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MAINTENANCE STRATEGY BASED ON EQUIPMENT RELIABILITY ANALYSIS OF A PULP BALING LINE

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ABSTRACT

The baling lines are the last stage in the cellulose production process. The cellulose coming from the dryer is cut in rectangular sheets of preset dimensions and in the baling lines are stacked, compacted, packed and tied for transport. Composed of a series of automatized and function-distinct equipment, the baling lines presents various and random failure modes, resulting in an elevated amount of corrective maintenance and increased reestablishment and production costs. The objective of this paper is to carry reliability analysis using tools like RBD, LDA and RAM aiming to determine the best maintenance strategy for the equipment based on the reliability of its subsystems and components. Upon realizing this work, it is verified that the failure behaviors of components and subsystems of the equipment that have the greatest contribution to the downtime of lines are related to failures in the initial phase of operation or shortly after maintenance interventions. Thus, it was necessary to deepen the analysis using the fault tree analysis tool (FTA) to identify the root causes and propose actions to prevent failures.

Keywords: Baling Line. Reliability Analysis. RAM Analysis. Reliability Engineering

INTRODUCTION

In the cellulose production process, after sheet formation, drying and cutting, the pulp bale is placed in piles containing approximately 250 kg and sent to the baling line, which is a fully automated process. The first equipment in the process is the bale scale conveyor, where the weight of the pulp bale is checked and last adjustments are made by the operator before packaging. Then, it enters the hydraulic press, where its volume is reduced so that it occupies less storage space and acquires resistance in order to allow stacking. Next, a cellulose protective wrap is applied (also made of cellulose), it is tied for fixation and the bale is sent to the folder, where folds are made at the ends so that it is possible to apply the last wires and thus form a packaged bale ready to receive the identification of the units with the appropriate numbering by means of a marking machine. These in turn are stacked in four bales and later undergo another stack of cellulose forming a unit. The units are transported to the warehouse, where they are collected for loading on ships. Figure 1 shows the process stages.

The equipment that makes up these lines is arranged almost entirely in series, so any failures that occur in these directly impact the availability of the line and the actual production of the plant. This is why there is a need to conduct work focused

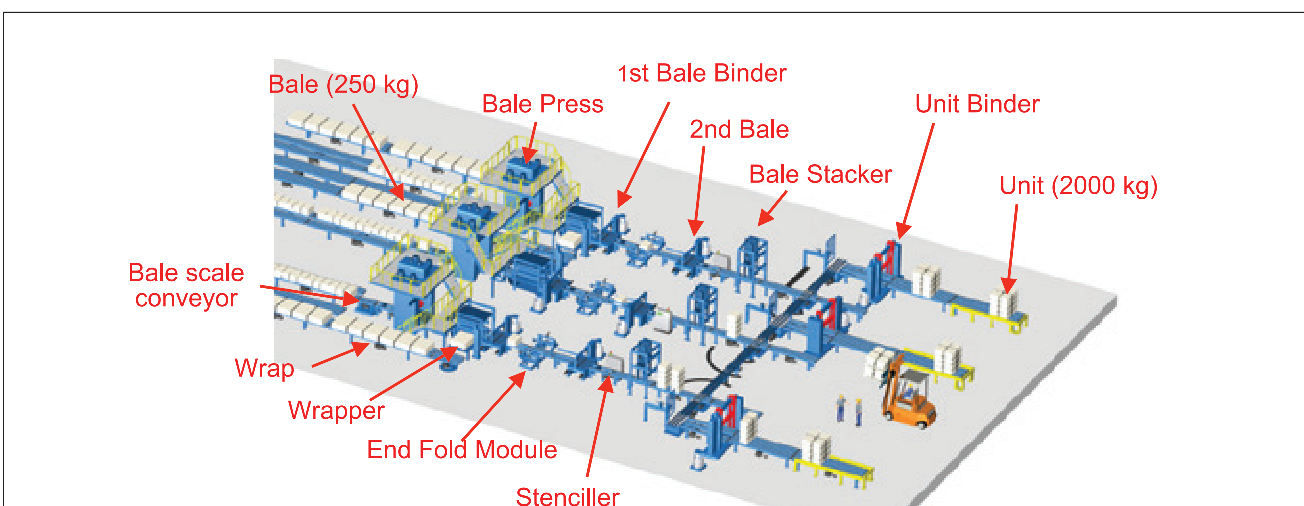

Figure 1. Baling Line layout

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on the availability and reliability of assets. Understanding failure modes, which machines present them most frequently, establishing reliability analyzes, carrying out failure tree analyses (FTAs) and, as a result, implementing preventive and/or predictive actions become essential premises in the development of the best maintenance strategy for the plant.

In Azevedo (2007), reliability deals with the probability of a machine being able to perform its functions properly in specific circumstances for a certain period. Through the application of statistical modeling, this discipline allows us to understand what happens to the machine when it operates under certain conditions.

Therefore, knowledge of the functioning and failure patterns of an equipment and its respective components plays a key role in the strategy adopted by maintenance in the area. The study was conducted at a company in the pulp and paper industry, where the line with the lowest availability to be worked on was selected. As these are lines with high constructive similarity, the actions once implemented and consolidated in this line will be extended to the others.

METHODS

Given the need to improve the availability of equipment for cellulose baling lines by reducing random failures that occur in the equipment, a study was carried out looking for the most appropriate set of tools to achieve the objective. Due to the availability of information that can be refined, the option is to use life data analysis (LDA) for the main subsystems and components of the equipment and the construction of reliability block diagrams (RBD) to determine and analyze the equipment, less reliable subsystems / components and define corrective and preventive actions.

Life data analysis (LDA)

In Reliasoft (2015), the of life data analysis consists of the study and modeling of life data from a sample of equipment (including its systems, subsystems and components) or products. Lifetimes can be measured in different units, such as hours, kilometers run, number of cycles, etc., that is, any measurable unit that can be associated with the life of the equipment.

According to Kececioglu (2002), reliability is the best quantitative measure of the integrity of a part, component, product or system. Reliability is the probability that parts, components, products or systems will perform the functions for which they were designed without failure under specific conditions for designated periods in a given level of confidence.

According to Reliasoft (2015), the life data analysis process aims to estimate or make predictions about the life of the components by adapting a probability distribution to the data. In this way, the distribution parameters can be used to estimate important life data of components such as reliability or probability of failure for specific condition and time of operation and average life. According to Kececioglu (2002), there is no industry in any country that can progress efficiently without the knowledge and implementation of reliability engineering.

Thus, the application of life data analysis is of fundamental importance to make the maintenance management system more robust, with gains exemplified below:

- Increase understanding about the life of equipment components;
- Make it possible to measure and estimate indicators for equipment performance;
- Establish best practices and maintenance strategies, based on information obtained through the application of life data analysis.
- Decrease maintenance costs by reducing corrective maintenance and more adjusted preventive maintenance.

In order to perform life data analyses consistently, it is necessary to follow the steps below:

- Obtain life data of the equipment, system or component analyzed;
- Select the best probability distribution that best fits the data;
- Estimate parameters for the distribution;
- Generate graphs and results of the product's characteristic life, such as reliability, probability of failure and average life.

Weibull distribution

In Reliasoft (2015), the Weibull distribution is widely used because it is very flexible, since the behavior of the failure rate can be increasing, decreasing or constant.

Equation 1 indicates the probability density function of the Weibull distribution:

$$f(t) = \frac{\gamma}{\theta} t^{\gamma-1} e^{-t\frac{\gamma}{\theta}} \quad (1)$$

Equation 2 shows the reliability function according to the Weibull distribution:

$$R(t) = e^{-(\frac{t}{\theta})\gamma} \quad (2)$$

Equation 3 illustrates the mean time to failure under the Weibull distribution model:

$$MTTF = \theta\Gamma(1 + \frac{1}{\gamma}) \quad (3)$$

Exponential distribution

According to Reliasoft (2015), the exponential distribution is characterized by having a constant failure rate function, being the only one with this property.

Equation 4 indicates the probability density function under the exponential distribution:

$$f(t) = \lambda e^{-\lambda t} \quad (4)$$

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Equation 5 shows the reliability function according to the exponential distribution:

$$R(t) = e^{-\lambda t} \tag{5}$$

Equation 6 illustrates the average time to failure according to the exponential distribution:

$$MTTF = \frac{1}{\lambda} \tag{6}$$

In mathematical terms, it is the simplest and is widely used to describe the characteristic life of a series of materials, equipment, systems and components.

Reliability Block Diagram (RBD) and RAM analysis

According to Reliasoft (2015), the reliability analysis applied to systems consists of the construction of a logical model (RBD - block diagram) that represents an equipment, system, subsystem or component, where each element has its own life distribution. Block diagrams are used to describe the relationship between components and define the system. The level of choice on the part of the reliability analyst (system, subsystem or component) will determine how detailed and deep the analysis will be.

According to Mazzei (2018), the equipment's representative diagram is used in the RAM - Reliability, Availability and Maintainability analysis to simulate and evaluate the performance of its systems and components in order to define those with the greatest criticality and impact on availability.

In Reliasoft (2015), in the series configuration, the component with the lowest reliability has the greatest effect on system reliability. If any of the components fails, the system will lose its function. In parallel configuration, at least one of the blocks must have satisfactory operation for the system to work. Parallel components are also called redundant. Redundancies are highly important for the development of reliable systems, being one of several methods of assigning reliability to a system. It is highly used in the aerospace and aviation sectors in the most critical systems. According to Mazzei (2018), in most cases, systems in the real world have more complex configurations, and cannot be represented only in series and/or parallel systems, they are represented with a combination of parallel and series, because of that it is known as a mixed system. The Figure 2 show an example of a mixed system.

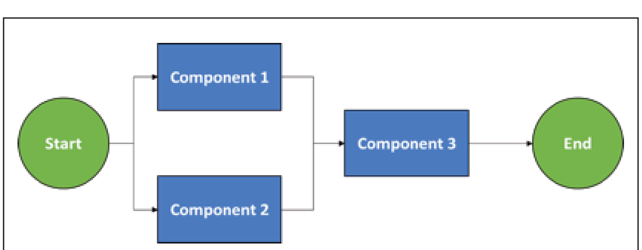

Figure 2. Mixed system example

FTA (Fault Tree Analysis)

In Rigoni (2018), the fault tree analysis (Fault Tree Analysis - FTA) consists of a deductive and logical method that starts from an undesired event (failure) looking for the possible causes of that event. FTA is a type of top-down analysis, starting from the effects to the causes.

Also, according to Rigoni (2018), when constructing an FTA diagram, it is possible to obtain a complete logical understanding of the basic causes and their relations with the top event. The objectives of carrying out an FTA are:

- Identify the causes of a failure and the logical relationship between its possible causes;
- Identify the deficiencies of a system;
- Identify consequences of human errors;
- Establish criticality of systems and equipment components.

RESULTS AND DISCUSSION

The database of maintenance and operation interventions (occurrence registration system) was used for data cleaning and subsequent insertion in the reliability analysis software. This database was selected because it is richer in information than the company's ERP system.

A spreadsheet was built containing the data on maintenance and operational interventions for the baling line. The range of the database is 4.5 years, from January/2015 to July/2019. The interventions of the maintenance disciplines (mechanical, electrical, instrumentation, boilermaking and welding) related to the downtime of the line were filtered, being programmed emergency and preventive corrective measures.

Since it is working with a large amount of downtime information and is data loaded by operators, it was necessary to carry out a review and treatment of this failure and repair data. A modeling worksheet was used to treat this information, preventing possible inconsistencies from affecting the results of the analysis.

The life data of the components and subsystems of the equipment were inserted in the Weibull ++ software (Figure 3) and the calculations of the reliability parameters were made, obtaining the reliability and failure rate curves.

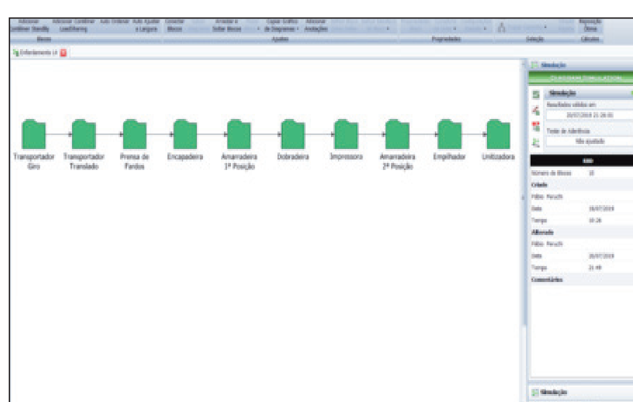
Figure 3. Baling line modeling

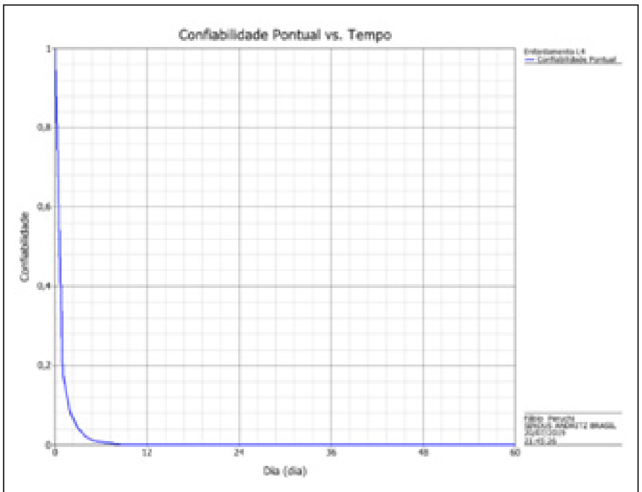

Figure 4. Baling Line punctual reliability curve

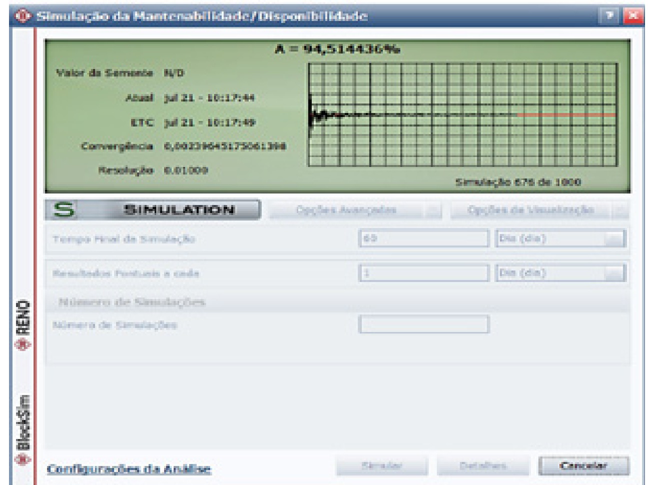

Figure 5. Simulation of reliability, availability and maintainability

A total of 10 machines were analyzed to make up the reliability curve of the baling line, shown in Figure 4.

The point of reliability drops sharply in a relatively short interval of operation of the line, reaching values very close to zero in 8.4 days of operation. This directly reflects line availability and corrective maintenance costs.

Afterwards, each equipment of the baling line had its components and systems modeled in Blocksim. Life data was entered for each component, in addition to corrective and equipment repair data in case of failure.

With the baling line model built, the RAM analysis was performed with simulation of the block diagram that contains the TTF and TTR data of the equipment individually, shown in Figure 5.

For the simulation, a period of 60 days was considered, which is the target time for establishing scheduled stops in the baling lines. The main objective is to check the availability and reliability of the equipment and the line, seeking to treat the components and/or subsystems with less availability, greater expected number of failures and more time unavailable for corrective maintenance, as shown in Table 1.

Analyzing the data, the items highlighted in red in Table 1 were used to assess the behavior of the failure rate as a function of time. Faults that stop the line for more than 1.0h

Table 1. Result of simulation of reliability, availability and maintainability of the baling line

Resumo Individual do Bloco						
Nome do Bloco	Disp. Média (Todos Evento	# Esperado Falhas	Tempo Indisponível do Bloco (h)	Tempo Disponível do Bloco (h)	Quantidade de MCs	Tempo Indisponível da MC (h)
PF - Cilindro Hidr.	0,995469	1,09	6,525042	1433,474958	1,09	6,525042
Unit. - Cj. Cilindros Hidr.	0,996073	0,944	5,654614	1434,345386	0,944	5,654614
PF - Tubulações	0,996113	1,6	5,59672	1434,40328	1,6	5,59672
Unit. - Unidade de Torção	0,996472	1,453	5,080557	1434,919443	1,453	5,080557
1 Am - Cj. Sequência	0,996703	1,899	4,7475	1435,2525	1,899	4,7475
PF - Cj. Bombas Hidr.	0,996716	0,947	4,728586	1435,271414	0,947	4,728586
Emp. - Alinhador Fardos	0,997067	0,845	4,22372	1435,77628	0,845	4,22372
Impr. - Cabeçote	0,997172	2,037	4,072084	1435,927916	2,037	4,072084
Encap. - Sist. Dobra	0,997539	0,886	3,544	1436,456	0,886	3,544
Dobr. - Cilindro Hidr.	0,997558	1,173	3,515849	1436,484151	1,173	3,515849
Encap. - Sist. Alim. Capa	0,997793	0,91	3,178037	1436,821963	0,91	3,178037
Dobr. - Mesa de Giro	0,998019	0,713	2,852	1437,148	0,713	2,852
Encap. - Sist. Vácuo	0,998481	1,094	2,188	1437,812	1,094	2,188
Tr Transl. - Cabo Guia	0,998739	0,521	1,815359	1438,184641	0,521	1,815359
PF - Barreira de Luz	0,998741	0,726	1,812906	1438,187094	0,726	1,812906
Encap. - Cj. Cilindros Pneum.	0,999019	0,565	1,4125	1438,5875	0,565	1,4125
Tr Giro - Cabeamento Elétrico	0,999073	0,445	1,335	1438,665	0,445	1,335
1 Am - Unidade de Torção	0,999128	0,42	1,255349	1438,744651	0,42	1,255349
Emp. - Transportador	0,999153	0,611	1,219197	1438,780803	0,611	1,219197
Encap. - Motor Eletr.	0,999227	1,114	1,11241	1438,88759	1,114	1,11241
Tr Transl. - Cj. Sensores	0,999241	0,729	1,0935	1438,9065	0,729	1,0935
PF - Sist. Vedação	0,999303	0,402	1,003487	1438,996513	0,402	1,003487
PF - Transp. Correia	0,999311	0,663	0,992572	1439,007428	0,663	0,992572
Unit. - Alavanca de Armação	0,999324	0,649	0,9735	1439,0265	0,649	0,9735
1 Am - Cj. Alimentação Arame	0,999337	0,382	0,955	1439,045	0,382	0,955
Emp. - Bomba Hidr.	0,999374	0,259	0,901408	1439,098592	0,259	0,901408
Emp. - Cilindro Hidr.	0,9994	0,216	0,864	1439,136	0,216	0,864

were taken as the cut-off limit, totaling 22 components and subsystems analyzed.

The behavior of the form factor β of the Weibull distribution was used to indicate the type of failure event, considering β <1 "premature", β = 1 "random" and β> 1 "end of life". Based on this information, the analysis and deepening of the basic causes was done. Subsystems or components with β <= 1 were analyzed using the FTA tool. For items with β> 1, a preventive maintenance plan will be addressed.

The analyses are presented as follows, with the purpose of showing failure rate by lifetime and the failure trees analyses (FTA) of the most critical components of each equipment.

SWING CONVEYOR: The behavior of the failure rate as a function of the time of the electrical cabling set is displayed in Figure 6, the failure rate is decreasing as a function of time (initial portion of the bathtub curve). From the FTA, it was observed that the blocking actions are basically focused on inspection and lubrication routines. There are cases in which damage to the cables occurs during maintenance interventions, which will require training and awareness of the team.

TRANSFER CAR CONVEYOR: The behavior of the failure rate as a function of the time of the guide cable is presented in Figure 7, the failure rate is decreasing and is very close to random behavior (central portion of the bathtub curve). As verified in the FTA, the basic causes of the failures in the guide cable are associated with wear, locking of rollers and corrosion of fasteners.

BALE PRESS: The behavior of the failure rate versus time of the hydraulic pump set is shown in Figure 8, the failure rate is decreasing as a function of time (initial portion of the bath curve). As verified in the FTA, the failures of the pumping system, according to the history analyzed, are associated with the end-of-life of components, failures in seals and the filtration system.

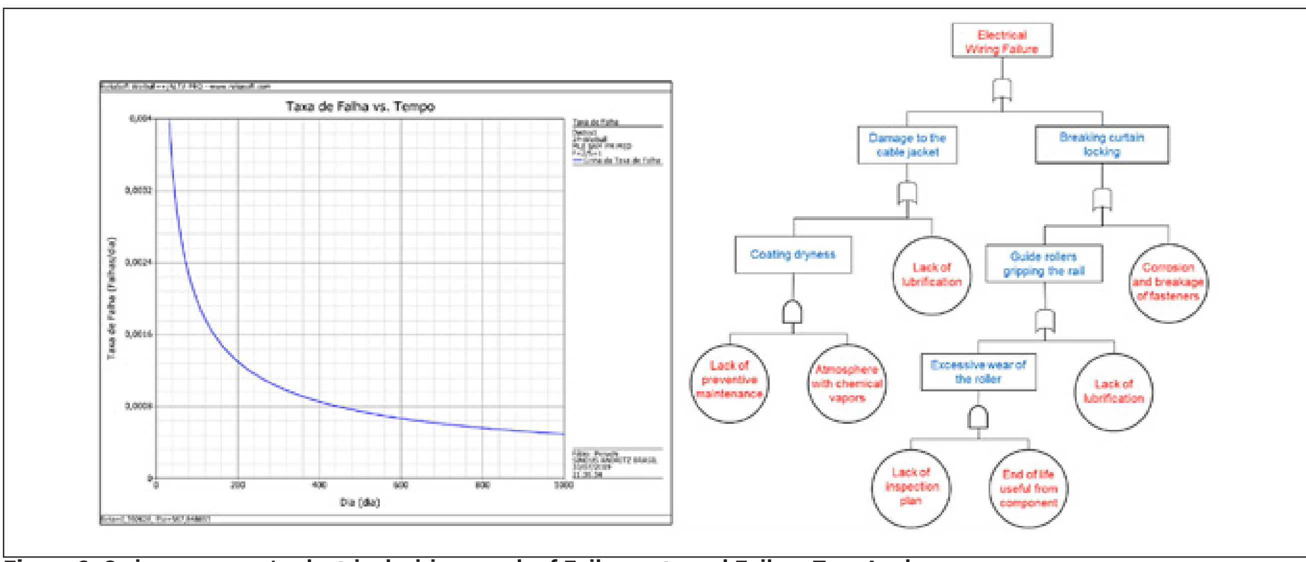

Figure 6. Swing conveyor's electrical wiring graph of Failure rate and Failure Tree Analyses

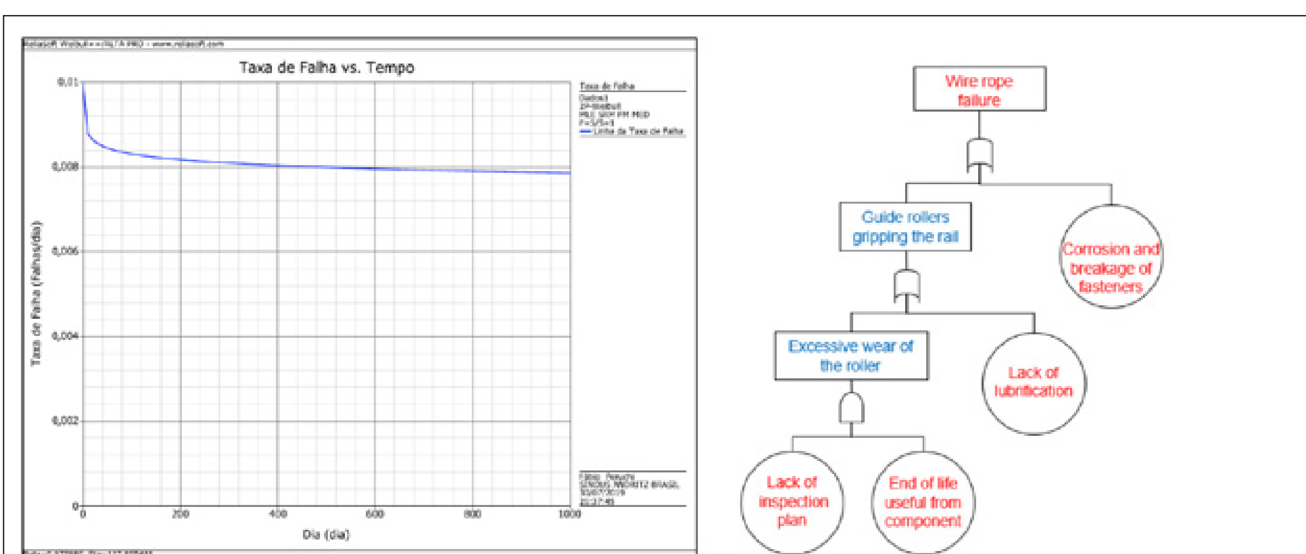

Figure 7. Transfer car conveyor's wire rope graph of Failure rate and Failure Tree Analyses

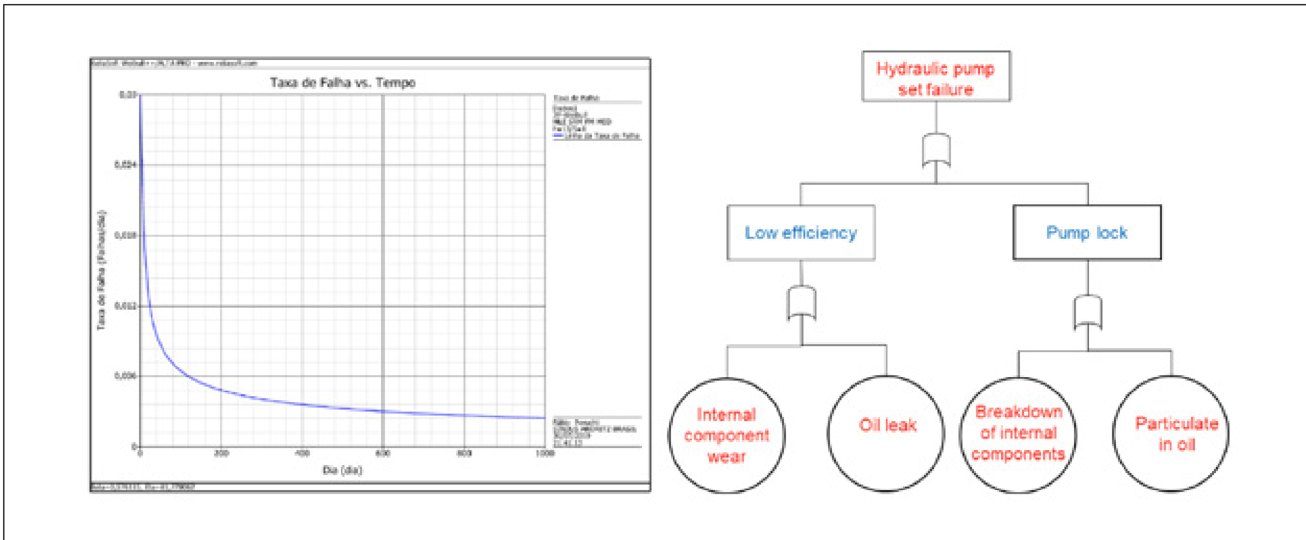

Figure 8. Bale Press hydraulic pump graph of Failure rate and Failure Tree Analyses

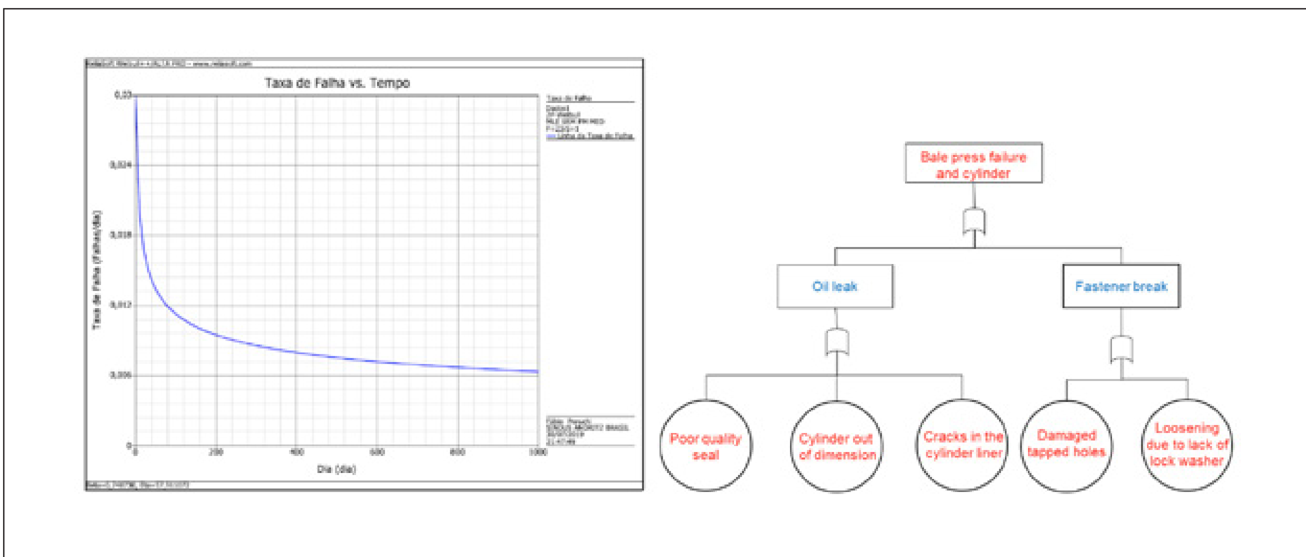

Figure 9. Bale Press hydraulic cylinder graph of Failure rate and Failure Tree Analyses

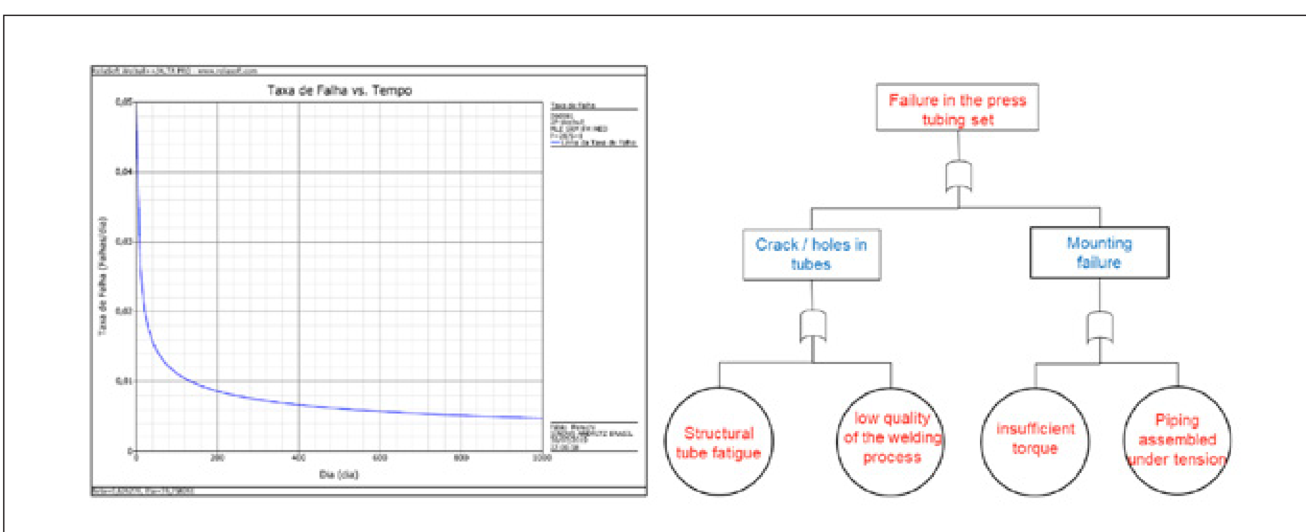

Figure 10. Press piping set graph of Failure rate and Failure Tree Analyses

BALE PRESS: The behavior of the failure rate as a function of the time of the hydraulic cylinder set is shown in Figure 9, the failure rate is decreasing as a function of time (initial portion of the bath curve). As verified in the FTA, the failures of the press cylinders are strongly associated with the repair carried out at external suppliers and the detachment of rod fasteners.

BALE PRESS: The behavior of the failure rate as a function of the time of the piping set is shown in Figure 10, the failure rate is decreasing due to time (initial portion of the bathtub curve). As verified in the FTA, the failures of the piping set are strongly associated with cracks and holes in the tubes and assembly failures.

WRAPPER: The behavior of the failure rate as a function of the bending system time of wrap is shown in Figure 11, the failure rate is decreasing due to (initial portion of the bathtub curve). As verified in the FTA, the failures of the folding system of the hoods have a strong association with high impacts during operation due to incorrect flow adjustments.

BALE BINDER: The behavior of the failure rate as a function of the time of the sequence set is shown in Figure 12, the failure rate is decreasing due to (initial portion of the bathtub curve). As verified in the FTA, the failures of the sequence set are associated with the failure of the sequence valve and wire grab / misalignment on the rails.

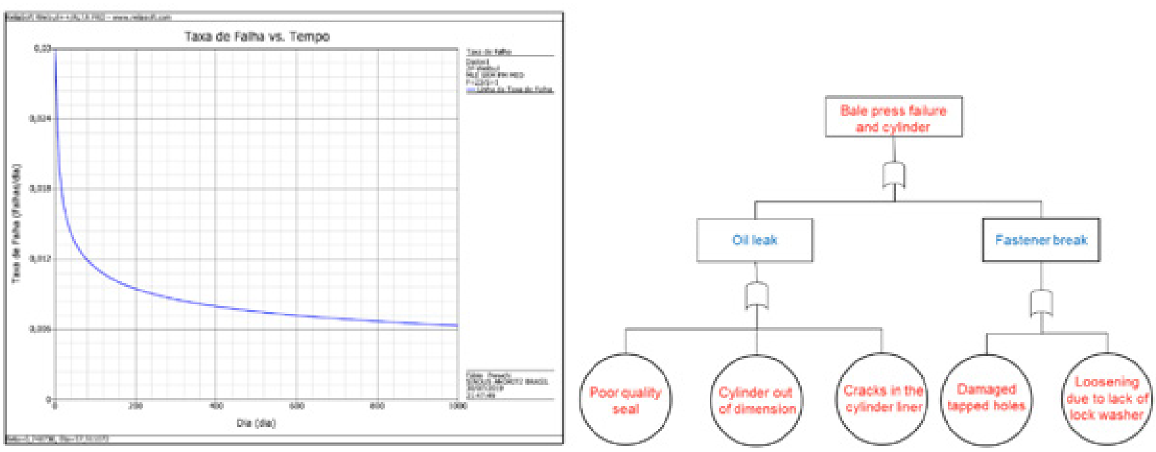

Figure 11. Wrapper flap folding graph of Failure rate and Failure Tree Analyses

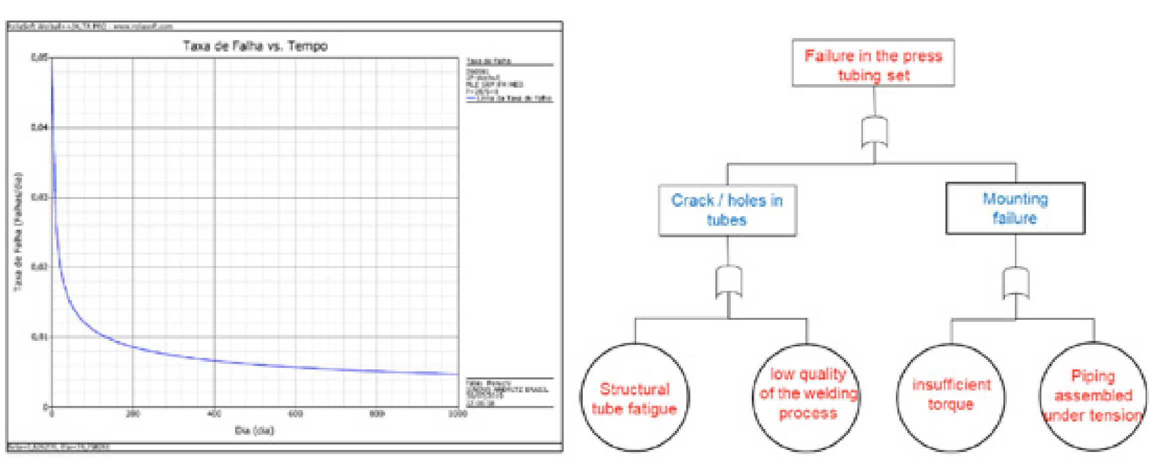

Figure 12. Bale Binder sequence set graph of Failure rate and Failure Tree Analyses

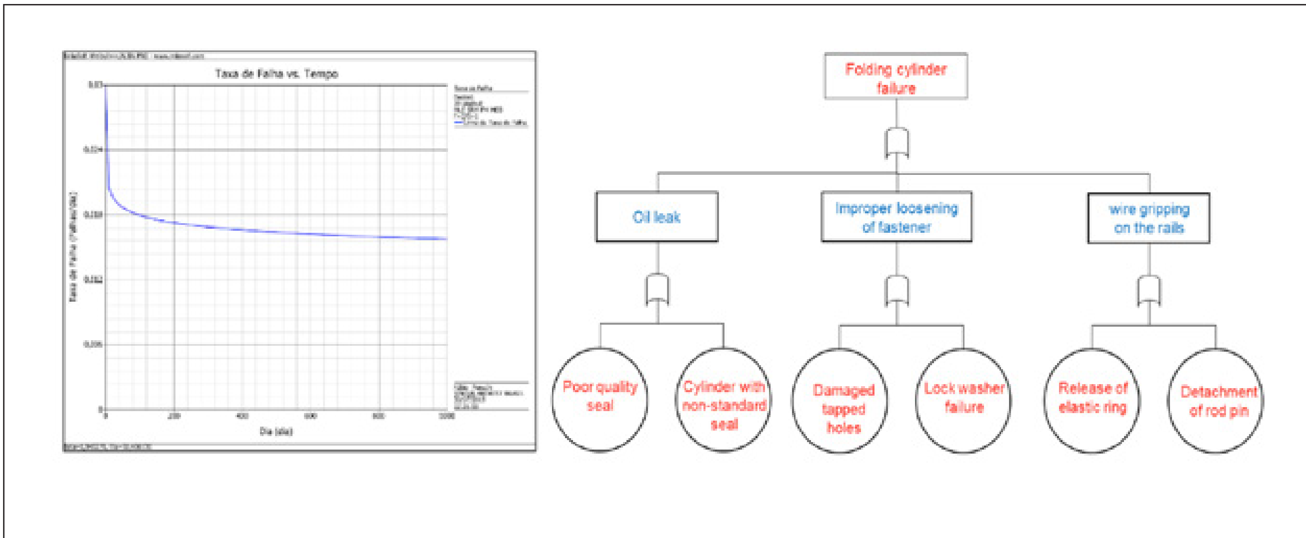

Figure 13. Folder cylinder graph of Failure rate and Failure Tree Analyses

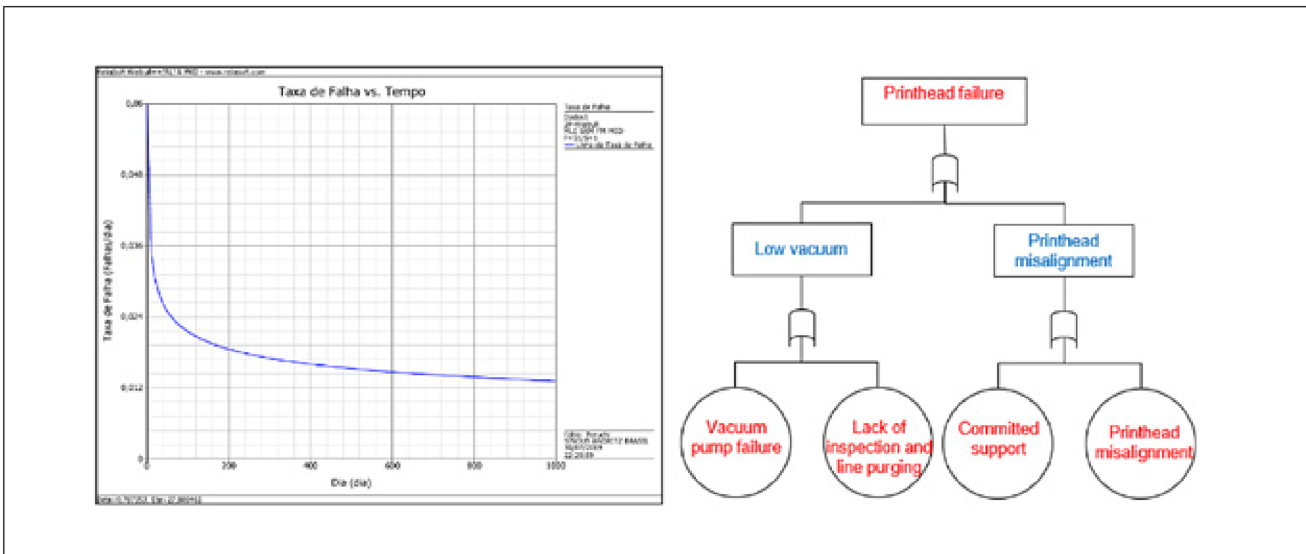

Figure 14. Stenciller printhead graph of Failure rate and Failure Tree Analyses

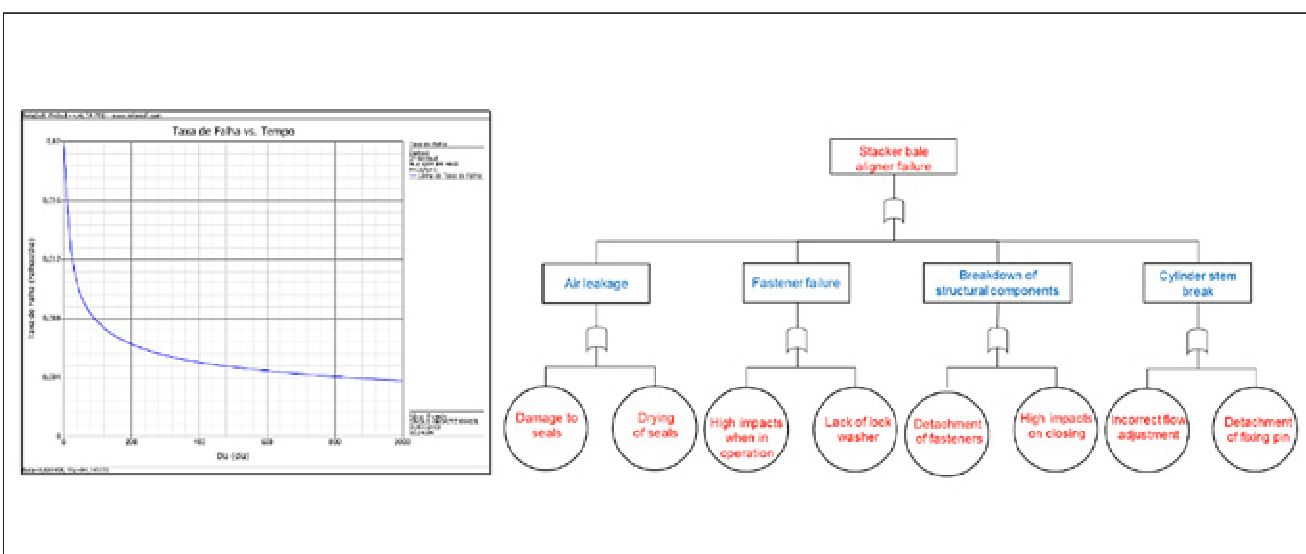

Figure 15. Bale Stacker bale aligner graph of Failure rate and Failure Tree Analyses

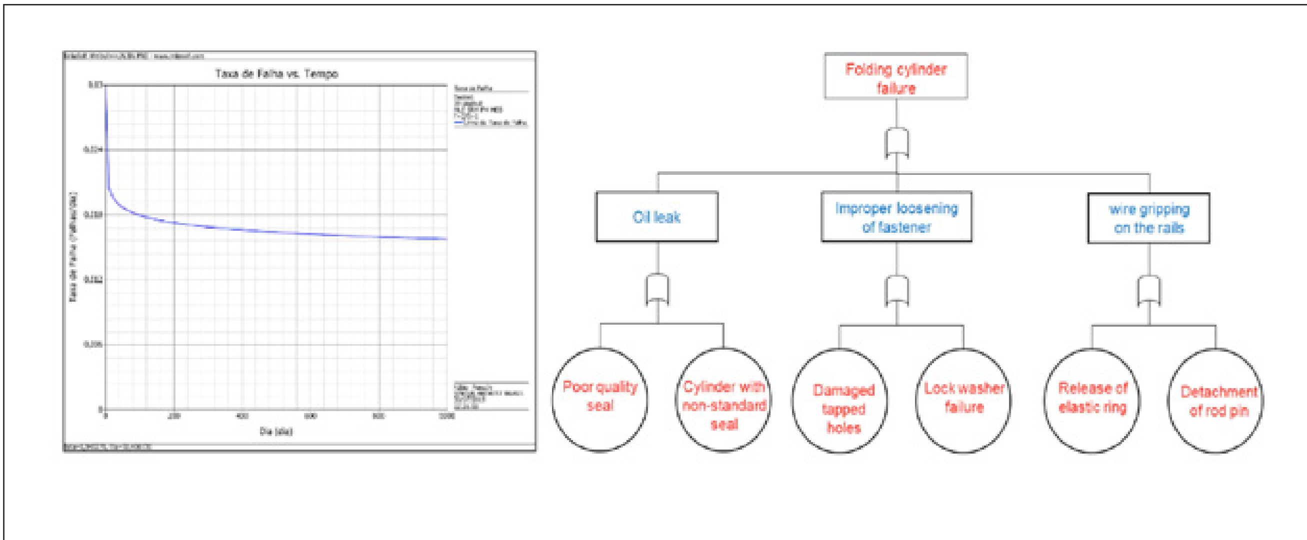

Figure 16. Bale Unit hydraulic cylinders graph of Failure rate and Failure Tree Analyses

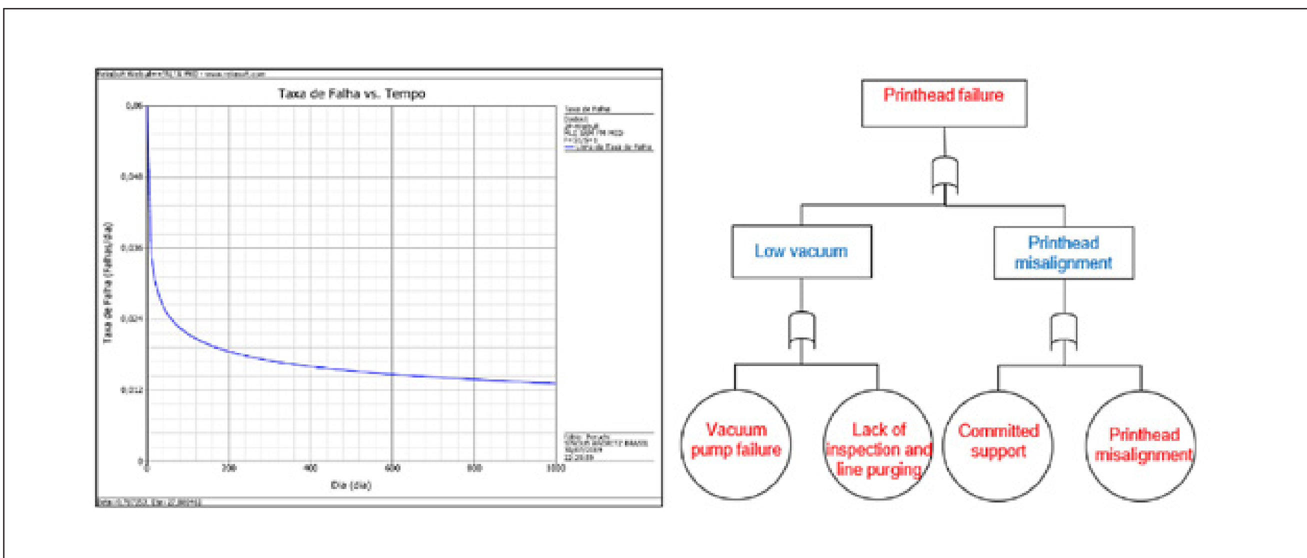

Figure 17. Bale Unit twisting unit graph of Failure rate and Failure Tree Analyses

FOLDER: The behavior of the failure rate as a function of the time of the hydraulic cylinder set is shown in Figure 13, the failure rate is decreasing and very close to random behavior (central portion of the bathtub curve). As verified in the FTA, the failures associated with bending cylinders are associated with oil leaks and detachment / breakage of fasteners.

STENCILLER The behavior of the failure rate as a function of the printhead time is shown in Figure 14 the failure rate is decreasing as a function of time (initial portion of the bathtub curve). As verified in the FTA, the failures of the printhead are directly linked to the vacuum pump failures, misalignment of the printhead and lack of purging in the line.

BALE STACKER The behavior of the failure rate as a function of the time of the stacker baler is shown in Figure 15, the failure rate is decreasing as a function of time (initial portion of the bathtub curve). As verified in the FTA, the failures of the bale aligner occur largely due to the high impacts that result in breakages of structures, fasteners and cylinders.

BALE UNIT The behavior of the failure rate as a function of the time of the unit hydraulic cylinders is shown in Figure 16, the failure rate is decreasing as a function of time (initial portion of the bathtub curve). As verified in the FTA, the failures of the hydraulic cylinders of the bale unitizer are associated with the oil leaks and breakage of fasteners.

BALE UNIT The behavior of the failure rate as a function of the time of the twisting unit is shown in Figure 17, the failure rate is decreasing as a function of time (initial portion of the bathtub curve). As verified in the FTA, the failures of the torsion unit are strongly associated with the wear of internal elements, oil leakage and the presence of wire chips inside the unit

An action plan was prepared for each item analyzed, shown in Table 2, and a new simulation of reliability, maintainability and availability of the baling line under study was made, considering that the failure modes of the components and subsystems were addressed and actions successfully implemented in the area.

Table 2. Preventive, predictive and corrective actions based on the FTA analysis

Equipment	Subsystem / Component	β	Fail mode	Causes Identified (FTA)	Prevention / Improvement Actions	Frequency
SWING CONVEYOR	Electrical Wiring Failure	0,39	Damage to the coating	Corrosion and breakage	Maintenance team instruction	-
			Coating dryness	Lack of preventive inspection plan	Creation of inspection plan	6 months
			Coating dryness	Atmosphere with chemical vapors	None - inherent condition	-
			Guide roller wear	Lack of preventive inspection plan	Creation of inspection plan	6 months
			Guide roller wear	End of life useful	Creation of preventive replacement plan	24 months
			Guide rollers gripping the rail	Lack of Lubrification	Creation of lubrification plan	6 months
			Breaking by curtain locking	Lack of preventive inspection plan	Creation of inspection plan	6 months
TRANSFER CAR CONVEYOR	Lead cable	0,98	Guide roller wear	Lack of preventive inspection plan	Creation of inspection plan	6 months
			Guide roller wear	End of life useful	Creation of preventive replacement plan	24 months
			Guide rollers gripping the rail	Lack of Lubrification	Creation of lubrification plan	6 months
			Cable corrosion	Lack of preventive inspection plan	Creation of inspection plan	6 months
BALE PRESS	Hydraulic pump	0,58	Low efficiency	Internal component wear	Creation of preventive replacement plan	60 months
			Low efficiency	Oil leak	Creation of preventive replacement plan	15 months
			Pump locking	Breakdown of internal components	Creation of inspection plan	2 months
			Pump locking	Particulate in oil	Creation of preventive replacement plan	24 months
	Cylinders	0,75	Oil leak	Poor quality seal	External repair suitability	-
			Oil leak	Cylinder out of dimension	External repair suitability	-
			Oil leak	Cracks in the cylinder liner	Creation of inspection plan	15 months
			Fastener break	Damaged tapped holes	Creation of inspection plan	15 months
			Fastener break	Loosening due to lack of lock washer	Maintenance team instruction	-
	Tubing set	0,63	Crack / holes in tubes	Structural tube fatigue	Creation of inspection plan	15 months
			Crack / holes in tubes	Low quality of the welding process	Maintenance team instruction	-
			Mounting failure	Insufficient torque	Maintenance team instruction	-
			Mounting failure	Piping assembled under tension	Maintenance team instruction	-
WRAPPER	Pneumatic Cylinders	0,77	Air leaks	Damage to seals	Creation of inspection plan	3 months
			Air leaks	Deterioration of seals	Creation of preventive replacement plan	24 months
			Breakage of fasteners	High impacts in operation	Operation team instruction	-
			Breakage of fasteners	Lack of lock washer	Maintenance team instruction	-
			Cylinder stem break	Detaching pin	Maintenance team instruction	-
			Cylinder stem break	Cylinder stem break	Operation team instruction	-
BALE BINDER	Sequence set	0,78	Cycle problems	Sequence valve mismatch	Maintenance team instruction	-
			Wire gripping on the rails	Track wear	Creation of inspection plan	2 months
			Wire gripping on the rails	Wire without lubricating film	Operation team instruction	-
			Wire misalignment	Track wear	Creation of inspection plan	2 months
FOLDER	Folding cylinder	0,94	Oil leak	Poor quality seal	External repair suitability	-
			Oil leak	Cylinder with non-standard seal	External repair suitability	-
			Improper loosening of fastener	Damaged tapped holes	External repair suitability	-
			Improper loosening of fastener	Lock washer failure	Operation team instruction	-
			Wire gripping on the rails	Release of elastic ring	Maintenance team instruction	-
			Wire gripping on the rails	Detachment of rod pin	Operation team instruction	-
STENCILLER	Printhead	0,79	Low vacuum	Vacuum pump failure	Creation of preventive replacement plan	15 months
			Low vacuum	Lack of inspection and line purging	Operation team instruction	-
			Printhead misalignment	Committed support	Creation of inspection plan	2 months
			Printhead misalignment	Printhead misalignment	Maintenance team instruction	-
BALE STACKER	Bale aligner	0,69	Air leakage	Damage to seals	Creation of preventive replacement plan	15 months
			Air leakage	Drying of seals	Creation of inspection plan	2 months
			Fastener failure	High impacts when in operation	Operation team instruction	-
			Fastener failure	Lack of lock washer	Maintenance team instruction	-
			Breakdown of structural components	Detachment of fasteners	Operation team instruction	-
			Breakdown of structural components	High impacts on closing	Maintenance team instruction	-
			Cylinder stem break	Incorrect flow adjustment	Operation team instruction	-
			Cylinder stem break	Detachment of fixing pin	Operation team instruction	-
BALE UNIT	Hydraulic cylinders	0,73	Oil leak	Poor quality seal	External repair suitability	-
			Oil leak	Cylinder out of dimension	External repair suitability	-
			Fastener break	Damaged tapped holes	Maintenance team instruction	-
			Fastener break	Lack of lock washer	Maintenance team instruction	-
			Pin break	High impacts during operation	Operation team instruction	-
			Pin break	Excessive clearance of the housing	Maintenance team instruction	-
	Wire twisting	0,71	Wire misalignment	Wear of internal elements	Creation of preventive replacement plan	2 months
			Wire misalignment	Incorrect assembly	Maintenance team instruction	-
			Oil leak	Damage to the hydraulic block seat	Operation team instruction	-
			Oil leak	Lack of retainers in the assembly of the unit	Operation team instruction	-
			Dirtiness	Accumulation of wire filings	Operation team instruction	-
			Dirtiness	Accumulation of cellulose fines in the unit	Operation team instruction	-

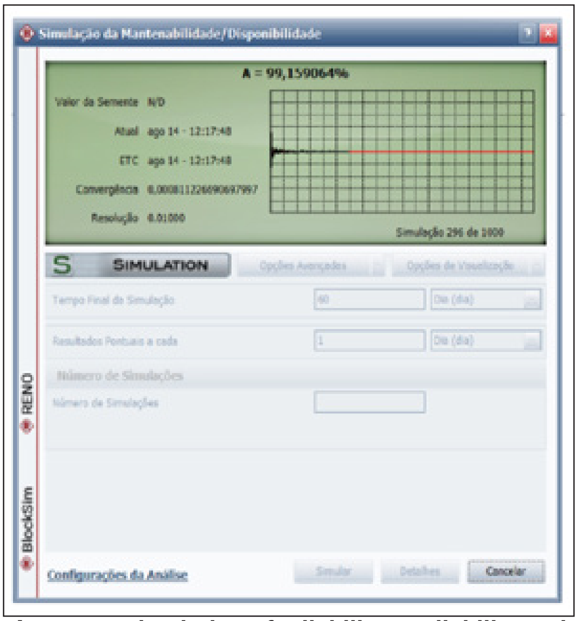

Figure 18. Simulation of reliability, availability and maintainability

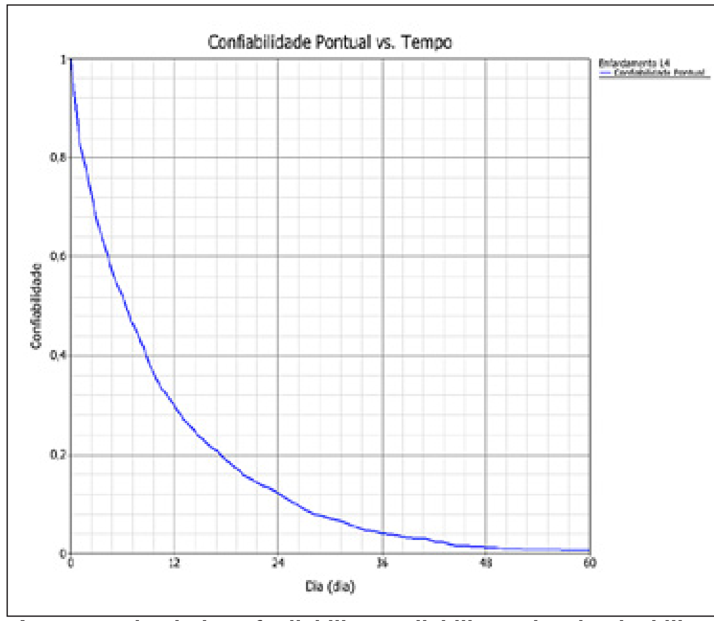

Figure 19. Simulation of reliability, availability and maintainability

The results of the new simulation are shown in Figure 18.

Comparing the new RAM simulation in Figure 18 with the first simulation performed in Figure 5, there is a significant increase in availability, from 94.51 to 99.15 after the elimination of the failure modes of the 22 main equipment components and subsystems of the baling line. The timely reliability of the system also increased significantly, as seen in Figure 19.

Increasing system reliability directly impacts availability. It can be seen in Figure 19 that, compared to Figure 4, the decline in the point reliability curve occurs very smoothly after solving the main problems that impact the line's availability.

CONCLUSIONS

The result of this work is a maintenance strategy appropriate for the current condition of the baling equipment. It appears that establishing a preventive maintenance routine is not the best tactic for increasing availability, since the main items of impact on availability have a characteristic of decreasing failure rate. This makes it necessary to take a first step, eliminating the failure modes with the greatest impact on availability, in order to subsequently implement a scheduled maintenance routine. This observation was made possible through an analysis using the LDA and RAM tools, from which a unique view of the equipment's behavior was obtained.

In order to deepen the understanding of basic failure causes by failure tree analyses (FTA's) specific to the systems and components of less availability were carried out. This enabled us to come up with action plans aimed at solving the problems that result in failures. With the new simulation of reliability, availability and maintainability, there is a possibility of a significant increase in availability with the elimination of the failure modes studied in this work.

In this way, the items presented in Figure 6 will be detailed and the action plans implemented, seeking the result of availability verified in the second simulation, showing a 4.64% increase in baling availability (Figure 20).

The main challenges encountered in carrying out this work were focused on data treatment. It was necessary to read more than 1,500 occurrences and insert information (which component or subsystem failed, the failure mode and the calculation of average life or MTBF), so make it possible to proceed with the analysis of life data. ■

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