Increase of the Production Lines' Performance in a Chewing Gum Confectionery

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Abstract

This paper presents the improvement efforts to increase the major performance indicator of the production lines in a chewing gum confectionery. Extensive knowledge of the system under study was acquired through the analysis of the current situation of the system and all the variables involved. With this analysis, it was possible to determine the most influential root causes that prevented a better performance. Having identified the main four root causes, six different strategies were designed and established, which were implemented with their respective control method. The results of the case showed that after only the four months of the project, an increase of 9.45% in the performance indicator was achieved; resulting in a historical record of production rate in the plant.

Keywords
DMAIC, chewing gum production, synthetic performance index, production line improvement.

1 Introduction
The chewing gum confectionery plant, in which this project is developed, is located in Santa Catarina, Nuevo Leon, Mexico. Its products have a presence in nine American countries, with more than 10 commercial chewing gum brands. The four lines, the subject under study, process chewing gums of one specific flavor each in one presentation: 4-Pellet (packages that contain four chewing gum pellets). With a total demand increase of 186% from 2015 to 2018 and almost doubling the market share in the same period, the production rate is now approaching their capacity; meaning that the need for improvement in the productivity of the lines is evident. Therefore, an investigation of similar projects such as those of Sánchez (2018), Puentes (2018) and Chavero (2017) –where strategies for continuous improvement of production lines were carried out– was made.

1.1 Problem Definition
Before defining the problem, a brief description of the process and the performance indicator of interest is presented.

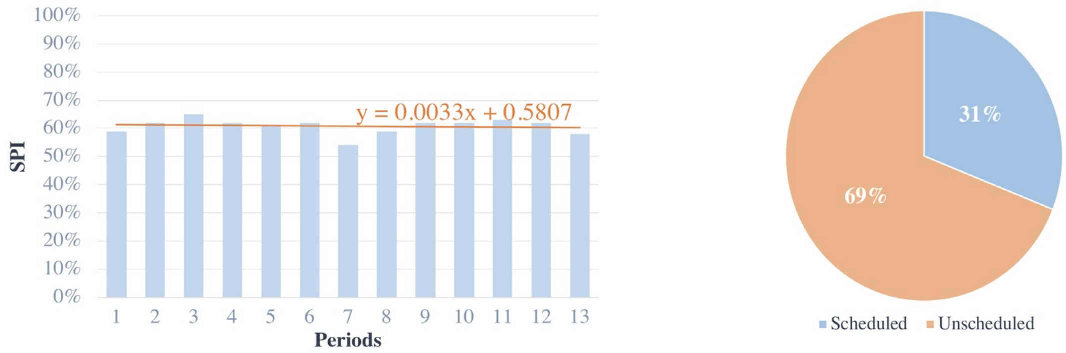
Process Description. The raw material is received from the US. Once the bulks arrive –each one consisting of 500 kilograms of chewing gum pellets–, the packaging process is carried out at the confectionery plant. The process, which is pictured in Figure 1, has five stations where the sorting, wrapping, counting, packing and palletizing processes are executed. In the sorting area, a bulk of raw material arrives at the sorter station, where the inadequate chewing gum tablets, or pellets, are filtered, while the approved ones pass through a metal detector and then a machine operator is responsible for manually removing the pellets identified as non-compliant. In the wrapping station, the packing process is carried out, where the 4-Pellet packages are formed. Then, at the counting station, an operator is responsible for assembling displays –which contain 40 packages of 4-Pellet each–, that later will be supplied by the counting machine. Then another operator is responsible for closing the displays and placing them in the packing station, where the displays are covered with polyolefin.

Subsequently, an operator puts 24 displays in a corrugated box. Finally, the boxes are moved to the palletizing station, now ready to be distributed.

Figure 1. Chewing gum process flow

Synthetic Performance Index. The Synthetic Performance Index (SPI) is the main effectiveness performance indicator used in the plant. It is calculated obtaining the percentage of planned hours in which a line was working (i.e. planned hours minus shutdowns, whether scheduled or not). Compared to the General Equipment Efficiency (OEE), the SPI takes into account the acceptable finished products made against the total amount of finished products that could have been produced in the time the plant is open; while the OEE takes into account the acceptable finished products made against the total amount of finished products that could have been produced in the time the machine has a workload. The OEE is recommended if what is sought is to observe the performance of the machine, on the other hand, the SPI is recommended if what you want is to assess what could be done if there were always orders. The SPI indicator has been used as a key element in the development of other similar projects, for example, in the cosmetic industry, the authors Caro and Ortiz (2013), used the indicator comparing their real situation against the objective SPI. In this case, the Lean Manufacturing philosophy was implemented to reduce times for unscheduled shutdowns. First, an analysis was conducted to determine the existing types of unscheduled shutdowns. Once identified, the ones with the greatest impact on the SPI were cataloged and prioritized.

Problem description. Given the current demand, it is required for the four lines to be running with an SPI of at least 70%. The Figure 2(a) shows that the average SPI in 2018 was of 61% with almost no improvement at all. Besides, the plant set a goal of achieving an SPI of 75% to be authorized for a new line installation in 2020.



(a) (b)

Figure 2. (a) SPI during the first 10 periods of 2018 – 4-Pellets; (b) Proportion of shutdowns duration in 2018 – 4-Pellets.

The four lines of 4-Pellet have scheduled and unscheduled shutdowns affecting the SPI. The reduction or elimination of unscheduled shutdowns would generate a positive impact on the SPI. Scheduled and unscheduled shutdowns are cataloged in the items described below.

Scheduled shutdowns:
- Training and Meetings: Training or meetings for personnel.
- Lunch: When part of the personnel has lunchtime and there is no personnel available for replacement.
- Cleaning: When shutdowns are made for cleaning the lines.
- Startup: Time it takes to start the machine.
- Trial: When tests are done.
- Maintenance: When some type of maintenance –usually preventive– is given to the machines.

Unscheduled shutdowns
- Breakdowns: Regarding any machine breakdown.
- Lack of Personnel: Lack of personnel to complete a shift.
- Short Stops: Regarding any adjustment made to the machine.
- Lack of Semifinish: It is given when for some reason the amount of necessary pellets is not received, due to a missing order.
- Managerial Loss: Unplanned events.
- Quality Loss: Regarding any defective feature in the pellets, for example, deformities of any type and dimensions smaller or larger than those specified.
- Speed Loss: When you have part of the personnel in training and the shifts are not complete.
- Utility failure: When there is a lack of an external resource such as electricity or water.
- Maintenance: When unplanned maintenance is given to the machines.
- Material Changes: When material changes are not considered.

1.2 Objective
The general objective of this project is to design and implement improvement strategies that allow the plant to increase in eight percentage points the average SPI of the four lines of 4-Pellet.

After looking at the data of each of the thirteen periods of 2018 –each consisting of four weeks– obtained from the database generated by the plant, it was noted that the total of unscheduled shutdowns during production represented a 66%, equivalent to 4,624 shutdowns during the year, while scheduled shutdowns represented the remaining 34%, equivalent to 8,924 shutdowns during the year. Whereas, as can be seen in Figure 2(b), out of the total minutes of shutdowns during production, unscheduled shutdowns are 69%, equivalent to 187,187 minutes per year and the scheduled shutdowns are the remaining 31%, equivalent to 410,317 minutes per year. Meaning that, both in frequency and in time, unscheduled shutdowns are those with the greatest negative impact on the SPI. Also, because unscheduled shutdowns are the ones that must be decreased or eliminated, it was decided to focus on them to achieve the increase in the SPI. Based on a Pareto analysis of the type and impact of the shutdowns for each of the four lines, the following specific objectives were proposed:
- Reduce 83 hours the time lost due to Short Stops.
- Reduce 64 hours the time lost due to Material Changes.
- Reduce 51 hours the time lost due to Quality Loss.
- Reduce 35 hours the time lost due to Breakdowns.

Table 1 shows the specific objectives' impact on the general one.

Table 1. Specific objectives

Shutdown type	Weight	Duration (h)*	Target duration (h)	General objective weight
Short Stops	35.63%	134	51	2.85%
Material Changes	27.47%	103	39	2.20%
Quality Loss	21.87%	82	31	1.75%
Breakdowns	15.02%	56	21	1.20%

* Time that production stops due to shutdowns of this type during the period.

2 Methodology

For this project, the process improvement methodology used was DMAIC, named for its stages' acronym: Define, Measure, Analyze, Improve and Control. It is described as a methodology for hard-engineering solutions that consider the measurement of the relevant aspects, the variance reduction of the process, and the statistical analysis as the basis for the improvement (Berardinelli, 2012). As also, it was found that Cisneros et al (2017), Zulkifli and Firdaus (2018), Sánchez et al (2018), and Ibarra et al (2019) used this methodology in successful improvement engineering projects in manufacturing lines and logistics contexts. Being a continuous improvement (CI) project, it utilizes a dedicated project team to improve a process or system typically with minimal capital investment and over a relatively short time to improve organizational performance (González Aleu and Van Aken, 2016). A scheme of the activities performed at each stage is presented in Figure 3. The first two stages, Define and Measure, were summarized in the previous section.

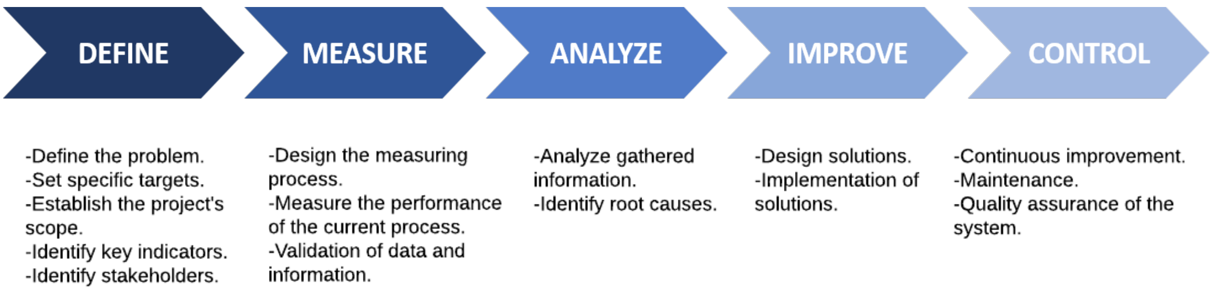


Figure 3. DMAIC Methodology Scheme

3 Analyze Stage

To develop the analysis stage, information was collected from sources such as observations, interviews and historical data provided by the plant. Subsequently, through the use of tools, such as graphs and diagrams, root causes and opportunities for improvement were determined.

First, a comparison was made between scheduled and unscheduled shutdowns during production with the internal performance database, which covers a period of one year, from January 2018 to December 2018. It was verified that unscheduled shutdowns have a greater impact in both, frequency and time. Figure 2(b) shows the proportion in time. Each line stops approximately 6 times a day due to unscheduled shutdowns, and approximately 3 times a day because of scheduled shutdowns. Both types of shutdowns can last from a few minutes to full shifts. The mean, standard deviation and sample size of each of the shutdown categories were also calculated. From a sample of 4624 scheduled stops, it was concluded that on average 40.4816 minutes are stopped for this type of shutdown of production, although it may vary by 83.4904 minutes; which says the shutdown can last only a few minutes or it can take up to two hours. Of 8924 unscheduled shutdowns, it was concluded that they last 45.9790 minutes on average with a variation of 73.6601 minutes.

There is a record of unscheduled shutdowns at a general level, as well as by line, which are reflected in the Pareto charts in Figure 4, in which it can be seen that the shutdowns with the greatest impact on time on the 4-Pellet line 1 are short stops, material changes, quality loss, and speed loss, as shown in Figure 4(a). In line 4-Pellet 2 are short stops, material changes, quality loss and lack of personnel, as shown in Figure 4(b). In line 4-Pellet 3 the main unscheduled shutdowns are short stops, quality loss, material changes, and breakdowns, as shown in Figure 4(c). And finally, in line 4-Pellet 4 are short stops, material changes, speed loss, and breakdowns, as shown in Figure 4(d).

Afterward, to find the main problems within the four lines, a deeper analysis was carried out for these unscheduled shutdowns.

3.1 Short Stops

This type of shutdown represents 25.76% of unscheduled shutdowns, which are 68.67% of total shutdowns. They last on average 38 minutes, however, they can last from 10 minutes to almost a full shift –depending on the maladjustment–. It was until this year that the causes and duration of this shutdown's type began to be recorded in greater detail.

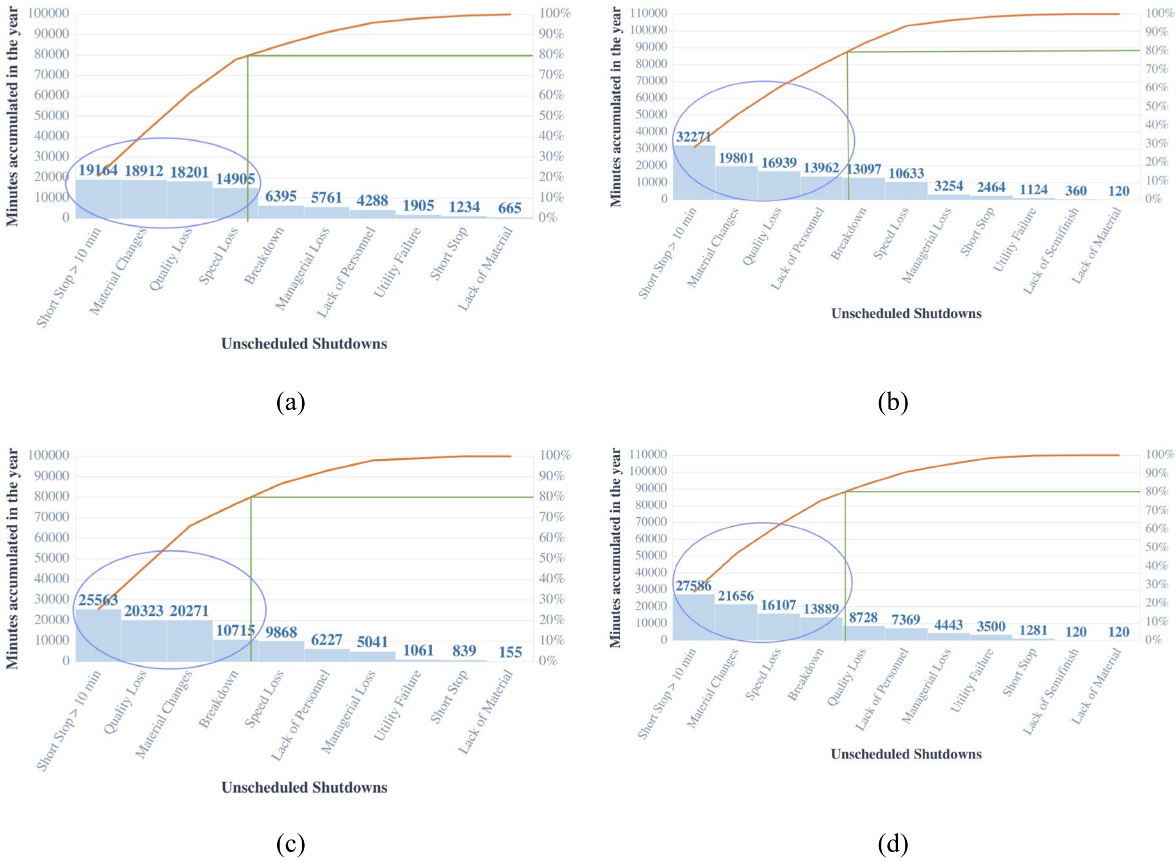


Figure 4. Pareto charts for unscheduled shutdowns during 2018 in 4-Pellet lines
(a) line 1, (b) line 2, (c) line 3, (d) line 4.

In Figure 5 we can see the spent time (in minutes) of these causes in each of the lines during the period December 31 of 2018 to February 02 of 2019. With this information, it could be concluded that the main reasons why the machine has to stop 10 minutes or more are due to failures in the label head, in the forming limits and in the final forming guides. An average of 98.43 minutes was also obtained, as well as the minimum and maximum being 10 and 584 minutes respectively.

It can be seen that lines 2 and 3 stop the production for a longer time due to short stops, since line 2 for approximately 50 hours per period and line 3 for approximately 75 hours per period to make machine adjustments.

3.2 Material Changes

These shutdowns represented 20.88% of unscheduled shutdowns in 2018. Figure 6 shows the most recurrent material changes in all lines. The behavior at each line is similar. There are two types of material changes: machine changes, which are the ribbon ink that prints the code –changed approximately 3 times per shift– and the knives used for cutting the label of the packages–changed about 4 times per shift–. While changes in consumable materials refer to the materials that remain within the product, such as the label rolls –changed approximately 13 times per shift– and the polyolefin –changed approximately 2 times per shift–.

Likewise, the average and standard deviation of each stop were obtained due to the change of material. The mean and standard deviation of ink ribbon change was obtained from a sample of 3,882 repetitions and an average of 4.3 minutes and a standard deviation of 1.04 minutes were obtained. The average change of knives is 3.39 minutes with a standard deviation of 0.84 minutes from a sample of 5,144 times. An average of 1.05 minutes and a standard deviation of 0.23 minutes from a sample of 17,446 were obtained from the rolls label change. Finally, the polyolefin change has an average duration of 7 minutes with a standard deviation of 1.53 minutes from a sample of 2,058. With this, it can be seen that the changes are short-lived since they last at least 1 minute and 7 minutes. However, the number of repetitions is high, so we will aim to reduce its frequency and not the time of the activity itself.

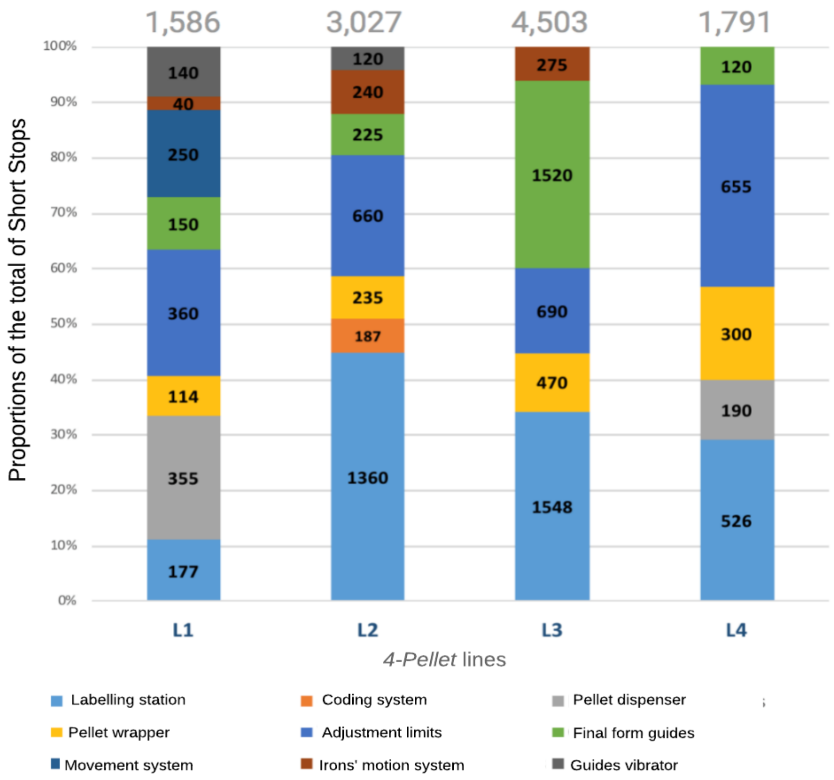
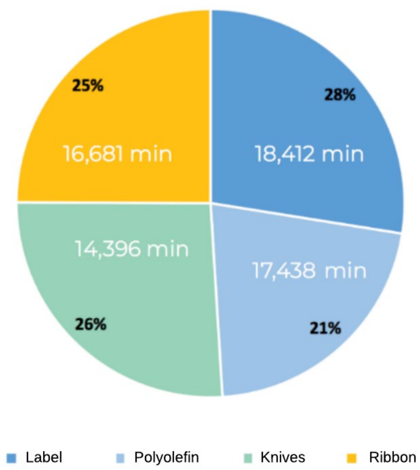
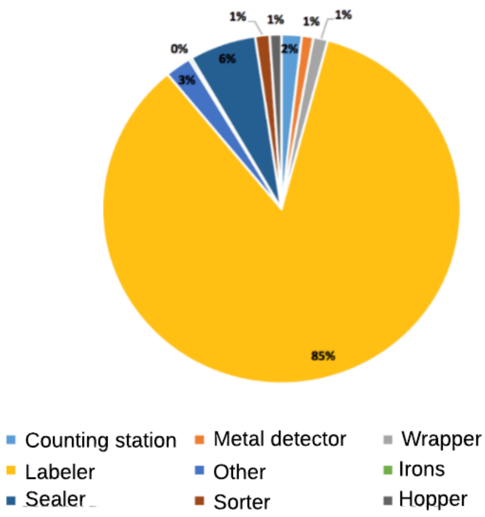


Figure 5. Causes and spent time proportion in Short stops (January 2019)





(a) (b)

Figure 6. Shutdown Causes in 2018. (a) Material Changes, (b) Breakdowns.

3.3 Quality Loss

This type of shutdown represents 14.87% of the total of unscheduled shutdowns. It was found that during 2018 the lines stopped on average 115.45 minutes per shift for non-compliant pellets, which refer to half pellets, pellets stuck together, pellets outside the dimensional specification, oval pellets, deformed pellets, rough pellets or pellets that come with a bump. These pellets cause packages to come out open, exposed, waved, malformed or with an incomplete number of pellets.

3.4 Breakdowns

They are unscheduled shutdowns referring to any machine breakdown and represent the 11.23% of unscheduled shutdowns. According to Figure 6(b), it is clear that the problem lies in the labeler machine, presenting an average of nine stops per line per period and stopping on average 122.61 minutes. However, every time they stop due to maladjustments of screws in that machine it can last between 15 minutes or up to 4 hours, depending on where the fault is and the time it takes to identify it.

3.5 Root Causes Identification

With the information collected, an Ishikawa diagram was created. This diagram is also known as cause and effect diagram or fishbone diagram, it is a tool used to help visualize a complex problem with all its elements and connections reflected at the level of detail needed (Zapata and Villegas, 2006). This diagram –not shown here– was collaboratively made with the areas of continuous improvement, production, quality, maintenance, and industrial engineering to find the root causes of the problem, obtaining a total of 105 symptoms through a 5-Why analysis. The diagram is divided into 6 branches which are labor, machinery, raw material, measurement, environment, and method. After positioning the symptoms in the diagram categories, there were found 15 root causes. Out of the fifteen root causes, four of them are the ones that have the greatest impact, so these are considered the main root causes and in which the project will focus first. Table 2 summarizes the symptoms or problems caused by these four root causes. The next four are considered problems adjacent to the root causes and they will be addressed indirectly. While solving the remaining causes are beyond the scope of the project.

To align the root causes obtained to the particular objectives previously expressed, they were related according to the way in which they are directly affected as shown in Table 3. The root cause 1 refers to the quality of the pellets and is directly connected with the particular objective 3 on reducing the time lost due to unscheduled shutdowns for quality loss. Root cause 2 over the standard settings parameters directly affects the objective of reducing the time lost by short stops. Root cause 3 talks about machine failures due to hardware, which is directly related to the particular objective of breakdowns. Root cause 4 is about efficient materials and affects the particular objective of reducing the time lost by shutdowns due to material changes.

Table 2. Main four root causes and their symptoms

Root cause	Problem
Pellet quality (1)	The 4-Pellet lines stop on average 114.44 hours per period due to non-compliant pellets, which cause problems; such as leaving the package open, exposed, with a wave, badly formed, pellets may be missing in the package or the pellets may get stuck in the guides where they pass to the packaging process.
Machine settings (2)	4-Pellet lines stop on average 183.72 hours per period because the machine in the packaging process needs adjustment during production and the machine operator does not know what measures to adjust since the confidence intervals cover a wide range.
Screws control (3)	The 4-Pellet lines stop on average 73.57 hours per period because parts are broken or exploded because the screws located in the packaging machine become loose during production.
Efficient materials (4)	The 4-Pellet lines stop on average 139.50 per period due to material changes, such as the label used to wrap the packages, the knives that cut the coil and the ribbon ink with which the code is printed on the package.

4 Improve Stage

For the process of finding solutions for each of the root causes defined in the analysis stage, a series of meetings were conducted in which the use of the brainstorming tool was held, in which representatives from different areas of the company such as production, quality, safety, projects, maintenance, among others participated. The number of participants in each meeting varied between five and seven. It should be noted that during this stage, no idea was discarded.

In order to select the solution to be implemented, among the available ideas, a prioritization matrix inspired by the The Boston Consulting Group (BCG) matrix (Mohajan, 2017) taking into account the feasibility of the solution in terms of implementation time, feasibility and resources on the y-axis, as well as its impact on the SPI indicator on the x-axis. A number scale of 0-10 was handled, 0 being the lowest and 10 the highest. The matrix hierarchically classifies previously formulated ideas according to specific criteria and helps to find the most feasible solutions. (McCain, 2011). Out of a total of 20 concrete strategies that were proposed, 6 strategies were selected to be designed, implemented, and controlled as part of the scope of this project. These strategies, their relationship with the root cause attacked and the objective to be achieved is presented in Table 3.

Table 3. Strategies are chosen to achieve the objectives

Root Cause	Strategies	Particular Objective
Pellet Quality	1. Installation of a machine before the packaging process with the ability to filter non-compliant pellets.	Quality loss
Machine Settings	2. Definition of adjustment measures for each of the 4-Pellet machines using the historical data.	Short stops
Screws Control	3. Control strategy for the adjustment of screws through the use of a format.	Breakdowns
Efficient Materials	4. Change of code printing method for 4-Pellet packages. 5. Increase in coil dimensions for pellet packing. 6. Change of the type of knife for coil cutting.	Material changes

5 Control Stage

A description of the specific action performed for each strategy is presented (e.g. implementation, documentation, experimentation, etc.), with their respective control methods to ensure that the process remains in the new direction, and the results obtained during the 6 weeks of implementation.

5.1 Strategy 1: Machine to filter non-compliant pellets.

The specifications of the machine's functionality were defined to subsequently establish contact with the supplier to define a joint design and begin manufacturing. After carrying out a series of tests and determining that the equipment was ready, on May 8th, the filtering machine was transferred to the plant and installed on May 9 and 10 on the 4-Pellet 1 line, since this was the line that presented the greatest number of shutdowns for this type of problem.

Previously, the 4-Pellet 1 line stopped 132.05 minutes on average every time there were pelet problems and this happened on average 13 times per period, so 28.61 hours of production were lost. During the implementation period, there were no shutdowns for non-compliant pellets, however, for conservative estimation purposes, the sorter is expected to have an 80% effectiveness, 22.89 hours of shutdowns in the 4-Pellet 1 line are reduced; which is equivalent to a 0.78% increase in the general SPI.

5.2 Strategy 2: Definition of adjustment measures for each of the 4-Pellet machines.

To reach a range of settings for each of the lines, information was first collected with historical data on the 16 systems that require machine settings. With this, a database was created with the adjustments and the number of boxes obtained per shift. The data was subsequently filtered, in a self-benchmark of the days on which there was a better performance. With the average of each variable, hypotheses tests and correlation analyses were carried out and preliminary proposals of ranks were tested. To adjust these ranges, the same procedure was done with the medians (instead of the averages) of the dice, thus avoiding the effects of extreme data. The ranges obtained were expressed in a documented procedure, which includes an adjustment format that must be filled before each shift.

The implementation of these formats and procedures was carried out during one week, including training, so the results were measured during the last two weeks of the implementation period. The lines stopped on average in 28 shifts per period during production and previously these stops were 98.43 minutes on average. When using the new ranges, it now takes them an average of 41.25 minutes to make adjustments of this type. That is, an increase of 106.72 hours of production per period was calculated, which is equivalent to an increase of 3.65% in general SPI.

5.3 Strategy 3: Screws adjustment control

First, the operators defined the key screws needed for the operation of the machine, as well as the tools necessary to adjust each one. With this information, washers were installed in 28 of 75 screws that needed adjustment, in the remaining 47 screws, it was not possible to install washers due to space and machine design.

To ensure that the screws do not become loose during production and avoid machine breakdowns, a control procedure is carried out to check that the screws are properly adjusted at the beginning of the shift; So a format was implemented that consists of information on the number of screws that each system has and the tools needed to tighten them, as well as a column to indicate whether or not the hardware was checked, specifying if there was a need to re-tighten them. This review is mandatory by the machine operator at the start of the shift, however, they must also record if it was necessary to adjust during production and record the observations (e.g.if the screw was in poor condition). Formats are reviewed and received by the line leader, who then delivers them to the production manager to process the information.

Previously, the 4-Pellet lines stopped on average 73.57 hours per period due to breakdowns caused by mismatches of screws, this since there were on average 9 stops of this type per period per line and each lasted on average 122.61 minutes. After implementing the procedure, it was observed that there have been no shutdowns of this type because the screws are constantly being checked and adjusted in all shifts. Therefore, as this activity takes 5 minutes at the beginning of the shift, the four lines would be stopping on average 17.33 hours per period to correct this cause. Therefore, 56.24 hours of unscheduled shutdowns on the 4-Pellet lines were reduced; which is equivalent to an increase of 1.93% in the general SPI.

5.4 Strategy 4: Change of the code printing method for 4-Pellet packages.

To reduce the shutdown due to the change of the encoder ink, a change to a laser encoder was chosen. First, the printing specifications required by the company were defined to look for options that met them. It was decided to collaborate with a supplier with whom the plant had previously worked, and after analyzing two possible options a Domino D320i laser encoder was selected and installed in the four 4-Pellet lines during the implementation period.

This laser requires cleaning in the extractor since it began to present burrs, its control is done at the beginning and half of the shift where each operator, supported by an air blowtorch, cleans the burrs from it. The control of this cleaning was annexed in the format mentioned above in Strategy 3.

When making the change from ribbon to laser, the shutdowns were reduced due to the change of ink in its entirety, that is, 44.72 hours of shutdowns - and these stops lasted on average 4.30 minutes and during the period it passed 156 in each line. However, considering that cleanings will be done during shifts, they are stopping 17.33 hours on average for the four-line period; that is, 27.39 hours were reduced in work shutdowns, which represents an increase of 0.94% in the general SPI.

5.5 Strategy 5: Increase in coil dimensions for pellet-packing.

An area of opportunity was detected by noting that the 9-kilogram coils that were used had a spare room in the machine. Therefore, taking into account ergonomic restrictions, test coils of 10 to 15 kilograms were requested. After carrying out the tests, it was verified that the 14-kilogram coils had the correct dimensions and the machine was working properly, so the procedure necessary to change the order to the supplier was held, as well as changing the specifications for the receiving of materials.

By implementing the new weight of the label coils, a total of 237 coil changes were reduced per period, which being 1.06 minutes long each is equivalent to the release of 16.75 hours of production per period by the four 4-Pellet lines; equivalent to an increase of 0.57% in the general SPI.

5.6 Strategy 6: Change of type of knife for coil cutting.

After researching the materials that the label is made of, as well as possible knife and test materials, the option of a tungsten carbide knife was found, which is significantly stronger than the brand knives that were being used previously and that lasted only 3 hours. This knife is provided by a supplier specialized in blades and cutting materials, and has a duration of 8 shifts per corner of the knife; So each machine requires only 2 knives per period.

Now four changes are made during a production period and four changes during preventive maintenance, that is, without the need to stop the machine. If each change of knife took an average of 3.39 minutes and 4 stops of this type were made per shift, 46.11 hours of production were increased per period by the four lines, which is equivalent to an increase of 1.58 percentage points in the general SPI.

Taking into account the six strategies implemented, a total increase of 9.45 percentage points of general TRS was achieved, as can be seen in Table 4.

Table 4. Summary of the impacts of the solution strategies

Shutdown	Solution	Reduction [h/period]			Impact on SPI
		Objective	Real		
Quality Loss	*Sorter*	83	22.89		0.78
Short Stops	Adjustments	64	106.72		3.65
Breakdowns	Screw adjustments	51	56.24		1.93
Material Changes	Coder	35	90.25	27.39	0.94
	Coil dimensions			16.75	0.57
	Knives			46.11	1.58
Total		233	276.10		9.45*

*Assuming all other factors remain the same.

A difference of means t-test was conducted to validate the statistical improvement. We took as first set, the values of SPI of the 13 periods of 2019, called it "before"; and as the second test, the values of the last 5 periods, right after the strategies starting running. We called this set "after". As shown in Figure 7, the results show that the SPI actual increasing was 9,80 points, a little above the 9.45 estimated; and the statistical difference was proved with a p_value < 0.001. The minimal difference (improvement) proved with α=0.05 was 6.74 points.

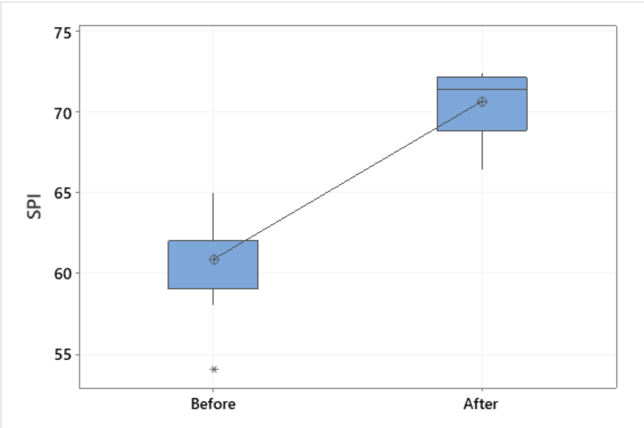


Figure 7. Boxplots of SPI before and after the strategies' implementation.

6 Conclusions

The increase of a performance indicator, the synthetic performance index (SPI) –in this case– requires extensive knowledge of the system under study, a deep analysis of the actual situation and of all the variables involved to determine the root causes of the problem in the case. With the four root causes of the case under study, six different strategies were designed and implemented with their respective control methods. The result of the case shows an increase of 9.45% in the SPI rate, assuming that all other factors are constant. The increase in the SPI is greater than the 8% goal established in the general objective. During the last production period of the study, a historical production record in the plant was broken with 10.43% above the average. In addition, a statistical improvement of 6.7% was proved.

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