Waste reduction in a toast production line using Six Sigma Methodology

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Abstract
The application of improvement methodologies such as Six sigma enables companies to achieve better performance and quality in their processes, products or services. This paper presents the case of a multinational company in the food industry in Colombia, where a Six sigma project was developed to reduce waste from a production line of toasts. Each one of the DMAIC process phases are developed and evaluated, in order to identify the principles causes of waste in the process. Finally, a 0.5% waste reduction is achieved with the solution presented, producing approximate savings of 136`594.834,4 millions of Colombian pesos per year. Thus, it is shown that Six sigma is a strategy that provides engineering tools and statistical techniques that allows solve organizational problems satisfactorily.

Keywords
Six sigma, quality, waste percentage, Lean production, DMAIC process, engineering tools, statistical techniques.

1. Introduction
Nowadays, there are several improvement tools that companies can use to achieve high levels of efficiency and effectiveness, one of these is Six Sigma methodology, a strategy focused on improving the understanding of: customer needs, business system, productivity and company's financial performance (Kwak & Anbari, 2004) . In recent years, Six Sigma has transformed into a flexible method applicable to any aspect in organizations, it has been used as an initiative to improve processes, increase staff skills and change the organizational culture (Siddiqui, Ullah, & Thaheem, 2016), that is why the implementation of this methodology has generated a great impact on quality management of processes, products or services of big companies around the world.

The purpose of the article is to present a case in which Six Sigma methodology is implemented for reducing waste in a toasts production line. The company in which the project was developed, is a multinational dedicated to the manufacture and commercialization of bakery food, its purpose is to have high production at low cost, maintaining a higher quality level in its products and production processes. Currently, the company has different production lines for each type of product they offer, the project will focus on the line of toasts, in which the percentage of waste exceeds the maximum limit established by the company and this also affects the efficiency of the production line. Thus, by applying Six Sigma methodology it will be provide a viable solution to optimize the production of toasts in the company and reduce the current waste.

2. Methodology
For the development of the project Lean Six Sigma methodology was implemented, it consists in the continuous improvement of processes in organizations, it focused on reducing variation, eliminating defect and improving quality in products, processes and services (Cudney & Kestle, 2011).

The Lean Manufacturing philosophy was first introduced in the 1990s from the production system of Toyota, is a methodology based on offering products and services, in the right quantities, with the appropriate quality level and just in time (JIT), looking for companies to have an immediate and effective response if any change in customer requirements and demand is presented (Gómez Botero, 2010). Basically, the focus of Lean Manufacturing is reducing cycle time and waste in processes (Furterer, 2009).

Moreover, the concept of Six Sigma was originated in the 1980s in Motorola, the implementation of this methodology allowed the company to win the Malcolm Baldrige National Quality Award (Pyzdek, 2003). Six Sigma focuses on solving problems by applying statistical tools, the purpose is to reduce defects and variations of the critical variables in order to achieve 3.4 defects per million opportunities in product design, production and administrative processes, this is equivalent to have an efficiency in processes of 99.99966% (Gutiérrez & De la Vara, 2009). The methodology is developed in five steps defined and standardized in the DMAIC cycle (George M. L., 2002), the purpose of each step is described below:

- ***Define.*** It is determined the problem in the company, the scope of the project and the process to be study improve.
- ***Measure.*** The information of the current state of the process is obtained and evaluated, as well as the measurement system is validated.
- ***Analyze.*** The information collected to identify the principal causes of the problem is studied.
- ***Implement.*** The improvement proposals are identified and prioritized. Pilot tests are designed and implemented and new process are documented.
- ***Control.*** The results of the pilot tests are evaluated and implemented, the changes are managed in the process and also a control plan is developed to ensure long-term improvement.

3. Results

The results obtained in all stages of the methodology are presented below.

3.1. Define phase

Currently, the company that has been studied has a performance indicator in each production line for the finished product out of specifications, called “waste percentage” as well as they have an indicator for the finished product out of specification and product that is swept from the floor, like bread crumps, called “sweep percentage”. From the information provided in monthly reports used by managers in the factory, it was observed that the waste percentage of the toasts line is lower than the target set by the company, however, in interviews with experts it was discussed that this information does not reflect the current status of the line. The difference between the actual figures and the figures used by management, arises because the methodology for collecting information is inappropriate, due to the fact that operators responsible for the measurement and report of waste. not always record the amount of waste in the control formats used for this purpose. For this reason, and in order to have the correct data to measure the actual performance of the waste in the line, the need for a measurement that reflects the reality on an accurate way emerged. In Chart 1, it can be observed the difference mentioned between the data handled by the company and the information taken from the measurements of kilograms of waste:

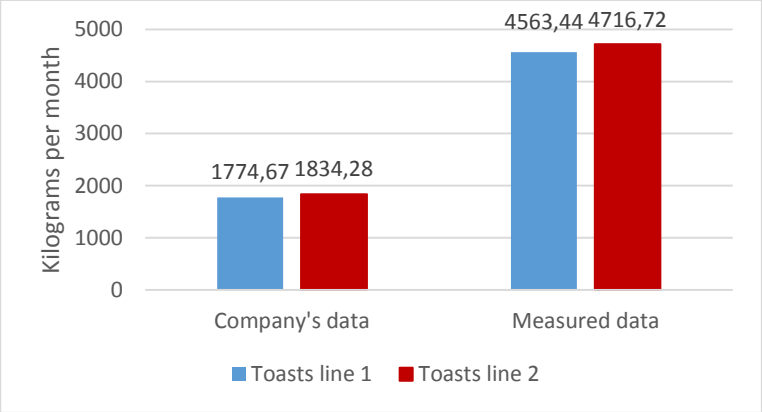

Chart 1. Comparison in kilograms per month of the collected and the company information.

Based on the measurements taken, it was evident that the line has a waste percentage higher than the target set by the company for the production of toasts, this reflects that there is a considerable amount of waste and therefore the line is not efficient enough. It is important to clarify that the toasts line has two independent production lines, called "Toasts 1" and "Toasts 2", so the company has waste indicators for each one of these. The company aims to reach 1% of waste, however, the indicator of waste in toasts lines 1 and 2, estimated from the measurements taken, is 1.35% and 1.14%, respectively. Thus, the relevance of the project for the company is justified and it is evidenced the need to reduce the amount of wasted toasts. It is important to clarify that, in this case, waste is understood as the amount of toast, in kilograms, that have to be reprocessed to produce bread crumb. Therefore, income received by the company from selling toasts are higher than the income received from the sale of bread crumbs, even the company has higher production costs for reprocessing waste. Thus, the importance of reducing waste lies in the fact that the company can save 136`594.834,4 million Colombian pesos per year, if the waste indicator on both toasts lines is decreased by 0.5%, this is equivalent to reduce the amount of waste in 1268 kilograms per month for Toasts 1 and 1310 kg per month for Toasts 2. That means, that with the development of the project, the goal is to have a 0.85% and 0.64% of waste for toasts lines 1 and 2, respectively. Then in Chart 2, it will be seen the current and expected level of waste in kilograms per line:

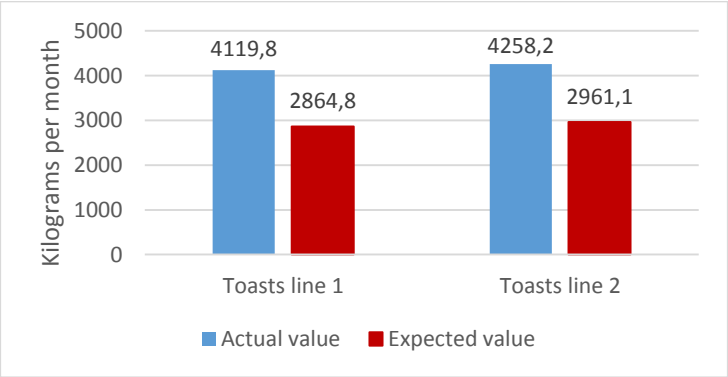

Chart 2. Actual and expected amount of waste in kilograms per month for toasts lines 1 and 2.

To have a better understanding of the production of toasts process that is being studied, it is shown and explained the map of high-level process (George M. , 2005):

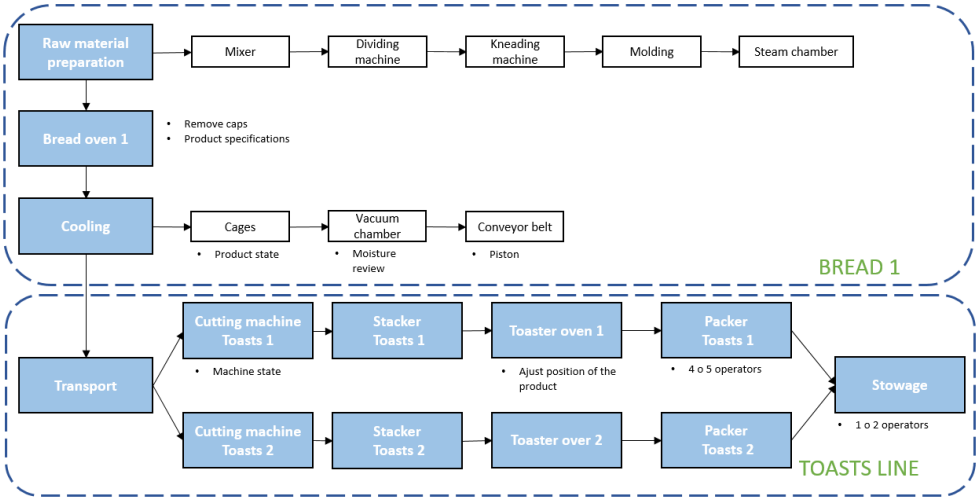

Chart 3. High level process of the toast production line.

From Chart 3, it can be seen that the process of production of toasts begins with the production of breads in line Bread 1, this process starts with the preparation of raw material and once the amount of ingredients is selected, they pass through the mixer where they are mixed, then the mixture passes through the divider, there the dough is separates into several dough portions, each portion passes through the kneading machine, where there are kneaded and flour is poured to the masses. Subsequently, these are placed in molds of breads, pass the steam chamber, where the action of yeast is turn on. Then the molds enter to the oven and once the bread baking is finished, all breads are loaded into cages where there are grouped together to be transported and passed through the vacuum chamber, here about a 4% of moisture is extracted from the products. Cages is the term used in the factory to make reference to carts that facilitate breads transportation. Then, the cages are unloaded and breads are placed on a conveyor belt that takes them all to the toasts line and that is how the bread production process in the Bread 1 line finished. While the breads are transported to the toasts line, these go through a cooling process on the conveyor belt, which then is divided into two, to take breads to the toasts lines 1 and 2. Breads first pass through the cutter, where each bread is cut into 18 slices, then they go through stackers, these machines locate the slices on a conveyor belt that take them to the toaster oven, after the slices are totally roasted and cooled, they reach the packing area where the corresponding packaging is set. Finally, toast packages are stowed to be transported to the dispatch area.

3.2. Measure phase

According to the detailed observation of the toast production process and the data collected of waste in the toasts lines, it was possible to assess the current state of waste in the process, and also the existing system of measurement was validated with the purpose of finding an improvement opportunity. Thus, in order to establish the way how data should be collected, first the operational definition was developed (John & Meran, 2008) at which it is defined the variable "Y" as the amount of waste in kilograms of toasts production lines 1 and 2. In regard to this variable, the goal is to take measurements of some particular factors that are related to that variable and those are: the products reference "X_1", the point in the line where waste are generated "X_2" and the waste feature or causes of waste "X_3". Chart 4 shows in detail the operational definition:

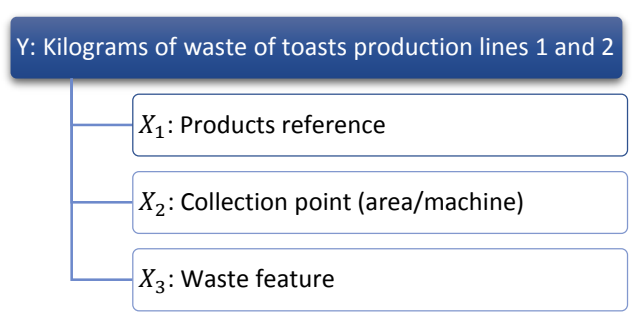

Chart 4. Operational definition of the kilograms of waste of the toasts production lines 1 and 2.

3.2.1. Data collection plan

Taking into account the detailed operational definition presented above, it was designed a data collection plan to measure the performance of different aspects as: the kilogram of waste produced at certain points or areas of the line for each product reference and each toasts line and the frequency of waste for each cause and product reference in different areas of the whole line. In this way, for each aspect it was defined how and when the data should be collected, also it was specified the amount of information and the use that will be given to it. It is important to clarify, when speaking about the points of the line, it make reference to the places where waste is collected, those are: the packing area, the stackers area and the Bread 1 line. In the same way, speaking about the product reference it refers to the type of product that is produced, these are: whole wheat and butter toasts.

The data collection plan for each aspect mentioned is shown:

- The data of the amount of kilograms of waste produced at certain points of the line for each product reference, is obtained weighting on a scale 140 cages that contain waste and are taken to reprocess product out of specifications to produce bread crumbs. This information is obtained to stablish the current level of waste, identify critical points where the most of the waste are produced and quantify waste by reference.
- Information about the frequency of waste by cause and reference, is obtained based on the observation of the process of 120 cages of breads and the count of the times a waste is produced by certain cause and product reference. In this way, the cause of most waste in the line should be determined.

The information gathered from the collection plan mentioned above, will be analyzed in the next phase of the methodology.

3.2.2. Measurement System Analysis

Once initiated the data collection the measurement system was validated, for this purpose an analysis of repeatability and reproducibility was performed in order to estimate the degree of precision and the measurements stability when these are taken by the same object in similar and variable conditions (Gutiérrez & De la Vara, 2009). Three different operators were involved in the analysis, they weighed 10 cages, each one in a different order. The results of the study are shown below:

Table 1. results of the analysis of repeatability and reproducibility.

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	1,427	0,54
Repeatability	1,427	0,54
Reproducibility	0,000	0,00
Part-To-Part	265,209	99,46
Total Variation	266,636	100,00

Source	StdDev (SD)	Study Var (6 × SD)	%Study Var (%SV)
Total Gage R&R	1,1945	7,1668	7,31
Repeatability	1,1945	7,1668	7,31
Reproducibility	0,0000	0,0000	0,00
Part-To-Part	16,2852	97,7115	99,73
Total Variation	16,3290	97,9740	100,00

Number of Distinct Categories = 19

According to Table 1, the results show that the measurement system is acceptable, the R & R% or the rate of accuracy/tolerance is 7.31%, which means that the measuring cages with waste has an excellent quality, because the variability that provides the way the measurements are taken is less than 10% (Gutiérrez & De la Vara, 2009). Even the variability associated with the measurement process is only 0.54%. Thus, it can be concluded that the measurement system is reliable.

3.2.3. Process Capability

In order to evaluate the ability of the toasts production process, to accomplish the specifications of waste on the line, an analysis of process capability (John & Meran, 2008) was performed, in which the lower specification limit it is 0% monthly waste and the upper specification limit is 1% of waste per month, this is equivalent to have 101.5 kilograms of waste per day. The results obtained from the analysis of process capability are shown below:

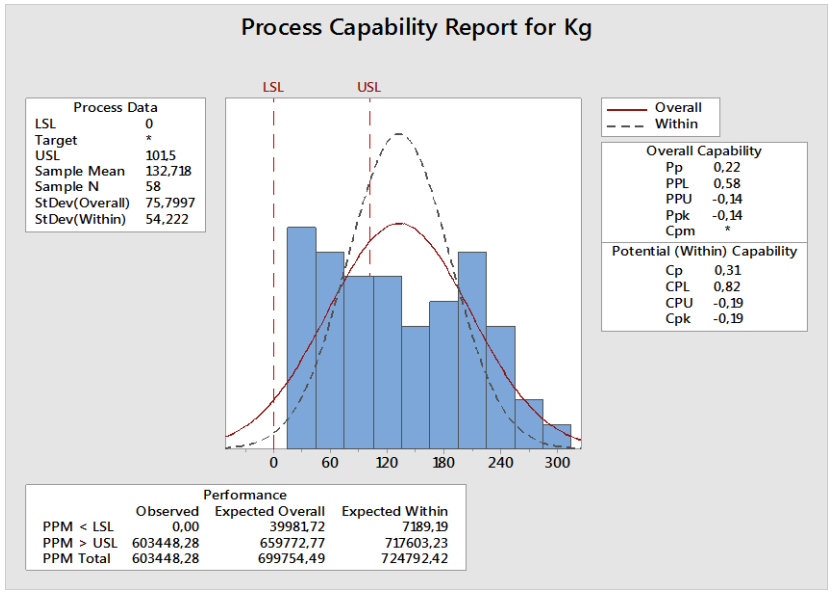

Chart 5. Results of the analysis of process capability.

Chart 5 shows that the rate of potential capacity C_p of the process is equal to 0.31, this means that the level of quality of the process is inadequate, reflecting that the process is not considered potentially able to accomplish the specifications about the level of waste in the toasts production line. In addition, in the short term, and based on the observed results it is estimated that the process would have a percentage of waste out of the specifications of 60.34%, which is equivalent to having a number of defects per million opportunities of 603,448.28.

3.3. Analyze phase

3.3.1. Analysis of the data collected in measure phase

From all data collected of the kilograms of waste that were generate in both toasts lines per day, it was expected to obtain information about the product reference and the collection point in the line that had the greatest amount of waste. Likewise, it was expected to know the cause why more waste is generated frequently. Thus, the following analysis shows that information.

In assessing the factor of the product reference, it was found there was recorded on average 108.9 kilograms of waste per day and 142.8 kilograms of waste per day for whole wheat and butter references. It was also found that the factor of the product reference, does have an impact on the amount of kilograms of waste in toasts lines 1 and 2, this is reflected in Chart 6, there can be observed that there is a difference between the daily average of waste kilograms of butter and whole wheat references is significant, because the intervals bars does not overlap. Also, in Table 2, the statistical analysis performed to evaluate the factor of "Product Reference" is shown:

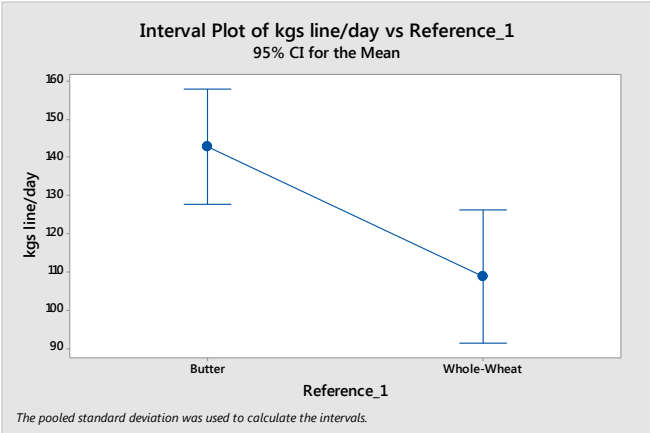

Chart 6. Interval plot of the kilograms of waste per day for each reference.

Table 2. ANOVA of the product reference factor.

One-way ANOVA: kgs line/day versus Reference_1

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Method

Null hypothesis         All means are equal
Alternative hypothesis  At least one mean is different
Significance level      α = 0,05
Equal variances were assumed for the analysis.

Factor Information
Factor       Levels  Values
Reference_1       2  Butter; Whole-Wheat

Analysis of Variance
Source        DF  Adj SS  Adj MS  F-Value  P-Value
Reference_1    1   39198   39198     8,40    0,004
Error        138  644104    4667
Total        139  683302

Model Summary
S    R-sq  R-sq(adj)  R-sq(pred)
68,3185  5,74%      5,05%       3,00%

Means
Reference_1   N    Mean  StDev       95% CI
Butter       80  142,75  69,78  (127,65; 157,86)
Whole-Wheat  60  108,94  66,31  ( 91,50; 126,38)

Pooled StDev = 68,3185
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By studying the factor of location, which refers to the point on the line in which most of waste are collected, it was found that about 53% of waste are given in the packing area, so in this case the point on the line where a larger amount of waste is collected is the packaging area (see Chart 7). This happens because in the packing area a thorough inspection of the finished product is made, while in the other areas waste is collected only when there are failures that stop and affect the process.

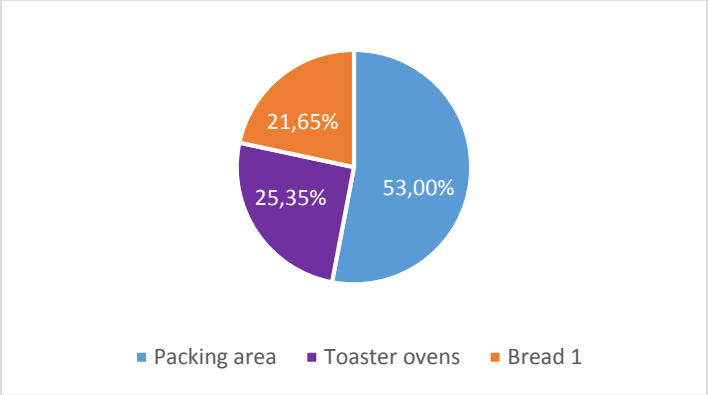

Chart 7. Percentage of waste in kilograms per day in each collection point.

Finally, to determine potential causes of waste, a frequency diagram of causes was developed for each reference. According to the graphs 8 and 9, for whole wheat references, 48% of the times that waste had been generated because of damaged product, 30% per product bad toasted, 16% per product that was outside the specifications for size and 5% by defective product. Also, for reference product butter, 45% of the time that casualties had been maltreated, 39% for evil roasted product, 9% per product out of the specifications of size and 7% by defective product. In this way, it can be concluded that most of the waste is produced by damaged product.

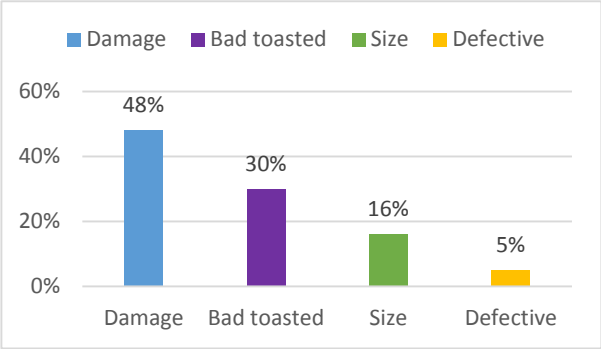

Chart 8. Frequency of causes in whole wheat reference.

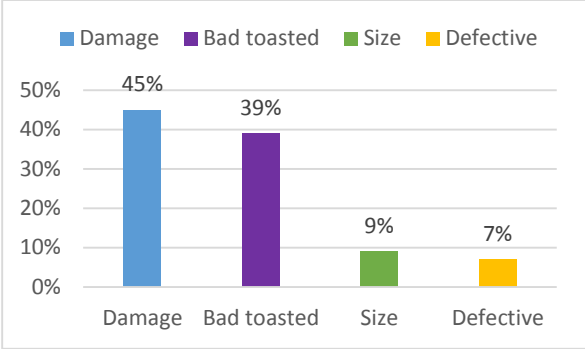

Chart 9. Frequency of causes in butter reference.

3.3.2. Prioritize causes

To obtain more information about damaged product and to prioritize the causes that have a greater impact, a failure of modes and effects analysis (Carlson, 2012) has been done. The following failure modes where the ones that present the highest risk priority index: 1) Toasts damaged, bad toasted and with an inappropriate size, 2) Damaged breads because they are broken, scraped or sunk and 3) Damage toasts because breads are wet when they arrived at the stackers.

The failure mode of toast damaged, bad toasted and with an inappropriate size, is given as a result of toast stuck in the stackers, it was observed that this is where originally toasts are damaged, because toast deformed for getting stuck. Thus, when discussing with line supervisors and seeing that damaged product was the most frequent cause, it became clear that this was because the breads, from which toasts are cut, came damaged from Bread 1 line. Also, sometimes these breads arrived with high humidity, which make toasts get attached to the stackers and waste is produced by damaged product. Undoubtedly, this failure mode is directly related to the other two failure modes that also had a high risk priority index, so it was decided to continue the analysis of other failure modes to find the main cause of damaged products and waste.

Regarding to damaged breads it is evidenced that this failure mode is generated by the handling of breads in the vacuum chambers area. There breads that get out of the oven in Bread 1 line are load into cages, they are transported to the vacuum chambers, where the product loses certain moisture percentage and after this process, the breads in the cages are unloaded and finally transported to the toasts line. It is important to mention that this whole process is done by operators. Thus, when loading and unloading breads from cages, operators have to manipulate them and sometimes they exert too much force on them or stumble breads upon the cages borders, which generates deformed product because bread is broken, scrape or sunk. Considering this, data of the number of damaged bread in the loading and unloading of the cages is taken and it was obtained the following results:

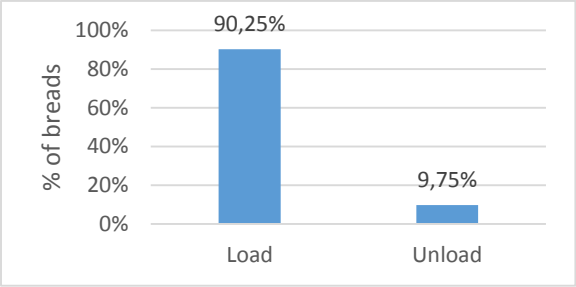

Chart 10. Percentage of breads that are damaged in the vacuum chambers area.

According to Chart 10, it can be seen that the 90.25% of total bread evaluated, are damaged when the cages are loaded, thus it is determined that this process is a principal cause that generates waste in the toasts production line.

Moreover, the failure mode in which toasts are damaged because breads are wet when they arrived to the stackers, is caused because as it was mentioned above, breads with high humidity make toasts get attached to the stackers. To see why this occurs, it must be verified that breads are really losing a 4% of moisture when they pass through the vacuum chambers, thus, the verification was carried out by two methods: in the first method measurements of breads weight in grams were taken before and after they go through the process on the vacuum chambers. Thus, the percentage of moisture lost was calculated by the weight difference; and in the second method samples of five grams of various breads were taken before and after the process on the vacuum chambers, in order to measure the humidity of these in the laboratory. These measurements were taken only for butter reference, because according to the results obtained in measure phase, this reference is the one with higher waste per day. It is necessary clarify that the company has two products for this reference, "Product A" and "Product B". Thus, the results of method 1 and 2 are shown in Charts 10 and respectively.

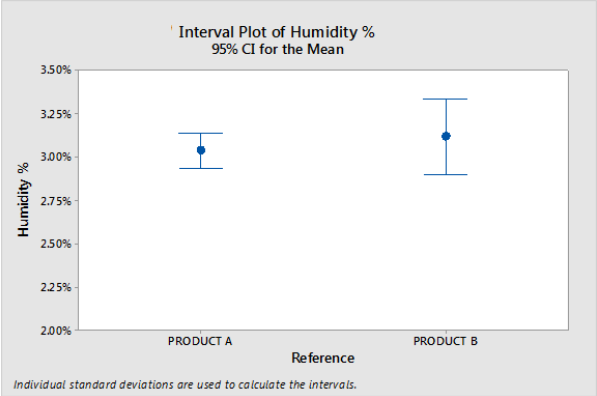

Chart 11. Method 1 interval plot of the percentage of moisture lost for each butter product.

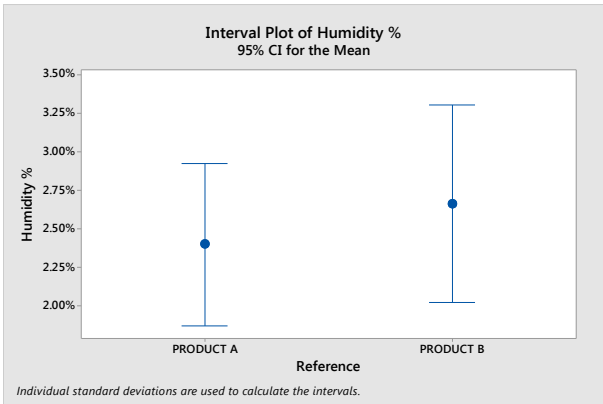

Chart 12. Method 2 interval plot of the percentage of moisture lost for each butter product.

Results of method 1 show that for the "Product A" and "Product B" the percentage of moisture lost on average is 3.04% and 3.12%, respectively. Also, results of method 2 present that the “Product A” lost 2.40% and “Product B” a 2.66%. This reflect that breads are not losing at least 4% of moisture, so this specification is not accomplished. Therefore, high humidity in breads is another principal cause of waste in toasts production line. Then it is necessary to modify the parameters of the vacuum chambers, according to the humidity specifications handled in the factory for breads, but when this situation was discussed with supervisors, they claimed humidity specifications for breads had not been established in Bread 1 line. Thus, in order to set the parameters of the vacuum chambers correctly, it was estimated an appropriated moisture percentage range that produce the lowest amount of waste for damaged toast that get attached to stackers. This moisture percentage range was estimated by taking 100 samples of 5 grams of breads of butter references, before and after they entered the vacuum chambers. Those bread samples were weighed before and after they were put into a laboratory machine that extracts moisture from the bread, so that, with the weight difference the humidity percentage of each sample was calculated. Then, in order to know the amount of waste for damaged toast, 100 samples of breads of different moisture for each butter reference, were taken and passed through the stackers and damaged toasts were counted to calculate the waste percentage for each sample. The moisture percentage was obtained using curves which shows the average percentage of moisture that breads should have to reduce the amount of waste. These curves were done for “Product A” and “Product B” of butter reference, there are shown below:

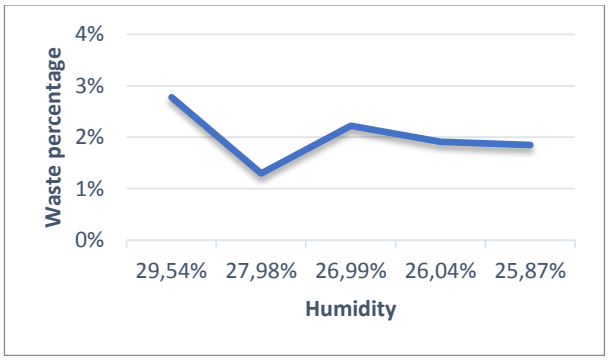

Chart 13. Humidity curve for "Product A".

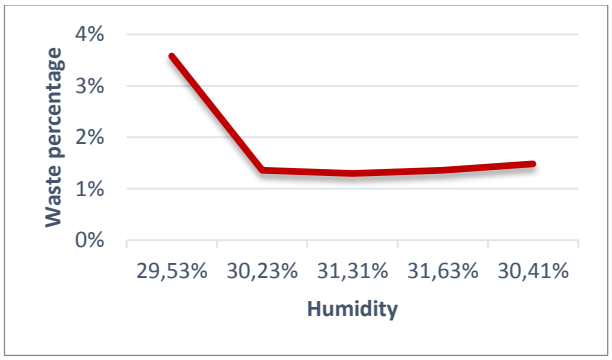

Chart 14. Humidity curve for "Product B".

From Charts 13 and 14 it can be observed that, for "Product A" of butter reference, the average moisture that produces less waste is about 27.98%, with an estimated range between 26.07% and 30.49% and "Product B" the average moisture that produces less waste is about 30.23% with an estimated range between 28.14% and 33.49%. Thus, it is recommended to adjust the parameters of the vacuum chambers according to the estimated moisture ranges to ensure the humidity of the outgoing product of Bread 1 line.

3.4. Implement phase

In this phase there are presented the solutions proposed for the two main causes: 1) Damage product by manipulation in the process of unloading the cages and 2) high humidity in breads that arrived to stackers, with the purpose of reducing waste in the toasts production line.

3.4.1. Improvement proposals

In order to identify the improvement proposals that should be implemented the impact and effort matrix (Pyzdek, 2003) was performed. To develop this matrix, it was discussed with line supervisors the benefit or impact and the effort that could be obtained by the implementation of each proposal. Then, it was concluded that the proposals that should be implemented because they require less effort and generate a greater impact or benefit for the company, are shown below:

Change the position in which the breads were located inside the cages: This proposal is focused on reducing the force exerted by operators on breads, when they handle them when cages are unloaded. Actually, breads are located in groups of 14 (see Figure 1) and the idea is to placed breads in groups of 7 (see Figure 2) so is less the amount of breads that operators have to hold. Therefore, they exert less force on them because less weight must be lifted, in this way, the amount of damaged product is reduced.

Figure 1. Current position of breads in cages.

Figure 2. Proposal for the position of breads in cages.

Establish a quality control plan of outgoing breads of Bread 1 line: In order to reduce the amount of waste generated in the toasts line by bread that arrived damaged from Bread 1 line, this proposal was developed and it basically consists on showing operators images of damaged bread that should not be sent to toasts line and images of breads in good

condition, in this way, operators will be aware of been more careful when handling the products and also they would be more strict regarding to the breads quality. By the way, the amount of damaged breads that arrived to the toasts line is reduced and therefore waste in the entire toasts production decrease.

Modify parameters of the vacuum chambers according to the estimated specifications of moisture: This proposal was developed in order to reduce waste generated by the high humidity of breads. The parameters that can be modified are: 1) the temperature which breads have after getting into the vacuum chambers, this parameter can be changed because if the incoming temperature of the breads is higher, the water extraction is better, therefore, the machine will be more efficient; 2) the pressure at which the breads are exposed within the vacuum chambers, changing this parameter can make breads be a longer time at low pressure, this make the extraction of moisture greater and 3) the time that cages remain inside these machines.

3.4.2. Pilot tests

In the first place, to measure the impact that had the change of the position of breads in the cages, data of the amount of damaged breads by implementing this proposal was taken. Chart 15 shows that the amount of damaged breads decreases by the implementation of this proposal, showing an improvement of 20.13%.

Moreover, in order to evaluate the impact, that should have the implementation of the quality control plan in Bread 1 line should have, there was taken data of the waste for damaged and undamaged bread of the "Product A" and "Product B" of butter reference. Looking at the Chart 16, it can be concluded that it is very important to send breads in good condition to toasts line, because to "Product A" this reduces the amount of damaged toasts in a 95.05%, while for the "Product B "the improvement is 91.58%.

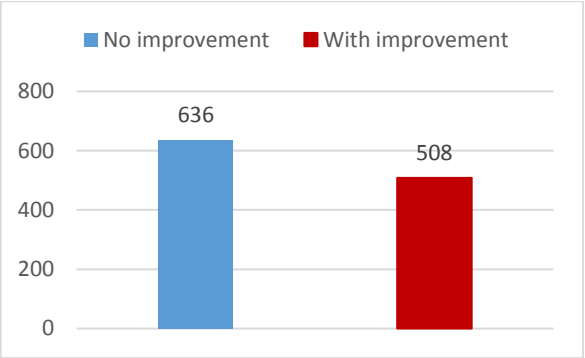

Chart 15. Amount of damaged bread implementing the change of breads position.

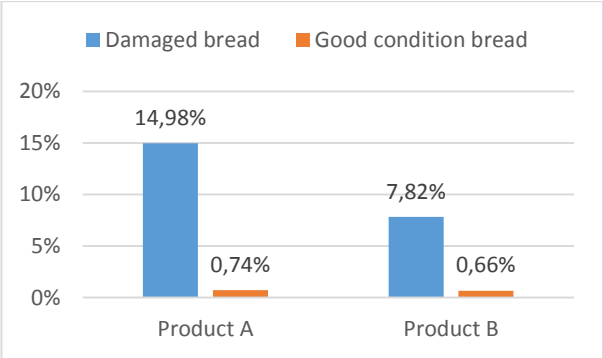

Chart 16. Waste percentage for damaged and good conditions breads.

Concerning the modification of the vacuum chambers parameters, the implementation of this proposal must be reviewed with the line experts, in order to set the pressure, temperature or the adequate time to obtain breads with the estimated average range of humidity. Thus, the improvement presented is reducing waste because there would be less toasts stuck in the stackers.

Finally, the improvements of each proposed solution must be documented and methods of support should be developed to complete the control phase and thereby ensure an improvement implementation of these methods in a long-term.

4. Conclusions

- ✓ Reducing the percentage of waste by 0.5%, generates savings of approximately 136`594.834,4 million Colombian pesos per year.
- ✓ According to the statistical tests made, there is a significant difference between the means of whole wheat and butter product, butter reference present 34.34 kilograms of waste per day with regard to whole wheat reference. Therefore, it is concluded that most waste are presented in butter references.

- ✓ For butter and whole wheat references, respectively, 45% and 48% of the times that waste was produced was for damaged product, leading to the conclusion that the most frequent cause that justifies the greatest amount of waste is damaged product.
- ✓ From the analysis done two main causes of the problem of waste that presents the toasts line, were identified: handling the product in the area of the vacuum chambers and high humidity of the outgoing product Bread 1 line.
- ✓ To solve the product being damaged by the handling of it in the area of the vacuum chambers, the change in position of breads in groups of 7 should be implemented, because this proposal reduces the amount of damaged breads in a 20.13%. In addition, the quality control plan of outgoing breads of Bread 1 line must be implemented, because it reduces the amount of damaged toast in a 95.05% for "Product A" and 91.58% for "Product B".
- ✓ A solution for high humidity of outgoing breads of Bread 1 line, is to modify the parameters of the vacuum chambers, in order that for "Product A" of butter reference, the humidity percentage fluctuate in a range between 28.14% and 33.49% and for "Product B" the humidity percentage should be in a range between 26.07% and 30.49%. Thus, waste can be reduced for butter reference product which leads to having fewer waste in toasts production line.
- ✓ For the company it is recommended to have more control over the report of daily waste.

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