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APPLICABILITY OF CRITICISM IN THE MAINTENANCE OF EQUIPMENT

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Abstract. This work presents an information system of preventive, predictive and corrective maintenance related to the data obtained from Criticality Matrix whose parameters were based on the history of maintenance interventions and the visual and auditory observation of equipment such as Mechanical scales, Winches, Hoppers and Sterilizers. Criticality analysis determined trends of preventive and predictive maintenance for the pairs "Hoppers, Sterilizers" and "Mechanical scales, Winches", respectively, establishing in this way a preventive maintenance planning system for Hoppers and Sterilizers through the design, elaboration and data feed to the information system that anticipates the planned control over the actions of the maintenance and production department. These actions generate benefits such as the availability and safety of the equipment plant, improvement in the quality of the products, a better register with the capacity of first hand information on the conditions of the machinery, a good capacity in quantity and quality of maintenance activities, optimization in the handling of repair parts, improvements in the design of equipment which leads to reduction of costs for maintenance.

Keywords: Maintenance, faults, criticality matrix, planning

APLICABILIDAD DE LA CRITICIDAD EN EL MANTENIMIENTO DE EQUIPOS

Resumen. Este trabajo presenta un sistema de información de mantenimiento preventivo, predictivo y correctivo relacionado con los datos obtenidos a partir de una Matriz de Criticidad cuyos parámetros fueron basados en el historial de intervenciones de mantenimiento y la observación visual y auditiva de los equipos tales como: Básculas mecánicas, Malacates, Tolvas y Esterilizadores. El análisis de Criticidad determinó tendencias de mantenimiento preventivo y predictivo para los pares "Básculas mecánicas, Malacates" y "Tolvas, Esterilizadores", respectivamente, estableciéndose de esta manera un sistema de planeación de mantenimiento preventivo para Tolvas y Esterilizadores mediante el diseño, elaboración y alimentación de datos al sistema de información que anticipa el control previsivo sobre las acciones del departamento de mantenimiento y producción. Estas acciones generan beneficios tales como la disponibilidad y seguridad de la planta de equipos, mejora en la calidad de los productos, un mejor registro con capacidad de información de primera mano sobre las condiciones de la maquinaria, una buena capacidad en cantidad y calidad de actividades de mantenimiento, optimización en el manejo de partes de reparación, mejoras del diseño de equipos, lo cual conduce a reducción de costos por mantenimiento.

Palabras clave: Mantenimiento, fallas, matriz de criticidad, planeación

Introduction

Equipment maintenance is one of the main strategies applied at the company level, since through it is possible to reduce costs. Equipment maintenance represents savings for the economy of companies; in addition, it offers a way to maintain the continuity, security and efficiency of the same ones. Equipment maintenance is defined as the improvement or restoration, associated with services where the requirements for an adequate maintenance enable adding physical value and quality to the equipment. In addition, equipment maintenance offers alternatives of consideration that enables the identification of possible problems or causes of failure, as well as the possible consequences. Through maintenance, it is possible to decide if repairs or replacements of the damaged part or parts were executed, to carry out periodic maintenance, to fix intervals of revision or to simply give answer to user requirements (Horner, El-Haram, Munns, 1997). The application of an equipment maintenance system in general is defined as a methodology related to administrative and technical services, which help its control and measurement, facilitate its efficiency through operations that are focused on diagnosis and guarantee quality processes free of failures (Zul-Altfi, 2017). A maintenance system can be built through three diagnostic strategies such as preventive, predictive and corrective maintenance, which integrate an overall coordination system that improves communication between the operational and maintenance parts (Horner, El-Haram, Munns, 1997; Zul-Altfi, 2017).

Today, the principle of a preventive, predictive, corrective maintenance system in the industry marks a breakthrough in achieving productivity standards, world-class quality, and as a result, reduced cost (Swamson, 2001). Companies are implementing ever more preventive, predictive and corrective maintenance methods based on performance indicators, and practices based on the maintenance philosophy, since these enable ensuring the equipment’s functionality, as well as to reduce the deterioration and increase of the costs for repair or change of equipment (Swamson, 2001; Nazmul, Taib, 2013).

The development of these types of systems is done through the three phases mentioned above: a) preventive maintenance, which is based on operating times and the specific statistical operational history of each piece of equipment; b) predictive maintenance, which is based on direct monitoring, operating conditions, efficiency, and temperature distribution in the equipment, and non-operational indicators due to failure or loss of efficiency (Nazmul, Taib, 2013; Fluke, 2005); and finally, c) corrective maintenance operation, based on total equipment repair (Wang, Ye, Yin, 2016).

In general, we can say that preventive, predictive, and corrective maintenance processes are based on cleaning, verification and inspection. However, failures and maintenance requirements have become a key point in the operation and planning of different industrial processes (Kogbaa, Huang, 1992).

In recent years, the maintenance of fixed assets in the industry has undergone a series of technological, financial, and organizational transformations that are a consequence of competitiveness, which has led to the implementation of new tools that allow greater reliability in the life cycle of equipment. The maintenance of processing equipment increases productivity and reduces operating costs, which is why many organizations apply these types of activities to ensure that there are no inconveniences that affect production (Fluke, 2005). Conversely, maintenance failures result in equipment malfunctioning, that lead to poor quality products, reduced operational life, frequent repairs and, ultimately, equipment replacement (Swamson, 2001). Predictive, preventive and corrective maintenance represents one of the strategic analysis operations, suitable for critical operations, since it improves the operation of production equipment and represents a high reliability and availability for the productivity of industrial plants (Fore and Msipha, 2010).

General Maintenance Characteristics

Preventive Management (MP)

Preventive maintenance (PM) is an important component of maintenance activity, as it is one of the main parts of the total performance effort within the preventive system. Objectives include reducing critical equipment disintegration, prolonging the productive life of equipment, improving the planning of programs and activities such as: equipment maintenance schedules, reducing production losses due to failures, and promoting the health and safety of maintenance personnel (Dhillon, 2002; Duffua-Salih, Raoluf and Dixon, 2000).

This type of maintenance process has advantages such as equipment availability, good performance capability, good workload balance, reduction of overtime, increase in production profits, among other benefits. Among the disadvantages are exposure to possible failures, use of a greater number of parts, increase in initial costs, failures in new parts and greater frequency in demand for equipment and parts for repair (Dhillon, 2002).

In a study conducted on the implementation of a preventive maintenance program for palm oil extraction in Malaysia by Ahmad-Rasdan, Rafis-Suizwam, Rozli, Nor-Kamilah (2009), it was shown that the implementation of the preventive maintenance program can provide greater equipment availability and reduce the equipment failure rate. This is because it is possible to classify the main processes from reception and classification of oil palm fruits, sterilization, threshing, digestion, pressing, clarification and almond production, resulting in the organization, scheduling, inspection, and frequency of maintenance work.

Predictive Maintenance (PdM)

Predictive maintenance (PdM), is one of the maintenance measures which has revolutionized the industry, because through these measures, it is possible to improve the safety, quality and availability of equipment in industrial plants. It is considered as a program that enables establishing strategic decisions, analysis plans, and strategies related to the management and supervision of equipment permanently or intermittently. It also works as an indicator of quality control, as it facilitates the early detection of anomalies during the operation of equipment, in addition to avoiding failures in the process programs (Dhillon, 2002).

This type of process has a tool technology that enables knowing the operating status of the equipment in operation through non-destructive measurements such as: thermographic analysis, amplitude, speed and acceleration measurements; lubrication analysis and ultrasound tests for thickness measurement. Among the benefits of this type of maintenance are improvements in product quality, both in maintenance, and in the quantity and quality obtained on the information of industrial machinery, the ability to schedule maintenance activities, optimization when handling spare parts, support and design of industrial machinery, cost reduction and the ability to identify the root cause of the problem (Carnero, 2003).

In a study conducted by Kumar-Srivastava, Mondal (2014), it was demonstrated that by developing a modified failure mode and effect analysis (FMEA) model for predictive maintenance, competitive advantages and additional benefits can be obtained that minimize the use of costly technology and monitoring systems in processing technology for coconut palm oil extraction. Other studies, such as the ones conducted by Mendel, Rauber, Varejao and Batista (2009), present the method of diagnosis by marking the detection of faults in bearing machinery for oil extraction, which provides a characteristic vector for the identification of faults.

Corrective Maintenance

Corrective maintenance is an important activity, defined as a remedial action taken due to a failure or deficiency that occurs as part of or during preventive maintenance, either to repair equipment or to keep it in operation. The actions required are immediate, and are intended to avoid deficiencies in operation, and incidents or accidents caused by poor performance of repair actions and are classified as follows: breakdown repair, salvage, reconstruction, repair and maintenance (Dhillon, 2002).

Corrective maintenance is crucial to ensure that assets have good maintenance capacity, availability and reliability during plant operation; any failure means reduced profits for the company and reflects a negative impact on its performance (Salleh-Intan, Mohd-Yusof and Zahedi, 2012).

Corrective maintenance is a primitive maintenance model or the most basic version. Its objective is to speed up the operation of the equipment quickly and with minimum maintenance costs. However, it presents disadvantages such as parts disposition, which generates delays in repairs, production stoppages and affects in the operational quality of the equipment due to progressive wear (Duffua-Salih, Raoluf and Dixon, 2000).

Criticality

The planning and control of maintenance systems is complex and has been tested for the solution and operational improvement of facilities and components associated with fundamental aspects such as human reliability, process, design, maintenance and Criticality. The Criticality theory is a model that carries out the hierarchization of processes, systems and equipment, enabling the creation of a structure that facilitates effective decision making in terms of types of maintenance. Criticism focuses on the operational reliability of processes and even when it is a theory that is not so new, its scopes do solve current realities in the industry. It makes use of contextualized mathematical models that can lead to results that are not necessarily representative of the case to be analyzed, but in most cases they are.

Criticality Analysis is mainly based on the qualification of two corresponding attributes: the first one has to be with the origin of the failure, and the second one is related to the critical level that prevails in the fault However, although the appraisals of these qualification components are quantitative in nature, they also have a qualitative part (Visual), since the experience of the operators of the teams and the maintenance manager is applied to have a qualification closer to reality. The engineering part of this methodology is associated with the components of safety, environment, production, operating costs, maintenance, number of failures and repair time of the equipment. As presented below in some study cases where this methodology has been applied. For example, in a study presented by Díaz-Concepción, Pérez-Rodríguez, Del Castillo-Serpa & Brito-Vallina (2012), an analysis of Criticality and complexity in a production process of a plant of biological products was carried out. Therefore, a hierarchical list of the equipment was obtained from the comparison, through the Criticality matrix and other criteria that intervene in the criticality index and the complexity of each asset.

In the research developed by Aguilar-Otero, Torres-Arcique, Magaña-Jiménez (2010), in which they presented an analysis of failure modes, effects and Criticality, also known as FMEAC methodology, for maintenance planning, risk and reliability criteria were used for maintenance planning. It was concluded that the degree of Criticality of the risk in equipment is normally used for maintenance planning focused on reliability, since it enables achieving a global understanding of the system, as well as the operation and the way in which the failures of the equipment that compose the analyzed system may occur.

Furthermore, focused Criticism provides relevant results, as opposed to specific maintenance plans for equipment, increasing the expectations of efficiency and reliability in production. When all these components are integrated, the results have a positive impact on the industry, since the classification and reduction of maintenance operations depends on it. That is why this study has the purpose of generating a control system that intervenes in an adequate and effective way in the processes of preventive, predictive and corrective maintenance for equipment such as: Mechanical scales, winches, hoppers and sterilizers. Through the analysis and the current evaluation of the equipment of extraction of palm oil from coconut seed in a particular company, it is possible to submit them to maintenance directed to determine actions, routes and days that enable sustaining the production from a reliable park of machinery and available in most of the processing time.

Method

Problem to be Solved

It has been recognized that the diagnosis raises management’s awareness about the problems and the fulfillment of the area’s tasks and the repercussions that can result from the lack of organization and planning of both predictive and corrective maintenance processes (Wang, Ye, Yin, 2016; Duffua-Salih, Raoluf and Dixon, 2000; Bohórquez, 2004). When analyzing the current state of the machinery performance of the maintenance department, it was found that there is no adequate maintenance program for the plant equipment and parameters that lead to a real and future projection towards the planning and programming on the equipment. For this reason, the technification and organization of the maintenance department is required.

For this purpose, a study was carried out by means of the 7-steps-systematic application that are presented below, which have a constant relationship with the control of mechanical and electrical maintenance, in favor of the improvement of the operating conditions of the machinery.

- Equipment data sheet. It presents the relevant information to the general characteristics of the equipment; brand, reference, pieces and capacity.
- Resume In which the activities carried out on the machines are presented consecutively and chronologically.
- Plans. They allow to visualize the pieces that include special designs and in certain case to be manufactured by the department.
- Pictures. Most of the plant equipment to quickly reference its location.
- Work order. It is evaluated and implemented as a field document that allows to review and evaluate time and tools used to develop a programmed or emergency function on the equipment.
- Alarms. They show the main operations planned and established according to maintenance routes, dates and days analyzed for the convenience of the equipment; and communicate in a timely manner the time of intervention as well as materials and necessary spare parts.
- Company. That links the general information of the company, its representatives, its employees, headquarters, and suppliers.

The developed sections and scoring values for each topic were assigned according to parameters obtained directly from production equipment, cost limits for spare parts or repairs, as well as the reliability of each machine based on the resume.

Criticality Theory

The implementation of the Criticality Theory is based on the operation of equipment and logs. The qualification of the equipment is made through visual and auditory inspection of each of the components of the system, considering the contribution of life time and duration, as well as the work environment to which they are subjected, thus ensuring the availability and reliability of the operations through optimal maintenance (Bohórquez, 2004; Grall, Berenguer, Dieulle, 2002).

In accordance with the project objective, a sustainable maintenance plan was implemented in order to devise an improvement in production from the maintenance department and its actions. For this reason, a specialized technique (Criticality study) is proposed to help solve this problem (Grall, Berenguer, Dieulle, 2002; Duffua-Salih, Raoluf and Dixon, 2000).

The scope of this research according to the objective of the work focused on the design, development and implementation of a system that facilitates the actions and maintenance days, forming a performance and operational efficiency of the teams to have databases that provide criteria necessary to make opportune investment on them. In addition to obtaining the maintenance routines analyzed, established and recommended to promote in the operators and maintenance personnel a culture of care and continuous review of the equipment. The system will allow results to be obtained from simple, easy and comfortable language formats based on Criticality analysis (Kyiakidis, Dimitrakos, 2006).

The limitations of this work are related to the lack of an adequate computer support system, as it is presented in tables assigned by simple spreadsheets for each piece of equipment where data are recorded such as: machine specifications, resume distributed in the last actions performed, and missing data described in an unclear manner (Kenne, Nkeungoue, 2008). The disadvantages presented occur when trying to define exactly the operations carried out and the implements employed. The lack of documentation on the necessary parts, as well as some drawings on relevant parts of the machines; that is to say, that there is no technical record of equipment or that it is incomplete (Swamson, 2001; Fore and Msipha, 2010; Grall, Berenguer, Dieulle, 2002; Kenne, Nkeungoue, 2008). Therefore, the Criticality study could be affected by the lack of information. Based on the abovementioned, it was observed that there is a direct influence between the production teams, cost limits in spare parts and repairs, as well as in the reliability of each team. Below, in table 1, the general information of Criticality variables used for this study is presented.

Table 1
Variables used in the Criticality Study

Type of variable	Assessed variable	Score
Failure frequency, (FF)	Poor, 4 failures per year:	4
	Average of 2-3 failures per year:	3
	Good of 1-2 failures per year:	2
	Excellent, less than one failure per year:	1
Maintenance cost (MC)	Greater than or equal to $60,000	2
	Less than $20,000	1
Operational Impact (OI)	The factory stops working	10
	The system or section stops working and impacts other systems.	7
	Impacts inventory-wise	4
	Does not have any significant effect on operations or production	1
Impact on environment, health and safety (EHS)	It affects both internal and external human security and requires reporting by internal and external agents of the organization.	8
	It affects the environment and facilities.	7
	It affects facilities causing severe damages.	5
	It causes minor damages.	3
	It does not cause any damage to persons, environment and facilities.	1
Operational Flexibility, (OF)	There is no production option or spare part available for Purchase.	4
	There is an option to manufacture the spare part.	2
	Spare part available in stock.	1

Note: information taken from the thesis "Variable aplicada en el estudio de criticidad" (*Variable Applied in the Study of Criticality*), from the Industrial University of Santander, Engineering School, Colombia, (2004).

For the calculation of Criticality, the following operations given by the equations (1 and 2) were used, which are shown below:

Total criticality (***TC***) = Frequency (***FF***) x Cost consequences (***CC***) (1)

Where the consequences are calculated as follows, equation (2):

Consequences (***CC***) = ***IO*** x ***FO*** + ***CM*** + ***ISAH*** (2)

Where: ***FF***, is the frequency; ***CC***, are the consequences; ***IO***, is the operational impact; ***FO***, is the operational flexibility; ***CM***, is the cost of maintenance and ***ISAH***, Environment, health and safety impact.

Maintenance Matrix Calculation

Each of the teams to be studied was assigned a rating corresponding to each factor, and the final Criticality value was calculated using equations 1 and 2. Frequency and consequence columns were used for the development of the Criticality Matrix, which helps determine the applicable maintenance trend for each piece of equipment. Table 2 shows the model for the construction of the Criticality Matrix to be used. This Criticality Matrix indicates the dependence of the Frequency (***FF***) as a function of the Consequences (***CC***) and in it the degree of Criticality of the maintenance is reflected.

Table 2
*Medium Critical Maintenance Matrix (**MC**), Critical Maintenance (**C**) and Non-Critical Maintenance (**NC**)*

Frequency, FF	*4*	*MC*	*MC*	*C*	*C*	*C*
	3	*MC*	*MC*	*MC*	*C*	*C*
	2	*NC*	*NC*	*MC*	*C*	*C*
	1	*NC*	*NC*	*NC*	*MC*	*C*
		10	*20*	*30*	*40*	*50*
		Consequence, CC.				

Note: Authors' own creation, 2019.

The colored areas designate the application of operations with certain trends; the area in pink represents predictive maintenance, the color yellow denotes preventive maintenance and the color green symbolizes corrective maintenance. This methodology is appropriate for the development of maintenance programs, reflecting the real performance of the equipment, which means that it is possible to obtain positive productivity results from this model.

Integral Maintenance Plan

The comprehensive maintenance plan is based on the concept of Criticality, through which a maintenance program was designed capable of operating, storing, processing and presenting data in advance for the operation of maintenance processes, with the aim of optimizing them and allowing adequate decisions to be made, in equipment such as: Mechanical scales, Winches, Hoppers and Sterilizers that are key in the extraction of oil.

As a first step, each of the equipment was physically inspected, along with the analysis of the data captured from the operation logs of each equipment, as well as the recovery of data from the plates. In the analysis, the grades of the items indicated in table 1 were obtained, as: Failure Frequency (***FF***), Maintenance Cost (***MC***), Operational Impact (***OI***), Impact on environment, health and safety (***EHS***) y Operational Flexibility (***OF***). From these estimates, the Consequences (***CC***), Equation 2, were calculated and the Criticality Matrix ***FF*** vs ***CC*** from table 2 was plotted, which allowed classifying the type of maintenance in each of the equipment. The types of maintenance are described below:

Corrective Maintenance

Corrective maintenance consists of total repair until the defect is fixed to the point where the equipment operates efficiently (Duffa-Salih, Raouf and Dixon, 2000). This type of process implies a high degree of analysis and responsibility on the equipment, due to the fact that it is necessary to have a wide knowledge of the possible failures, availability of parts for a quick and effective execution in the face of unforeseen events, which is why corrective maintenance is justified in the following factors:

- Offline equipment or Critical Point of the process: does not cause serious disruption to production or maintenance.
- Equipment out of use or obsolete.
- Existence of the same equipment.
- Easily replaceable by new equipment.

These factors should be evaluated periodically based on the concept of Criticality, so that it can be established that corrective maintenance is adequate.

Preventive Maintenance

Preventive maintenance is planned, and scheduled maintenance based on the condition of the equipment (NASA, 2008). The condition is determined by monitoring variables such as: Temperature, Pressure, Humidity, Tension, Deformation, Mechanical Motion, Cyclic Action, Displacement, Degree of Change, Time, Acidity/PH, Discharges, Concentration, Composition, Electrical Function, Mechanical Function and Sequence, Electrical Sequence, Acceleration, Deceleration, Electrical, Magnetic and Electromagnetic Characteristics, Condition of Oils and Other Fluids (NASA, 2008; Chang, Young, 1986).

The study was carried out for each piece of equipment by means of frequency control (cycle, month and year) of maintenance provided to the equipment to avoid continuous delays in the production processes (Duffa-Salih, Raouf and Dixon 2000; NASA, 2008; Domínguez-Giraldo, 1998; Zho, Xi, Lee, 2007). Table 3 below presents the comprehensive programming plan for each piece of equipment, frequency, cycle and estimated day for the respective maintenance.

Table 3

Comprehensive programming plan for equipment for corrective and preventive maintenance: Mechanical Scale, Sterilizer, Winch and Hoppers

Mechanical scale	Frequency	Cycle	Day
Calibrate sensors from kilos to tones	Weekly	1	Saturday
General electrical system overhaul	Daily	1	Saturday
Weighting area overhaul	Daily	1	Saturday
Sterilizer			
Check steam leaks through lids and covers	Daily	1	Daily
General cleaning	Every 6 days	1	Saturday
Safety Valve Verification and Calibration	Daily	1	Daily
Condensate and steam piping inspection	Every 6 days	1	Saturday
Inspection of wear rails and sleeves	Every 6 days	1	Saturday
Inspection of moving parts of tracks	Monthly	1	Saturday
Steam Trap Cleaning	Monthly	1	Saturday
Safety valve trip	Monthly	1	Saturday
Steam Tray Overhaul	Monthly	1	Saturday
Steam inlet valve seal check	Monthly	1	Saturday
Discharge and condensate valve seal check	Monthly	1	Saturday
Winch			
Cylindrical drum overhaul	Daily	1	Monday
Gearbox status overhaul	Monthly	1	Monday
General overhaul of the electrical system	Weekly	1	Monday
Hopper			
Chain and harrow overhaul	Monthly	1	Monday
Sprocket overhaul	Monthly	1	Monday
General overhaul of the electrical system	Daily	1	Monday
Transmission chain overhaul	Monthly	1	Monday
Bearings overhaul	Quarterly	1	Monday

Note: Author's own creation, 2019.

The procedure of the activities carried out was performed through the systematic application of the 7 steps mentioned above whose constant relationship with the control of electrical and mechanical maintenance was necessary to achieve the objective of the work.

Results

Equipment Qualification

The obtained results of Criticality *FF*, *OI*, *OF*, *MC*, *EHS* and *TC* show the maintenance tendency through the *CC* and *FF* columns (table 4), for each of the equipment; Mechanical Scales, Winches, Hoppers and Sterilizers. The data enables classifying the maintenance, based on the visual and auditory inspection of each one of the components of the equipment classification system, considering its life time, duration and environment to which it is submitted; evaluated by means of the Criticality scale applied to each one of the items mentioned in table 1. The results obtained enable medium and long term maintenance projects to be programmed with actions that direct the good functioning of the equipment in the industries.

Table 4

Estimated Criticality Values for the equipment studied

EQUIPMENT	FF	IO	FO	CM	ISAH	CT	CC	FF
Mechanical scale	1	4	4	2	1	19	**19**	**1**
Winch	2	7	1	2	1	20	**10**	**2**
Hopper	3	7	2	1	1	48	**16**	**3**
Sterilizer	3	7	1	2	7	48	**16**	**3**

Note: Authors' own creation, 2019.

Based on the data obtained, the Criticality Matrix was plotted (table 5) for the aforementioned equipment (Mechanical scales, Winches, Hoppers and Sterilizers). According to the Criticality Matrix, equipment such as Mechanical scales and Winches must be subjected to predictive maintenance while Hoppers and Sterilizers must be subjected to preventive maintenance, thus it was also observed that no equipment indicates its application in corrective maintenance.

Table 5

Criticality Matrix for the equipment; mechanical scales, Hoppers, Winches, and Sterilizers

	4	*MC*	*MC*	*C*	*C*	*C*
	3	*MC*	***Sterilizer Hopper***	*MC*	*C*	*C*
Frequency, FF	*2*	***Winch***	*NC*	*MC*	*C*	*C*
	1	*NC*	***Mechanical Scales***	*NC*	*MC*	*C*
		10	*20*	*30*	*40*	*50*
		Consequence, CC.				

Note: Authors' own creation, 2019.

According to the results obtained from the inspections carried out on the equipment, preventive procedures were programmed in Hoppers and Sterilizers, as shown in table 6.

Table 6

Scheduled inspections for Hopper-and-Sterilizer-based equipment preventive actions

Equipment	*Preventive actions*
Hoppers	*Tubing hoses* *Rigid tube hoses* *Hopper Fittings* *Hopper Gate Bearing*
Sterilizers	*Door gaskets* *Wear sleeves* *Warrick electrodes* *Level sensor* *Pressure sensor* *Steam trap* *Compressor Belts*

Note: Author's own creation, 2019.

As previously discussed, the application of good maintenance planning generates benefits such as: reduction of operating hours, downtime, production cost savings and improved productivity (Efficiency x Effectiveness) thus avoiding hidden failures, unexpected damages and corrective maintenance (Swamson, 2001; Fluke, 2005; NASA, 2008; Gonzalez, 2001). Based on the analysis performed and the visual and auditory results, it is established that the information system for each equipment (EIS) should be modified under the following recommendations (table7).

Table 7
Recommended modifications to the maintenance equipment information system

Equipment information system	Recommended Modifications
Technical data	It must present relevant information on the general characteristics of the equipment: brand, reference, parts and capacity.
Resume	That they present the activities carried out on the machines in chronological order and in consecutive form.
Blueprints	That allow to visualize the pieces and include special designs and in certain case to be manufactured by the department.
Pictures	Plant equipment to reference its location.
Work order	Evaluated and implemented as a field document to review and evaluate the time and tools used to develop a programmed or emergency function on the equipment.
Alarm system	That show the main operations planned and established according to: maintenance routes, dates and days analyzed, for the equipment's benefit; that communicate in a timely manner the time of intervention, as well as materials and spare parts.
Company	That links the general information of the company, with its representatives, employees, headquarters, and suppliers.

Note: Authors' own creation, 2019.

Conclusions

A Criticality Matrix was obtained based on the visual observations of each of the equipment (Mechanical scales, Winches, Hoppers and Sterilizers) studied. Based on the Criticality analysis, preventive and predictive maintenance trends were determined for the pairs of Mechanical Scales, Winches and Hoppers, Sterilizers, respectively. A preventive maintenance planning system was established for Hoppers and Sterilizers. Finally, an information system was designed, elaborated and fed that anticipates the predictive control over the actions of the maintenance and production department. These actions generate benefits such as the availability and safety of the equipment plant, improvement in the quality of the products, a better register with capacity of first-hand information on the conditions of the machinery, a good capacity in quantity and quality of maintenance activities, optimization in the handling of repair parts, improvements in the design of equipment which leads to reduction of costs for maintenance. The implementation of maintenance systems reduces reprocessing, and constant practice and training facilitates diagnostics and control, improving maintenance operations.

Criticality analysis is recommended as a tool for continuous improvement of the industry. Based on the Criticality analysis, the standardization of the maintenance procedures that are executed, putting emphasis on those that are classified as preventive, since this type of maintenance results in greater savings by reducing failures and production stoppages due to flaws in equipment is recommended. It should be noted that procedures for preventive maintenance should be subject to adequate timing so as not to interfere with production. In addition, take into account that the maintenance derived from the Criticality model is not inflexible, since it must be adjusted through the continuous supervision inspections that must be carried out by the maintenance personnel. Should it be necessary to stop equipment for corrective maintenance and generate downtime greater than those established in the maintenance plan, they must be adequately justified, because otherwise it would be understood that the deliberated values of the equipment ratings shown in Table 1 were incorrectly selected. For these cases one recommends making the Criticality analysis again considering the deliberations of each equipment to obtain the correct consequence that gives place to the Criticality Matrix.

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