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A Preventive Maintenance Framework in Dairy Production Operations

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A PREVENTIVE MAINTENANCE FRAMEWORK
IN DAIRY PRODUCTION
OPERATIONS

A Thesis

by

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ABSTRACT

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Dairy operations suffer frequent stops. Product shrinkage is a consequence of downtime, which includes losses of packaging material, scraped finish product and capacity. This work proposes a troubleshooting methodology to identify causes of downtime, estimation of waste cost, and minimization of operation disruptions by applying a combination of a cost function to assess waste, and performance measurements.

The drinkable yogurt process is evaluated to find the principal areas for wasted bottles and yogurt. In order to make a decision about which of those sources to address, a General Cost Function is used to estimate waste cost which include measurements that evaluate the entire process. Further performance measure analysis such as Squared Coefficient of Variation, Utilization, etc. indicated the necessary maintenance strategy to normalize the process. After the root cause of shrink was found, improvements were implemented and the performance of the station was assessed again to confirm results.

DEDICATION

The development and completion of this master’s thesis would not be possible without the help and support of my family in Colombia and here, the company that allowed me to do this summer job and project, the faculty members, my advisor and the amazing people from Church.

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CHAPTER I

INTRODUCTION

1.1 Dairy production issues

The dairy industry is a complex manufacturing process due to product perishability, high purity and hygiene requirements and operation characteristics of the machines. Maintenance of the machines becomes difficult because of several reasons including, the protein of milk that produces a coat in the equipment, more specifically in heat exchangers, creating the need to clean more frequently. This condition receives de name of Fouling as seen in Figure 1 (*Bipan Bansal and Xiao Dong Chen*, 1998; *S. D. Changani et al. 1997*), but production times cannot be interrupted because of the perishability of the product (*Georgios M. Kopanos et al. 1998)*.

Figure 1 Fouling in heat exchangers

There are also machines that have been in operation for a long time, and they have issues that were not addressed in a timely manner. Consequently the vendor does not have the expertise to fix them anymore because the machine is no longer available for sale. Therefore, the supplier's experts cannot help and troubleshooting becomes more difficult. In addition, there are other issues that are normally found in all manufacturing processes that affect production and maintenance, normal scheduling, and timely deliveries of product (*Shahram Taj, 2007; Iiro Harjunkoski et al 2001)*.

1.2 Purpose of this study

The purpose of this study is to analyze continuous downtimes in dairy plants with drinkable yogurt operations, in order to identify waste and propose a preventive maintenance framework. Continuous downtimes and maintenance issues are causing loss of time and profit, and increasing production cost of drinkable yogurts. Drinkable yogurt demand has been increasing, becoming one of the favorite drinks for children and adults. AC Nielsen (2013) expects double digits growth in the next few years. Since the demand is increasing, it is important to identify the problem and its root cause.

The machines that manufacture this product, at the H-E-B plant in San Antonio where this research was conducted, are having issues and are not being as efficient as expected. The manufacturing process will be measured in order to find the root causes of waste and the reasons why production lots are taking much longer than expected. It is necessary to define the most critical issues in order to develop a preventative maintenance framework that can lead to an effective solution.

1.3 Description of methodology

This is a random process with variability that has a stochastic nature, and will be developed deterministic solutions to the issues found during the study. A General Cost Function will be used to propose a preventive maintenance process that can minimize operation disruptions and losses. This function will be based on costs to identify the root causes of shrink and solve the biggest problem. After identifying them, performance measurements including utilization and variability will be analyzed to understand how well is that station working, and what is affecting and generating shrinkage costs. Based on those measurements, the root cause of shrink and losses will be identified, making easier to focus on the main problem and improvements. Once the changes are applied, performance measurements will be analyzed again to compare them with the initial conditions and find out if the improvements did help or not.

1.4 Significance of this study

Drinkable yogurts are among the dairy products whose sales reached more than $1 billion worldwide in the last few years. They were number one worldwide because they had shown an increase in 40 of the 45 markets measured. With more than 10% growth in 29 of those markets (*ACNielsen's report, 2014*). Originally, yogurt drinks were focused on kids market, but recently, they are being targeted to adult consumers in the form of a smoothie yogurt. Therefore, the demand is increasing and dairy plants need higher capacity to meet it. Decreasing losses and downtimes will help this market continue to grow.

1.5 General inspection of the plant

Four lines that manufacture all products at the H-E-B plant were reviewed in order to identify the shrink points in the culture plant. The analyzed lines were:

- Creamy dips (Osgood machine)
- Blended yogurt (Autoprod machine)
- Greek yogurt (ATS machine)
- Drinkable yogurt (Evergreen machine)

1.5.1 Review of Osgood, Autoprod and ATS machines

The Osgood machine line worked with half liter and liter sizes of creamy yogurt and dips. This process was well in control. Other than the proper changeover and setup times, no major downtimes were found. In regards to waste, it was found that the used wrapping film was too wide and there was extra film on the sides of the four liters package. Several tests were conducted and it was found that narrower wrapped film can be used to package other products. The new film protects the half liter and liter sizes of creamy dips and two different types of wrapping film will not be needed. Solving this maintenance issue was straightforward and did not need any further analysis.

Most of the Autoprod machine line parts have been replaced with shop-made parts in order to keep it in production. There were some problems with product shrinkage because the line was losing cups and aluminum foils during setup. Some improvements were made before working on preventive maintenance in order to prevent failures and avoid common problems. Setup times were longer and changeover sometimes becomes a challenge because of no standardization of operations. This machine has little opportunity for improvement according to supervisors opinion at H-E-B.

The ATS machine, used for greek yogurt packaging, was still under adjustments since it is the newest one. It was purchased in 2013. The filling valves were not completely synchronized indicating that the shrink issue of this line was overfilling.

1.5.2 Review of Evergreen machine for drinkable yogurt packaging

Yogurt drinks are packaged by the Evergreen machine, as seen in Figure 2. This machine is the one that has the highest shrinkage. When the machine was observed during operation, points of bottles and yogurt waste were found. Shrinkage was also visible in the packaging area causing the line to stop constantly. Additionally setup and changeover times were taking longer than the expected.

Evergreen line produces drinkable yogurt in three different sizes and different flavors. An inspection was performed during two weeks to have a general idea of the complete packaging process. Parts required in finishing a product, changeovers, setup times and all the operations were reviewed and measured one by one to locate areas of waste. Performance measurements of the process were studied to find the cause of downtime during production and how long it takes to get a finished product.

Figure 2 Evergreen machine

1.6 Summary

This thesis is developed in five chapters. Chapter II describes the literature reviewed to have a better understanding of the dairy industry, its processes and main production issues. Chapter III explains the drinkable yogurt process and the production steps. This includes identifying the main shrink areas. In Chapter IV, analysis of the waste sources is conducted to identify the station with the most contribution to waste, as well as calculating these losses. Assessments of the results from the preventive maintenance improvement in the station are part of chapter V. Finally, the impact to the process is shown, and conclusions and recommendations for future works will be discussed as well.

CHAPTER II

LITERATURE REVIEW

Dairy plants have unique characteristics that make their production maintenance and scheduling more complicated because of frequent downtimes and perishability of products. Literature related to production maintenance and scheduling is reviewed in order to comprehend the latest research in dairy model performance. Papers about ordering production batches on single product and multi-product plants will also be discussed. In addition, mathematical and graphical models that were developed to improve the effectiveness of plant operations are included in this review. Finally, analysis of the maintenance scheduling and dairy plants problems such as Fouling and waste will be studied. The main focus of this review is to assess the troubleshooting of production shrink, and their maintenance options It is important to take a look at models from other industries to investigate what concepts can be taken in consideration.

2.1 Scheduling

In their survey paper, the authors Ying Ma et al. (2009) talk about scheduling with machine availability constrains. Most of the research papers in this review bring up maintenance scheduling with the consideration that machines are constantly working. The authors discuss papers that give deterministic models divided into quantity of machines or types of scheduling, such as parallel, dedicated machines and preemptive schedule with its proper variations.

2.1.1 Job shops and multiple product scheduling

In their paper, Xu and Gu (1994) consider a zero wait multi-product scheduling with dates under uncertainty where earliness / tardiness penalty is minimized. They use the ambiguous variable to express the imprecise processing time and the model was established based on fuzzy cut set theory. A new improved shuffled frog-leaping algorithm is introduced to search optimal objectives for the given problem that has a new updating rule.

Steve C. H. Lu et al. (1994) introduce the fluctuation smoothing policies. This is a type of scheduling procedure that can lead to a pseudo-optimal cycle time and the standard deviation for the cycle time. Focusing in a the semiconductor manufacturing industry, this procedure can be applied to processes where lots require repetitive use of several similar processing stages. The authors applied the policies in a research and development production setting obtaining reductions in the mean queue time and the standard deviation of the cycle time.

Catherine Azzaro-Pantel et al. (1997) propose a methodology for solving job shop scheduling problems it is formed in two parts or steps. The first part studies the development of a discrete-event simulation model representing the dynamic production system behavior, where probabilistic optimization algorithms are used as alternative for large scale models. In the second step, genetic algorithms for solving batch processes and scheduling problems are investigated. Their objective is to minimize the makespan in a multipurpose and multi-objective plant with unlimited storage.

The next paper reviewed is written by Iiro Harjunkoski et al. (2001). A decomposition strategy for solving large scheduling problems is presented. Using mathematical programming methods, the authors focused in steel production plants. Instead of formulating one large mixed integer linear programming problem, a decomposition scheme is proposed that generates smaller problems that may be solved to global optimality. The authors split the original problem into section of problems or sub problems. They use features of steel making process and diminish the need of use the expression of constraints and presenting an illustrative example problem. And present several real-world problems. The authors E. Sanmartí et al. (1998) deal with the production scheduling of multipurpose batch plants in this paper. The use a graph representation and consider characteristics of the schedule of chemical processes in order to get a better approach. The authors also use the branch-and-bound algorithm to consider a variety of production structures and multiple product processes. The efficiency of the proposed method is compared with the application of a generic branch-and-bound algorithm solving an equivalent mixed integer linear programming scheduling model. Similarly, the authors Nikisha K. Shah, et al.(2001) consider the integrated planning and scheduling problem for the multisite, multiproduct batch plant. They use and augmented Lagrangian decomposition to incorporate time periods to their method. The examples they study indicate that the proposed method saves computational time when compared to other full-scale integrated method.

In every production process, plant issues and machinery or product problems can cause late work and deliveries. To address this issue, Sterna Malgorzata (2010) reviews the scheduling problems using criteria of late work. The author stimates the quality of a schedule based on durations of late operations or jobs without including the amount of delay for fully late jobs. A few real world applications of the late work objective functions are presented and results obtained for some problems of scheduling jobs are listed.

2.2 Optimization

2.2.1 Models applied in other industries

C.A. Méndez et al. (2000), develop in their paper a mixed integer linear programming model to get a pseudo optimal short–term scheduling of batch plant. It satisfies multiple product orders with different due dates working on an analysis more approximated to the real industry scheduling activities. These continuous time models were used to analyze batch and scheduling processes and applied in three different examples. The methodology is formed by two parts. At first, the need to minimize the work in process inventory and meet the due dates. After that, Mixed Integer Linear Programming models are developed for batching and scheduling problems and heuristic rules can be added in the formulation of the scheduling problem. These analyses lead to better schedule that may be near the optimal and applicable to real industry problems. In their paper, Philip Doganis et al. (2006), discuss a Mixed Integer Linear Programming (MILP) that target the optimal production schedule for a single product line. Most of the standard constraints including materials, inventory, capacity, labor and personnel will be taken in to consideration. In addition, special yogurt plant constraints (product sequence) are considered.

In regards to dairy plant scheduling, Georgios M. Kopanos et al. (2009) define models based on families of products proposing a mixed discrete/continuous-time mixed-integer linear programming model (MILP). The authors focused on package stages where timing and capacity constraints take place.

S. Gupta et al. (2003) purpose an improved MILP formulation for multi-product and multistage batch plants for the chemical industry. They develop new constraints for consecutive orders and evaluate them to identify the best ones. Several examples are solved and compare with the previous work the new formulation requires 30% less constraints, and reduces computational times by 65%.

2.2.2 Other Models

In regards to food processes Georgios M. Kopanos et al. (2000) present a mixed integer programming and a solution strategy for the production scheduling of multiproduct process. They concentrate in an ice cream facility. The result of the combined optimization strategy shows that the plant increases the production capacity, reduces the production cost for final products and facilitates interaction among the different departments of the production process. Dario Pacciarelli et al. (2004) describe an optimization procedure for planning the production of steel ingots in steel making continuous casting plant. Their study was focused to a single process and single product problem paying special attention to the lack of information in the optimization process. They use a graph method where the analysis describes all the relevant constraints for the scheduling problem. They solve the problem by using a beam search procedure and then compare to the current performance measures in the plant.

Shahram Taj, (2007) investigates the possibility of adapting lean methods and assesses its state of practice in selected plants in electronics, telecommunication, wireless, computer, food/beverage, garment, pharmaceutical, chemical, petroleum, printing, A/C and heating, and a few others in China. The author conducted a survey of more than thirty questions were asked to executives and managers of manufacturing plants. The questions are related to inventory, team approach, quality, layout, suppliers, planning, handling, setups, scheduling and control. Some of the findings include low scores in layout design, setup and visual factory among others, and high scores in materials flow, scheduling control, on time delivery, including others.

2.3 Manufacturing Issues

In their paper, Bipan Bansal and Xiao Dong Chen (1993) explain the Fouling process, its disadvantages for the productive process and the quality of the product. They study the impact of this issue on the financials aspect, the machinery and the consumer is studied. S. D. Changani et al. (1997) describe the Fouling stages and characteristics. In addition, a chemical cleaning process is explained showing how it saves time and improves cleaning rates.

Wheeler Ruml et al. (2005) describe a real manufacturing problem. They use a hybrid algorithm approach to combine techniques from partial-order scheduling and state-space planning while domain-specific control is not used. They implement their proposed approach in a manufacturing environment with indications of increased productivity.

CHAPTER III

Production Overview

3.1 Drinkable yogurt operations

Drinkable yogurt production operations are mainly composed of product processing and packaging. The product goes through high and ultrahigh temperature processes in order to pasteurize milk and kill all bacteria. Then, it is transported in closed pipelines, station by station to avoid exposure and assure 100% purity. For yogurt drinks, the packaging part uses filling equipment that works by gravity, feeding a rotary bottle machine as seen in Figure 3. The filler is the integral packaging component in most of these lines.

Figure 3 Rotary filler

Machines have become faster, more precise, and hygienic over the years. The latest models offer sophisticated and integrated controls and engineering that enables ease of maintenance and changeover. Even though all these features help the packaging process, drinkable yogurt lines are still losing money and time because of the wasted material and the constant stops and downtimes. This line is losing bottles that are not even used in the process, and yogurt is lost in stations without standard procedures. In addition, the different production rates downstream affect continuity, and should be synchronized. During production, they do not have the same speed, causing downtimes in the filler since other operations are slower due to disruptions in the production line.

3.2 Production steps

Recall from chapter 1, that the analyzed lines were:

- Creamy dips (Osgood machine)
- Blended yogurt (Autoprod machine)
- Greek yogurt (ATS machine)
- Drinkable yogurt (Evergreen machine)

Initial analysis indicates that the research focus should be on the Evergreen machine. Within the Evergreen machine, the entire drinkable yogurt packaging process takes place. This is a serial process and follows six basic steps as shown in Figure 4 and each step will be discussed in the following subsection.

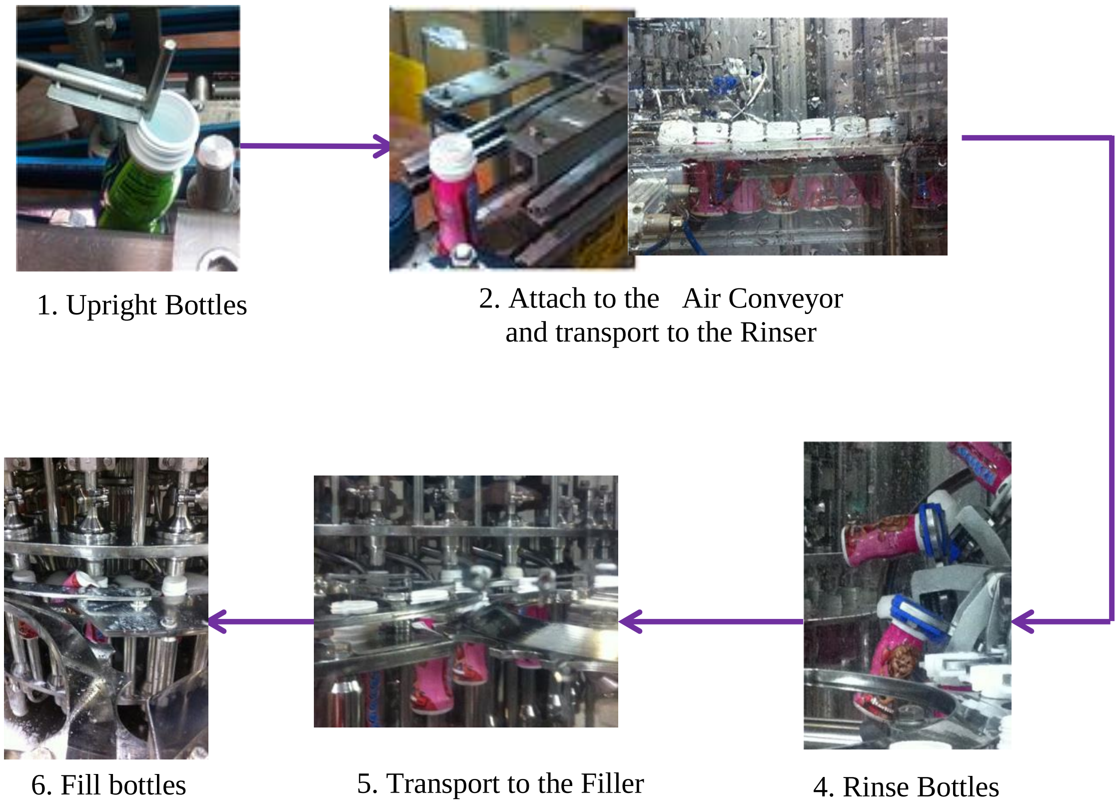

Figure 4 Drinkable Yogurt production steps

3.2.1 Descrambler

The descrambler uprights bottles. Here, bottles fall into a kind of rotary hopper with a wheel at its opening, picking the bottles one at a time. They are conveyed to the flipper that places them in the correct position to get into the air conveyor. Then, bottles are transported to the next step. In order to set up the descrambler, it is necessary to control some adjustments such as height control and tightness of the conveyor belts.

- Height Control
- At the moment bottles get upright, the flipper needs to be at a certain height that allows its arm to get correctly into the bottle’s neck. After that, they are turned to the right position as shown in Figure 5.

Figure 5 Bottle Flipper and right position of bottles

If the bottles are correctly upright, then they get into the air conveyor and go to the next operation. When bottles are not in the correct position they will drop and get discarded. If they are set upside down, they could still fit into the air conveyor causing an employee to stop the line in order to remove the bottle. If the bottle is not taken away, it will continue to the next steps until it gets stuck in the filler generating a major disruption as show in the Figure 6.

Figure 6 Bottles stuck in Descrambler

- Tightness of the conveyor belts

  Bottles leave the descrambler in a horizontal position and they need to be straight in order to be placed correctly by the flipper. Conveyor belts are necessary to hold them before and after being placed by the flipper. They need to be adjusted every setup in order to avoid over squeezing the bottles or to loosely and getting dropped (see Figure 7).

Figure 7 Conveyor belts

3.2.2 Air Conveyor

The air conveyor is actuated by air pressure that pulls the bottles through it to be transported to the rinse station. They are suspended from the neck in a way that bottles are not too wobbly to fall, but not too tight in order to get conveyed to the next operation as seen in Figure 8. When there is downtime and the conveyor holds a certain amount of bottles, the flipper stops sending bottles until the process is resumed.

Figure 8 Bottles suspended in Air Conveyor

In terms of setup, pressure needs to be adjusted depending of the size of the bottle since they have different weights. This setup process is standardized to continuously work at the correct air pressure. In addition, the height of the air conveyor needs to be adjusted since bottles should hang easily while they are being moved from the flipper. For correct operation, the height should be precise to avoid bottle collisions and cause them to get stuck.

When bottles come to the air conveyor correctly upright, they are easily moved to the rinse station. Otherwise, they drop and are discarded.

Bottles that drop from the conveyor or are taken off during these two operations cannot be reutilized because the hygienic chain is broken and would allow bottles to receive dirt particles suspended in the air. Although they would be sanitized and cleaned perfectly, bottles will not be able to have the same purity as the other bottles.

3.2.3 Rinse Station

Bottles are cleaned with Oxonia, a common sanitizer, in order to kill bacteria that exist inside the bottles. This station has 32 jaw clamps that grip the bottles from the neck. They turn bottles in a way that the neck is facing down. The nozzles apply the Oxonia upwards with a certain pressure rinsing the inside of the bottle as seen in Figure 9.

Figure 9 Oxonia Rinser

If bottles come to the clamps tilted or reversed, they can be brake and stuck the machine. After being rinsed, they are released in a horizontal star wheel that has half-moon spaces where the necks of the bottles get suspended and they are conveyed to the next operation.

3.2.4 Transport bottles to the filler

Bottles hang in a star wheel that links with another one in order to transport them to the filler. Bottles are suspended from the neck in the half-moon spaces of the wheels as Figure 10 shows.

Figure 10 Half-moon spaces and bottles suspended

Bottles that drop from the wheels get discarded. It is necessary to find the root cause of this loss because there is not a specific pattern for bottles that fall. When they fall around the star wheels it is necessary to rinse around the station because the bottles are not useable anymore. In regards to setup, the machine automatically sets the speed of the wheels and height does not need to be adjusted since they are not moved for any reason. This is only a transport operation, but it will be considered a station for purposes of this analysis.

3.2.5 Filler

It is composed by a rotary station that has 23 nozzles that are actuated by gravity putting yogurt into bottles. To perform setup, it is necessary to adjust the speed of the rotary filler, the amount of yogurt in each bottle. After being filled, bottles are conveyed to the next operation where caps are placed and correctly tightened.

When bottles come upside down to the filler, the machine gets stuck and the process needs to completely stop until the operator removes the bottle from the rotary filler as pictured in see Figure 11. In order to control the process, some bottles are weighted after being filled to check quality specifications.

Figure 11 Filler

3.2.6 Identification of shrink areas

In the beginning, the process was analyzed only by inspection during several days, station by station and searching for possible areas where shrink occurs. The initial areas of interest were identified by the amount of trash or bottles dropped by each station. After some inspection time, there main sources of waste were identified as shown in the flow diagram in figure 12.

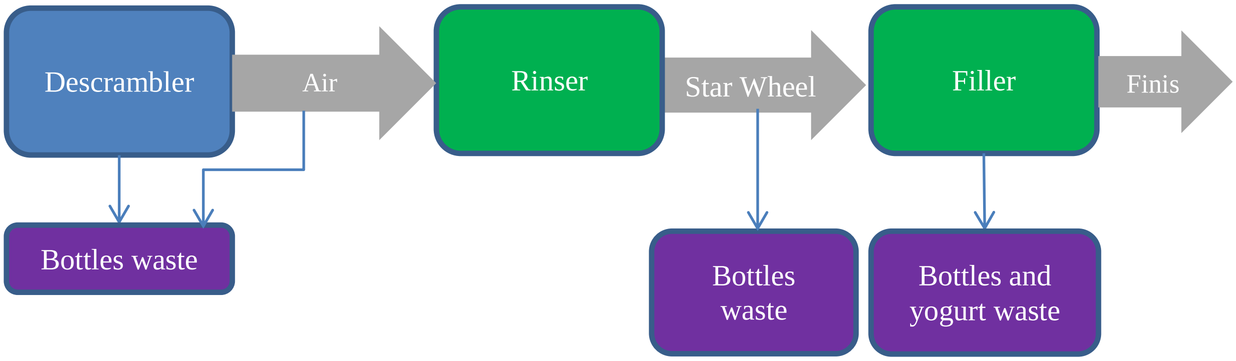

Figure 12 Main sources of shrink

Bottles wasted in the descrambler and air conveyor are dropped in the same place so these two steps are considered one station for analysis purposes.

Three different points of shrink were found at the descrambler, the star wheel and the filler. By inspection, it can be deduced that the area with the most losses and downtime is the filler. Since it was observed the highest amount of bottles and yogurt wasted. Examples of waste in each station are pictured in Figure 13.

Descrambler Rinser Star wheel Overfilling

Figure 13 Main points of shrink

CHAPTER IV

Research Methodology

The drinkable yogurt packaging process has opportunities for improvement that is important to review and discuss. To analyze these operations and find the shrink areas found, it is necessary to identify a measure that allows decision makers the opportunity to prioritize the stations that cause the most losses and downtimes. Waste has a significant impact on manufacturing costs, generating less profit and production capacity. Finding the cause will allow the company to make effective changes and improvements. For this reason, and to have a better idea of production capacity, it is important to analyze how much money is being lost in each station. Performance measures describe how well the processes or stations are doing when they are under control, and when the goals are being met. These measurements are a tool to help the executives in the company understand, manage, make decisions and improve processes or stations with better information. Having numerical results instead of just inspections and assumptions will lead to the real status of the production line, removing the possibility of biased conclusions.

4.1 Total Waste Cost

In order to identify where in the production line money is being lost. A General Cost Function (GFC) is used to find the Total Waste Cost (TWC) per station during the production process. The station with the highest shrink cost per station that is how much are costing the lost bottles or yogurt during production process. With this optimization model, the amount of bottles that go to trash in a specific station, and the cost of the empty bottle is considered in order to quantify the shrink loss. The highest TWC will show the station with the most significant impact.

In order to measure the improvement, the objective is to minimize the Total Waste Cost. The only limitations or constraints are non-negativity since we want TWC to be the closest to zero as possible.

Total Waste Cost optimization model is defined by the following function:

$$Min\ \text{TWC} = P \times \left(\sum_{r \in R} \sum_{i \in N} \kappa_i b_{ir} + \sum_{r \in R} \sum_{j \in M} \eta_j y_{jr} d_{jr} \right) \quad (1)$$

$$all\ vars \in \mathbb{R}^{+}$$

Notations

P = Number of periods per year

κ_i = Cost of bottles wasted in station i η_j =

Cost of yogurt wasted per bottle in yogurt station j

b_{ir} = Bottles wasted per period r in station i

d_{jr} = Bottles wasted per period r in yogurt station j

y_{jr} = Excess yogurt per bottle in yogurt station j i = Nonyogurt stations, with a total of N

j = Yogurt stations, with a total of M

r = Runs in a period, with a total of R

Yogurt station = Operation where yogurt is used

Non-yogurt station = Operation where yogurt is not used. Only bottles are being treated.

4.1.1 Influence of yogurt and non-yogurt stations in the GCF

Since there are yogurt and non-yogurt stations, cost of bottles wasted and yogurt excess cost were estimated to quantify losses. However, the cost of the bottle was validated to be investigated obtaining that $\kappa = \$0.18$, that is the purchasing price, regardless of the station or step in the process.

The yogurt that is overfilled in the bottle was quantified measuring how many grams were filled as extra in the bottles with an average of 15g. Therefore, the average excess yogurt cost is $\eta = \$0.026$ per bottle as shown in the appendix of this study.

In general, the cost of the bottle is significantly larger than the yogurt excess, with $\kappa > \eta$. Furthermore, product changeover due to flavor change caused some yogurt loss with minimal to no impact. Supervisors at H-E-B considered that he cost driver was the lost bottles and not the yogurt. Therefore, Equation 2 shows how the optimization model will be considered neglecting the yogurt excess cost. By separating the optimization model per station, the GCF will show the cost of bottles lost in each station identifying showing the impact of shrinkage.

$$Min\ \text{TWC} = P \times \left(\sum_{r \in R} \sum_{i \in N} \kappa_i b_{ir} \right) \qquad (2)$$

$$all\ vars \in \mathbb{R}^+$$

4.1.2 Approximation of waste cost

Since the TWC is calculated per production run, the manufacturer uses a Sample Size Factor (SF) to approximate the shrink and extrapolate it to the entire production period with each period lasting four weeks. The SF was used to comply with assessment conditions within the company since it is applied to all the processes, and it is used to compare waste. It correlates to the amount of production runs per period by as described in equation 3.

$$SF = \frac{Bottles\ produced\ per\ period}{Bottles\ produced\ per\ run} \tag{3}$$

Then, the waste cost analysis, considering the amount of runs per period is approximated by equation 4 as follows:

$$SF \times WC_i \cong \sum_{r \in R} \sum_{i \epsilon N} \kappa_i b_{ir} \tag{4}$$

Where the waste cost per station per run is calculated by equation 5 as follows.

$$\mathrm{WC_i} = \text{ Bottle cost} \times \text{Bottles lost per station per run} \tag{5}$$

4.2 General system performance measurements

Performance measurements for the entire system were identified in order to understand how the process is doing and pin point what can be affecting the productivity of the process, taking in consideration that this is a random process with stochastic variability. The performance measurements are discretized to be consistent with the company's own measures.

4.2.1 Throughput

Throughput is a measure of the efficiency of the machine. It is a rate that shows the number of completed jobs leaving the system per unit of time (Curry and Feldman, 2011). The manufacturer rates the throughput of the evergreen machine to be 12000 Bottles/hr. The slowest throughput is usually identified as the bottleneck station of the process.

4.2.2 Utilization

The system has an established available time and the machines are able to work during all this period continuously. But processes are not optimal and several stops occur during production. These performance measurements are discretized to be consistent with the company's own measures. This disruptions show the need to measure a real worked time that indicates the time when the machine is really working and transforming the product.

The Evergreen machine has an available time of 1 hour to produce 12,000 bottles. Several runs were measured during their hour in order to know the downtime of the machine, capturing every episode of stops during the production run. Table 1 has a summary of the downtimes per run. Furthermore, a machine downtime average was also calculated.

Run	Downtime (min)
1	25
2	23.5
3	27
4	24
5	24
6	22
7	21.5
8	27
9	23
10	22
Average	**23.9**

Table 1 Average downtime

Measurements on the machine indicated that the average downtime = 23.99min ≈ 24 min/hr.

Thus, the real working time is found subtracting the downtime from the available time.

Therefore, average time worked = 36min/hr.

Now, machine utilization is also known as machine effectiveness can be calculated in order to know how well the machine is working. Utilization is the ratio between available time worked and the total available time. Available time work refers to the interval which production is occurring, and available time includes time worked plus the period during which production is not taking place (Asking and Standrige, 1993). This is described in equation 6 as follows.

$$U = \frac{A.\ Time\ worked}{Available\ time} \qquad (6)$$

Therefore, the current Evergreen utilization is calculated to be,

$$U = \frac{36min}{60min}$$

$$U = 0.60$$

Having a utilization of 60%, it is noticeable that the machine has serious downtime issues that are necessary to be solved in order to increase this percentage.

4.3 Current state of operations

Figure 12 in chapter III identified the 3 stations with possible shrinkage. These stations were the descrambler, the star wheel and the filler. It is necessary to know how much shrinkage is occurring in each station. As discussed in section 4.1.2, each station was assessed in order to determine the highest contributor to waste.

4.3.1 TWC in the descrambler

This station has a considerable amount of shrink because bottles go to trash from the flipper when they are not upright and stay in a horizontal position as pictured in Figure 14.

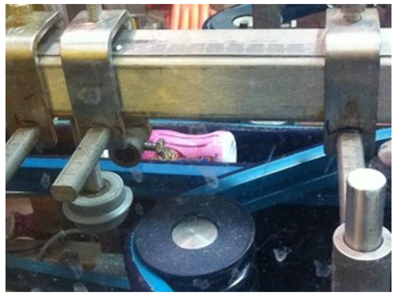

Figure 14 Flipper placing bottles

To quantify the amount of losses in this station, the waste cost per run was calculated first using equation 5. In the appendix, several runs were tallied and an average number of lost bottles per run was calculated. For the descrambler, the average bottles lost per run was 317. Therefore, in recalling the average bottles cost κ = $0.18 was determined in section 4.1.1, the WC_1 is,

$$WC_i = \ Bottle\ cost \times Bottles\ lost\ per\ station\ per\ run$$

$$WC_1 = \ \$0.18 \times 317$$

$$WC_1 = \$57.06$$

Now, the sample size factor was calculated to extrapolate the cost to a period by equation 3. Period 9 of 2014 was used to make calculations, and all stations were assessed using the same period information. Once the SF is calculated it is not necessary to estimate it for the other two stations.

$$SF = \frac{Bottles\ produced\ per\ period}{Bottles\ produced\ per\ run}$$

$$SF = \frac{234{,}893}{6{,}000}$$

$$SF = 39.16$$

After knowing how many runs were worked in a period, it is possible to calculate the waste cost per period to determine how much is being lost in the descrambler station using equation 4.

$$PWC_1 = SF \times WC_1 \cong \sum_{r \in R} \kappa_1 b_{1r}$$

$$\text{PWC}_1 = 39.16 \times \$57.06$$

$$\text{PWC}_1 = \$2{,}234.69 \approx \$2{,}235$$

In order to know the annual losses in the descrambler, the General Cost Function was applied as shown in equation 2. The total of periods per year is P=13 since a period is equivalent to 4 weeks.

$$\text{TWC}_1 = P \times \left(\sum_{r \in R} \kappa_1 b_{1r} \right) \cong P \times PWC_1$$

$$\text{TWC}_1 \cong 13 \times (2{,}234.69)$$

$$\text{TWC}_1 \cong \$29{,}050.95$$

Table 2 summarizes the waste cost in the descrambler.

Shrink in Evergreen descrambler				
			Production Run	6000
			Ave. Bottles Lost	317
			Bottle Cost	$0.18
			Waste per run	$57.06
PD 9	Sample Size Factor		Period Loss	**$2,234.69**
234983	39,16		Annual Loss	**$29,050.95**

Table 2 Summary of descrambler annual costs

4.3.2 TWC at the star wheel

Recall that the star wheel is a transport operation between the rinse station and the filler, this analysis it is considered as a station because bottles are lost in that operation.

Figure 15 shows an example of star wheel.

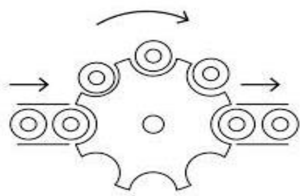

Figure 15 Star wheel example

There are two star wheels that are connected in order to move bottles from the rinse machine to the rotary filler. One of them receives them and rotates to take the bottles to the other wheel that puts the bottles into the filling machine as shown in Figure 16.

Figure 16 Star wheels connected

While transporting the bottles, they drop during the link from one star wheel to the other or when they are being released to the filler. The machine's floor is covered with water and yogurt waste; therefore, those bottles cannot be reutilized either since they lose purity.

Figure 17 waste in star wheel

Quantification of losses in this station is shown below. And with similar analysis, and using equation 5, the initial waste cost for the star wheel is estimated to be

$$WC_2 = 133 \times \$0.18$$

$$WC_2 = \$23.94$$

Sample size factor is already known. It was calculated in the first station; therefore, it can be directly used to find losses per period using equation 4.

$$PWC_2 = SF \times WC_2 \cong \sum_{r \in R} \kappa_2 b_{2r}$$

$$PWC_2 = 39.16 \times \$23.94$$

$$PWC_2 = \$937.49$$

To know the losses per year, it is necessary to use equation 2.

$$\mathrm{TWC}_2 = P \times \left(\sum_{r \in R} \kappa_2 b_{2r} \right) \cong P \times PWC_2$$

$$\mathrm{TWC}_2 = 13 \times (937.58)$$

$$\mathrm{TWC}_2 = \$12{,}188.57$$

Summary of the calculation of annual waste costs for star wheel are shown in Table 3.

Shrink in Star Wheel				
			Production Run	6000
			Ave. Bottles Lost	133
			Bottle Cost	$0.18
			Waste per run	$23.94
PD 9	Sample Size Factor		Period Loss	**$937,58**
234983	39,16		Annual Loss	**$12,188.57**

Table 3 Star wheel waste costs

4.3.3 TWC in the filler machine

This is the third station where high shrinkage was found. This rotary machine has 23 nozzles controlled electronically in order to set basically the filling level and speed of rotation. Bottles are being overfilled exceeding the specified grams per unit. Although fill bottles with extra yogurt is not a significant issue, but bottles need to be discarded because they can have leaking issues and could collapse during further transportation.

After filled and capped, bottles are weighted in order to control the filling level. Bottles that are over or under specs are rejected by and automatic control placed in the conveyor. Defective bottles go to a clear box, where they can be counted and classified after each run to know how many were under filled or over filled.

Figure 18 Filler waste

Applying the same methodology in using equation 5 the waste cost per run for the filler is calculated as.

$$WC_3 = 173 \times \$0.18$$

$$WC_3 = \$31.14$$

To approximate costs to a period, the sample size factor is used the by equation 4.

$$PWC_3 = SF \times WC_3 \cong \sum_{r \in R} \kappa_3 b_{3r}$$

$$\mathrm{PWC}_3 = 39.16 \times \$31.14$$

$$\text{PWC}_3 = \$1{,}219.56$$

Having already the losses per one period, the annual waste cost can be calculated.

$$\text{TWC}_3 = P \times \left(\sum_{r \in R} \kappa_3 b_{3r} \right) \cong P \times PWC_3$$

$$\text{TWC}_3 = 13 \times (1{,}219.56)$$

$$\text{TWC}_3 = \$15{,}854.30$$

The results of the calculation of losses per year in the filler were,

Shrink in Filler				
			Production Run	6000
			Ave. Bottles Lost	173
			Bottle Cost	$0.18
			Waste per run	$31.14
PD 9	Sample Size Factor		Period Loss	**$1,219.56**
234983	39,16		Annual Loss	**$15,854.30**

Table 4 Waste costs in the filler

4.3.4 Total losses

Total losses (TL) in the line are defined by the equation (7).

$$TL = TWC_1 + TWC_2 + TWC_3$$

$$TL = \$29{,}050.95 + \$12{,}188.57 + \$15{,}854.30$$

$$TL = \$57{,}093.8$$

Where,

TWC_1 = Annual losses in the descrambler station

TWC_2 = Annual losses in the star wheel station

TWC_3 = Annual losses in the Filler station

4.3.5 Shrink Percentage

Another important factor to take in consideration is the Shrink Percentage (SP). It means the portion of bottles that are lost in each station. Different runs were measured counting bottles, measuring one station at a time to be able to summarize all the lost bottles in a specific station. This measurement is defined in equation,

Average Shrink Percentage per station *(SP_i)* is:

$$\overline{SP_i} = \left(\frac{\sum_{r \in S} b_{ir}}{S \times BPO}\right) \times 100 \qquad (6)$$

Where,

- *BPO*= Bottles per run,
- S = Number of runs, $S \subseteq R$

Therefore, shrink percentage in the descrambler

$$\overline{SP_i} = \left(\frac{\sum_{r \in S} b_{ir}}{S \times BPO}\right) \times 100$$

$$\overline{SP_i} = \left(\frac{317}{1 \times 6{,}000}\right) \times 100$$

$$\overline{SP_i} = 5.28\%$$

The shrink percentage in the star wheel is

$$\overline{SP_i} = \left(\frac{\sum_{r \in S} b_{ir}}{S \times BPO}\right) \times 100$$

$$\overline{SP_i} = \left(\frac{133}{1 \times 6{,}000}\right) \times 100$$

$$\overline{SP_i} = 2.22\%$$

Finally, the shrink percentage in the filler machine is

$$\overline{SP_\iota} = \left(\frac{\sum_{r\in S} b_{ir}}{S \times \ BPO}\right) \times 100$$

$$\overline{SP_\iota} = \left(\frac{173}{1 \times \ 6{,}000}\right) \times 100$$

$$\overline{SP_\iota} = 2.88\%$$

One of those three stations is having the most impact to waste cost in the Evergreen machine. After measuring these two main characteristics, it is possible to make a decision about which of the stations is important to address. It is expected that improvements will reduce waste, generate savings, and increase the capacity of evergreen machine.

Table 5 gives a summary of the calculations made previously that are being used to make a decision.

	Descrambler	Star Wheel	Filler
Shrink Percentage	$SP_1 = 5.28\%$	$SP_2 = 2.22\%$	$SP_3 = 2.88\%$
Total Waste Cost	\$29,050.95	\$12,188.57	\$15,854.30

Table 5 Comparative information about losses

After reviewing the data obtained, it is determined that the station to improve is the descrambler, its shrink percentage and its annual losses are highest.

4.4 Detailed descrambler Performance Measurements

After defining the station that was affecting the most, it was necessary to measure its performance because of the importance of knowing the causes of the high shrinkage. Inter-arrival times of the bottles into the station and the standard deviations were measured in order to find the variability in the station process. This will indicate how normalized is the process. The lower variability, the more standardized the process is.

Run	Inter arrival times(sec)
1	0,337
2	0,369
3	0,343
4	0,360
5	0,350
6	0,382
7	0,369
8	0,305
9	0,375
10	0,356
11	0,390
12	0,303
13	0,361
14	0,381
15	0,377
16	0,37
17	0,393
18	0,39
19	0,373
20	0,367
Average	0,363
St. Dev	0,025

Table 6 Inter arrival times

There were 20 different runs analyzed and the arrival time was measured. Then, the average inter-arrival time and the standard deviation was calculated as seen in table 6.

TA=0.363s SA=0.025s

Where, TA will be defined as the average inter-arrival time and SA as standard deviation. It is noticeable that the inter-arrival rate is fast, approximately 3 bottles per second start the process, and then variability analysis becomes important because of the arrival dynamics. Even a low variation measure can have a significant effect.

The squared coefficient of variation (SCV) is the variance divided by the squared of the mean value. It is calculated to know how normalized is the station operation and its possible impact in losses. Square Coefficient of Variation of Arrivals (SCV_A):

$$SCV_A = \frac{(SA)^2}{(TA)^2} \qquad (8)$$

$$SCV_A = \frac{0.025^2}{0.363^2}$$

The obtained value is small, and it is due to the short inter-arrival time since every 0.3 seconds a bottle gets into the system. This variability value indicates that there is the need to normalize the process, and a further study needs to be made in the operations of this station in order to figure out which factor is affecting the variability in the station and how it can be reduced.

CHAPTER V

Results

5.1 Outcomes

After identifying the stations, the next step is to apply preventive maintenance. When measuring the performance of the descrambler operation, it was noticed that it has variation that needs to be reduced. In the flipper and in the air conveyor operations, the most evident variability was found. The speed and pressure of the air conveyor did not show significant variability. The flipper, as mentioned e in chapter III does not upright all the bottles, introducing variability in the amount of bottles that get into the air conveyor. When entering the air conveyor, there is another source of shrink and variability, since not all bottles hang on it. Here, some bottles just drop before getting into it or they get stuck generating loss of several bottles at the same time. In order to determine the root cause of these variations, 10 runs of the process were inspected and each of the points of variation were measured to investgate the reasons of the dropping and jamming of bottles.

5.1.1 Findings in the flipper

The height of the flipper arm, that uprights the bottles by grabbing them from the inside as seen in Figure 19. It was inspected, finding that every setup is different since each operator arranges it by inspection, not with a specific distance. Therefore, when a setup is performed the arm height is set at a different elevation.

Figure 19 Flipper grabbing bottles

Different runs were evaluated in order to see the effect of the flipper's arm height on the grabbing of bottles.

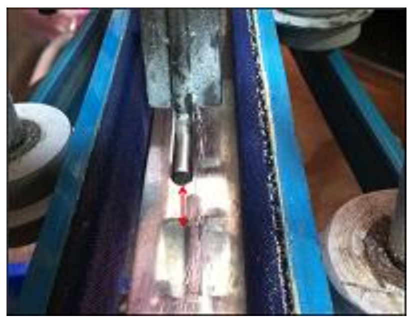

Figure 20 Flipper arm height

Figure 21 shows the measurements made at different heights and the number of bottles not grabbed per hour.

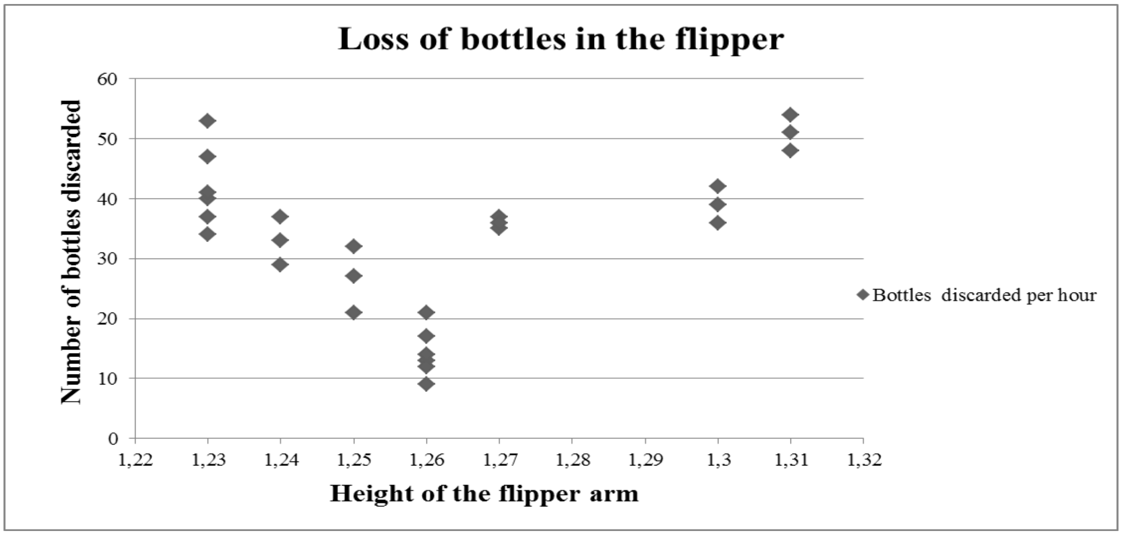

Figure 21 Flipper height measurements

As noticed in the results of the measurements shown in the table above, the height was set differently in every single changeover. The height where the least amount of bottles was lost is 1.26 inches from the arm to the descrambler conveyor.

5.1.2 Findings in the air conveyor

Preventive Maintenance was also applied in the air conveyor. When performing setup in this station, it is necessary to adjust the height in the entrance of the air conveyor, air pressure and width of the conveyor. Specific controls are used to set the same pressure at all times. The width of the conveyor is set by inspection, and each of the operators does it their own way, trying to make sure the bottles do not get too squeezed, or too loose, but just hang on the conveyor in a way that they can be moved to the next station. Ten different runs were inspected to measure the impact of the width variation. Findings showed that between 1.955 in. and 2.060 in. allowing the bottle would hang easily and avoid falling, this adjustment is not standardized yet, but it is not affecting waste.

Regarding the air conveyor height, there is a bottle adjuster that lets the operator set it up or down while spinning the top wheel in order to set an appropriate elevation that allows them to hang easily and do not get stuck and fall as shown in Figure 22. If the conveyor is too high, the bottles are not able to hang. If it is too low, they can get stuck and fall while entering to the conveyor.

Figure 22 Bottle Adjuster

Ten different runs were analyzed to determine the impact of the conveyor height on the bottle waste. The height to control is shown in Figure 23.

Figure 23 Air conveyor height

The results of the measured runs indicated that this height is definitely affecting variation and consequently wasted bottles

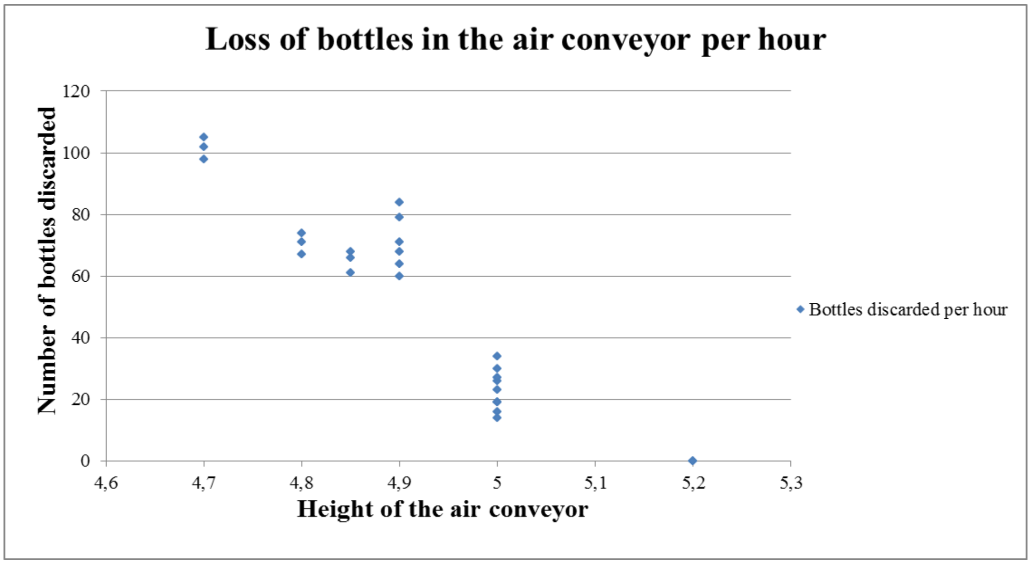

Figure 24 Bottle adjuster height

This variation shows that the process is not normalized and the height of the conveyor needs to be adjusted and maintained in order to reduce the variability and shrinkage. At 5.0 inches the quantity of wasted bottles is lower than the amount of the other runs inspected.

5.2 Improvements

After inspecting the Descrambler operation in a daily basis, the adjustment of heights was being set without standardization. To normalize the setup in this station, gauges were developed to get a uniform height in the flipper and in the air conveyor. Standardized heights help to get the same elevation every setup or changeover in the descrambler decreasing the amount of bottles wasted. To normalize the height in the flipper, a gauge was developed with the measure that grabbed the maximum amount of bottles (1.26 in) as shown below in Figure 25.

Figure 25 Flipper gauge

For the air conveyor, the gauge was also developed with height 5.0in. which allowed the most bottles to hang in the conveyor without drop, as a preventive maintenance measure.

Figure 26 Air conveyor gauge

To compare the implementation of the gauges used during setup, lost bottles were measured using runs with and without the preventive maintenance of normalized gauges, during an hour of operation obtaining the following results.

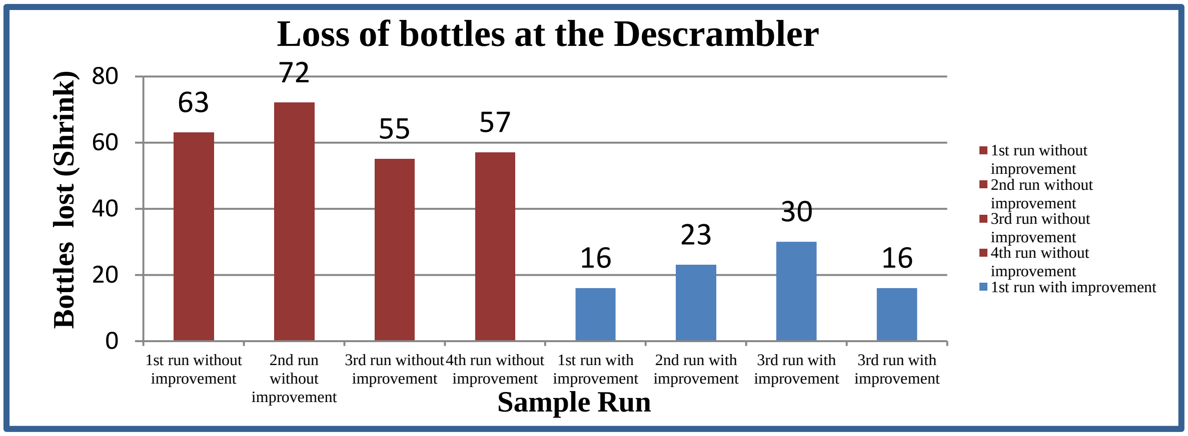

Figure 27 before and after gauges implementation

The dark bars are the runs measured before gauges were implemented, and the light ones represent the amount of waste after preventive maintenance was applied and the process was standardized. The reduction of shrink is in most of cases of over 50%, and the stations are losing less bottles since the preventive measure and correct height in the flipper was set.

5.3 New measurements

5.3.1 Performance measurements

After the implementation of standard gauges as a preventive maintenance, it was necessary to measure the performance of the station process again in order to compare them with the initial ones and confirm the improvement.

Downtime was inspected measuring 10 different runs during an hour and summarizing the durations of stops while in production.

Run	Downtime (min)
1	13
2	12.5
3	13
4	8.7
5	11.7
6	10
7	12
8	11
9	10
10	9
Average	**11,14**

Table 7 Downtime after improvement

Measurements on the machine showed that the new average downtime was 11.14min ≈ 11 min/hr. Therefore, subtracting the downtime from the available time the real working time is found. The new average Time Worked is 49min/hr.

Utilization can be now calculated in order to know how well the machine is working after the preventive maintenances of standard heights was used. Recall equation 6.

$$U = \frac{A.\ Time\ worked}{Available\ time}$$

$$U = \frac{11min}{49min}$$

$$U = 0.816 \approx 0.82$$

The new utilization increased from 60%, when the process was not normalized, to 82% after implementation of the preventive maintenance improvement. Inter-arrival times of the bottles into the station and the standard deviations were measured again in order to determine if variability decreased, results are in table 10.

Run	Inter arrival times(sec)
1	0,32
2	0,329
3	0,314
4	0,332
5	0,33
6	0,322
7	0,321
8	0,324
9	0,317
10	0,327
11	0,32
12	0,317
13	0,321
14	0,323
15	0,325
16	0,313
17	0,330
18	0,313
19	0,321
20	0,31
Average	0,321
St. Dev	0,011

Table 8 Inter-arrival time

New 20 different runs were analyzed, measuring times of arrival and their averages. Inter-arrival time and the standard deviation were calculated obtaining,

New $TA = 0.321s$ $\qquad$ $New\ \ SA = 0.011s$

The new inter-arrival time is significantly lower than the initial considering that this is a small quantity. With such a fast inter-arrival rate a small decrease in variability is significant. After the preventive maintenance was applied, the squared coefficient of variation is expected to decrease as a sign of improvement.

Measuring variability in the process, the square coefficient of variation of arrivals (SCV_A) after the application of the preventive maintenance improvement is,

$$SCV_A = \frac{(SA)^2}{(TA)^2}$$

$$SCV_A = \frac{0.011^2}{0.321^2}$$

$$SCV_A = 0.001174$$

Compared to the initial measurement, the SCV decreased, showing improvement in the process. With a standard height in the descrambler setup, inter-arrival times are more uniform because of fewer of bottles lost.

The percentage of shrink in this station was considerably high before the preventive maintenance with a 5.28% of losses. After implementing the use of gauges, the new shrink percentage is,

$$\overline{SP_i} = \left(\frac{\sum_{r\in S} b_{ir}}{S \times \ BPO}\right) \times 100$$

$$\overline{SP_i} = \left(\frac{55}{1 \times \ 6{,}000}\right) \times 100$$

$$\overline{SP_i} = 0.92\%$$

This reduction in waste confirms a quantifiable improvement was achieved. Although there are still more issues that need to be addressed in order to reduce shrink to zero, the biggest problem was reduced and this treatment gives an idea about what can be done in the other two stations.

5.3.2 New total waste cost

Considering that shrink and variation were already reduced, using the preventive maintenance framework it is now important to quantify the reduction to determine how much the company is saving per year.

The waste cost was calculated first.

$$WC_i = \text{ Bottle cost} \times \text{Bottles lost per station per run}$$

$$WC_1 = 55 \times \$0.18$$

$$WC_1 = \$9.9$$

Then, sample size factor did not change. The same period was evaluated with the difference that has the production after the preventive maintenance.

$$SF = \frac{\text{Bottles produced per period}}{\text{Bottles produced per run}}$$

$$SF = \frac{234{,}893}{6{,}000}$$

$$SF = 39$$

Waste cost per period is calculated to determine how much is being lost in the descrambler station after the gauges were used.

$$\mathrm{PWC}_1 = 39.16 \times \$9.9$$

$$\mathrm{PWC}_1 = \$387.72$$

Losses per period reduced significantly, they dropped from $2,235 to $387.72. Using the GCF one more time, the quantity that the line will be losing per year in the descrambler station was found.

$$\text{TWC}_1 = P \times \left(\sum_{r \in R} \kappa_1 b_{1r} \right) \cong P \times PWC_1$$

$$\text{TWC}_1 = 13 \times (387.72)$$

$$\text{TWC}_1 = \$5040.39$$

Losses per year decreased over 80%. Even though there is still loss of money it can be reduced even more if the other two stations are adjusted.

Table 11 summarizes the costs analysis after the preventive measure improvement in the descrambler

Shrink in Evergreen descrambler			
		Production Run	6000
		Ave. Bottles Lost	55
		Bottle Cost	$0.18
		Waste per run	$9.90
PD 9	Sample Size Factor	Period Loss	**$387,72**
234983	39,16	Annual Loss	**$5,040.39**

Table 9 New annual losses

	Down-time	Time worked	U	TA	SCV	SP	TWC	Annual Loss
Initial status	24	36	60%	0.363	0.005	5.28%	$2,235.0	$29,050.95
Current status	11	49	82%	0.321	0.001	0.92%	$368.0	$5,040.0

Table 10 Comparative between initial and current status of descrambler

Investment for Improvement	Savings
Less than $1000	$24,033.0

Table 11 Savings

With a minor expense, the preventive measure improved the performance and reduced shrink.

Losses have been decreased in a way that will be reflected in the annual savings.

CHAPTER VI

Conclusions and Recommendations

6.1 For Future works

With the purpose of improving after operations at the Dairy Plant, the door should be opened to define more preventive maintenance. Based on measures already made, the other stations can be analyzed in order to find the root causes of variation in the downstream stations of the evergreen line.

6.1.1 Preventive Maintenance at the star wheel station

This station was inspected and measured to get a general idea about the causes of shrinkage. Bottles are released from the rinse station and in the transit to the filler they drop. Analyzing the wasted bottles, it was found that they have a wrinkle in the neck, that is caused by the grippers that grab them to get rinsed as shown in Figure 28.

Figure 28 Bottle grippers

After observing and following up, the operation of the rinse machine, it was found that a possible operational issue is located in grippers 21, 22, and 25 that are the ones that can be generating wrinkles in the neck of the bottles. The machine runs at 200 or 300 bottles per minute depending on the bottle size, so in order to analyze the clamps or grippers, super slow motion videos were recorded to better understand the movement and find the grippers that were causing damage to the bottles. It was found that the grippers 21, 22, and 25 were affecting the diameter in the bottles' neck ring, and could benefit from additional preventive maintenance. Another aspect that can be taken in to consideration is the wheel itself. Its evenness might need to be adjusted or it can be evaluated looking for defects. Star-wheel can be unleveled or not centered enough. The speed of the wheel can be reviewed to find out if it is the same as the other wheel that is connected to move bottles to the filler. It is possible that the half-moon spaces that hold bottles in the star wheel are defective or not uniform in diameter. These defects may cause be causing the falling of bottles, and could be solved in the future with more analysis preventive maintenance application

6.1.2 Filler station

The machine has 23 filling valves that need to be review and set every changeover. When one of the valves is adjusted to comply with the target filling, the other three get misadjusted. For that reason, it is necessary to find the cause of this issue and know how to pair the nozzles from the electronic control.

Every operator runs the machine at a different speed depending of the downstream activities. If downstream operations are slow, filling speed decrease. If they are faster, filling speed increase causing to the filler nozzles get unpaired.

6.2 Final comments

Down time is one of the most important sources of loss of production time and consequently loss of money. This is highly noticeable since equipment failures and breakdowns are very visible, and month by month they are reflected in financial reports. When there is no preventive maintenance actively present, unexpected stops are frequent and all situations turn around, correcting the damage in the moment to keep machines running.

It is necessary to work on foreseeing the damage and act before it happens. Preventive maintenance adjustments normalizing gauges can be used by personnel in the plant. They help reducing setup time, reducing variation and get saving by decreasing shrinkage. Processes have the need of small preventive action and changes that make a significant impact on productivity. That is why it is important that to go to detail inspect the process and pay attention to all activities. It is also important to listen to people to get involved, learn about the operations to find failures and improvement opportunities.

Moreover, variability is a key indicator in regards to the stability and reliability of the process. Making decision based on performance measurements, including the squared coefficient of variation, is an effective way to u any problem in production. When there are operational issues, variability is not always taken in account, focusing in other factors that might improve processes but not as much as expected. Paying more attention to variation and its causes is very helpful to improve performance measurements as could be seen in this study. a general Cost Function was applied to detect the most costly station, then variation analysis was used to reduce shrink.

SCV played a significant role when analyzing the process of this line since applying a preventive maintenance framework, reduce variation productivity improved generating waste cost reductions around 83%.

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APPENDIX

Data for yogurt excess

Yogurt weight per bottle(gr)					Yogurt content per bottle(ml)				
240,3	239,3	235,3	239,3	236,3	226,7	225,8	222,0	225,8	222,9
239,3	237,3	238,3	238,3	235,3	225,8	223,9	224,8	224,8	222,0
240,3	233,3	235,3	244,3	236,3	226,7	220,1	222,0	230,5	222,9
242,3	235,3	243,3	236,3	242,3	228,6	222,0	229,5	222,9	228,6
240,3	236,3	243,3	236,3	237,3	226,7	222,9	229,5	222,9	223,9
241,3	237,3	237,3	235,3	237,3	227,7	223,9	223,9	222,0	223,9
235,3	235,3	237,3	238,3	233,3	222,0	222,0	223,9	224,8	220,1
236,3	235,3	235,3	234,3	231,3	222,9	222,0	222,0	221,1	218,2
239,3	236,3	239,3	239,3	227,3	225,8	222,9	225,8	225,8	214,5
234,3	236,3	238,3	239,3	237,3	221,1	222,9	224,8	225,8	223,9
238,3	234,3	239,3	238,3	240,3	224,8	221,1	225,8	224,8	226,7
236,3	242,3	239,3	236,3	238,3	222,9	228,6	225,8	222,9	224,8
238,3	237,3	236,3	234,3	241,3	224,8	223,9	222,9	221,1	227,7
234,3	231,3	241,3	235,3	242,3	221,1	218,2	227,7	222,0	228,6
230,3	237,3	237,3	239,3	240,3	217,3	223,9	223,9	225,8	226,7
237,3	235,3	237,3	235,3	242,3	223,9	222,0	223,9	222,0	228,6
236,3	234,3	234,3	237,3	236,3	222,9	221,1	221,1	223,9	222,9
234,3	232,3	239,3	234,3	235,3	221,1	219,2	225,8	221,1	222,0
233,3	236,3	238,3	236,3	234,3	220,1	222,9	224,8	222,9	221,1
234,3	237,3	237,3	240,3	242,3	221,1	223,9	223,9	226,7	228,6
237,3	237,3	235,3	235,3	234,3	223,9	223,9	222,0	222,0	221,1
235,3	235,3	236,3	233,3	234,3	222,0	222,0	222,9	220,1	221,1
236,3	234,3	240,3	235,3	236,3	222,9	221,1	226,7	222,0	222,9
236,3	237,3	235,3	232,3	233,3	222,9	223,9	222,0	219,2	220,1

241,3	234,3	238,3	232,3	237,3	227,7	221,1	224,8	219,2	223,9
233,3	233,3	237,3	235,3	234,3	220,1	220,1	223,9	222,0	221,1
239,3	236,3	238,3	235,3	232,3	225,8	222,9	224,8	222,0	219,2
241,3	235,3	243,3	235,3	227,3	227,7	222,0	229,5	222,0	214,5
233,3	237,3	235,3	237,3	232,3	220,1	223,9	222,0	223,9	219,2
234,3	235,3	237,3	238,3	233,3	221,1	222,0	223,9	224,8	220,1
234,3	234,3	238,3	236,3	235,3	221,1	221,1	224,8	222,9	222,0
235,3	233,3	235,3	238,3	237,3	222,0	220,1	222,0	224,8	223,9
239,3	236,3	239,3	231,3	233,3	225,8	222,9	225,8	218,2	220,1
237,3	236,3	241,3	236,3	233,3	223,9	222,9	227,7	222,9	220,1
236,3	242,3	236,3	237,3	234,3	222,9	228,6	222,9	223,9	221,1
243,3	242,3	238,3	236,3	238,3	229,5	228,6	224,8	222,9	224,8
236,3	233,3	243,3	233,3	241,3	222,9	220,1	229,5	220,1	227,7
231,3	242,3	240,3	223,3	240,3	218,2	228,6	226,7	210,7	226,7
234,3	237,3	237,3	231,3	241,3	221,1	223,9	223,9	218,2	227,7
234,3	243,3	238,3	243,3	234,3	221,1	229,5	224,8	229,5	221,1
238,3	243,3	236,3	235,3		224,8	229,5	222,9	222,0	
236,3	238,3	237,3	236,3		222,9	224,8	223,9	222,9	
236,3	242,3	240,3	236,3		222,9	228,6	226,7	222,9	
230,3	235,3	236,3	237,3		217,3	222,0	222,9	223,9	
233,3	234,3	237,3	235,3		220,1	221,1	223,9	222,0	
240,3	242,3	239,3	232,3		226,7	228,6	225,8	219,2	
242,3	235,3	241,3	241,3		228,6	222,0	227,7	227,7	
241,3	243,3	236,3	238,3		227,7	229,5	222,9	224,8	
237,3	242,3	236,3	240,3		223,9	228,6	222,9	226,7	

Yogurt excess per bottle(ml)					Yogurt cost per bottle ($)				
19,7	18,8	15,0	18,8	15,9	0,3389	0,3375	0,3318	0,3375	0,3333
18,8	16,9	17,8	17,8	15,0	0,3375	0,3347	0,3361	0,3361	0,3318
19,7	13,1	15,0	23,5	15,9	0,3389	0,3290	0,3318	0,3445	0,3333
21,6	15,0	22,5	15,9	21,6	0,3417	0,3318	0,3431	0,3333	0,3417
19,7	15,9	22,5	15,9	16,9	0,3389	0,3333	0,3431	0,3333	0,3347
20,7	16,9	16,9	15,0	16,9	0,3403	0,3347	0,3347	0,3318	0,3347
15,0	15,0	16,9	17,8	13,1	0,3318	0,3318	0,3347	0,3361	0,3290
15,9	15,0	15,0	14,1	11,2	0,3333	0,3318	0,3318	0,3304	0,3262
18,8	15,9	18,8	18,8	7,5	0,3375	0,3333	0,3375	0,3375	0,3206
14,1	15,9	17,8	18,8	16,9	0,3304	0,3333	0,3361	0,3375	0,3347
17,8	14,1	18,8	17,8	19,7	0,3361	0,3304	0,3375	0,3361	0,3389
15,9	21,6	18,8	15,9	17,8	0,3333	0,3417	0,3375	0,3333	0,3361
17,8	16,9	15,9	14,1	20,7	0,3361	0,3347	0,3333	0,3304	0,3403
14,1	11,2	20,7	15,0	21,6	0,3304	0,3262	0,3403	0,3318	0,3417
10,3	16,9	16,9	18,8	19,7	0,3248	0,3347	0,3347	0,3375	0,3389
16,9	15,0	16,9	15,0	21,6	0,3347	0,3318	0,3347	0,3318	0,3417
15,9	14,1	14,1	16,9	15,9	0,3333	0,3304	0,3304	0,3347	0,3333
14,1	12,2	18,8	14,1	15,0	0,3304	0,3276	0,3375	0,3304	0,3318
13,1	15,9	17,8	15,9	14,1	0,3290	0,3333	0,3361	0,3333	0,3304
14,1	16,9	16,9	19,7	21,6	0,3304	0,3347	0,3347	0,3389	0,3417
16,9	16,9	15,0	15,0	14,1	0,3347	0,3347	0,3318	0,3318	0,3304
15,0	15,0	15,9	13,1	14,1	0,3318	0,3318	0,3333	0,3290	0,3304
15,9	14,1	19,7	15,0	15,9	0,3333	0,3304	0,3389	0,3318	0,3333
15,9	16,9	15,0	12,2	13,1	0,3333	0,3347	0,3318	0,3276	0,3290
20,7	14,1	17,8	12,2	16,9	0,3403	0,3304	0,3361	0,3276	0,3347
13,1	13,1	16,9	15,0	14,1	0,3290	0,3290	0,3347	0,3318	0,3304
18,8	15,9	17,8	15,0	12,2	0,3375	0,3333	0,3361	0,3318	0,3276

20,7	15,0	22,5	15,0	7,5	0,3403	0,3318	0,3431	0,3318	0,3206
13,1	16,9	15,0	16,9	12,2	0,3290	0,3347	0,3318	0,3347	0,3276
14,1	15,0	16,9	17,8	13,1	0,3304	0,3318	0,3347	0,3361	0,3290
14,1	14,1	17,8	15,9	15,0	0,3304	0,3304	0,3361	0,3333	0,3318
15,0	13,1	15,0	17,8	16,9	0,3318	0,3290	0,3318	0,3361	0,3347
18,8	15,9	18,8	11,2	13,1	0,3375	0,3333	0,3375	0,3262	0,3290
16,9	15,9	20,7	15,9	13,1	0,3347	0,3333	0,3403	0,3333	0,3290
15,9	21,6	15,9	16,9	14,1	0,3333	0,3417	0,3333	0,3347	0,3304
22,5	21,6	17,8	15,9	17,8	0,3431	0,3417	0,3361	0,3333	0,3361
15,9	13,1	22,5	13,1	20,7	0,3333	0,3290	0,3431	0,3290	0,3403
11,2	21,6	19,7	3,7	19,7	0,3262	0,3417	0,3389	0,3149	0,3389
14,1	16,9	16,9	11,2	20,7	0,3304	0,3347	0,3347	0,3262	0,3403
14,1	22,5	17,8	22,5	14,1	0,3304	0,3431	0,3361	0,3431	0,3304
17,8	22,5	15,9	15,0		0,3361	0,3431	0,3333	0,3318	
15,9	17,8	16,9	15,9		0,3333	0,3361	0,3347	0,3333	
15,9	21,6	19,7	15,9		0,3333	0,3417	0,3389	0,3333	
10,3	15,0	15,9	16,9		0,3248	0,3318	0,3333	0,3347	
13,1	14,1	16,9	15,0		0,3290	0,3304	0,3347	0,3318	
19,7	21,6	18,8	12,2		0,3389	0,3417	0,3375	0,3276	
21,6	15,0	20,7	20,7		0,3417	0,3318	0,3403	0,3403	
20,7	22,5	15,9	17,8		0,3403	0,3431	0,3333	0,3361	
16,9	21,6	15,9	19,7		0,3347	0,3417	0,3333	0,3389	
		Total	3906,4				Total	78,8615	
		Bottles that could be filled	18,9						

Lost bottles per run, per station

DESCRAMBLER	
Run	**Bottles lost**
1	321
2	318
3	315
4	310
5	322
6	317
7	311
8	321
9	317
10	318
Avg	**317**

STAR WHEEL	
Run	**Bottles lost**
1	137
2	135
3	129
4	131
5	133
6	134
7	132
8	135
9	130
10	134
Avg	**133**

FILLER	
Run	**Bottles lost**
1	170

2	175
3	174
4	173
5	173
6	179
7	170
8	172
9	174
10	170
Avg	**173**

Lost bottles in the descrambler after the improvement

DESCRAMBLER	
Run	**Bottles lost**
1	51
2	57
3	60
4	55
5	56
6	54
7	53
8	52
9	59
10	53
Avg	**55**

Initial raw data

Date	Bottle size	Down time	un per hour
20/06/2014	3 oz	18.15	56
20/06/2014	3 oz	28.28	57
23/06/2014	7 oz	32.46	63
26/06/2014	3oz	20.20	66
26/06/2014	3 oz	27.00	63
02/07/2014	3 oz	24.1	89
07/07/2014	3 oz	17.58	32
30/07/2014	3 oz	23.16	72
10/07/2014	7 oz	21.34	102
10/07/2014	7 oz	25.28	97
10/07/2014	5.5 oz	21.44	65
14/07/2014	5.5 oz	25.08	83
22/07/2014	7 oz	19.33	76
28/07/2014	7 oz	23.54	86
29/07/2014	7 oz	20.13	60

Heights an loss of bottles in the descrambler

Air Conveyor	
Height (in)	**Bottles discarded per hour**
4,7	102
4,7	98
4,7	105
5,2	0
5,2	
5,2	
4,9	79
4,9	84
4,9	71
5	23
5	19
5	26
4,8	71
4,8	74
4,8	67
4,85	66
4,85	61
4,85	68
5	30
5	34
5	27
5,2	0
5,2	
5,2	
5	16
5	19

5	14
4,9	64
4,9	60
4,9	68

Flipper	
Height (in)	**Bottles discarded per hour**
1,1	40
1,1	37
1,1	43
1,31	54
1,31	48
1,31	51
1,26	17
1,26	13
1,26	21
1,27	35
1,27	37
1,27	36
1,23	34
1,23	40
1,23	37
1,23	47
1,23	53
1,23	41
1,26	12
1,26	14
1,26	9

1,24	33
1,24	37
1,24	29
1,3	42
1,3	36
1,3	39
1,25	27
1,25	21
1,25	32

BIOGRAPHICAL SKETCH

Maria F. Vargas was born in Bogotá Colombia in 1984 and raised in the same city. Finished high school at the age of 16 years old in the Eucaristico Mercedario School in 2000. Then started college at Universidad de America in Bogota, graduating as Chemical Engineer in 2007. After graduation, she started to work in several industries such as pharmaceutical, cosmetic, food and textiles until 2012.

In 2012 at The University of Texas-Pan American began the masters program in Manufacturing Engineering working at the same time as graduate assistant.