Improvement of the Output of a Berries Producer Through Lean Six Sigma: A Case Study

Isidora Venegas and Mervyn Márquez
Industrial and Systems Engineering Institute
Universidad Austral de Chile
Valdivia, Chile
isidora.venegas@alumnos.uach.cl, mervyn.marquez@uach.cl

Abstract

To increase the output of a production line, it is necessary to identify the main causes of stoppages and establish measures to avoid them. This research describes the development of a Lean Six Sigma (LSS) project in a Chilean company that produces berry-based products. The aim is to increase output on dried fruit (DF) production line. A methodology based on the DMAIC cycle, and the application of principles and methodologies Lean was used. The output increase problem was divided into two sub-problems: unexpected stops and waste, based on the overall equipment efficiency (OEE) concept. The solutions focused on the cutting and selection, which are intended to maintain a stable flow of fruit throughout the process and avoid defects within the production line. The production solutions included mandatory temperature controls of the fruit to be processed, changes in the interior design of machines, application of visual management for cleaning, and action protocols. According to the results of the case study, a 42% decrease in the time lost due to breakdowns and a 50% reduction in the waste generated were obtained. In general, an increase in the output of the DF product of 9.3% is estimated.

Keywords
Six Sigma, Lean production, Continuous improvement, OEE and Output.

1. Introduction
The food industry today is characterized by production through automated online systems, where several machines or equipment are connected sequentially through transport systems to achieve simultaneous work, and therefore continuous flow production (Tsarouhas 2020). However, any stoppage or failure in any part of the line generally has effects on the entire line, which can cause high costs, loss of quality, reduction in production volume, and a direct impact on productivity. This is the case of the production of dried fruit (DF), object of study of this work, whose process includes operations of cutting, thawing, extraction, infusion, drying, oiling, and packaging, developed in automated production lines, with reduced human participation.

One way that the effectiveness of equipment on the DF production line could be measured is through the concept of overall equipment efficiency (OEE). According to this, the equipment is only effective if it is available when it is required, running at the ideal speed, and producing a result within the specifications (Kenneth 2018). The OEE model operationalizes efficiency through the analysis of six major losses, which are grouped into three categories: availability, performance, and quality. Although the OEE concept was born from total productive maintenance (TPM), it has currently been adopted as one of the lean practices (Dave and Sohani 2019, Jebaraj et al. 2015). One of the goals of the lean manufacturing environment is the elimination of all types of waste such as: space, time, energy, movements, materials, inventories, and defects. In this way, the measurement and monitoring of OEE becomes a strategy that contributes for that purpose, by evidencing some of the waste.

The detection or measurement of losses is not enough since it is only the recognition of opportunities for improvement. A research and analysis work must be developed to identify the root causes that originate one or another type of arrests or failures in the process. The Six Sigma methodology provides a very good option to carry out this research and analysis work that allows knowing the past behavior of the problem, trying to explain it from its critical variables and identifying key elements for improvement. The Six Sigma process emphasizes the use of statistical tools for the improvement or redesign of the process that impacts the result of the organization, based on a systematic approach to problem solving (Krishnamoorthi et al. 2019).

This work refers to a case study in which the Lean Six Sigma methodology was implemented to reduce the main stops in the process, based on OEE losses, and reach the production goal expected by the company in one of its products. The company is in the south of Chile, works continuously 24 hours a day, and is dedicated to the production of berries-based products. Their products include dried berries, juices, and others. The company has been presenting a high variability in the DF daily output. In addition, it has not been possible to reach the production goal of 110 thousand pounds per day. The average daily production level in the months prior to the study was 101.1 thousand pounds.

1.1 Objectives

This study aims to improve the production of DF in a Chilean berries company, based on the identification of the main types of waste present in its production line, the analysis of its causes, and the generation of customized production solutions. The objective is to reduce variability and increase the daily output by at least 10%. For the detection of losses in the production process and the increase in the performance of the process, the integration of the Six Sigma methodology and the OEE concept is proposed.

2. Literature Review

The popularization of Six Sigma is achieved in the 1990s, when AlliedSignal and General Electric companies adopt this system, which was considered different from all previous quality improvement methods, mainly due to because the previous methods did not assume the management of the companies as a fundamental part (Eckes 2004). Six Sigma refers to implementing the principles and techniques related to quality in a highly effective, rigorous, and focused way. Six sigma aims to ensure that the performance of some process is free of errors, and for this, sigma (σ) is used, a Greek letter used by statisticians to measure the variability of any process (Pyzdek and Keller 2003). Six Sigma was created to help eliminate much of the waste found in companies and its objective is to reduce variability to 3.4 defects per million units. When a specific process or a company in general, has a six-sigma level, it means that, if a million products are produced, only 3.4 of them have a defect, that is, the sigma level is a measure of customer satisfaction that seem like perfection (Eckes 2004).

One of the main characteristics of the Six Sigma methodology is the specific way in which it operates. Six Sigma is ruled by the DMAIC cycle (acronym of Define, Measure, Analyze, Improve, and Control), which consists of a standardized guideline made up of five clear and defined stages. Define: this stage must be carried out taking time to explore all the possible areas of the business that present opportunities for improvement. To do this, it is necessary to talk with workers, suppliers, clients and in general with all the stakeholders that participate in the company, since they are the ones who really know and understand the processes and their possible improvements. After having these considerations, it is recommended to make a list with the possible projects to be carried out and the project that represents the most transcendental improvement for the company should be selected. Measure: consists of calculating the current performance of the process selected in the previous phase. To do this, the measurements should focus on three areas: measurements of supplies to measure the efficiency of suppliers, measurements of the process, to measure the efficiency of the company (such as cycle time, labor, costs, etc.) and finally, measurements must be made on the product and have metrics of how much the customer's requirements are currently being met or not (Eckes 2004). Analyze: in this phase the root causes of the problem are sought. It is important to differentiate between the symptoms of the problem and the underlying reasons that cause it, since these are the ones that must be solved later (Pérez 2013). Improve: this phase will be quick, easy, and satisfactory if the team does a good job in the root cause analysis phase (Eckes 2004). Creativity should be used in this phase to find a way to do things in a better way, either in terms of costs (cheaper) or in terms of time (faster). Control: this phase is carried out to be sure that the improvement proposed in the previous phase is really working and has better performance. Two things must be considered in this phase: determine the technical method that will be used for control and create a response plan specifying what is ideal, how to measure what is currently happening and what to do if these measurements do not match (Eckes 2004).

Lean Six Sigma (LSS) is the integration of the Six Sigma methodology with the Lean manufacturing approach. Both are two different but complementary process improvement strategies that are widely used to increase productivity and profitability of the company. While Six Sigma contributes to remove defects, reducing variability and process costs, Lean initiatives contribute to reducing waste (activities that do not create value for the customer) in all processes and increasing speed. LSS is a management strategy capable increasing the performance of a process, resulting in increased customer satisfaction and financial results for the organization (Murmura et al. 2021, Sordan et al. 2020, Swarnakar et al. 2019, Muraliraj et al. 2018). Swarnakar et al (2019) specify the key factors that companies that use Lean Six

Sigma must consider achieving success in their projects. They mention four levels within the most important factors. The first and most important level refers to the commitment and support of the company's management. The second level includes the communication and participation of staff, with the support of top management. On a third scale are skills and experience, and education and training, which are related and mutually supportive. The last level incorporates the cultural change component. In this regard, Pérez-Ortiz (2016) also identifies four critical factors for the implementation of the Lean Six Sigma methodology in Latin American companies. The first refers to the support and leadership of top management (62% of the organizations consulted mentioned this factor as key). This factor coincides with the one indicated earlier by Swarnakar. The other critical factors identified are the integration of the methodology with the quality management systems; the use of information technologies for extraction and subsequent analysis; and staff training and education.

The OEE concept was developed around the maintenance and effectiveness of equipment at producing good output, recognizing that equipment is only effective if it is available when required, running at the ideal speed, and producing perfect or within-specification output (Kenneth 2018). OEE is commonly used as a key performance indicator (KPI) that measures equipment potential, identifies and tracks losses and identifies opportunities for improvement. Its calculation considers three factors: availability, performance, and quality, from the analysis of the six big losses. These losses are breakdowns, setup/adjustments, idle/stops, reduced speed, scrap, and start-up yield (Stamatis 2011). Currently, the OEE is part of the Lean tools. Any of these losses represent a disruption to normal operations leading to inefficiencies, which can increase costs that may be difficult to recover.

3. Methods

For this study, the DMAIC cycle was considered, to which an initial phase called knowledge and preliminary study was added. This phase is important to contextualize the improvement project (Añaguari 2016). Table 1 specifies the tools used in each phase, arranged according to a chronological sequence. Statistical analyzes were done using Minitab.

Table 1. Methodology used

Phase 0	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Preliminary	Define	Measure	Analyze	Improve	Control
• Meetings • Flowchart • Plant visits • Operator interviews	• Semi-structured interviews • Pareto chart • Project charter • Quality costs identification • VOC (voice of customer) • CTQ (critical to quality) • VSM (value stream mapping) • Lean waste identification • Six big loss analysis • Parameter diagram	• Internal data collection • Time series plot • Boxplot • Anderson Darling test • Other distributions test • Six Sigma metrics • Process capability • Process stability	• Pareto chart • Interviews and surveys • Cause-effect diagram • Five why technique • Equipment filling analysis • Correlation • Bin temperature analysis • Screw tank analysis • Calibration and cutoff analysis • Fines separator analysis	• Brainstorm • Evaluation and selection of ideas • FMEA matrix	• Response and control plan • Benefit verification • Project closure

As an information collection technique, the researcher's diary is used. In this way, a continuous and systematic record of events, anecdotes, informal conversations, experiences, observations, reflections, interpretations, explanations of what happens and situations of interest for research is kept.

4. Results and Discussion

4.1 Define Phase

The DF production process can be subdivided into three main lines: 1) Fruit reception line: it is responsible for cleaning and storing the berry fruit in 650 kg bins. It works only a few months a year. 2) Process line: it consists of a cutting and initial selection line, where the frozen fruit is received, cleaned, and cut according to a specified caliber. Then the fruit continues through a stage of thawing, extraction where the acidity is removed from the fruit, infusion where sweetness is added to increase its brix degree and finally drying. Here the fruit becomes DF. 3) Packaging line: it is responsible for packaging the final product in 25-lb boxes to be dispatched later.

In order to identify and quantify the activities that add and do not add value to the customer, a VSM (Figure 1) was built. In this way, the activities that add value for the customer are cutting, thawing, extraction, infusion, drying, application of oil and packaging, since they change or add something that enriches the final product. In addition, it is specified that the lead time is approximately 5 hours and a half, that is, from the time the berry enters the cutting and selection line until it becomes a packaged raisin. The goal of increasing the output of the DF production line by 10% was established to meet the speed expected by the company.

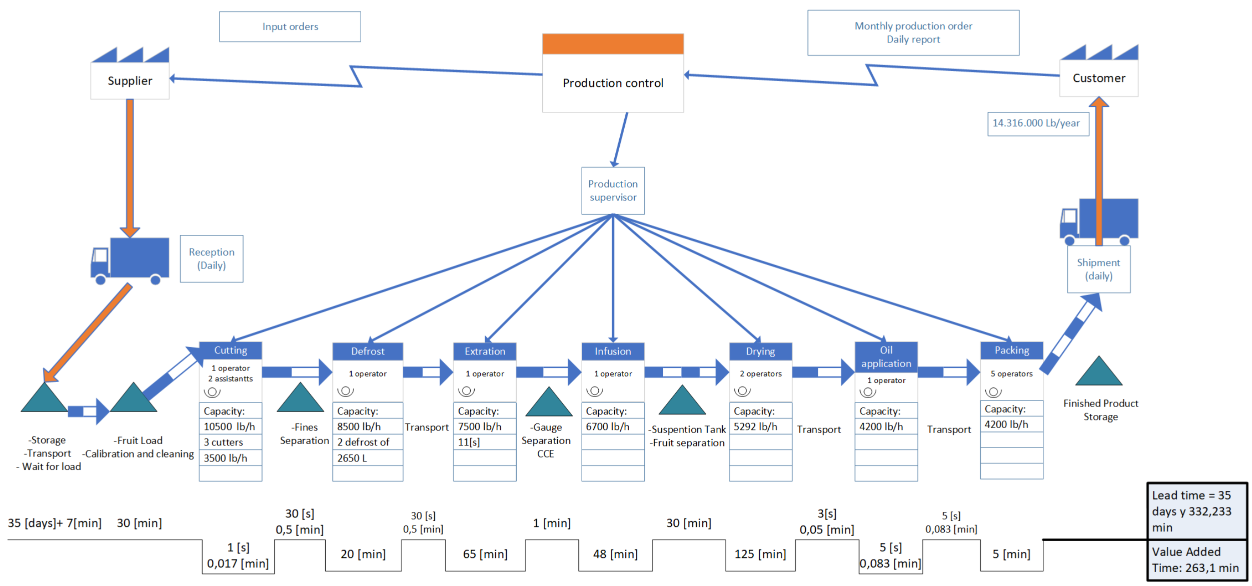

Figure 1. VSM of the current process

To guide the solution of the problem, the option of analyzing and reducing some of the six major losses raised by the OEE was considered. To quantify them, the data recorded by the company in the last three months of 2020 was used. The times lost due to breakdowns, setup and adjustments, and minor stops (less than five minutes) are recorded by the company. The reduced speed refers to the difference between the capacity of the machine and what it is processing, that is, the production time not used due to not performing at 100%. This value was calculated considering the bottleneck of the entire process, that is, the packaging line.

Referring to defective products (quality rate), three types were considered: waste, rework, and fruit under standard (SUF). Waste refers to the product that leaves the production line and must be disposed of. Rework is related to the fruit that comes out of the dryer and does not meet the expected brix degree (although it is not very far from this value), so they are removed from the line and stored in bins. SUF refers to the discard of the cutting and selection line that is reused in the juice production line. The company has records of waste, rework and SUF. However, we do not want to know how much of each one is lost, but rather how much time was lost in processing fruit that did not become a final product, to compare with the other loss times. To do this, the registered value of the company (lb. lost) was multiplied by the cycle time of the last machine where it was processed (h/lb.). Regarding start-up, this refers to the time lost from the start of the process, with all the machines stopped, until it reaches its point of stability. This last component of the six major losses was not considered since the necessary data for its calculation were not available.

The loss values indicated in Table 2 were obtained. Data from 32 days were used to calculate each one, so the accumulated values represent approximately one month of production.

Table 2. Lost time in production in hours

Availability		Performance		Quality		
Breakdown	Setup and adjustment	Minor stoppage	Reduced speed	Waste	Rework	SUF
92.35	12.53	1.19	53.57	19.75	8.93	5.39

Grouping the lost times by line, we have that the process line accumulates a lost time of 138.95 hours and the packaging line, which includes the losses of reduced speed and minor stops, accumulates a lost time of 54.76 hours. For this reason, it is decided to consider for this study the greatest losses found in the process line, which correspond to breakdowns and generated waste. Therefore, to achieve the goal of increasing output by 10%, it is proposed to reduce the times associated with the main losses identified. To find out by what percentage each subproblem must be reduced to increase output by 10%, different scenarios were calculated with possible percentage reductions for each subproblem. In this way, it is proposed to reduce the time lost due to breakdowns by 50% and the waste generated by 35%. The possible factors that affect each subproblem were specified. For this, a parameter diagram was used for each subproblem (Figure 2 and Figure 3).

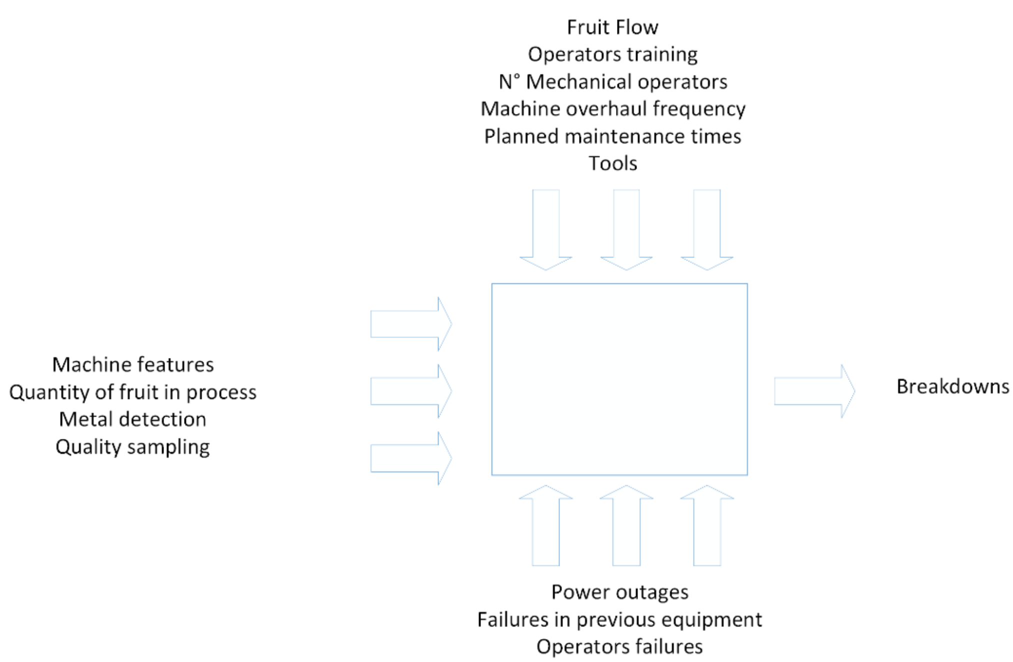

Figure 2. Parameter diagram for breakdown problem

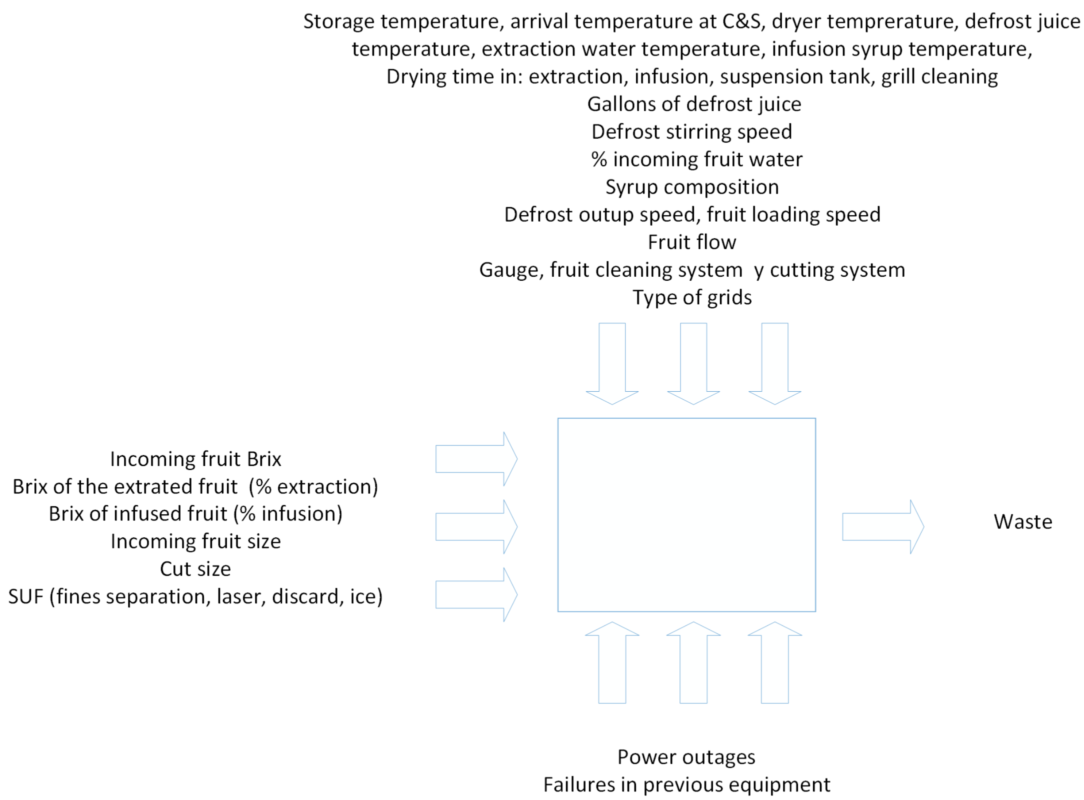

Figure 3. Parameter diagram for waste problem

4.2 Measure Phase

In order to know the status of each subproblem, six sigma metrics were used. Yield percentage, the number of defective parts per one million parts produced (PPM), sigma level and value-added percentage were calculated. Table 3 shows the metrics associated with each subproblem. Regarding the metric of percentage of added value, obtained through the VSM, it was found that the percentage of added value is 82%. This means that 82% of the process activities add value for the end customer.

Table 3. Metrics of each subproblem

Metric	Breakdowns	Waste
Yield	28%	34%
PPM	718,750	656,250
Sigma level	0.921	1.098

The results are not as expected, so each subproblem represents an opportunity for improvement. Yield percentage and sigma level are very low. In the case of breakdowns, for example, only 28% of all the data used meets the objective expected by the company. To know the current behavior of each subproblem with respect to the desired behavior, a process capability report was used. (Figure 4) For this analysis it was necessary to establish specification limits. For example, there must be a maximum breakdowns time tolerated by the company. For the calculation of these specification limits, the desired percentages of reduction of each subproblem obtained in the define phase were considered. Figure 4 shows the capacity report for both subproblems. An Anderson-Darling (AD) normality test was previously performed for both subproblems. The AD value for breakdowns was 1.518 with a p-value < 0.05, however, after testing with other distributions, the most appropriate is the normal distribution, so normality was assumed. In the case of waste, an AD value of 0.622 was obtained with a p-value < 0.096, so it is assumed that the data is normally distributed.

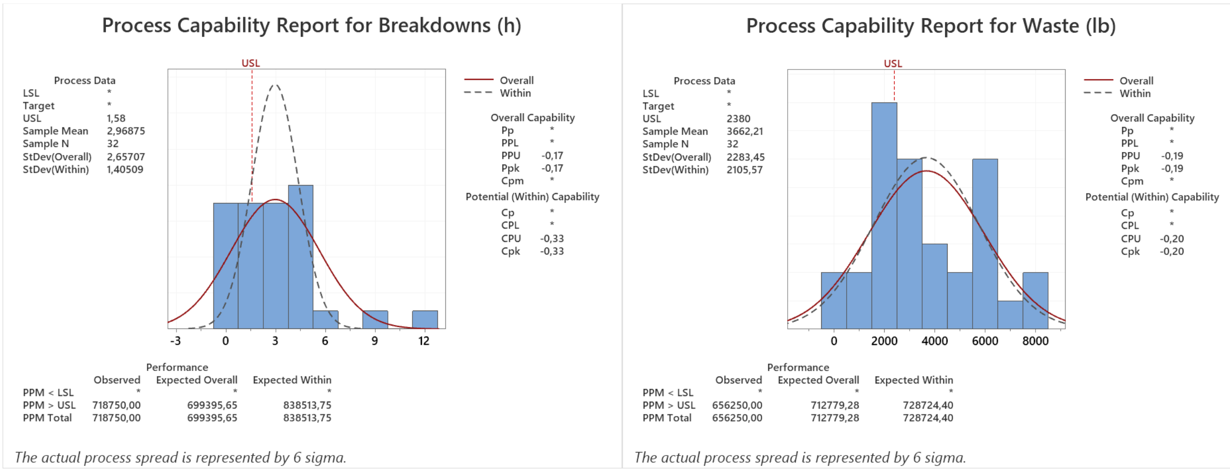

Figure 4. Process capability report for: breakdowns (left) and waste (right)

In the capacity analysis of both subproblems, there is a negative Ppk far from the target value (Ppk > 1.33). This indicates problems with media over the upper specification limit. In the case of waste, 66% of the data exceeds the upper specification limit, while 72% of the breakdowns data does not meet the upper specification according to the PPM. This means that, based on the records of breakdowns and waste, the expected goal is not met.

To know the stability of the process in terms of both data sets, control charts were made (Figure 5 and Figure 6). The control graph for the waste subproblem indicates that the variable is stable over time. In the case of the control graph of time lost due to breakdowns, out-of-control points attributable to special causes were identified. Points 10 and 11 were reviewed and correspond to a particular known cause, according to the shift reports of those days. Therefore, these points were removed from the graph, since they do not represent what generally happens on the production line. It is noted on the I-MR plot that it fails test one at point one. This failure is attributed to a special cause (top graph). In the lower graph the points fall within the control limits. In general, the breakdowns data set is not in control, as the reason for special cause failure at point one cannot be determined.

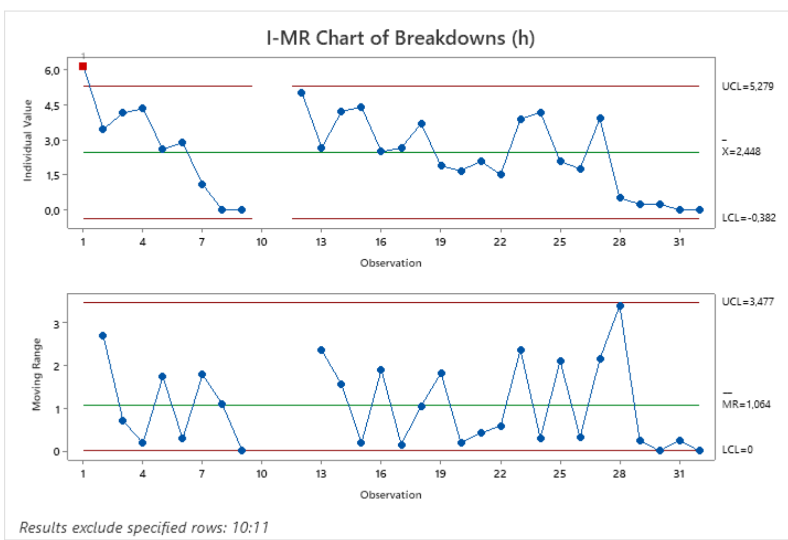

Figure 5. Control chart for breakdowns

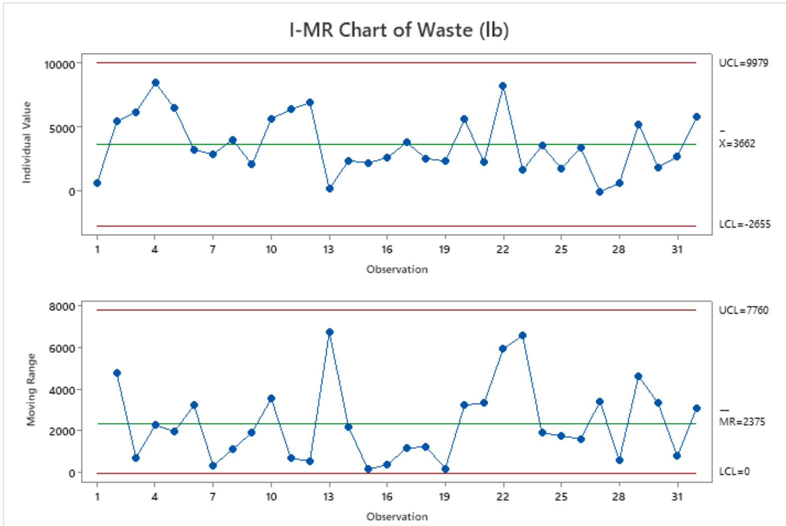

Figure 6. Control chart for waste

4.3 Analysis Phase

Since the subproblems do not meet the expected objective, their root causes must be sought. There are many reasons and parts of the process line for which the plant can stop production (breakdowns) and generate waste. For this reason, a Pareto diagram was used to identify the main types of breakdowns and waste and focus on the most common. From the Pareto diagrams, it is concluded that the filling of extraction and infusion equipment is the most recurrent stop according to the data used, representing 56% of all breakdowns. This refers to the stopping of the line due to the capacity of these machines being exceeded, as too much fruit arrives. To avoid collapse, the operator stops the line, affecting all other operations backwards. The waste that has the greatest impact is the press waste, which is collected at the exit of the extraction equipment. This represents 62% of the pounds of fruit lost. So, the root causes of the breakdowns in the extraction and infusion equipment and the causes of the generation of press waste, at the exit of the extraction process, must be sought. To investigate the root causes, interviews and surveys were applied to the company's personnel who are directly or indirectly related to the process, such as operators, administrative personnel, maintenance personnel and leadership. Based on the responses provided and direct observation, the different causes were organized using an Ishikawa diagram.

Several of the causes identified come from the cut and select (C&S) line, that is, the initial part of the process line. In the C&S line, the fruit bins are dumped to enter the process, followed by cleaning and selection, where the fruit goes through different machines that remove sticks, leaves, ice, and unsuitable fruit according to color. Then the fruit advances through calibration grids where, according to their caliber, they fall into the respective slicer. Next, the pieces of fruit pass through the fine's separator, where the pieces smaller than 4 mm leave the line. The good pieces continue to the screw tank that works as a buffer, to keep the line operational. Finally, there is the dynamic scale that indicates the pounds per hour that the C&S line transfers to the rest of the process. In general, the irregularity in the loading of fruit by the C&S line sometimes causes too much fruit to go to the extraction and infusion equipment, collapsing their capacity and consequently generating unforeseen stops (breakdowns) and press waste.

Parameters such as temperature and speed of the other machines are fixed and are established according to the expected fruit flow; therefore, as the flow of the fruit does not remain stable, press waste is generated. The quality of the loaded fruit (piece of fruit between 4 mm and 8 mm) also influences both problems. For example, if pieces less than 4 mm are not discarded in the fines separator and continue the line, a fruit counting error is generated on the scale, which causes the extraction and infusion equipment to receive more fruit, exceeding their capacity. In addition, the fines take up space that they shouldn't in the extraction process and will be discarded as press waste when they leave the extraction machine. To find the root causes of both problems, specific sub-analyses were carried out according to the causes and sub-causes mentioned Table 4.

Table 4. Sub-causes identified

Cause	Sub-cause
Irregularity in fruit load	1. Variability in temperature of fruit bins 2. No use of the screw tank
Quality problem in loaded fruit	3. Poor calibration and poor adjustment of cutters 4. Poor operation of the fine's separator

1. Variability in temperature of fruit bins.

To demonstrate that the temperature of the bins is really a factor that influences the variability of the fruit flow, a design of experiments (DOE) was carried out. The DOE was adapted to the production line to avoid interrupting the process. Registration forms were used, where the operator indicates the time, the bin was dumped, classifying the response into categories of frozen or normal. The experiment served to verify if the variation in fruit load is due to the type of bin (frozen/normal) and/or the shift (night/day). Eight data were considered for each shift, four from frozen bins and four from normal bins. From the fruit load data (lb./h) provided by the dynamic scale, and the total processing time of the cutting and selection line, the fruit load data (lb./h) of each bin was obtained. Figure 7 shows the graph of main effects for fruit flow on the left and the graph of interaction between factors on the right.

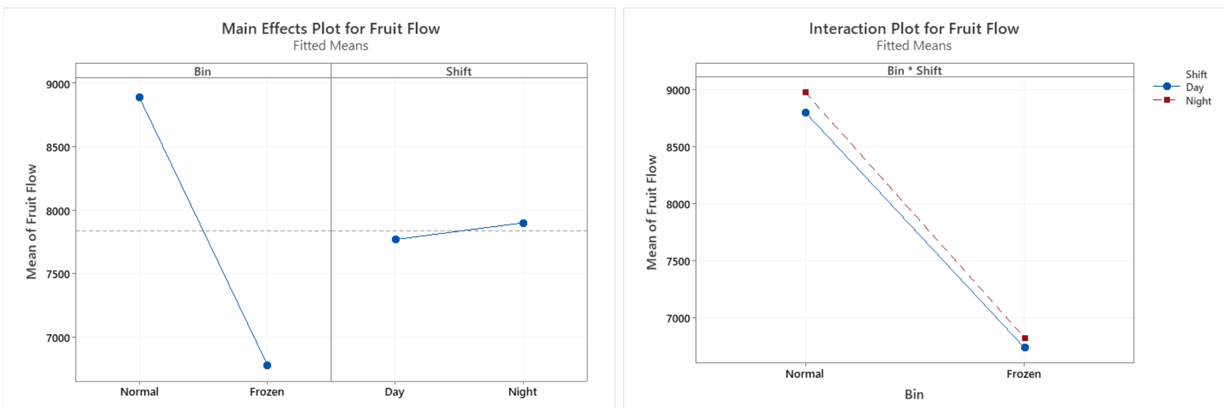

Figure 7. Main effects (left) and interaction (right) plot for fruit flow

The steep slope of the bin factor indicates that with a change from frozen bin to normal bin, the flow of fruit increases considerably. The shift factor shows a low slope, so the shift change from day to night is not significant, the flow of the fruit remains similar. The interaction graph shows that the relationship between the bin factor and the turn factor does not exist, so they can be considered as independent factors. It is then shown that the temperature of the fruit in the bin at the beginning influences the variability of fruit load. To demonstrate that fruit bins arrive at the C&S line at different temperatures, operators were asked to record the temperature of all bins in a shift. It was found that there is variability in the initial temperature of the bins, which implies that there is no temperature control in the dumping of bins.

2. No use of the screw tank.

The initial function of the screw tank was to function as a buffer, that is, to accumulate fruit in process in the tank and adjust the speed of the screw to deliver more or less fruit, as indicated by the dynamic scale. For example, when the dynamic scale carries less fruit than it is intended for, it automatically alerts the screw to deliver fruit at a higher speed since the screw has a fruit buffer. The problem is that this machine has never fulfilled its initial function. Currently the screw works at a constant speed and the fruit tank is kept with a very low level of fruit, because the fruit breaks when there is a lot inside the tank and the screw is working. This was indicated by the organization's engineering staff. The screw tank only delivers the fruit that arrives, managed according to the operator's experience. The problem of fruit breakage is given by its internal design. When the tank reaches a higher level of accumulated fruit, there is a very wide area of exposure between the fruit and the screw.

3. Poor calibration and poor adjustment of cutters.

The gauge of the fruit that comes out of the C&S line is given by the proper functioning of the calibration grids that allow the fruit to be classified according to its size in one of the three cutters, as well as the good cutting of these machines. Cutter 1 must cut fruit with a gauge between 10 mm and 13 mm. Cutter 2 must cut fruit with a gauge between 13 mm and 16 mm. Cutter 3 must cut fruit with a gauge of 16 mm or more. On visit to the plant, it was found that the grids in charge of calibration had ice and fruit stuck, especially the first grid. This causes small fruit to fall into the cutter 1 or 3, increasing the number of fruit fines. Regarding the cutting of each of the three machines, an analysis was carried out to determine what gauge each cutter should have to make the most of the fruit. It was found that the ideal gauge to make the most of the cut should be 6 mm, 8 mm, and 7 mm for each cutter, respectively. To determine the current size, a sampling of the size of the fruit was carried out at the exit of each cutter. 66 data were taken from each cutter. According to this study, cutter 1 is cutting the fruit to a gauge of 8 mm, cutter 2 to a gauge of 9 mm and cutter 3 to a gauge of 8 mm, which indicates that the cutters do not are working properly and should be adjusted to avoid fruit fines.

4.- Poor operation of the fine's separator.

The fines separator is a part of the C&S line that eliminates from the process the cut pieces that do not meet the expected gauge. Pieces less than or equal to 4 mm are discarded from the line through the fine's separator. If a fine continues to circulate through the rest of the process, it will be counted by the dynamic scale that indicates the pounds per hour of fruit that comes out of C&S. Then, by not having the indicated gauge, it will become waste. To check the operation of the fine's separator, 10 samples were taken at the entrance and exit of the fine's separator with the help of C&S operators. The percentage of fines at the entrance and exit of this machine was calculated. The ideal is to hope that at the exit of this machine there are no fines. Efficiency refers to the filtration performance of the fine's separator. Considering the 10 samples carried out, the best performance shown by the fine's separator was 53.45%, that is, it only extracted half of all the fine fruit that it had to remove from the process, when it reached its maximum efficiency. The average efficiency was 44.2% and the median is 47.42%. Therefore, the fines separator is not working as it should. The malfunction of the separator could be explained by the amount of fruit in the shaker. Some fines remain on top of the rest of the fruit and are not filtered as they should be, that is, the capacity of the shaker is exceeded. The vibration of the separator could also be poor for fruit received. On visits to the plant, it was found that the grids were covered with fruit and ice. If the grids are not cleaned, they become clogged and the unsuitable fruit (fines) passes over, continuing in the process.

4.4 Improve Phase

Once the main causes are known, improvements are proposed to meet the objective set in the define phase. Through brainstorming, many solution options were identified, without eliminating any of them, since the purpose of this stage is to find quantity of ideas, not quality of solutions. Then, those with the greatest solution potential are pre-selected and complemented with suggestions from the plant's continuous improvement manager. Advantages and disadvantages in the implementation of each proposal were considered and those shown in Table 5 were selected. All the selected improvement proposals were known and approved by the company's staff.

Table 5. Selected improvement proposals

Root cause	Improvement
Variability in temperature of fruit bins	Mandatory temperature control of each bin. Installation of temperature sensors inside each hopper.
No use of the screw tank	Interior redesign of the tank (add inclined stainless-steel sheet), which avoids direct contact of the fruit with the endless screw.
Poor calibration and poor adjustment of cutters	Visual cues every 30 minutes to remind workers to clean grates. Gauge adjustment on cutters. Create slicer gauge review protocol.
Poor operation of the fine's separator	Visual signals for grid cleaning. Use of a compressed air gun for cleaning with a stopped line. Insertion of deflectors in the shaker.

The proposals have been partially implemented by the company. Some of the changes made are related to the screw tank. Currently, it has been possible for the tank to operate as a buffer for the line, that is, maintaining the level of fruit to absorb variability. The adjustment and revision of the gauge of each cutter was regulated to have less fines discarded. Regarding the proposals for cleaning grids (in the fines separator and calibration grids), visual management has not yet been implemented; however, special emphasis was given to the operators in charge so that they comply with the cleaning in their determined time. As for temperature control, this has not been implemented as such; however, the analysis carried out has led to new improvement projects, specifically the control of the cold chambers to standardize the temperature of the bins loaded onto the line.

To verify that the proposals have made it possible to meet the goal established in the define phase, that is, to increase throughput by 10%, it is enough to compare data before and after the implementation of the improvement proposals for unforeseen stops and waste generated. Before the improvements were implemented, there were stoppages for filling extraction and infusion equipment of 1.66 hours a day on average. After implementing the improvements, considering the data for the months of July and September of the year 2021, an average per day of 0.42 hours was obtained. This represents a decrease of 75%. Before the improvements were implemented, there was an average of 2,270 pounds per day of press waste. After implementing the improvements, a decrease of 81% was obtained, achieving an average value of 434 pounds per day. These values show that the gradual implementation of the proposals presented have helped to reduce breakdowns and waste in the extraction and infusion equipment.

However, the goals of the project are based on the reduction of breakdowns and waste in general, that is, considering all types of waste and all types of breakdowns that occur in the process line. These improvements obtained represent a 42% reduction in total breakdowns and a 50% reduction in total waste. When comparing these values with those presented in the define phase, it is found that the percentage of reduction in time lost due to breakdowns does not meet the goal in accordance with what was previously established (it was expected to decrease by 50%). Meanwhile, the generated waste decreases more than expected (it was expected to decrease by 35%). Considering these values and the main objective of this project (increasing the output by 10%), it is possible to increase the output by 9.3%.

4.5 Control Phase

After generating and obtaining improvement proposals, it is necessary to design action protocols for the use of these alternatives. In this way, possible failures in the implementation can be prevented and, in addition, it allows the changes made to be under control. The response and control plan (Table 6) provides clear information on who is responsible for complying with the required specifications of each option. It is a summary of how each improvement proposal should work and what should be done if the plan is not being carried out correctly.

Table 6. Response and control plan (extract)

Description of the operation	Specification	Technical	Frequency	Control method	Reaction plan
Temperature control bins	The loaded bins must be between -8ºC and -12ºC	Use of digital thermometer	For each bin	Operator inspection	Don't load the bin. Wait for it to thaw / send back to storage
Work as indicated by the screw tank level sensor	The tank level must be kept medium high (green traffic light)	Visual	Continuous	Operator inspection	Load more or less fruit as appropriate. Record the time that was outside the expected level
Grid cleaning (calibration and fines separator)	Free grids without ice or stuck fruit	Use of plastic shovel and gloves. Visual warning	Every 30 minutes	Operator inspection	Clean the grill anyway. Record the time of delay in cleaning
Cutter gauge adjustment	Cutter 1: 6mm gauge Cutter 2: 8mm gauge Cutter 3: 7mm gauge	Process line stopped. Maintenance personnel adjust the knives. It is checked with a caliper	At each DF production start	Inspection of maintenance personnel	Inform the production manager
Caliber review of slicers	Cutter 1: 6mm gauge Cutter 2: 8mm gauge Cutter 3: 7mm gauge	Using a caliper to measure outgoing fruit	Weekly	Operator inspection	Inform the production manager

5. Conclusion

The improvement proposals presented achieve a significant increase in the production of DF in the berry company studied, considering that they have not yet been fully implemented, so the methodology used is validated with the results presented, the root cause analysis and the proposals found from this analysis. The established goal (10%

increase in output) has been achieved by 93%, so the goal will surely be exceeded once the changes are completed. The use of the DMAIC methodology was a success in terms of achieving in a short time some of the most important root causes of the problem presented, as well as understanding the problem and searching for customized production solutions. The adaptation of the Six Sigma methodology to a problem more related to production or time, than to product quality itself, was a useful practice for the company. Likewise, the incorporation of the OEE concept made it possible to focus from the beginning on critical variables from the point of view of loss of time in production, which constitutes a fundamental factor in the search for an increase in production.

References

Añaguari, M. Integración Lean Manufacturing y Seis Sigma. Aplicación pymes, Available: https://riunet.upv.es/bitstream/handle/10251/72921/TFM%20Integraci%C3%B3n%20Lean%20Seis%20Sigma_%20Miluska%20A%C3%B1aguari.pdf?sequence=3, July 2021.

Dave, Y. and Sohani, N., Improving productivity through Lean practices in central India-based manufacturing industries, *International Journal of Lean Six Sigma*, vol. 10, no. 2, pp. 2040-4166, 2019.

Eckes, G., *El Six Sigma para todos*, Editorial Norma, 2006.

Jebaraj, S., Marathamuthu, S. and Murugaiah, U., The use of 5-Whys technique to eliminate OEE's speed loss in a manufacturing firm, *Journal of Quality in Maintenance Engineering*, vol. 21, no. 4, pp. 419-435, 2015.

Kenneth, R., *Understanding, Measuring, and Improving Overall Equipment Effectiveness,* Taylor & Francis Group, Boca Raton, 2018.

Krishnamoorthi, K.S., Krishnamoorthi, V. and Pennathur, A., *A first course in Quality Engineering. Integrating statistical and management methods of quality,* 3rd Edition, Taylor & Francis Group, Boca Raton, 2019.

Muraliraj, J., Zailani, S., Kuppusamy, S. and Santha, C., Annotated methodological review of Lean Six Sigma, *International Journal of Lean Six Sigma*, vol. 9, no. 1, pp. 2-49, 2018.

Murmura, F., Bravi, L., Musso, F. and Mosciszko, A., Lean Six Sigma for the improvement of company processes: the Schnell S.p.A. case study, *The TQM Journal*, vol. 33, no. 7, pp. 351-376, 2021.

Pérez, M. L. *Seis Sigma. Guía didáctica para Pymes,* Ediciones Unibagué, Ibagué, Colombia, 2013.

Pérez-Ortiz, H. El impacto de Lean Six Sigma en organizaciones latinoamericanas y sus factores críticos de éxito, Available: https://rei.iteso.mx/handle/11117/3873?show=full, July 2021.

Pyzdek, T. and Keller, P.A. *The Six Sigma Handbook: A Complete Guide for Green Belts, Black Belts, and Managers at All Levels,* McGraw-Hill, New York, 2003.

Sordan, J., Oprime, P., Lopes, M., Chiabert, P. and Lombardi, F., Lean Six Sigma in manufacturing process: a bibliometric study and research agenda, *The TQM Journal,* vol. 32, no. 3, pp. 381-399, 2020.

Stamatis, D.H., *The OEE Primer: understanding overall equipment effectiveness, reliability, and maintainability*, Taylor & Francis Group, Boca Raton, 2011.

Swarnakar, V., Tiwari, A. and Singh, A.R., Evaluating critical failure factors for implementing sustainable lean six sigma framework in manufacturing organization: A case experience, *International Journal of Lean Six Sigma*, vol. 11, no. 6, pp. 1069-1104, 2020.

Tsarouhas, P., Overall equipment effectiveness (OEE) evaluation for an automated ice cream production line. A case study, *International Journal of Productivity and Performance Management*, vol. 69, no. 5, pp. 1009-1032, 2020.

Biography

Isidora Venegas holds a Bachelor of Sciences degree in Industrial Engineering from the Austral University of Chile (2021). She is currently in the process of studying a master's degree in operations and logistics management from the University Andres Bello. She is working like a trainee engineer in supply chain area. Her main areas of interest are continuous process improvement, logistics and inventory control.

Mervyn Márquez is an Auxiliar Professor of Industrial and System Engineering Institute at the Austral University of Chile. He holds a Bachelor of Science degree in Industrial Engineering (2001) and a Master of Science degree in Industrial Engineering (2008) from the University of Tachira, Venezuela. He earned Doctorate in Engineering (2017) from the University of Carabobo, Venezuela. He is Six Sigma Black Belt. He has published journal and conference papers. He was Director of the School of Industrial Engineering at the University of Tachira, Venezuela and Director of the Institute of Industrial Engineering and Systems at the Austral University of Chile. His research interests include human factors and ergonomics in the manufacturing industry and business process improvement.