two sheets (63% larger), which indicates that process time decreased by 19%.

By increasing the production capacity, it was achieved a production of 3 sheets of plastic wood to 4 during a working day, this indicates an improvement of 25% in its production.

With the analysis of the results obtained before and after the process, it could be concluded that the higher capacity index improved from 0,49 to 0,99. However, it is not within the established limits as it is lower <1. This is since there is still a lack of knowledge of the working method and the operation of the machinery on the part of new operators.

The application of the Six Sigma DMAIC methodology for any type of organization is very useful since it allows an exhaustive analysis of the process and in this way to identify and implement improvement opportunities that adjust the production process.

It is suggested that future researches define strategies and methods to improve the capacity indicator >1. For this purpose, it is recommended to analyze the variability of the labor force in the productive process, due to the high turnover rate of plant workers. This leads to new hiring and poor training in the method of work and use of machinery.

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