UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

Optimización de la disponibilidad en líneas de extrusión: Aplicación de la metodología esbelta en la industria acuícola

.

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RESUMEN

Con la intención de incrementar la disponibilidad de líneas de extrusión en una empresa productora de alimento para camarones, ubicada en Ecuador, este estudio tuvo como objetivo evaluar la aplicación de herramientas Lean Six Sigma para mejorar un sistema de mantenimiento. La metodología DMAIC se utilizó junto con la Ingeniería de RAMS como premisa para detectar oportunidades de mejora y analizar las causas raíz de fallos. Del método *Reliability Centered-Maintenance* (RCM) se tomaron los índices MTBF y MTTR para evaluar la capacidad de un sistema complejo para resolver fallas inesperadas. En menos de dos meses se obtuvo un incremento de 2.5 horas disponibles en promedio, entre la ocurrencia de una parada no planificada y la siguiente, así como un aumento del 2% en el tiempo de disponibilidad operativa para la línea piloto de extrusión seleccionada.

Palabras clave: paros, disponibilidad, fallos, mantenimiento, MTBF, MTTR, confiabilidad, extrusión de camarón

ABSTRACT

With the intention of increasing the availability of extrusion lines in a shrimp feed producer company located in Ecuador, this study aimed to evaluate the application of Lean Six Sigma tools to improve a maintenance system. The DMAIC methodology was used together with RAMS Engineering as a premise to detect improvement opportunities and analyze the root causes of failures. The MTBF and MTTR indexes were taken from the Reliability Centered-Maintenance (RCM) method, to evaluate the capacity to resolve unexpected failures of complex system. In less than two months, an increase of 2.5 hours available on average was obtained, between the occurrence of an unplanned stoppage and the next, as well as a 2% increase in operational availability time for the selected pilot extrusion line.

Keywords: stoppages, availability, failures, maintenance, MTBF, MTTR, reliability, shrimp extrusion process

TABLA DE CONTENIDOS

ÍNDICE DE FIGURAS

ÍNDICE DE TABLAS

1. INTRODUCTION

Aquaculture industry is considered as one of the fastest-growing segments among animal feed production (Helmstetter, 2019). The Food and Agriculture Organization (FAO, 2020) reports that aquaculture yield will increase by 32% of tons produced compared to 2018 output, which means over 109 million tons by 2030. Further, farmed aquatic animal production has been dominated mostly by Asia, Indonesia, Thailand, Vietnam, and Ecuador (FAO, 2020). The latter being among the main producers of farmed shrimp during the last decade, its production has increased from 146 056 MT in 2010 to 675 853 MT in 2020, representing an income of $3.6 billion to the country (Molinari, 2021). Thus, shrimp industry appears among the most beneficial economic activities for Ecuador, for which a key success factor is the correct management of feed mill production.

Currently, Ecuadorian food animal industries face the challenge of transforming their internal procedures into the most efficient and capable possible, given both the increase of market competitiveness and the need to offer high quality products that ensure manufacturing efficiency (Fam et al, 2017). Aligned with the previous context, this study examines the production processes of an Ecuadorian company, located in Guayaquil, which is dedicated to the shrimp feed fabrication, focusing on pelleting and extrusion technologies. Although the company directs its productive forces for both processing techniques, extruded feed has demonstrated greater market acceptance (Lastein, 2021). Commonly between 12% of pelleting product is lost by sinking, lessening cost effectiveness as nutrients dissolute more promptly in the water (Cuzon and Lim 1994). Therefore, extrusion has become the preferred processing for aquafeeds (Barrows, Stone and Hardy 2007), as its higher density and stability allows to exploit nutrients with a greater digestibility, and provides a profitable and quality product for farmers (Aguilar-Palazuelos, Zazueta-Morales, Harumi and Martínez-Bustos 2010; Barrows, Stone and Hardy 2007; Dibaq Group 2019; Hollingsworth 2001).

Considering that the company has experienced a growth in its demand, it also evidenced 12% of unavailability in its extrusion line in fiscal year 2020, due to unscheduled pauses or minor stoppages. These increases the probability of not complying with the production plan, causing losses in produced tons by approximately 4% monthly, which represent annual outgoings of approximately $1´000,000.

1.1. Objetive

This study aims to evaluate the application of Lean Six Sigma tools to increase extrusion lines availability at a shrimp feed production company located in Ecuador. The case study is conducted using the DMAIC methodology, also RAMS Engineering perspective is adopted to identified improvement opportunities, specifically the Reliability Centered Maintenance (RCM) technique, through the implementation of Failure Modes and Effects Analysis (FMEA).

2. LITERATURE REVIEW

Since its early implementation in automotive companies, Lean Manufacturing (LM) has expanded broadly among various productive areas as a process improvement method for waste elimination (Palange and Dhatrak 2021; Gbededo, Farayibi, and Mohammed 2018; Kam, et al. 2021). It derives from the Toyota Production System, whose philosophy focuses on the holistic understanding of any system in terms of waste (Paladugu and Grau 2020). Which means that each step until the delivery of the final product is affected by non-value added activities, causing delays and leak of resources. The commonly agreed waste reduction perspectives, also known as ‘mudas’ (Lazai et al. 2020), are: waiting, over-processing, overproduction, transportation, inventory, movement, and defects.

LM aids to achieve higher efficiency ratings, fewer rework or breakdowns, and an increase in production capacity (Adlin, et al. 2020; Kam, et al. 2021), which turns to lower costs and a reduced production variability (Gbededo, Farayibi, and Mohammed 2018). Besides, lean tools include, but are not limited to, the following concepts.

According to Mirsa (2008), RAMS engineering, acronym for Reliability, Availability, Maintainability, and Supportability, contemplates the use of analytical methods to evaluate the complexity of any system in terms of the aforementioned factors. In that sense, a reliable system is one that works with the minimum of failures meeting specific conditions of time and production capacity, and it can be accomplished by maximizing its inherent and operational availability. One of the best-known methods within RAMS engineering is the Reliability Centered Maintenance (RCM) which, as Mora-Gutiérrez (2009) expresses, is defined as a maintenance management technique aimed to develop organized programs based on equipment reliability. RCM is regulated by the SAE JA 1011 Standard and proposes to deploy the equipment taxonomy in order to identify its parts, functionalities, and possible forms of failure, as well as their causes, effects, and ways of prevention. In other words, to conduct a reliability-focused Failure Modes and Effects Analysis (FMEA).

In addition, availability depends on two important incident parameters to achieve a higher rate of "good parts" produced at a minimum of hold-ups and delays (Godina, 2019; Vorne Industries Inc. 2021; International Labour Organization 2017). The defining parameter for reliability is meantime between failures (MTBF), which embodies the amount of time between one stoppage and the next, scilicet, until the system runs until failure (Balc, 2017). Secondly, maintainability can be understood by mean time to repair (MTTR), which is the average of time required to repair a malfunction. Both indicators are not only useful to corroborate the production panorama, but also to raise priorities according to failure occurrence (Godina, 2019; Alvarez, 2013), which can be done through the Pareto diagram.

The objective is to optimize the current maintenance plan while preserving the system functions integrity and reducing unplanned downtime due to failures. With that intention, the RAMS engineering was taken as a strategy for conducting the project, which, aligned with the DMAIC methodology, allowed the development of a series of steps with their respective expected deliverables. Besides, since it is a problem related to the maintenance system, the steps of the RCM method are followed to determine preventive and/or corrective proposals based on the production line reliability and the FMEA development. Among these, Lean Six Sigma tools were used according to the identified improvement opportunities. Analyze tools such as the Root Cause Analysis (RCA) and the 5 Whys method were used to distinguish the reasons for losses in production capacity (Silveira and Andrade 2019). As a quick win, 5'S method (sort, set in order, shine, standardize, and sustain) was implemented to enhance the efficacy and safety of the operator's workstation (Creative Safety Supply 2017). The 5'S usefulness has been demonstrated in multiple studies (Godina, 2019; Łyp-Wrońska and Tyczyński, 2018; Romana, 2021) together with Poka Yoke (International Labor Organization 2017) as a visual organization tool, which is used for restructuring error-proof designs.

3. METHODOLOGY

The case study is developed through the DMAIC methodology in order to employ a continuous improvement cycle with the use of Lean Six Sigma tools. Six Sigma is a business initiative developed at Motorola by the engineer Bill Smith in mid-nineteenth century (Snee, 2010). While its application, Motorola recognized that there was a pattern to improvement that could naturally be divided into the five phases of problem solving (Michael, 2002). Then, the success of the Six Sigma initiative is due to the step-by-step approach that include Define, Measure, Analyze, Improve, and Control (DMAIC) phases. This principle aims to sort out any complex problem with many uncontrolled variables to a situation where quality can be controlled and enhanced (Mohamad et al., 2019 and Pugna and et. al., 2016). The motivation of using this methodology stands in several case studies in food industry (Upadhye, Deshmukh and Garg, 2010; Benazzouz, Idrissi, and Mesfioui 2016) that demonstrate the successful improvement on production conditions and equipment availability.

The deliverables for each phase of the DMAIC methodology were strategically defined through the perspective of RAMS engineering. The chosen approach is the one presented by Lundteigen, Rausand and Utne (2009) for the holistic vision of RAMS together with the safety life cycle of IEC 61508, and it is as follows:

- Step 1: Establish the requirements of business strategies and define system general guidelines, as well as the desired performance.
- Step 2: Perform reliability analysis starting with the components breakdown and calculate indicators that assess the RAMS factors.
- Step 3: Identify and update critical items and hazard list, perform system security analysis, and recognize root causes.
- Step 4: Build improvement prototypes and analyzed them in a controlled environment, update and finalize maintenance support.
- Step 5: Monitor the performance of improvement actions and evaluate factors to drive a new improvement cycle.

Thereby, each step is the motto for each phase of the DMAIC methodology. It is important to highlight that, from the method chosen within RAMS engineering, RCM is executed during the Measure, Analyze, and Improve phases. The Basic Steps Guide for RCM proposed by Hottinger Bruel & Kjaer Inc. (2007), a provider of industrial measurement control solutions, was taken and is summarized as follows:

1. Prepare for the analysis: Perform a cross-functional analysis and identify the assets and the impact of their malfunction.
2. Select the analyzed equipment: Choose the level at which the analysis will be conduct (component, assembly, subsystem, among others) and document the technical information of the system.
3. Relate and evaluate functional failures and their effects: Define function statements and how the system is composed, identify and categorize failures by common characteristics and if it causes a local or a multi-subsystem operational problem.
4. Identify failure causes: Describe causes in as much detail as possible in order to select appropriate contingency measures or corrections, for each failure mode distinguish its probability of occurrence.
5. Select maintenance tasks: Drive preventive and corrective actions based on proposed scheduled failure-finding inspections and condition monitoring to determine failures that are about to occur.

The accomplishment of the presented methodology is depicted in Table 1.

1. RESULTS

1.1. Define

For the purposes of this study, a stoppage is defined as any time interval in which the line is not producing and there are two macro-classifications: planned and unplanned stops. The latter are the result of failures or consequences of a malfunction. The company drives a preventive maintenance plan to mitigate the recurrence failures, however, there is a need to minimize the rate of corrective actions, or unplanned stoppages, as it implies the existence of detected non-conformities that negatively impacts the production system (EEE, 2020).

RAMS guidelines	**DMAIC methodology**	**RCM method**	**Deliverables**
Step 1: business strategies requirements, system guidelines	Define		SIPOC Operation process chart Project Charter
Step 2: Reliability analysis and indicators	Measure	1. Prepare for the analysis	Diagrama de spaghetti Taxonomy Review of current controls Sample size calculation
Step 3: Identify critical items and hazard list, system security analysis	Analyze	2. Select analyzed equipment 3. Identify and evaluate functional failures and effects 4. Identify failure causes	Operational availability MTBF and MTTR indexes Pareto diagram Inherent availability FMEA RCA 5 Why diagram
Step 4: Improvement prototypes, finalize maintenance support	Improve	5. Select maintenance tasks	5's method T-Test Poka Yoke Maintenance proposals
Step 5: Monitor performance, drive new improvement cycle	Control		Red 5's Tags 5’s Control sheet 5W1H format Gemba Walk

* Reliability, Availability, Maintainability, and Supportability engineering (RAMS), Reliability-centered maintenance (RCM), Supplier, input, process, output, customer (SIPOC), Mean time to repair (MTTR), Mean time between failures (MTBF), Root cause analysis (RCA), Failure mode and effect analysis (FMEA).

Table 1: Lean six sigma tools implementation through the DMAIC methodology.

An overview of the extrusion process was held using a SIPOC diagram (Fig. 1), which allowed to document the business process and to evaluate the different variables involved. The production process consists of pre-grinding, pre-mixing, grinding, post-mixing, extrusion, drying and cooling. It was possible to identify that operators, formulation, supplies, and maintenance are critical variables in the extrusion process, as directly influence operating time, the amount of extruded product produced, plan adherence, and non-planned stoppages frequency.

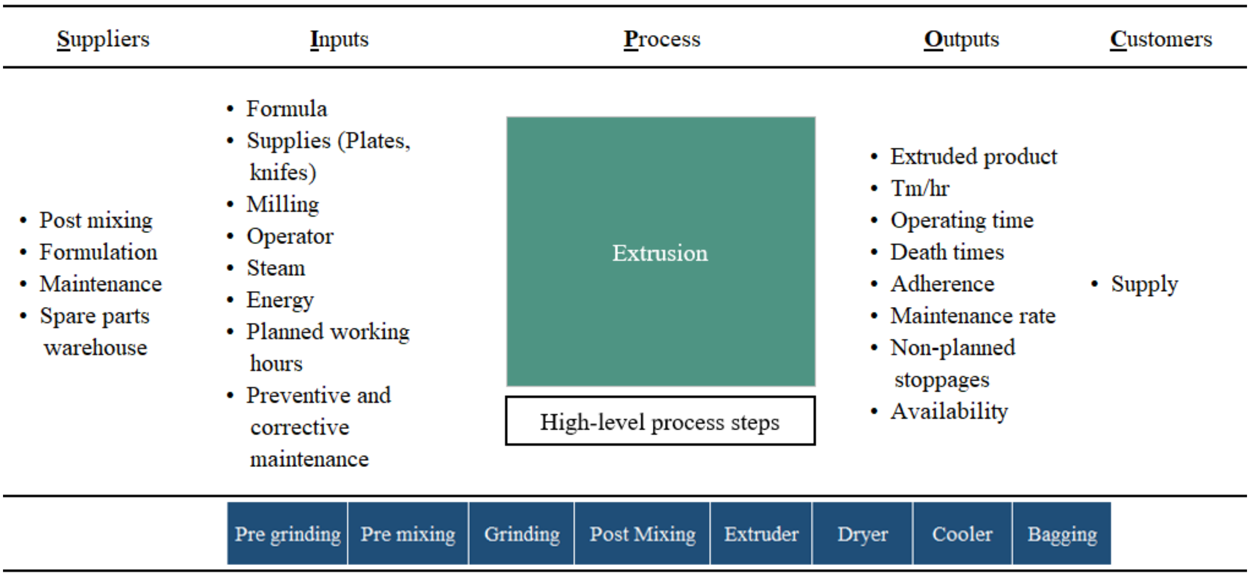


Fig. 1: SIPOC diagram of the company under study – Define phase.

On the other hand, the ISO 14224 Standard (2016 version) defines taxonomy as the systematic classification into generic groups with common characteristics. The components taxonomy was developed based on the ANDRITZ refraction manual, taking the location of the system assemblies as the principal categorization (See Annex 1 for details). Thus, the extrusion phase was identified as the central subsystem.

It is intended to develop short- and medium-term proposals by applying Lean Six Sigma tools that increase the availability rate of the extrusion lines from 88% to 92% for the next fiscal year. Then, with the proposed methodology, the starting point is the analysis of the chosen pilot line.

1.2. Measure

The company has three production lines conformed of ANDRITZ extruders EX 1250, high-capacity machinery (10-20 TPH) that offers a high degree of processing flexibility (ANDRITZ, 2021). Line 1 is not within the scope of the study since it is dedicated to the production of pelleted feed. For the two remain, the current availability is evaluated to define the pilot line in which the RCM analyzes and the implementations will be carried out. Downtime data is obtained from the Network Information System and Power Apps used by the company. For a six-month period, from May 1 to November 8, 2021, the average operating availability ($\boldsymbol{O_A}$) was determined, obtaining 91% for L2 and 90% for L3. $\boldsymbol{O_A}$ is expressed by equation 1 and Line 3 was chosen as the pilot line.

$$\boldsymbol{A_O = \frac{Running\ Time}{Available\ Time} * 100\%} \qquad (1)$$

In the analyzed period, 383 unexpected stoppages were evidenced for L3, which are classified into 24 categories of alphanumerically coded failures (refer to Table 3).

Type	**Count of stops**
Planned stoppages	383
Unplanned stoppages	224
Total	607

Table 2: Number of stoppages per type, period of time considered May 1 – November 8, 2021.

As mentioned before, the second step aligned with the RAMS perspective is also concerned with the evaluation of indexes. The chosen parameters were MTBF and MTTR incident rates as represented in equations 2 and 3. An average of 4.84 hours between failures and 0.94 hours to repair (56 minutes) was obtained for Line 3. It is important to consider that the higher the MTBF the more reliable the system is, since it represents a longer time interval in which the line was producing without stoppages.

Code	Detail
E02	Software failure
E03	Steam problems
E04	Mechanical failure
E05	Electrical fault
E06	Sensors failure
E07	Operational failure
E08	Equipment review
E10	Dryer clogging
E11	Other equipments clogging
E12	Non-compliance with quality specifications
E13	Corrective equipment maintenance
E15	Other
E16	Covered plate
E21	Lack of 1st and / or 2nd mix
E22	Lack of ground mix
E23	Hoppers full
E24	Electrical cut

Table 3. Unplanned failure codes identified for extrusion Line 3.

$$\boldsymbol{MTBF = \frac{Running\ Time}{Number\ of system\ failures}} \tag{2}$$

$$\boldsymbol{MTTR = \frac{Death\ Time}{Number\ of\ system\ failures}} \tag{3}$$

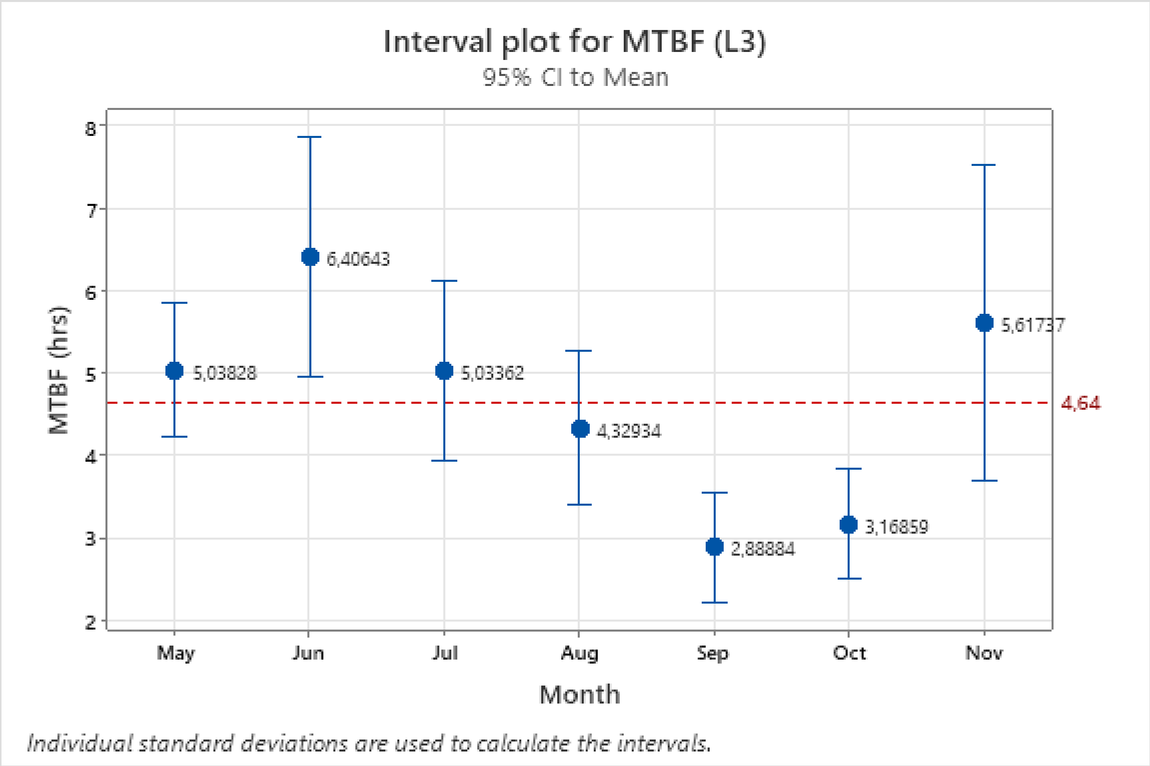


Fig. 2: MTBF interval plot for dowtimes per month for extrusion Line 3. Global average 4.84 hours.

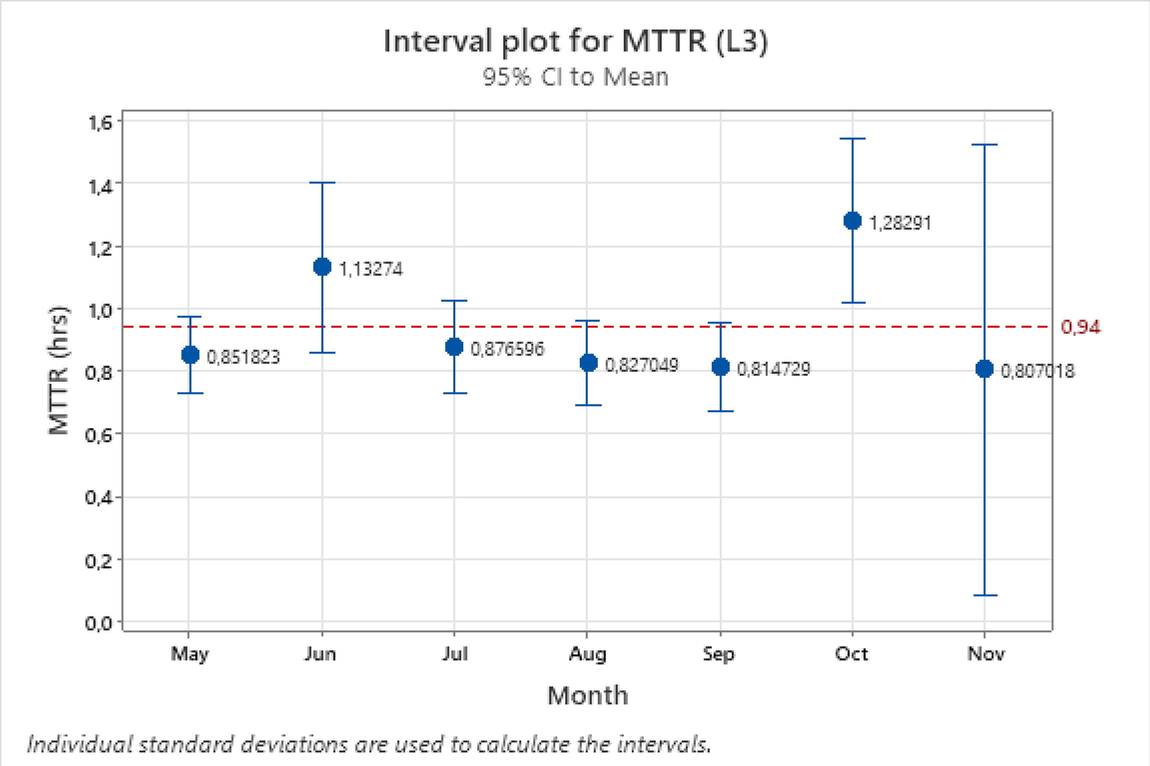


Fig. 3: MTTR interval plot for dowtimes per month for extrusion Line 3. Global average 0.94 hours.

It was also obtained the Inherent Availability (A_I) for L3, which involves both MTBF and MTTR to its calculation and considers the intrinsic downtime to the isolated corrective maintenance system (Elsayed, 1996), to be precise, when the analysis of unplanned failures does not consider delays in the logistics, supply or administrative system. Mathematically, A_I is given by the following expression:

$$A_I = \frac{MTBF}{MTBF + MTTR} * 100\% \quad (4)$$

The ongoing Inherent Availability for L3 was 80%, being the value to be evaluated post implementations.

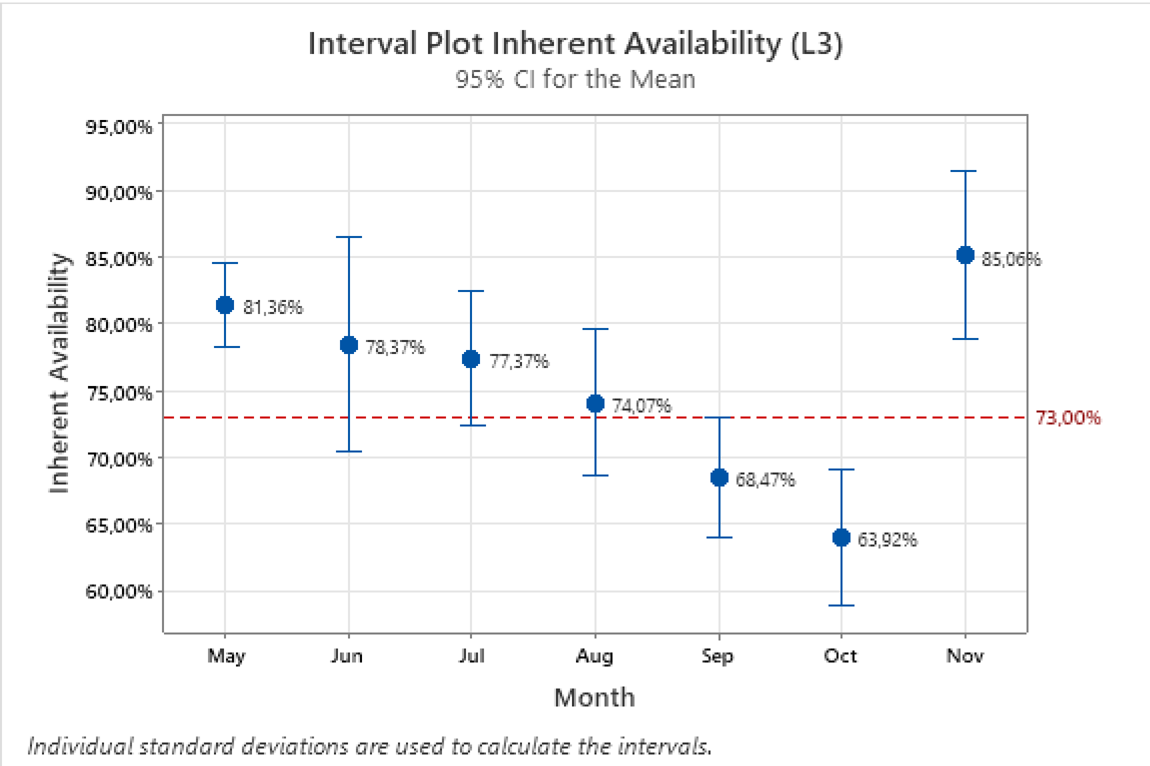


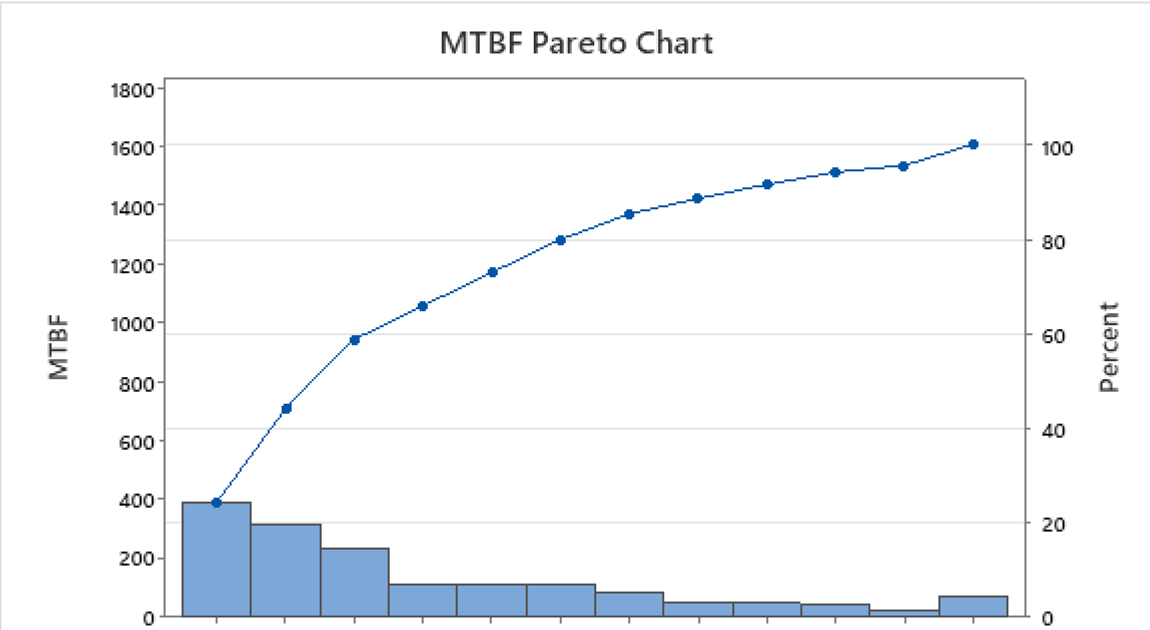
Fig. 4: Interval plot of MTTR per month for extrusion Line 3. Global average 0.94 hours.

Therefore, for the Measure phase, the sample size was obtained using the formula for means with a finite population (equation 5). As Aguilar-Barojas (2005) mentions this is the case where the total number of observation units that comprise the data population is known. Applies to this case since the unplanned downtime population is finite and countable.

$$\boldsymbol{n} = \frac{Z^2_{\propto/2} * \sigma^2 * N}{Z^2_{\propto/2} * \sigma^2 + e^2(N-1)} \quad (5)$$

1.3. Analyze

According to the RCM method, the reasons for the occurrence of stoppages must be prioritized, for which the Pareto diagram was used for the MTBF results. Along with the 80/20 theory, it is considered that 20% of the reasons are the cause for 80% of the problem and its effects (Barroso-Tanoira, 2007), that is, the causality of unplanned stops. For the motives presented in Table 3, the following result was obtained:



Code	E16	E12	E22	E04	E21	E11	E15	E06	E05	E08	E13	Other
MTBF	392.6	316.8	233.7	113.7	113.0	111.5	87.6	51.9	47.6	42.0	22.9	71.4
Percent	24.5	19.7	14.6	7.1	7.0	7.0	5.5	3.2	3.0	2.6	1.4	4.4
Cum %	24.5	44.2	58.8	65.9	72.9	79.8	85.3	88.5	91.5	94.1	95.6	100.0

Fig. 5: Pareto chart of the reasons for unplanned stoppages at Line 3. The 80% of the causes of the problem are condensed into E16, E12, E22, E04, E21, and E11.

The priority causes are: a) E16 - mechanical failure, b) E12 - other equipment clogging, c) E22 - non-compliance with quality specifications, d) E04 - covered plate, e) E21 - lack of 1st and / or 2nd mix, and f) E11 - lack of ground mix. Subsequent, the Failure Modes and Effects Analysis (FMEA) was performed. It was conduct by answering to the following questions retrieved from the SAE JA1011 Standard:

- What are the role of the functional element in its operating environment?
- How can it fail to accomplish its function?
- What are the causes of functional failures and their effects on the production system?
- What are the preventive and corrective measures currently being used?

Two possible environments without convergence constraint were taken into account, extruder and other equipment, and it were found 8 assignable causes of very high priority, according to the Risk Priority Number (RPN) triage presented by Devianti and et. al (2018) for risk assessment to a commercial bank in Indonesia. See Table 4. Afterwards, agreeing to the urgencies determined in conjunction with the plant operators and the maintenance team, the FMEA made it possible to raise the work plan that consists of i) applying the 5's method, ii) the analysis of the covered plate which has represented one of the greatest challenges in recent months, and iii) other proposals that may be included in the maintenance plan. See Annex 2 for the full FMEA resolution.

Risk Level	RPN Scale	Assignable causes Qty.
Very Low	$x < 20$	0
Low	$20 \leq x < 80$	4
Medium	$80 \leq x < 120$	7
High	$120 \leq x < 200$	1
Very High	$x > 200$	8

Table 4: Count of assignable causes collapsed according to the RPN scale. Source: Devianti and et. al., 2018.

Covered plate was identified as one of the main problems that affect L3 availability. Although the company has dedicated its efforts to solve it, a solution has not been reached thus far. That being the case, it was decided to focus on improving subprocesses directly related to the covered plate, so that set up time could be minimized. Due to resources limitations, the plate exchange process was selected as it is one of the main corrective actions carried out after the plugging occurs. An arrow and a spaghetti diagram were held to depict the process baseline, obtaining a total distance traveled of 108 meters and a cycle time of 17 minutes. (See Annex 3).

Furthermore, a Root Cause Analysis (RCA) was developed with a downstream process Ishikawa diagram. With the support of the maintenance area, it was specified that the working methods and mill categories are those that have a greater impact on the process effectiveness. Among the main causes are the lack of a protocol for mills unclogging, the shortage of personnel knowledge to switch mill meshes and control product filtration, rotaries and/or deflector plates deterioration, failures in remote box, and excessive mills vibration. Through a 5 Why analysis several solutions were found that may be added to the maintenance plan, e.g., clean elevator bag filters, remove the poorly ground mixture by the elevator bypass, and install magnets in both the reprocessing elevators and the turbosifter discharge.

1.4. Improve

1.4.1 5's implementation

To eliminate unnecessary movements and delays in the plate exchange process, the 5'S method was held following the Toyota Production System to reduce maintenance execution time, convey and inspection activities. This methodology seeks to sustain organization, orderliness, and cleanliness through a five phases standardized continuous cycle (Hirano, 1990). By implementing it together with Poka Yoke techniques, the company experienced an increase in the quality of its products as well as in the safety of its processes, without incurring high costs. As a result, the availability rate of the production lines was improved. During the ‘sort’ phase, operators and maintance technicians clasified tools by its frequency of usage, as seen on Figure 6, so that for the ‘set in order’ phase, the remaining tools could be placed in a especific area where Poka Yoke method was introduced as a visual management tool. See Figure 7. Next, a leakage mitigation plan was perform during the ‘shine’ phase to maintain workstations and machines spotlessness without the need of a permanent cleaning process (i.e., Figure 8). Finally, to achieve ‘standarization’ and ‘sustain’ stages, operators were instructed on how tools and workstations interact with the process (including plate exchange). To guarantee the succesful continous practice of the 5’S cycle, control sheets were given to the production supervisor to audit, at the end of every shift, the orderliness and cleanliness at the workstations.

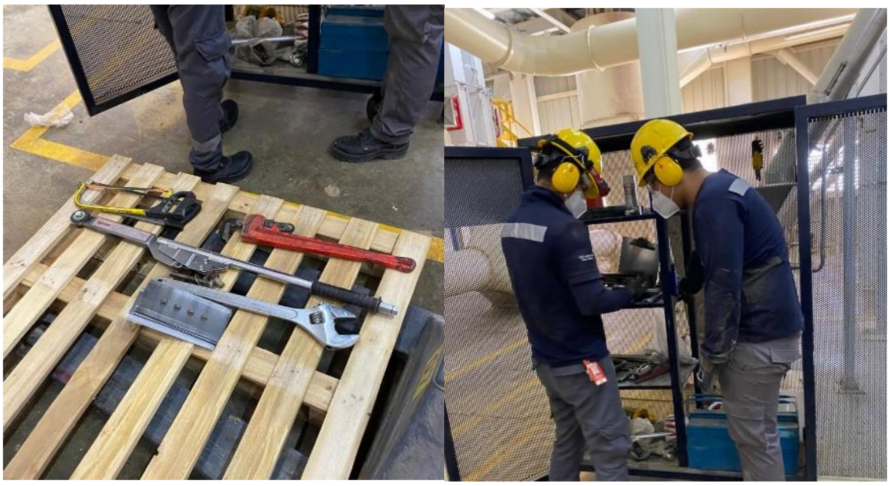


Fig. 6: Sort phase through the 5’s method implementation.

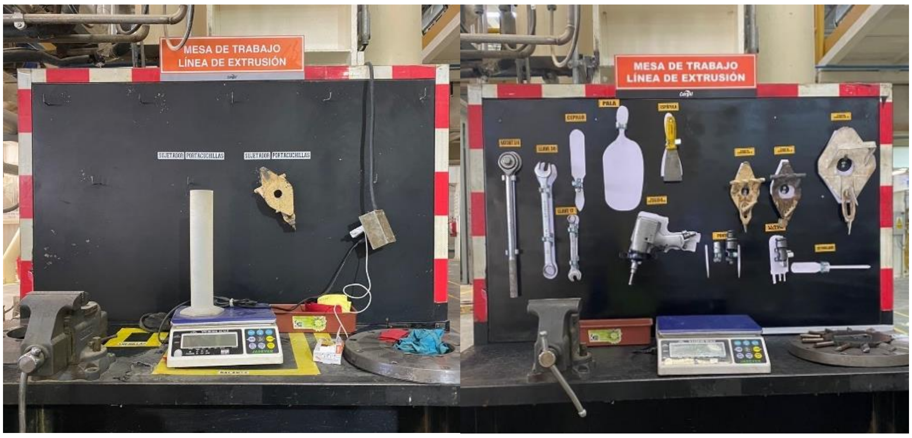


Fig. 7: Set In Order phase through the 5's method implementation.

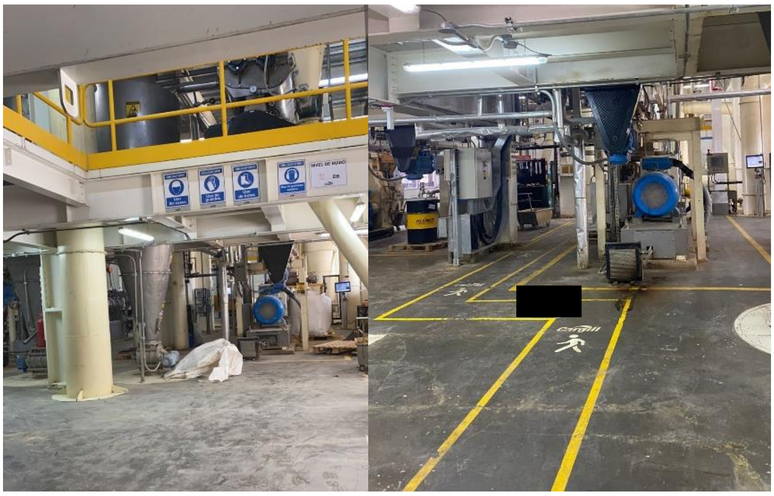


Fig. 8: Shine phase through the 5's method implementation.

1.4.2 Statistical Analysis

A statistical analysis was compassed using MINITAB Statistical Software. A Two sample hypothesis test was used in order to prove whether there's a statistical difference between the plate exchange process average time before and after the implementation. The first sample size is N = 97 and the second is N = 42. Normality and randomness was tested to prove assumptions of the t-test (See Annex 4). Following, the null hypothesis to evaluate is depicted in equations 6 and 7 which illustrate that the difference between the mean of sample 1 is equal to the mean of sample 2.

$$\boldsymbol{Ho}: \boldsymbol{\mu_1} - \boldsymbol{\mu_2} = \mathbf{0} \tag{6}$$

$$\boldsymbol{Ho}: \boldsymbol{\mu_1} - \boldsymbol{\mu_2} > \mathbf{0} \tag{7}$$

Futhermore, the results obtained from the study shows a p-value of 0.045 which , comparing to an $\boldsymbol{\alpha} = \mathbf{0.05}$, the null hypothesis is rejected and is possible to conclude that there is a statistical difference between the two means, in other words, it indicates that the implementation of the 5's method in fact helped to reduce the variation of the amount of time it takes for the operator to make the change, after the covered plate occurs (i.e. Figure 9).

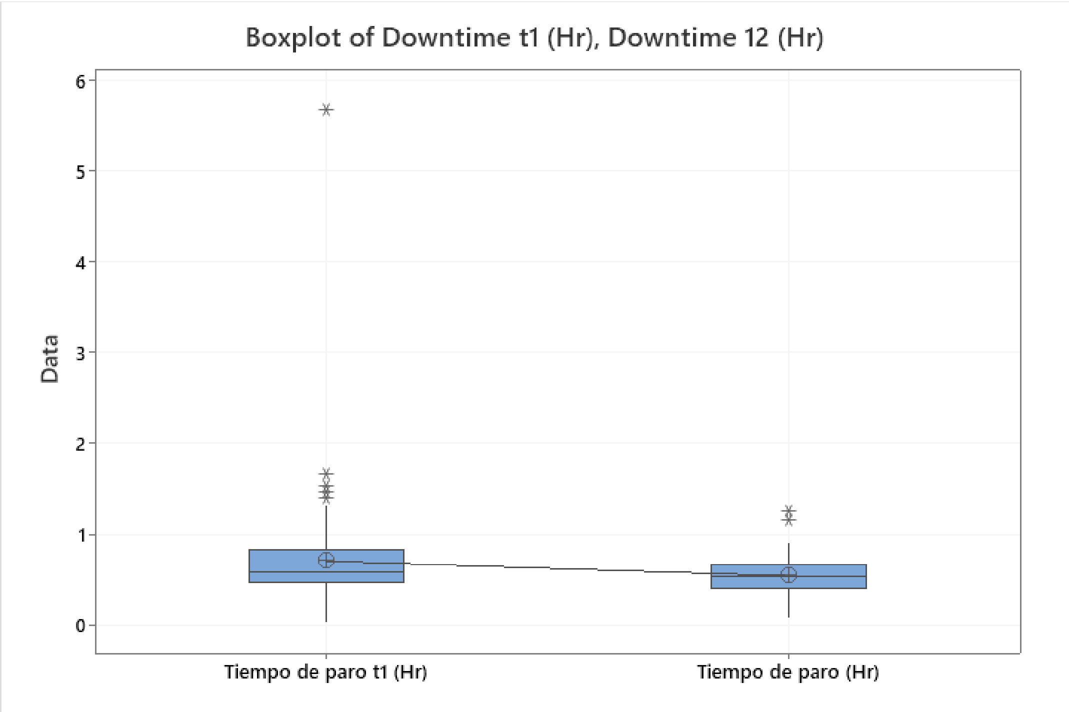


Fig. 9: Statistical test comparison of means using the boxplot graph.

1.4.3 Maintenance range

The list of preventive actions is commonly known as maintenance range and helps to maintain work standardization. It contains the description of the tasks to be execute and the subsystems where they must be performed (Sanmartin and Quezada, 2014). The maintenance range collects the recommended actions to be added to the maintenance plan, which were obtained throughout the different analyzes carried out during this study; particularly for the mill, mixer, and extruder. See Annex 5.

1.5. Control

Relative to the DMAIC methodology, control measures were proposed to ensure the continous practice of the 5'S method. During the Improve phase, a card sorting strategy was used to categorize and place tools in areas where value is generated, i.e. that make maintenance processes more efficient. The green card was used to classify frequently used functional items, and the red tag for those not needed, defective or considered waste. (Figure 10).

RED TAG 5'S	
Name of the tool:	Quantity:
Location:	
Function / Classification	
Suggested Action	
Date:	

RED TAG 5'S			
Name of the tool:		Quantity:	
Location:			
Reason			
Not needed		Other	
Defective object			
Waste			
Suggested Action			
Discard		Sell	
Donate			
Donate to other area			
Date:			

Figure 10: Green and red tag used in the Set in order phase.

Also, as mention before, in the Standardize phase a control sheet was provided to production supervisors so that it was ensured to maintain workstations orderliness and cleanliness in every work shift. The company was strongly recommended to draw up a training plan to keep the 5'S method throughout a continuous improvement cycle and a control plan, which leads to periodically assessing the system state and the supplies obsolescence.

On the other hand, if implemented the maintenance range, the maintenance Team must ensure its relization to conformity, according to the defined periodicity, as well as the accomplishment of daily checks. With that intention, the application of Gemba Walks was proposed.

In the Tervene company guide (n.d.) this practice is defined as a control management scheme that consists of walking through the production line to identify problems or improvement opportunities. Each Shift Supervisor was appointed as the leader and the person in charge, who must complete their review using a checkpoint list, with a frequency of two times per shift and a 15 minutes duration (Gemba Walk checklist see Annex 6). According to Schwalbe-Fehl (2016), Gemba Walks are developed by asking the following questions in order. These were taken to build the monitoring template.

- What is the subsystem or area under observation?
- Is the subsystem or area working under normal conditions?
- Are the standards being followed? Is there any unexpected variation?
- Are there sources of waste that could be optimized (waiting, over-processing, overproduction, transportation, inventory, motion, and/or defects)?
- Are the workstation conditions good? Is there any identified hazard?
- What are the corrective or preventive actions to be taken based on what was found?

It was also recommended to set targets for the number of new improvement opportunities the supervisor must present in a team meeting each week. It is equally important to mention that the company keeps a constant record of the completeness of every maintenance activitis, for what was encouraged the addition of maintenance ranges as follow-ups to the preventive actions. In addition, the team was trained on the use of Lean tools for re-evaluations, such as, for example, the FMEA to control improvements through its RPN, the rating being the reflection of severity, occurrence and detection capacity.

2. DISCUSSION

Due to the company's production expansion, there are uncontrollable variables that affect the performance of any implemented improvement. By operating the plant 24 hours a day, 7 days a week, there are three successive work shifts differentiated by the variability of its expected operational planning and number of workers. Each case requirements were taken into account as shift rotation directly affected implementations uniformity. Thereupon, one of the main intentions was to bring off a thorough step-by-step improvement plan, since the complexity aroused in reaching an agreement between the Shift Supervisors.

For a successful implementation of the principles of autonomous maintenance, LM Six Sigma tools such as Pareto diagram, RCA methods, the 5'S, spaghetti and processes diagrams were used. It was detected that the plate change process had the greatest loss in terms of time, assignable to transport and inspection activities, which is an indicator of tools disorder and poor workstations distribution.

A standard system organization based on the 5’S phases was sought to reduce the mean time to repair a fault (MTTR), what was achieved through a better classification of maintenance supplies along with clear signage. It allowed greater efficiency of preventive maintenance. Specifically for the covered plate category, the distance traveled by the operator when changing the plate was significantly reduced from 108 meters to 49 meters, minimizing transport activities in this process by 86%. (See Annex 3). Consequently, the cycle time of the plate change was reduced from 17 to 11 minutes, involving a 35% reduction in the process non-value added activities.

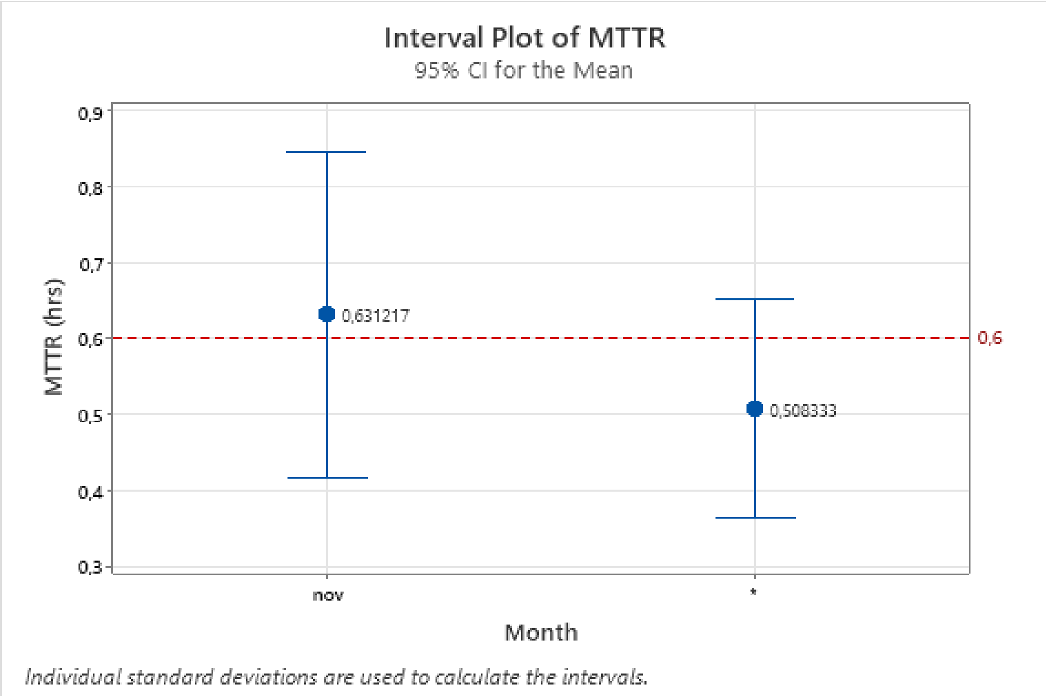


Fig. 10: MTTR Interval plot per month for extrusion Line 3 after implementing the 5'S. Global average 0.6 hours.

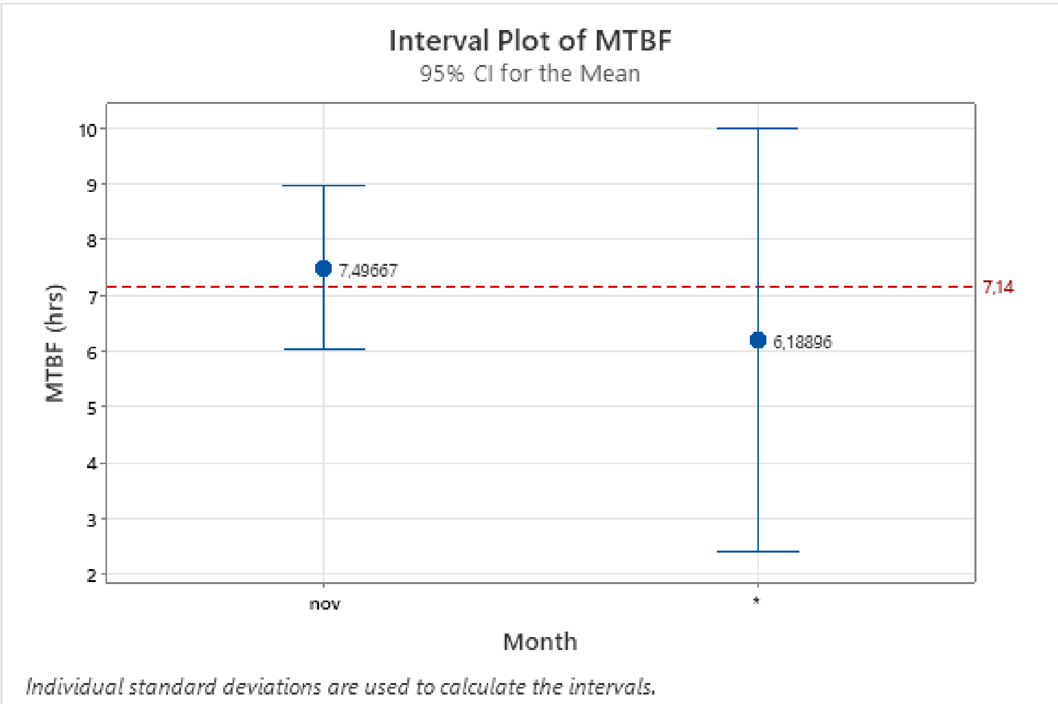


Fig. 11: MTBF interval plot per month for extrusion Line 3 after implementing the 5'S. Global average 7.14 hours.

This result represents a reduction in the total corrective maintenance time since the covered plate, as an unplanned maintenance motive, had both high levels of occurrence and severity. The inherent availability (A_I) of Line 3 was calculated after the 5'S implementation for the period from November 9 to December 14, 2021. It was obtained an average of 90% availability; i.e., 17 percentage points above the baseline. Similarly, a 20.4 minute reduction in MTTR was observed, which means that maintainability improved, shutdowns can be resolved more quickly, and operational time increases. The latter is represented by the MTBF index, achieving in average an increment of 2.5 hours of time between failures (productive time). Thus, by increasing the extruder availability, the company covers the unsatisfied demand due to lack of product in 1% , which translates into $ 3,376 increase in monthly income.

Finally, for the other maintenance proposals, which are aimed at detecting anomalies in the initial phase of occurrence or even in advance, expert analysis is required to determine the appropriate execution frequency. Although it means an additional effort for the company under limited resources, the inclusion of the range will make preventive maintenance a robust system. In this regard, a re-evaluation of the implementation performance is needed to distinguish possible rectifications. One of the recommended actions is to re-evaluate the failures by work shifts, so it would be possible to identify assignable causes according to shift changes, such as insufficient preventive control. Not to mention what Sicilia (2008) defines as the factors that affect the maintainability system: scarcity of information or misinterpretation, lack of qualified personnel and, thus, difficulty to detect failures causes.

3. CONCLUSIONS

Following the proposed methodology and based on the company current controls, actions were successfully distinguished, mostly preventive, to minimize the occurrence of unforeseen failures and unplanned stoppages. A risk assessment method was used together with root causes evaluations, where the main improvement opportunities were identified for the mixer, mill, and extruder areas. This alludes that bottlenecks existed in the production process, since the three subsystems are connected sequentially. The proposed actions were collected in a maintenance range, for which the company maintenance team had good acceptability, although it is considered necessary to evaluate the application frequency prior to its implementation.

The main benefit of the project was evidenced after applying one of the potential solutions. With the 5'S method, the system reliability significantly increased, with which the company reached the capacity of producing about 13 additional tons per hour. Market demand was met and even it was possible to cover the production deficit that had been dragging. To rephrase it, an increase in revenue of more than 3 thousand dollars came by improving the tools and jigs distribution around the production plant, along with promoting and maintaining a standardized organization system between work shifts. As a result, the availability of the pilot line increased remarkably, remaining only two percentage points below the fiscal year expected objective. This could be owning to not implementing the other maintenance proposals. It is known they would aid to minimize downtime, nonetheless, recall that its theorization and not execution was due to the lack of resources accessibility.

What has been achieved in this case study will not stand out in the medium and long term without ensuring its constant application. This means that the suggested actions within the Control phase must be continuously executed to start new improvement cycles. Besides, constant communication is a key factor to continue with the 5'S as a management strategy, together with the execution of Gemba Walks to actively involve all stakeholders. Part of the latter implies integrating spaces for the resolution of doubts and opportunities evaluations. Lastly, Lean Six Sigma methodology allowed the company to meet higher production standards while focusing on organization and safety necessities. It was achieved to implement reliability maintenance to reduce non-planned stoppages by increasing maintainability capacity. To achieve beneficial improvements in a short term period of time, the importance of having an organized centered-maintenance scheme was revealed. Despite the fact that the scant time was the greatest limitation for the realization of this project, just 35 days after its implementation the results presented were obtained, which emphasizes the effectiveness of the joint methodology presented. This success was due to the participation of operational and maintenance teams, when using tools and methods from a maintenance-centered approach, evaluating the RAMS engineering factors.

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ANNEXES

Annex 1: ANDRITZ EX1250 extruder taxonomy

Fig. 1: Subsystem division guide. Source: ANDRITZ, 2021.

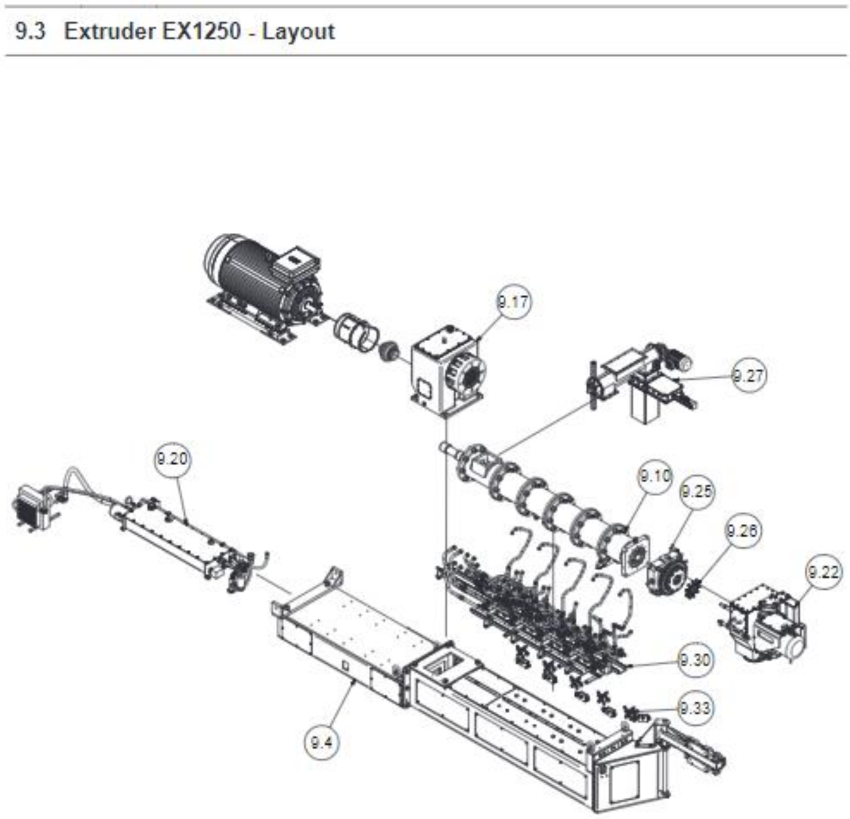


Table 1: Extruder taxonomy based on supplier parts list. Source: ANDRITZ , 2021.

	Description	Item	Subcomponents
9.7	Base Frame	1	Base frame for main ex1250
		2	Base frame for holding knife housing ex1250
		3	Base frame for motor console welded ex1250
		4	Bracket for ex1250 cable box
		5	Hex head screw iso4017 - m8x20 - a2-70 iso3506-1
		6	Plain washer iso7089 - 8 - 200hv
		7	Spring washer :din127 - b - 8 - a4 iso3506-1
		8	Plain washer iso7089 -10 - 200hv
		9	Spring washer :din127 - b - 10 - 1.4404 en10088-2
		10	Hex head screw iso4017 - m10x20 - a2-70 iso3506-1
		11	Cable box

Table **2**: Extruder taxonomy based on supplier parts list **(continuation)**. Source: ANDRITZ , 2021.

	Description	Item	Subcomponents
9.10	Screw Assembly	9.13	Screw configuration 1
		9.14	Screw configuration 2
		9.15	Screw configuration 3
9.17	Gearbox	1	Gear box machined v3 - ex1250
		2	Cover for gearbox l 395 w 660 mm ex1250
		3	Gasket for gearbox ex1250
		4	Socket head cap screw iso4762 - m8x40 - 8.8 iso898-1
		5	Cover inspektion gear ex1250
		6	Gasket for inspection cover, ex1250
		7	Socket head cap screw iso4762 m8x12
		8	Eye bolt din580 - m20 - c15e+u zinc-plated
		9	Housing assembly for shaft sealing ex1250
		10	Socket head cap screw iso4762 -8.8 iso898-1 zinc-plated
		11	Labyrinth seal for shaft ex1250
		12	O-ring ~iso3601-1 -240x3 fpm
		13	Spacer ring for sealing ex1250
		14	Support ring for sealing l 14 mm ex1250
		15	Sealing ring 220x250x15 oafp viton 0,5 bar grooved outside
		16	Cover for main shaft on gear box ex1250 l 37 mm
		17	Socket head cap screw iso4762 - m12x30 - 8.8 iso898-1
		18	Oil plug with magnet ex1250
		19	Breather cap magnaloy fb-a-008p
		20	Connection assembly, ex1250
		21	Seal bonded dunlop 9088000616 1” aisi316
		22	Seal bonded dbs 2”
		23	Fitting hexagon nipple, 22 mm hose 100550.1 mated hose fitting is m30x2 the other thread is g1”
		24	Fitting nipple, 60d dunlop 2540003232 hex nipple 2”bsp-2”bsp 60g
		25	Fitting elbow 90d, snap coupling w/out 1/8” mecman 8215-06-180, nm 10247-0 ø6
		26	O-ring -10x3 viton dupont
		27	Hose for greasing on gearbox ex1250
		28	O-ring - 280x5 viton dupont
		29	Fitting nipple 1” out - 1” and 3/4” in - ex1250 l 60 mm
		30	Fitting blanking plug parker vsti1ed g1a iso8434-1 male stud bspp threaded
		31	Socket head cap screw iso4762 - m20x55 - 12.9 iso898-1
		32	Complete shaft seal

Table **3**: Extruder taxonomy based on supplier parts list **(continuation)**. Source: ANDRITZ , 2021.

	Description	Item	Subcomponents
9.20	Lubrication unit	1	Plain washer iso7089 12 - 200hv
		2	Hex head screw iso4017 m12x20
		3	Filter housing w/o element type bpb32b12cn**03xx fritz schur teknik filter housing w/o element 52001116 bpb32b12cn**03xx
		4	Seal bonded dbs 2”
		5	Fitting hex nipple, w/ 2” outs. Cyl. W/ ins. Cone and 2” outs. Conic 2540303232
		6	Heating element
		7	Hose 2” hy hose 900 lig/lig nut dunlop hydrolic hose 91172 l=900 mm 2” 900 lig/lig nipple
		8	Filter insert epb32fcc viton (fits on bpl32..)
		9	Pressure switch filter
		10	Fitting fritz schur teknik a/s e7210138125 reducing adapter 1 - 1 bsp
		11	Fitting e7178122125 fritz schur teknik a/s adjust, straight connector ege22l-1”edswivel nut m30x2
		12	Nipple . Hexagon. Ge22lred1”-71 stainless steel
		13	Flow switch
		14	Nipple . Hexagon. Ge22lred1”-71 stainless steel
		15	Hydraulic hose fritz schur teknik a/s 1sn12-24003 745 mm
		16	Hydraulic hose fritz schur teknik a/s 1sn12-24003 745 mm
		17	Plain washer iso7089 - 10 - 200hv a2 iso3506-1
		18	Spring washer :din127 - b - 10 - spring steel zinc-plated
		19	Socket head cap screw iso4762 - m10x20 - 8.8 iso898-1
		20	Fitting swivel nut 90°. W-ew22l e73780220002 swivel nut thread m30x2 fritz schur teknik a/s
		21	Oil pump unit with tank fritz schur teknik a/s 811446
9.22	Knife housing for pellets	1	Knife housing machined ex1250, expanded machined l 730 w 644.29 h 824 mm ex1250
		2	Gasket for knife housing ex1250 l 306 w 276 mm
		3	Hatch for knife housing ex1250 l 276 w 306 h 12 mm
		4	Handle elesa m643/140 170397/sl m8 thread
		5	Gasket for cover knife housing ex1250 l 610 w 1.5 h 320 mm
		6	Cover for knife housing without ecs ex1250 l 610 w 320 mm
		7	Plain washer iso7089 - 8 - 200hv a2 iso3506-1
		8	Spring washer :din127 - b - 8 - a4 iso3506-1
		9	Socket head cap screw iso4762 - m8x20 - a2-70 iso3506-1
		10	Seal bonded seal ai316 10mm dunlop 9089000610 ai316 10mm
		11	Hex head screw iso4017 - m10x25 - a2-70 iso3506-1

Table **4**: Extruder taxonomy based on supplier parts list **(continuation)**. Source: ANDRITZ , 2021.

	Description	Item	Subcomponents
9.25	Nozzle head	1	Base for nozzle ring ex1250 l 169 mm
		2	Die ring without hole ex1250 l 30 mm
		3	Sealing ring for expanded knife housing, standard die size ex1250 for knife housing l 50 d 500 mm
		4	Adjustment bolt adjusting bolt knife housing l 85 mm ex1250
		5	Throat for die ex1250 l 130 mm
		6	Nozzle neck insert ø55 and ø85 for ex1250
		7	Housing for nozzle base ex1250
		8	Hinge for noozle holder l360 w130 m... For nozzle holder l 360 mm ex1250
		9	Hinge stud for nozzle holder l 378 mm ex1250
		10	Lock pin for knife housing
		11	Washer "50x26x0,5 stainless" l 50 w 50 mm ex1250
		12	Nut for screw l 105 mm m48
		13	Bearing slide bearing cardboard 2525 p10 permaglide ø25/ø28 l=25
		14	Washer washer teflon 50x26x5 teflon 50x26x5
		15	O-ring - 340x5 and 422x6 viton dupont
		16	O-ring ~ iso3601-1 -455x5 viton dupont
		17	O-ring - 270x6 viton dupont
		18	O-ring - 74.5x3 viton dupont
		19	Retaining ring din471 - 25 mmx1.2
		20	Socket head cap screw iso4762 - m20x50 - 2.9 iso898-1 and m20x150 - 12.9 iso898-1
		21	Socket head cap screw iso4762 - m36x150-8.8 iso898-1
		22	Socket head cap screw iso4762 - m10x20 - a2-70 iso3506-1
		23	Socket head cap screw iso4762 - m12x35 - 12.9 iso898-1
		24	Socket head cap screw iso4762 - m16x50 - a2-70 iso3506-1
		25	Hex nut iso8673 - m20x1.5 - a2-70 iso3506-2
		26	Plain washer iso7092 - 36 od=60 - 200hv a4 iso3506-1
		27	Plain washer iso7089 -16 - 200hv
9.26	Knife head	1	Knife head machined
		2	Clamping plate for knife blade
		3	Knife blade stanley 1992n/1-11-916
		4	Countersunk head screw iso10642 - m6x10 - a2-70 iso3506-1

Table **5**: Extruder taxonomy based on supplier parts list **(continuation)**. Source: ANDRITZ , 2021.

	Description	Item	Subcomponents
9.27	Material inlet	1	Screw with wide inlet ex1250
		3	Plain washer iso7089 -10 - 200hv
		4	Plain washer iso7089 - 6 - 200hv a2 iso3506-1
		5	Hex head screw iso4017 - m6x12 - a2-70 iso3506-1
		6	Spring washer :din127 - b - 6 - a2 iso3506-1
		7	Cable channel l745mm ex1250
		8	Socket head cap screw iso4762 - m6x16 - a2-70 iso3506-1
		9	Junction piece screw ex1250
		10	Plate for cable box
		11	Outlet slide
		12	Hex head screw iso4017 - m10x30 - a2-70 iso3506-1
		13	Cheese head screw iso1207 - m4x10 - 4.8 iso898-1 zinc-plated
		14	Hex nut iso4032 - m10 - a2-70 iso3506-2
		15	Plain washer iso7090 - 10 - 200hv a2 iso3506-1

Table **6**: Extruder taxonomy based on supplier parts list **(continuation)**. Source: ANDRITZ , 2021.

	Description	Item	Subcomponents
9.30	Hose system	1	Fitting bulkhead connection straight dunlop 2x3/4"g a316
		2	Hose visiflon 1" dunlop 1602670016 l=550 mm d.o= 1 aisi 316 90d coupling
		3	Fitting bulkhead connection straight 2x1"g a316 dunlop straight 2x1"g a316
		4	Fitting nipple hex nipple dunlop best.nr: 26 4000 12 16 3/4"bsp-1"bsp a316
		5	Hose visiflon 1" dunlop 1602670016 l=550 mm da=1 aisi 316 90d coupling / 90d
		6	Fitting nipple vvs nr. 03 1780.008 1" aisi316
		7	Hose visiflon 1" l=300 dunlop 1602670016 l=300 mm da=1 aisi 316 straight / 90d coupling
		8	Hose visiflon 1" l=400 dunlop 1602670016 l=400 mm da=1 aisi 316 straight / 90d coupling
		9	Hose visiflon 1" dunlop 1602670016 l=950 mm d.o= 1 aisi 316 straight coupling
		10	Hose visiflon 1" l=300 dunlop 1602670016 l=300 mm d.o= 1 aisi 316 straight / 90d coupling
		11	Hose visiflon 1" l=400 dunlop 1602670016 l=400 mm d.o= 1 aisi 316 straight / 90d coupling
		12	Hose visiflon 1" dunlop 1602670016 l=800 mm da=1 aisi 316 straight coupling
		13	Hose visiflon 1" dunlop 1602670016 l=800 mm d.o= 1 aisi 316 straight coupling
		14	Hose visiflon 1" dunlop 1602670016 l=950 mm da=1 aisi 316 straight coupling
		15	Hose dunlop 1602670012 l=500 mm d.o= 3/4 aisi 316 90gr. Coupling straight
		16	Fitting adaptor 90° angle aisi 316 316106 3/4"-3/4" 315 bar
		17	Hose visiflon 1" dunlop 1602670016 l=400 mm da=1 aisi 316 straight coupling
		18	Needle valve wj13-40w dn25 1" bspp - aisi420
		19	Hand wheel elesa mbt.60-gxx1 elesa mbt.60-gxx1
		20	Fitting nipple hex nipple dunlop 26 4000 16 1"bsp aisi316
		21	Hose dunlop hose visiflon 3199999999 l=600 mm da=3/4 ptfe straight couplings. Stainless steel in ends.
		22	Hose 3/4" straight / straight connection dunlop visiflon 60448 l=400 mm aisi 316
		23	Hose visiflon 1" dunlop 1602670016 l=550 mm da=1 aisi 316 90d coupling / 90d
		24	Hose visiflon 3/4" dunlop 1602670012 l=1150 mm da=3/4 aisi 316 90gr. Coupling straight
		25	Countersunk head screw iso10642 - m5x12 - a2-70 iso3506-1
		26	Hose visiflon 3/4" dunlop 1602670012 l=850 mm da=3/4 aisi 316 90gr. Coupling straight
		27	Cover l= 2 w= 40 h= 40 mm
		28	Hose visiflon 3/4" dunlop 1602670012 l=850 mm da=3/4 aisi 316 90gr. Coupling straight
		29	Hose visiflon 3/4" dunlop 1602670012 l=850 mm d.o= 3/4 aisi 316 90gr. Coupling straight
		30	Hose visiflon 1" dunlop 1602670016 l=400 mm da=1 aisi 316 straight coupling
		31	Hose dunlop hose visiflon 3199999999 l=600 mm da=3/4 ptfe straight couplings. Stainless steel in ends.
		32	Hose visiflon 3/4" dunlop 1602670012 l=700 mm d.o= 3/4 aisi 316 90gr. Coupling straight

Table **7**: Extruder taxonomy based on supplier parts list **(continuation)**. Source: ANDRITZ , 2021.

	Description	Item	Subcomponents
9.33	Sensor assembly	1	Connection box for pressure/temp. Ex1250
		2	Socket head cap screw iso4762 - m4x12 - a2-50 iso3506-1
		3	Temperature gauge , complete, short, ex1250
		4	Pressure gauge complete, short
		5	Pressure gauge complete, long
		6	Temperature gauge , complete, short, ex1250

Annex 2: FMEA

Table. 1: Failure modes and effects analysis (FMEA) for the extruder subsystem.

System: Extrusion line
Subsystem: ANDRITZ EX1250 extruder

ID	Item	Process requirement	Failure mode	Effects	Severidad	Causes	Ocurrence	Preventive control	Detection control	Detection	RPN	Proposed action: Action
1.1	Mechanic system	Comply with productive capacity	Mechanical failure	Impact on the production line / quality of final product requiring immediate intervention	8	Material wear	7	None	Immediate intervention	7	392	Train personel on different types of mechanical failures, disseminate knowledge on prioritization according to the type of failure and how to respond
						Failure during maintenance intervention, the element was not installed correctly (lack of effective maintenance)	7	None	Immediate intervention	7	392	
				Impact on the production line / quality of final product without the need for immediate intervention	8	Material wear	7	Inspection and maintenance planning	Failure reported and scheduled for next maintenance plan	2	112	
						Failure during maintenance intervention, the element was not installed correctly (lack of effective maintenance)	7	Inspection and maintenance planning	Failure reported and scheduled for next maintenance plan	2	112	
1.2	Breaker plate	Material flow break	Covered plate	Plugging that causes abnormal expansion of the product, in turn non-compliance with size, flotation and / or emergence parameters	9	Presence of impurities in the mixture (mesh breakage or jamming in the mill): inclusion of metallic residues or lumps in the mixture	8	Product density control (pressure switch in the last jacket of the extruder), verify pressure, an increase indicates that the plate is clogging	Alert for increased pressure in the last steam jacket	7	504	Define priorities and response times. Check broken meshes periodically. Verify replacement of hammers for better grinding. Promote the cleaning process of equipment in mills to avoid cross contamination (different texture product)
						Problem in ground mix that causes the texture to be too thick for the plate (occurs in calibers 1.2 mm to 0.6 mm)	8	Grinding sampling	Visual inspection to verify product swelling	7	504	
1.3	Raw material grinding	Product availability to be processed	Lack of ground mix	Decreased extruder performance due to lack of product to process	7	Power outage (unplanned)	8	None	None	8	448	Evaluate system to change hammers for a different model, which allow increasing performance with fewer changes day by day and fewer texture problems
						Jamming in elevators or conveyors; texture problems	8	Visual inspection when the mill is at minimum performance	In non-serious cases, solve with the maintenance team on duty	2	112	
						Wear on hammers that cause the line to be stopped gradually	8	None	Stop to check hammer wear, propose rotation change and if it does not work, schedule maintenance intervention or change hammers	2	112	

Table. 2: Failure modes and effects analysis (FMEA) for the extruder subsystem.

System: Extrusion line
Sub-system: Other equipment

ID	Item	Process requirement	Failure mode	Effects	Severidad	Causes	Ocurrence	Preventive control	Detection control	Detection	RPN	Proposed action: Action
2.1	Post extrusion equipment (drying, cooling)	Equipment outside and after the extruder that allows the continuity of the extruder product output	Jamming in other equipment (elevator)	Impact on the performance and availability of the	7	Mechanical or electrical failure that causes product build-up	4	None	Rise in amperage, belt misalignment	6	168	Frequent verification of the production line (visual inspection by inspection gates, noises), define and prioritize points where jams can occur and classify reasons. Define revision frequency based on line stability.
			Jamming in other equipment (dryer)	Impact on the performance and availability of the equipment		Shutter hydraulic system failure and distribution belt failure	8	None	Hydraulic pump verification, blind calibration, band adjustment or change	5	280	
				Non-compliance with the humidity quality specification		Product compaction due to change in physical characteristics (e.g., Moisture)	6		Immediate intervention	5	210	
2.2	Sub - processes before and after extrusion	Compliance with uncontrollable quality specifications during the process	Dryer heater failure / Cooler failure	Non-compliance with quality specifications (humidity)	8	Filtration in beds or accumulation of product due to belt failure	4	Sampling at the product and / or dryer outlet	Review process parameters, if not, check product accumulation and cooler ventilation	1	32	Define limit of tons to produce until fault is fixed
			Failure during mixing process	Non-compliance with quality specifications (diameter, emergence, float, or length)		Existence of impurities	8	Sampling at product outlet	Intervention for equipment cleaning (covered plate). Impurities control	1	64	Review and, if necessary, redefine control frequency (daily visual control range)
			Blade or blade holder problems	Non-compliance with quality specifications (presence of lumps or paste)		Knife housing failure	7	Sampling in dryer and / or cooler	Change of blades or calibration of knife housing	1	56	Inclusion in maintenance plan, define frequency according to blades useful life
			Dryer heater failure / Cooler failure	Non-compliance with quality specifications (hydrostability)		Formulation problem failure or extruder failure	6	Sampling at product outlet, dryer and / or cooler	Identify if it is an atypical failure (formulation problems)	1	48	Check causes of formulation problems
			Failure during mixing process Extruder screw wear	Non-compliance with parameters (floating, hydrostability, emergence)		Lack of mixing conditioning extrusion and mixing process	6	Sampling at product outlet, dryer and / or cooler	Inspection at maintenance stop	7	336	Review and, if necessary, redefine control frequency (daily visual control range)
2.3	Mix and / or post mix	Pre - conditioning and inclusion of material prior to extrusion	1st and / or 2nd mix missing	Stop to release jams	6	Conveyor or elevator failure	8	Preventive maintenance for conveyors and elevators	Stop to release downloaded product line, e.g., bucket drop	2	96	Training project to improve detection and solution capacity
						High hammer wear causing texture problems and low grinding performance	8	None	Verification of wear and tear, inclusion as a scheduled change	2	96	Inclusion as a scheduled change
						Clogging in post mixer discharge hoppers	8	Activate vibrator to release jam, verification by sight glasses	Stop and open hoppers to release accumulated product	2	96	Evaluate include moisture sampling prior to hoppers

Annex 3: Plate change process pre and post 5's method implementation

Fig. 1: As Is spaghetti diagram for the definition of plate change process movements.

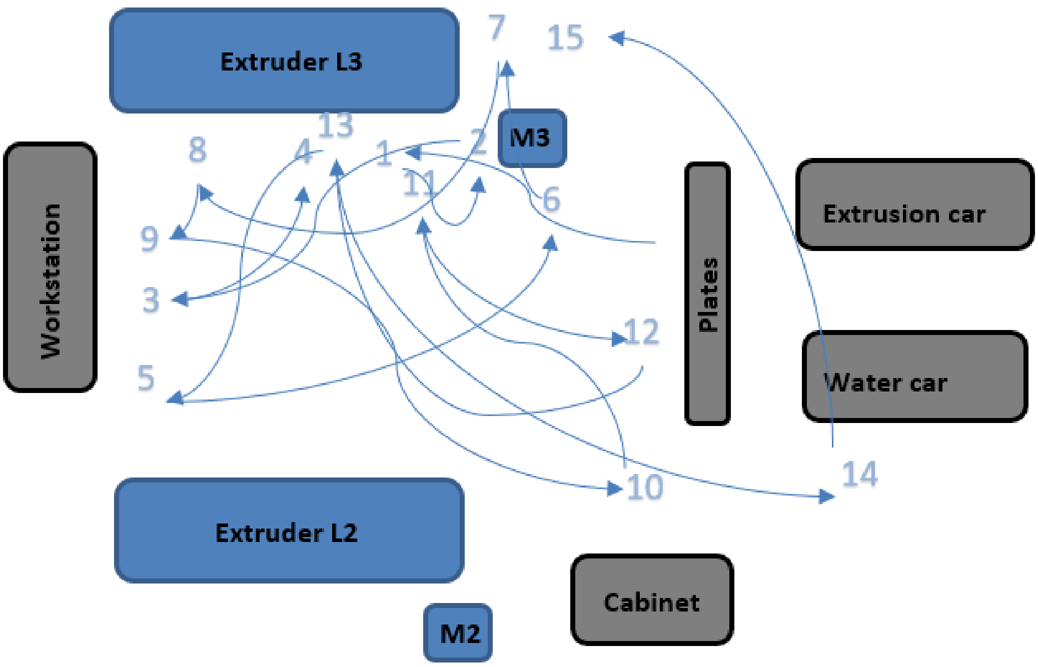


Fig. 2: As Is process flow diagram for the identification of value-added and non-value-added activities in the plate change process.

Step #	Activity description	Time (minutes)	Distance (meters)	Operation ○	Transport ⇨	Inspection □	Delay D	Storage ▽	VA.ENVA.NVA Value Category
1	Put tools' car aside from the extruder	0.3	5	x					ENVA
2	Stop machine	0.1	2	x					VA
3	Move to machine	0.2	2		x				NVA
4	Open knife housing	0.17	1	x					VA
5	Remove bolts with 27mm socket	0.58	1	x					VA
6	Take out first bolt	0.1	0	x					VA
7	Walk to workstation	0.55	6		x				NVA
8	Put bolt in workstation	0.1	0					x	ENVA
9	Search spatula	0.2	1			x			NVA
10	Take spatula	0.1	0	x					VA
11	Walk to machine	0.4	6		x				NVA
12	Clean plates' back	0.3	1	x					VA
13	Clean plates' front	0.28	1	x					VA
14	Walk to workstation	0.3	6		x				NVA
15	Search hex wrench 10 mm	0.2	1			x			NVA
16	Take hex wrench 10mm	0.1	0	x					VA
17	Walk to machine	0.4	6		x				NVA
18	Take out bolts	0.57	1	x					VA
19	Walk through the machine	0.2	3		x				NVA
20	Take the paddle	0.1	0	x					VA
21	Walk to the knife housing	0.2	3		x				NVA
22	Take out the plate	0.4	0	x					ENVA
23	Put plate on tools car	0.05	1					x	ENVA
24	Take spatula	0.05	1	x					VA
25	Walk to extruder' monitor	0.1	2		x				NVA
26	Turn on extruder	0.16	0	x					ENVA
27	Search carry on water car	0.82	0			x			NVA
28	Walk to the place where the car is	0.5	9		x				NVA
29	Move car to machine	0.5	9		x				NVA
30	Inject water from extruder	0.3	0	x					VA
31	Take out remaining groun mixture	0.6	2	x					VA
32	Wait until all mixture is out	2.1	2				x		ENVA
33	Walk to workstation	0.4	6		x				NVA
34	Search 27mm die	0.2	3			x			NVA
35	Take the bolts	0.1	0	x					VA
36	Walk to machine	0.44	6		x				NVA
37	Put bolts on the plate	1.34	3	x					VA
38	Put plate	1.2	0	x					VA
39	Walk to workstation	0.4	6		x				NVA
40	Take pneumatic gun	0.2	1	x					VA
41	Walk to machine	0.4	6		x				NVA
42	Adjust 18 bolts	0.8	2	x					VA
43	Close the knife housing	0.2	1	x					VA
44	Turn on extruder	0.4	2	x					VA
			Count:	22	14	4	1	2	
			Time per process step:	8.15	5.34	0.8	0.4	0.25	

Fig. 3: To Be spaghetti diagram for the plate change process after the 5's method implementation.

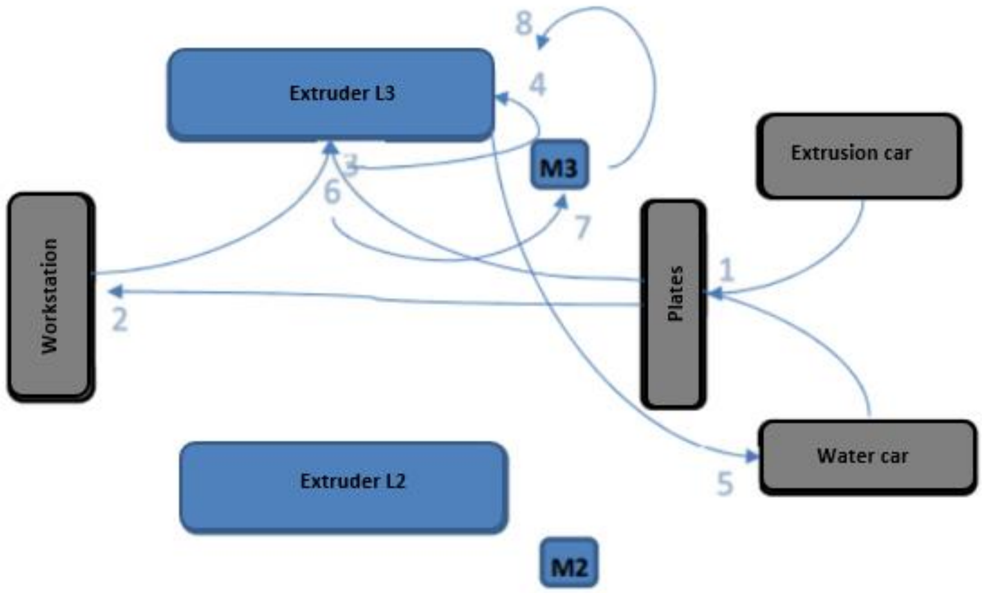
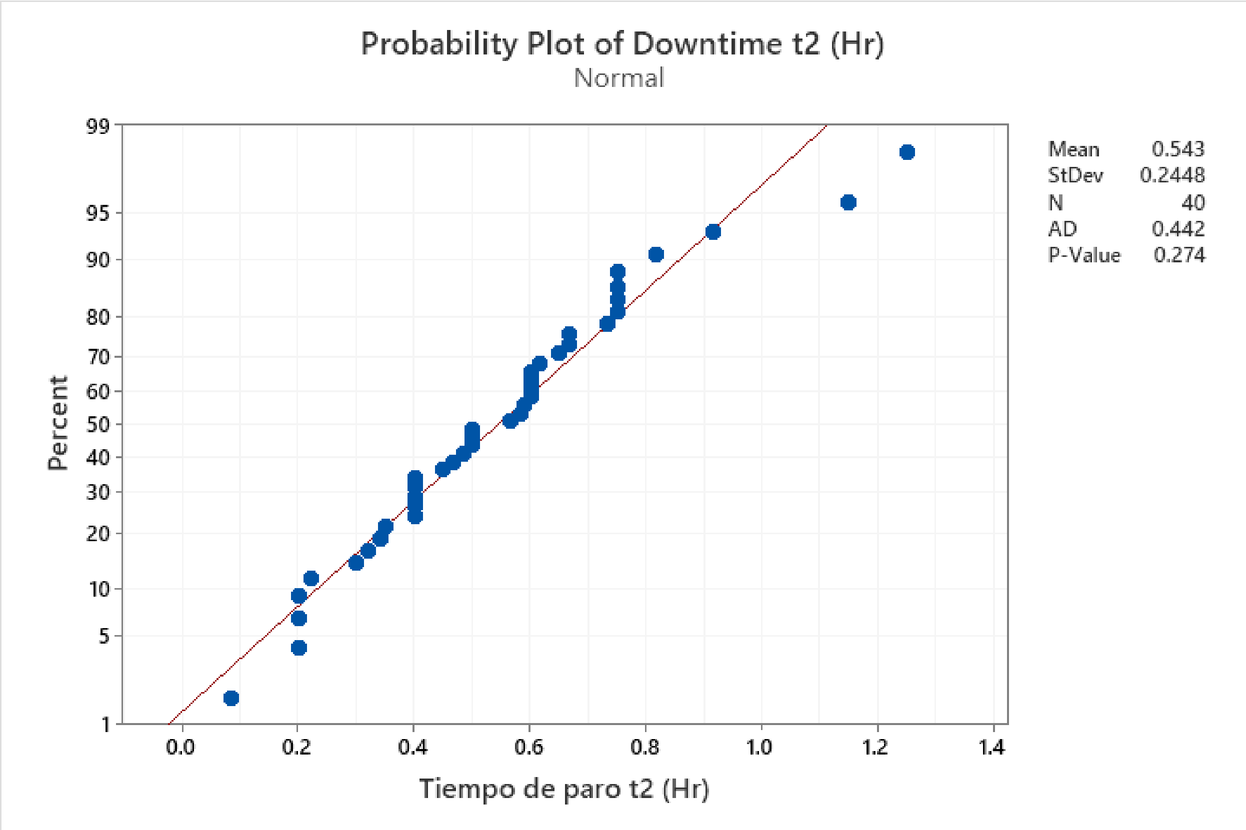


Fig. 4: To Be process flow diagram for the plate change process after the 5's method implementation.

Step #	Activity description	Time (minutes)	Distance (meters)	Operation ○	Transport ⇨	Inspection □	Delay D	Storage ▽	VA.ENVA.NVA Value Category
1	Put tools' car aside from the extruder	0.3	5	x					ENVA
2	Put tools on the car following the visual signs	0.4	0	x					ENVA
3	Stop machine	0.1	2	x					VA
4	Move to machine	0.2	2		x				NVA
5	Open knife housing	0.17	1	x					VA
6	Remove bolts with 27mm socket	0.58	1	x					VA
7	Take out first bolt	0.1	0	x					VA
8	Put bolt on extruder car	0.1	0					x	ENVA
9	Take spatula	0.1	0	x					VA
10	Clean plates' back	0.3	1	x					VA
11	Clean plates' front	0.28	1	x					VA
12	Take hex wrench 10 mm	0.1	0	x					VA
13	Take out bolts	0.57	1	x					VA
14	Take the paddle	0.1	0	x					VA
15	Walk to the knife housing	0.2	3		x				NVA
16	Take out the plate	0.4	0	x					ENVA
17	Put plate on tools car	0.05	1					x	ENVA
18	Take spatula	0.05	1	x					VA
19	Walk to extruder' monitor	0.1	2		x				NVA
20	Turn on extruder	0.16	0	x					ENVA
21	Walk to the designated water car place	0.5	5		x				NVA
22	Move car to machine	0.5	9		x				NVA
23	Inject water from extruder	0.3	0	x					VA
24	Take out remaining groun mixture	0.6	2	x					VA
25	Take the 27mm die	0.2	3	x					NVA
26	Take the bolts	0.1	0	x					VA
27	Put bolts on the plate	1.34	3	x					VA
28	Put plate	1.2	0	x					VA
29	Take pneumatic gun	0.2	1	x					VA
30	Adjust 18 bolts	0.8	2	x					VA
31	Close the knife housing	0.2	1	x					VA
32	Turn on extruder	0.4	2	x					VA
			Count:	25	5	0	0	2	
			Time per process step:	9.05	1.5	0	0	0.15	

Annex 4: Assumptions check for statistical analysis

Fig. 1: Normality test.



Randomness test result:

Test

Null hypothesis	H_0: The order of the data is random
Alternative hypothesis	H_1: The order of the data is not random

Number of Runs

Observed	Expected	P-Value
23	21.00	0.522

Annex 5: Maintenance range

Fig. 1: Resulting maintenance range with daily, weekly, monthly inspections, etc. Pending approval.

LOGO	**MAINTENANCE RANGE**	**Frequency:** TO DEFINE	**Broadcast date:** 26/11/2021
	GENERAL INSPECTION	**Versión:** 0.0	**Type:** Preventive
		Code: MP01	**Sheet:** 1/1

AREA TO INSPECT: Extrusion line

Equipment	Description	Periodicity
Mill (M1 M2 M3 M4)	Pocket feeder exchange review to plan change	Monthly
	Baffle plate replacement M1 M2 M3 M4	According to evaluation
	Implement disk method for mill balancing	One time only
	Evaluate change hammer type	According to evaluation
	Weigh worn hammers before installing	Daily
	Promote the cleaning process of mill equipment to avoid cross contamination	Daily
	Change rotor discs if there is wear in gaps and greater thickness of the product	According to evaluation
	Staff training on mesh installation in 1st and 2nd grinding station	According to evaluation
	Change vibration attenuators	Biannual
	Visual inspection by inspection gates or noise detection	Daily
Mixer	Check broken meshes periodically	Daily
	Check the existence of poorly ground mixture and, if it is the case, remove it through the elevator bypass	Daily
	Evaluate change of rings where meshes rest	According to evaluation
	Place neoprene in mesh of station number 1	According to evaluation
	Packaging change at station number 2	According to evaluation
	Visual inspection by inspection gates or noise detection	Daily
Extruder	Identify covered plate priorities and response times	According to evaluation
	Check pressure rise (pressure switch at last steam jacket)	Daily
	Visual inspection by inspection gates or noise detection	Daily

COMMENTS:

* Frequencies pending definition require further analysis by the maintenance area for its inclusion in the maintenance plan.

Annex 6: General Gemba Walk control worksheet

Fig. 1: Template designed for Gemba Walks, based on Tervene's guide.

LOGO	GENERAL GEMBA WALK WORKSHEET	**Frequency:** Twice per shift	**Leader:** XX XX
	GENERAL INSPECTION	**Versión:** 0.0	**Type:** Preventive
		Code: GW01	**Sheet:** 1/1

SUBSYSTEM TO INSPECT: Extruder

Time	No.	Analyzing processes
PAST	1	Has there been any problem related to materials, tools, personnel or information since the last revision? ☐ Yes ☐ No ☐ N/A
	2	Has there been any problem related to quality since the last revision? ☐ Yes ☐ No ☐ N/A
NOW	3	Is the subsystem or area working under normal conditions? ☐ Yes ☐ No ☐ N/A
	4	Is the process expected standard being met? ☐ Yes ☐ No ☐ N/A
	5	Is the operator at his workstation? ☐ Yes ☐ No ☐ N/A
	6	Does the employee have all the necessary tools? Are the tools in good working order? ☐ Yes ☐ No ☐ N/A
	7	Is the equipment working well? Does it need maintenance? ☐ Yes ☐ No ☐ N/A
	8	Are the safety standards respected? Does the operator wear PPE? ☐ Yes ☐ No ☐ N/A
	9	Does the product meet quality standards? ☐ Yes ☐ No ☐ N/A
	10	Does the production rate follow the schedule? ☐ Yes ☐ No ☐ N/A

Comments and suggested actions:

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