Application of RCM and FMEA Methodology to Improve Industrial Maintenance Management: A Case Study of Fibers for Mattresses

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Abstract
In industrial manufacturing, there are techniques that can identify certain risks in the processes that cause inconsistencies in the operation of equipment, hazards for the operator and waste. One of the supports of industrial engineering in the company are the Preventive Maintenance (PM) tasks that focus their efforts on analyzing the operation of critical devices that could degrade the quality of the products obtained. Companies that have an average system of attention to machinery and equipment perform corrective maintenance (CM) or preventive maintenance tasks that are not very successful, due to a deficient knowledge or training in repair, which generates high percentages of waste, low quality, and even reprocessing. Failure mode and effects analysis and reliability-centered maintenance are systematic tools based on team working which usually can be used for identify, prevent, eliminate or control the potential errors causes of failure in a system or process. In this paper, it is intend to reorganize preventive maintenance planning and obtain effective results with all the information and data available specifically on a machine dedicated to the transformation of a raw material to obtain fibers used in mattress filling.
Keywords: Preventive Maintenance, Failure mode and effect analysis, reliability centered maintenance.

1. Introduction
The research indicates that the origins of what we know today as a mattress date back to prehistoric times. By lying on piles of leaves, straw and animal skins, early humans were able to sleep more comfortably and more soundly than on hard surfaces. As more people moved away from a nomadic, hunting lifestyle to an agrarian, sedentary lifestyle, primitive furniture, including the bed, began to develop. (López, 1989) The mattress, in most cultures, is the most used product; however, there are those who do not consider it as a key element in their lifestyles, neglecting its quality and adequate support (Toro E. , 2015). Until the twentieth century, they generally consisted of lumpy pads filled with horse hair, cotton, or rags. Mattresses are presently made of many materials, both natural and synthetic. The insulator consists of semi-rigid netting or wire mesh, and the cushioning layers can comprise a number of different materials including natural fiber, polyurethane foam, and polyester. (Pepper, 2018). In order to ensure that the products that make up the support and internal comfort of a mattress, we propose the development of an analysis of the machinery in the company Fibras de Colima S. A de C.V who is responsible for producing nonwoven fabrics (compressed) and has incidents in the production process such as production stoppages caused by the equipment, it is worth mentioning that the production process consists of production lines that are classified into line A, line B, Jumbo 1 and Jumbo 2. In the last decades, manufacturing industries had experienced an unprecedented degree of changes such as product specifications, process technologies, supplier attitudes and customer's requirements. This rapid changes environment had forced the manufacturers to enhance and improve effectively their performance by focusing on cost reduction, productivity levels increment, high quality products and prompt deliveries in order to satisfy customers. Because of the competitive market,

improvement of maintenance strategy and scheduling has attracted manufacturers to adopt decision-making tool. (Ramli & Nizam, 2012). The execution of this project is supported by two tactical level maintenance methodologies, which are RCM and FMEA. RCM, better known as Reliability Centered Maintenance, is used to determine what must be done so that any physical resource continues to operate normally, thus reducing downtime due to unforeseen failures; the objective of this methodology is to increase the reliability of the facility. (Rausand, 1998) The FMEA methodology refers to failure mode and effect analysis, which consists of the identification and classification of the effects, causes and elements of an occurrence in order to prevent failures. It should be added that, in order to carry out this project, first of all, the equipment with the highest number of failures in the production process was determined, and then the studies were focused on this equipment. Thus, the main objective was to evaluate this equipment by means of the aforementioned methodologies. (Command, 1983), (Afefy, 2010).

1.1 Objetives of the study

Develop an analysis of a company's fiber compactor equipment, applying RCM and FMEA methodologies, to reconfigure the preventive maintenance plan and integrate activities to improve operational performance.

1.1.1 Specific Objetives

- Determine the specific functions of the fiber compacting machine.
- Identify potential failures in the system in a normal operating environment.
- Reconfigure preventive maintenance actions to extend the time between failures.

2. Description of the process

The continuous production system for nonwoven fabric fibers is divided into five main areas, Jumbo Line 1 and Jumbo Line 2, which are in charge of producing the flock or raw material for the production lines, which are Line A, Line B and Line C. (Ivester & y Neefus, 2012)

The process begins by sending bales of garment waste from the raw material warehouse to one of the Jumbo lines (Jumbo 1 and Jumbo 2), which are responsible for shredding the fabric waste, so that at the end of these lines a type of yarn known as flock is produced, which is compressed and stored until it is required. Once requested, it is deposited in one of the Production Lines (Line A, Line B and Line C), which are in charge of manufacturing fibers.

Jumbo 1and 2 Processes

The bales of clothing catalogued as "unusable" pass from the raw material warehouse to cutter 1 and 2 in series, then to the metal detector and subsequently, the pieces of fabric are directed to the silo and the milling machine to finally be deposited in the Jumbo machine, transforming them into lint. The material goes directly to Line A or to the condensers, which add cotton and then through pipes it is deposited in one of the lines. Finally it is transferred to a subdivision of the raw material area where it is compressed and stored for future production.

Line A

The process begins with the deposition of lint and cotton threads in the loaders, the material is directed by a conveyor belt to the horizontal opener and the firt opener, which open and distribute the compacted raw material. It then passes through a metal detector and then goes to the cyclone that captures and removes the dust. It then enters the Airlay Flexiloft equipment (Airlay Condenser, Loader, Airlay, Scale, Flexiloft) that processes the slurry. At the end of this process, it passes through lateral cutters that eliminate the excess. Then, it goes to the furnace, the calender and the cooling extractor. It reaches the side cutters and the guillotine, which are adjusted according to the shift measurements. Finally, they are picked up by the personnel who stack the material and send it to the finished product warehouse.

Line B

Raw material is deposited in the loader and opener, passing through the following stages: DOA system, punching machine, side cutters that eliminate the excess, advances to the impregnation rollers that were previously loaded with glue, thanks to the glue foaming system, oven and the calender. Finally, it collects in the receiver zone by the personnel who stack the product and when the number of pallets is completed, by means of a forklift they are transferred to the finished product area.

Line C

The process of this line starts by feeding the loaders with flock and cotton threads, then the material is directed through a belt to the mixing piker that controls the length of the yarns. If there are traces of metal detected by a magnet, the material is diverts to the silo, otherwise the process continues to the opener.

The process continues in the Airlay Flexiloft system (condenser, loader, Airlay, scale and flexiloft). The material is then transferred to the side cutters, passing through the oven, cooling chamber, receiver, adjustment, cutting and guillotine according to specifications. Finally, it is collected, stacked and once the limit is reached, it is moved by forklift to the finished product warehouse.

3. Method

During the operation phase of any equipment or system, the physical, mechanical and electrical resistance gradually deteriorates, leading to system failure. This failure of infrastructure or equipment due to component deterioration is a sign of the severity of the system. Today, more emphasis is being placed on the availability, reliability and safety of production plants. Therefore more and more companies have seen the need to replace their maintenance strategies with predictive maintenance (Dominic, 2021). One of the methodologies used in failure mode analysis is Reliability Centered Maintenance (RCM), and is defined as a process used to determine what must be done to keep any physical resource operating normally. The methodology is based on four objectives: preserve functions, identify failure methods that can disrupt functions, prioritize function needs, select only preventive and effective maintenance tasks. (Altaf, 2014) The application of the methodology follows a series of steps mentioned below.
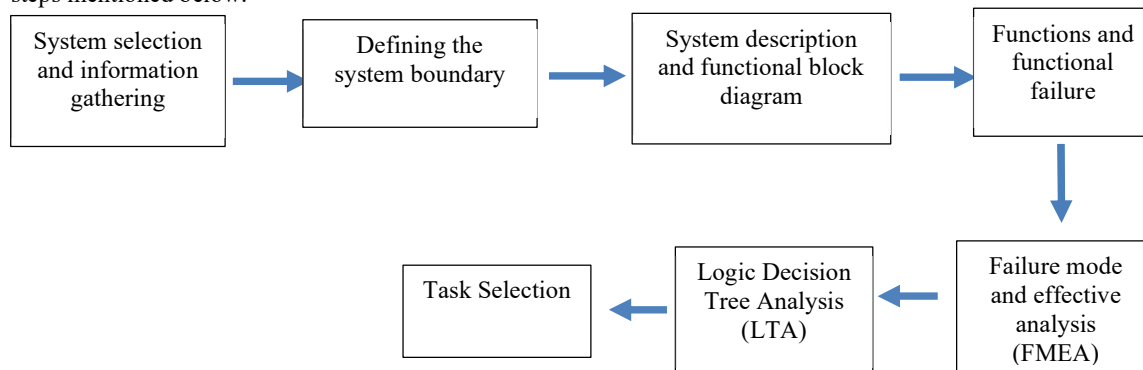
Figure 1. Steps for the RCM Methodology
System selection and data collection.

To select the line of study, the scheduled maintenance records for 2020 and the corrective maintenance records for February 2021 were analyzed. From the information of the first study, we extracted the data of the three main equipment that occupy more time in preventive repair and from the second one we obtained information of the failures in the equipment.

Table 1: Preventive maintenance frequency.

Machinery and Equipment	Estimated time	Frequency per year	Total time per year (hr)
Line JUMBO 1			
Jumbo 1	10	6	60
Bramalin Press PH-30	3	10	30
Cutter 1 and 2	4	5	20
Line A			
Guillotine LA	2	52	104
Furnace	10	8	80
Airplay	4	7	28
Line B			
Punching machine	2	50	100
Furnace B	5	10	50
cutters	1	48	48
Line C			
Guillotine LC	2	52	104
Furnace	10	6	60
Silo C	9	6	54
Line JUMBO 2			
Jumbo 2	10	5	50
Dust collector	5	6	30
Silo	4	4	16

Table 2: Corrective maintenance. (February, 2021)

Unit	Failures per month	Time (Hours)
Line A		
Flexiloft	7	03:50
Furnace	7	02:00
Mix	6	03:00
Airlay	10	05:20
Cotton threads opener	3	01:30
Receiver	6	01:50
Line B		
DOA	11	07:38
Side cutter	1	00:25
Furnace	2	01:15
Receiver	4	02:10
Opener	1	00:15
Punching machine	1	01:15
Glue	1	00:55
Line C		
Flexiloft	3	01:40
Receiver	6	01:50
Mix	12	09:15
Cotton threads opener	2	01:15
Silo	4	05:35
Furnace	2	00:40
Airlay	2	03:20
Piker (horizontal band)	1	00:55

Based on the analysis of the information, it was determined that Line C receives more preventive maintenance and has a frequency of 12 failures per month, making it the line with the most failures. It should be noted that the failures that stand out are mechanical, electrical and process failures.

Definition of the system boundary

The function of line C is to manufacture nonwoven fabrics, it is composed of various equipment such as openers, airlay flexiloft, furnace, cutters, guillotines, dust collectors, silo, piker and belt. For this project, the analysis was limited to the piker blending system.
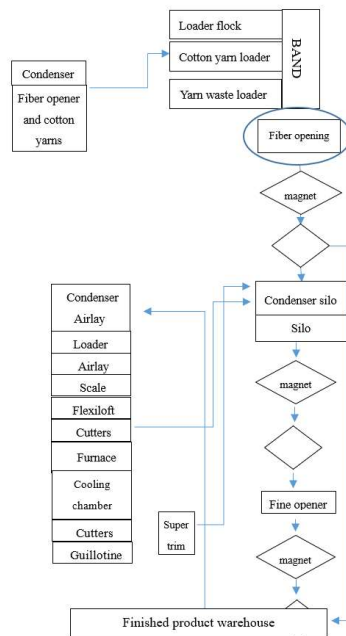

Figure 2. The production system

Fiber blender

Piker mix, (figure 3) is an equipment that combines the flock and the yarn strands homogeneously and at the same time eliminates dust from the flakes coming from the loader lines. It consists of rollers, mixer, silos and a lower screen that simultaneously recovers fibers from the silo.
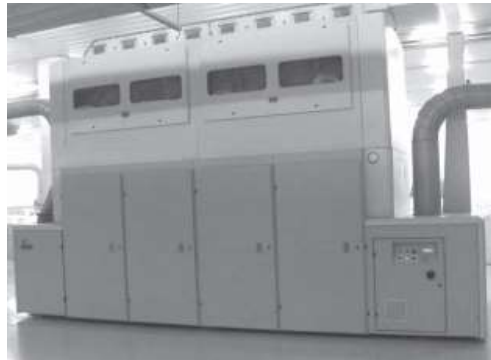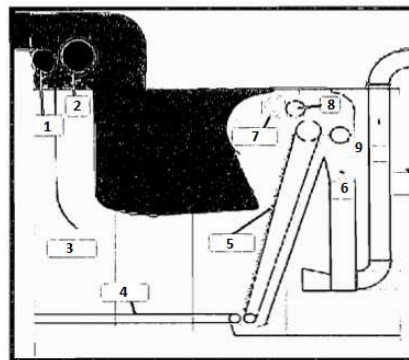

Figure 3: Piker Mix

Figure 4: Main mixer components
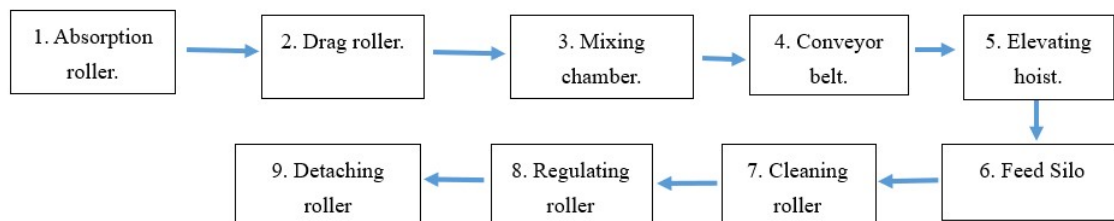
Figure 5: Description of mixer components

D. Function and functional failure.

Although, RCM is still not applied in many process plants, due to the lack of adequate methodology and tools, for this case, a general RCM analysis model suitable for the type of process and subsystems where the functional failures and failure modes that fall on critical components are exposed is proposed. (Vishnu & Regikumar, 2016). The model is suitable for all types of process plants with any number of components and for any configuration. By evaluating the effects, it allows to increase the availability of the equipment. This section answers the question: How can they fail, can they fail in a total or partial way?. It can be seen in Table 3.

Table 3. Information sheet

RCM INFORMATION SHEET, SYSTEM: LINE C					
RCM Information Sheet	System/ Active: Line C			Facilitator:	
Fibras de colima S.A de C.V.	Subsystem/component: Fiber blender			Collaborator:	
Function	**Functional failure**		**Failure Mode**	**Cause**	**Effect**
1 Raw material input to the system	A	Failure of the absorption roller and the drag roller	1 Slow operation.	Metal-to-metal contact.	Raw material enters slowly so production yield decreases.
				Thin lubricant film.	Failures due to wear.
			2 Poor operation.	Repeated stresses on the gear surface.	Surface fatigue.
			3 Difficulty in operation.	Tooth stress overload beyond limit.	Tooth breakage.
2 Fiber blends	A	Failure in the mixing chamber.	1 Slow operation.	Problems with the internal components of the mixing chamber	The process stops or slows down.
			2 Camera does not work.	Insufficient power provided.	The operation cannot be performed.
	B	Conveyor belt failure.	1 Material spills	Grooves on each side of the belt due to pressure generated by the side guards.	Provisioning damage.
				Belt overtension or severe trough angle.	Belt concave.
				Small diameter of structure pulleys	Separation of belt layers
			2 Accumulation of material	Twisted belt loads.	Band not aligned
				Belt not aligned.	Splice failure
				Due to belt manufacturing or incorrect belt storage	Failure in longitudinal bending
				Difference between belt and pulley diameters.	Coating cracks
	C	Failure in the elevator screen.	1 Material is not conveyed to the feed silo	Very high chain speed.	Breakage of pins, bushings or rollers
				Excessive impact loads.	Breakage of teeth.
			2 Slow transfer	Stiff chain.	Misaligned wheels
				Lateral wear of plates on chain links and sprockets.	Chain breakage
	D	Failure in the feeding silo.	1 Incorrect operation of the light sensor.	Failure of insulators	Internal short circuits.
				Dirt due to metal particles	Sensor slows down
3 Return the fiber to continue the mixing process.	A	Clogging in the cleaner and stripper	1 Slow roller operation.	Problems with the starter pulley system and belt.	The fibers are not removed from the regulating roller and the elevator web.
			2 Roller does not start..	Engine problems.	The process stops.
	B	Flock adhesion	1 Flock clogging in the system.	Roller movement is slow.	The roller stops and there is a shortage of flock.

E. Failure Mode and Effect Analysis (FMEA)

The FMEA method allows the analysis of potential errors a priori. Research in this field aims to mitigate this risk

with combinations of case-specific approaches, identifying functional failures and failure modes (Peter, Aldon, Schupp, & Salzwedel, 2021). In its analysis, the aim is to avoid critical errors, proposing actions oriented to solve them. The FMEA uses the Risk Priority Number (RPN) technique to determine risk impact (severity), risk likelihood (occurrence), and risk opportunities (detection). The RPN value is obtained by multiplying the value of the three parameters. Risks with the highest values are considered important and should receive a high priority compared to risks with low RPN values (Privadi & Fadilah, 2020). This section answers the question "What causes the failure"?, an analysis is performed using the FMEA methodology as shown in Table 4. Values are assigned to the cases of severity, occurrence and detection consisting of a weighting from 1 to 10 to define the severity of the effect and the occurrence of the causes of failure being 1 minimum and 10 very high, in the case of the controls their current detection was evaluated using a weighting from 1 to 10 being the number 1 high and 10 minimum. (Mulet, Carlos, Chulvi, Ramos, & Bovea, 2011)

Table 4: FMEA

FAILURE MODE AND EFFECTS ANALYSIS									Subsistema: Mezcladora
Function	Functional failure	Failure Modes	Effect	Severity	Potential causes of failure	Occurrence	Current Process Controls	Detection	RPN	Actions to recommend
Raw material input to the system	Failure of the absorption roller and the drag roller.	Slow operation.	Slow raw material input and low production yield.	7	Metal-to-metal contact.	5	Visual and with lubricant indicator	3	105	Use of high viscosity anti-wear lubricants and regular inspection to verify condition.
			Failures due to wear.	6	Thin film lubricant	2	Visual and with lubricant indicator	3	36	
		Poor operation.	Surface fatigue.	6	Constant stresses on the gear surface	3	Visual and sometimes detected in preventive maintenance	5	90	Reconditioning of lubrication oil or grease.
		Difficulty in operation.	Tooth breakage.	7	Overloaded teeth stress beyond limit.	4	Visual and sometimes detected in preventive maintenance	5	140	Verify proper distribution of forces along the tooth, check lubrication system, and improve surface finish and hardness.
Fiber mixture	Failure in the mixing chamber.	Slow operation.	The process stops or slows down.	8	Problems with the internal components of the mixing chamber.	2	Visual detection or by cleaning and maintenance.	5	80	Establish a frequent review of the system.
		Camera does not work.	The operation cannot be performed.	9	Insufficient power provided.	2	Visual detection or by cleaning and maintenance.	5	90	
	Conveyor belt failure.	Spill material.	Damage to the feed.	8	Grooves on each side of the belt due to pressure generated by the side guards.	4	Visual detection	6	192	When installing the cover has a positive inclination in the running direction of the belt.
			Belt concave.	7	Belt over tension or severe trough angle.	4	Visual detection	6	168	Ensure that the running distance is adequate for the belt (not excessively short).
			Separation of belt layers	7	Small diameter of structure pulleys.	3	Visual detection	6	126	Establish belt purchase quality standards.
		Accumulation of material	Misaligned belt	8	Non-uniform belt loads.	3	Detection during maintenance.	5	120	When placing the belt, make sure that the conveyor structure is aligned.
			Splice failure	8	Belt misalignment.	3	Detection during maintenance.	5	120	Establish a correct transition distance according to the belt.
			Failure in longitudinal bending	7	Belt manufacturing or incorrect belt storage.	5	Detection during maintenance.	5	175	Properly store the belts and establish quality standards with respect to the purchase.
			Coating cracking and splitting	8	Difference between belt and pulley width	4	Detection during maintenance.	5	160	Establish parameters to ensure accuracy between belt and pulley diameters.

	The material is not transferred to the feed silo.	Breakage of pins, bushings or rollers.	8	High speed in chain	4	Visual detection and during maintenance	5	160	Develop a detection plan that monitors the tension in the chain drives, replacing it if it is greater than 3% and adequate lubrication.
Elevating hoist failure.		Breakage of the gear teeth	7	Excessive impact loads.	3	Detection during maintenance.	5	105	Carry out an adequate cleaning and greasing program for the chain.
	Slow transfer	Rigid chain.	7	Misaligned guide rollers	5	Visual detection and during maintenance	5	175	Establish a frequent cleaning schedule, as well as proper maintenance and lubrication.
		Chain breakage	7	Lateral wear of the plates on the chain links and guide teeth.	4	Visual detection	6	168	Periodically check chain sprocket alignment.
Failure in the feeding silo.	The light sensor is not working properly.	Internal short circuits.	8	Failure of insulators	3	Visual detection during maintenance.	5	120	Frequent sensor check.
		Delayed sensor operation.	8	Dirt due to metal particles	7	Visual detection or by cleaning and maintenance.	5	280	
Return the fiber to continue the mixing process.	Poor roller performance.	Roller blockage	Fibers are not removed from the regulating roller or in the fiber elevator.	8	Problems with the starter pulley and belt system.	4	Visual detection.	6	192	Conditioning of a lubrication program
		Roller does not rotate	The process stops.	8	Engine stalled	3	Visual detection during maintenance.	5	120	
	Adhesion of flock	Flock blockage in the system.	Roller stalls and does not deliver adequate flocking level	7	The movement of the regulating roller is slow.	3	Light sensor	3	63	

The FMEA method allows the analysis of potential errors a priori. Research in this field aims to mitigate this risk with combinations of case-specific approaches, identifying functional failures and failure modes. In its analysis, the aim is to avoid critical errors, proposing actions oriented to solve them.

F. Decision tree analysis.
In order to determine the appropriate type of maintenance with respect to the failure mode, the tasks to be carried out per system were defined; it should be added that the failures detected are only mechanical.

G. Task selection.
Finally, the tasks are shown below.
Table 5. Task selection

PREVENTIVE MAINTENANCE, SYSTEM: LINE C			
	System/ Active: Line C	Facilitator:	
Fibras de colima S.A de C.V.	Subsystem/component: Fiber blender	Collaborator:	
Component	Activity	Priority	Categories
Rollers	Use of high viscosity anti-wear lubricants.	High	Mechanical
	Verify proper distribution of forces along the tooth, improve surface finish and hardness.	Medium	Mechanical
	Regular inspection to verify condition.	Medium	Mechanical
Mixing Chamber	Frequent system inspection.	Medium	Mechanical
Conveyor belt	When installing the belt, ensure that the cover has a positive inclination in the running direction of the belt.	Medium	Mechanical
	Ensure that the running distance is adequate for the belt (not excessively short).	Medium	Mechanical
	Establish belt purchase quality standards.	Medium	Mechanical
	When placing the belt, make sure that the conveyor structure is aligned.	Medium	Mechanical
	Establish a correct transition distance according to the belt.	Medium	Mechanical
	Properly store the belts and establish quality standards with respect to the purchase	Medium	Mechanical

	Establish parameters to ensure accuracy between belt and pulley diameters.	Medium	Mechanical
Fiber elevator	Carry out a plan to control the tensioning of chain drives, replacing it if it is more than 3%.	Medium	Mechanical
	Establish frequent cleaning, as well as proper maintenance and lubrication.	Medium	Mechanical
	Periodically check chain sprocket alignment.	Medium	Mechanical
Feed Silo	Frequent sensor check.	Medium	Mechanical

CONCLUSIONS

The development of the RCM methodology allowed to establish an analysis of the production lines of the company Fibras de Colima S.A de C.V, where, in the first place, the system was selected based on data provided by the company, such as preventive maintenance during the year 2020 and corrective maintenance during the month of February of this year (2021), thus, the selected system was the Line C, specifically in the Mixer or fiber opener, where the functions and functional failures were determined. Thus, a failure mode and effect analysis was established, which consisted of developing a detailed study of the equipment function and determining the failure modes, the effect that this produces, the causes and the current process controls. This information makes it possible to establish the activities to be carried out to correct or reduce the inconsistencies.

In this way, the central objective of the project is fulfilled, which consisted in the analysis of the factory's equipment, applying the RCM and AMEF methodologies, in order to improve its operational performance. Likewise, the contributions of the present project, which are the activities resulting from the plan that aim to improve the current maintenance system.

The most relevant activities are the application of high speed anti-wear lubricants, as well as the verification of the system's rollers and gears, which are intended to reduce mechanical failures that result in system failures.

Future research work should be oriented towards the application of the Bathtub Curve methodology, evaluating the moment in which the equipment or machinery reaches a maximum rate, implementing actions and extending the mean time between failures (MTBF).

References

Afefy, I. (2010). Reliability-Centered Maintenance Methodology and Application: A Case Study. *Scientific Research*, 863-873.

Altaf, M. (2014). Study Reliability Centered Maintenance (RCM) of Rotating Equipment through Predictive Maintenance. *2nd International Conference on Research in Science, Engineering and Technology (ICRSET'2014)*, 216-221.

Aristizabal, E. T. (2015). *Análisis del sector colchonero en latinoamérica.* Armenia.

Command, N. S. (1983). Naval Sea Systems Command. *Reliability-Centered Maintenance Handbook*, 1-56.

Dominic, M. (2021). Optimization of condition-based maintenance strategy prediction for aging automotive industrial equipment using FMEA. *International Conference on Industry 4.0 and Smart Manufacturing*, 229-238.

Ivester, A., & y Neefus, J. (2012). Industria de Productos Textiles. En A. Ivester, & J. y Neefus, *Industria de Productos Textiles* (págs. 2-30). México: ENCICLOPEDIA DE SALUD Y SEGURIDAD EN EL TRABAJO.

López, L. (1989). *Nómadas y Sedentarios.* CDMX: Instituto Nacional de Antropología e Historia.

Mulet, E., Carlos, M., Chulvi, V., Ramos, J., & Bovea, D. (2011). *Problemas resueltos de análisis de riesgos en instalaciones industriales.* Castelló de la Plana, España: Publicacions de la Universitat Jaume I. Servei de Comunicació i Publicacions.

Pepper, D. (Noviembre de 2018). *http://www.madehow.com/Volume-1/Mattress.html*. Obtenido de http://www.madehow.com/Volume-1/Mattress.html

Peter, B., Aldon, T., Schupp, S., & Salzwedel, J. (2021). Risk Management in Factory Planning – A Literature Review. *54th CIRP Conference on Manufacturing Systems*, 1191-1196.

Privadi, A., & Fadilah, N. (2020). The consistency analysis of failure mode and effect analysis (FMEA) in information technology risk assessment. *Heliyon*, 1-12.

Ramli, R., & Nizam, M. N. (2012). Reliability Centered Maintenance in Schedule Improvement of Automotive Assembly Industry. *American Journal of Applied Sciences*, 1232-1236.

Rausand, M. (1998). Reliability Centered Maintenance. *Reliability Engineering and System Safety*, 121-132.

Toro, e. (s.f.).

Toro, E. (2015). *ANÁLISIS DEL SECTOR COLCHONERO EN LATINOAMÉRICA.* Armenia.

Vishnu, C., & Regikumar, V. (2016). Reliability Based Maintenance Strategy Selection in Process Plants: A Case Study. *Procedia Technology* , 1080-1087.