IMPLEMENTATION OF THE RELIABILITY-CENTERED MAINTENANCE METHODOLOGY IN A BLACK MOISTURE PRODUCTION GROUP: A CASE STUDY.

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Abstract: *The globalization of the markets provides a high competitiveness among companies in the same segment being their great challenge the ability to generate profitable and sustainable results in their business units. However to generate profits for the shareholders, it becomes salutary that: the expectations and needs are exceeded, the current laws in force are respected, the manufactured products are safe and valuable, their processes have a high level of reliability and efficiency to assure that their stock are lean and balanced, the information and data flow between the different sectors is effective, the knowledge about the manufacturing good practices is stored in databases and can be linearly deployed to all employees and the human capital is engaged with their mission. This paper aims to present a successful example about the deployment of the Reliability-Centered Maintenance (RCM) methodology in a black moisture production group of a tire plant located in southeastern Brazil. The effective and disciplinary application of this methodology allowed the balance and the qualitative and quantitative improvement of the existent maintenance plans and hence the sustainable results in an organizational setting that needs consistent and continuous rates of the plant availability and reduced costs of production.*

Keywords: *Process Mapping, Reliability-Centered Maintenance.*

1. INTRODUCTION

The current economic context is characterized by high competitiveness, low levels of profitability, demand and the sophistication of consumers and the speed with which changes occur. It is of globalization, open market, free competition, where the survival of companies depends largely on the flexibility of its structures, the sustainability of its processes and effective management of its human and intellectual capital.

According Antoniolli and Lima (2010), globalization can be understood as a set of convergent changes towards a more integrated and interdependent world, where trade, finance, markets, and production have not only a local scope. She has been driven by several factors, such as increasing deregulation of markets, falling trade barriers, developing new modes of transport and the change of the consumer profile, which requires greater value.

Confirming what was explained above, Arcuri (2005) points out that the search for effective enterprise performance, especially in competitive environments, requires the formulation of strategies based on an integrated view of organizational networks, with adequate flexibility and connectivity for rapid correction direction in planning, management and technical and administrative operation.

In this sense, organizations have sought to develop new patterns of work, communication, infrastructure and technologies through new links with the various actors with whom they interact. In a competitive environment as it presents itself today, there is no sustainable technological advantage through knowledge but added that the company has, how it is used and speed as we seek to learn and develop something new. Tied to this new culture, the maintenance activity needs to be strategic and integrate effectively into the production process, making it a proactive agent, for the changes to succeed in high speed.

As Fontes and Clement (2007), organizational change consists of a set of theories, values, strategies and techniques that is scientifically sound that aims to change the work environment and improvement of individual and organizational performance.

In this context, emerged the need to implement a pilot project using the methodology of Reliability Centered Maintenance (RCM), integrated maintenance management system in a business unit of a tire manufacturing company located in southeastern Brazil, in order that the assets of a group of production with daily capacity of 90 tons of black mixture could effectively carry out their functions and thus operate as designed capability. This tight integration allowed sustainable results in an organizational setting aimed at financial profitability through reliability, safety and quality of its products and services.

2. CASE STUDY

The organization object of this case study has five business units in the country, starting the implementation of the RCM methodology in 2008, in a pilot production group of black moisture manufacturing, looking for earn profits in the qualitative and quantitative balance of the several maintenance processes.

The most appropriate way for this approach, according to the classification proposed in Silva and Menezes (2001), is the applied origin research, which generates knowledge for practical application turned to the solutions of specific problems in the form of case study that involves deep research of one or a few objects that allows their broad and detailed knowledge.

Confirming what was explained above, Santos et *al.* (2007) define a study case as "an empirical investigation that searches a contemporary phenomenon inside its real life context, especially when the limits between the phenomenon and the context are not clearly defined".

Sellitto (2005) lists five kinds of contribution of a case study:

- Ideographic-configurative, which offers a deep and specific description of an object for other studies;
- Configurative-disciplined, which the researcher interprets any irregularity, expected or not, observed in an object;
- Heuristic, which a situation is deliberately built to expose potentially generalizable relations;
- Plausible polls around the proposed theory by the heuristic mode;
- The crucial case that supports or refute a theory.

3. RELIABILITY

In its broadest sense, reliability is associated with the successful operation of a product or system in the absence of failures. In engineering analysis, however, requires a quantitative definition of reliability in terms of probability, thus the reliability Lafraia second (2001), can be defined as the level of "confidence" that a particular component, equipment or system to perform the basic function for which it was designed and installed during a period of preset time and under standard operating conditions.

Martins and Leitao (2009) rate the availability (A) as a characteristic of a repairable system and the composition of the attributes of reliability and maintainability, can be said that the availability function translates the proportion of time that the system is able to be used and thus able to perform their specific functions.

Duarte et *al.* (2009) describe the rate of availability of procedural functions is calculated using the mathematical "Eq. (1)", which uses as the basis of the indicators described below:

- Opening Potential (OP): Theoretical time available for the process according to execute a program to produce pre-defined sector of production planning;
- About capacity (AC): Any shutdown function process because there is no production programs developed by industry production planning;
- Opening Real (OR): Sum (Σ) Real Time available for the process according to execute a program to produce pre-defined sector of production planning;
- Time Stop Function Process (TSFP): Any failure of the function process, and this time counted in minutes.

$$A = ((OR - \Sigma TSFP) / OR) * 100) \tag{1}$$

To calculate the availability of manufacturing production group, we consider the charts for the setup of the line, scheduled stops operating or non-original, quality or raw materials, which are still not computed in this study.

Billinton (1992) describes the calculation of the attributes of reliability of repairable systems procedural functions and series configuration, among other uses, the indexes called System Failure Rate (λ_S), which represents the amount of risk associated with loss function in hours per unit of time "t", the Mean Time Between Failures (MTBF) which is the average time of operation between failures of the production process that culminated in the arrest of the function procedure, the repair rate (r_S) which is the repair time required for the production process to return to work in hours and the Mean Time To Repair (MTTR) which is the average time to completion of repairs carried out intrusive function due to a procedural failure, these indicators are calculated using mathematical "Eq. (2), (3) and (4)".

$$\lambda_S = \lambda_A + \lambda_B + \cdots \lambda_n \tag{2}$$

$$MTBF = \frac{1}{\lambda_S} \tag{3}$$

$$r_S = \frac{\lambda_A * r_A + \lambda_B * r_B}{\lambda_A + \lambda_B} \tag{4}$$

4. RELIABILITY-CENTERED MAINTENANCE

The Reliability-Centered Maintenance (RCM) is a management methodology of physical assets used in the determination of maintenance tasks, to ensure that a system or process meets the needs of its users, within its present operating context, with the expected performance. This methodology also makes the systematic consideration of the functions of a physical item, its failure modes and the prioritization criteria for defining a maintenance policy of the process functions.

Niu et *al.* (2010) claim that RCM is an industrial improvement approach focused on the identification and establishment of operational improvements of capital maintenance, which will manage the risks of failure of assets effectively, that is, an engineering structure that allows definition of a full maintenance regime.

In this sense, Oliveira et *al.* (2010) point out that due to an increasing need to improve the reliability, several methods and techniques for minimizing / eliminating failures is becoming popular. These methods and techniques are designed to improve reliability of products or processes, or increase the likelihood of an item to perform its functions without fail.

Through a systematic action and focusing on the function of the system, maps to the manufacturing process in order to prioritize which features are most important to the production process, their functional failures, failure modes and consequences of failure, providing improvement plans maintenance to begin to generate schedules with a focus on tasks that add to system improved frequencies, inventory levels, reduction of items and equipment to be checked periodically or to redesign the system.

According to Souza and Lima (2003), the answers to the seven questions were developed in seven steps:

1. Choose the proper productive process area for the RCM application;
2. Define the desired performance functions and parameters;
3. Indicate the functional failures;
4. Indicate the failure mode, its effects and consequences;
5. Choose the kind of maintenance;
6. Formulate and implement the maintenance plan;
7. Continued improvement.

Briefly and according to the report of Nowland and Heap (1978), RCM refers to a Maintenance program made to preserve the reliability of an item, in order that it performs its function in the process. The policy consists in the selection of tasks based on the reliability characteristics, accompanied by a logical and systematic analysis that aims the technical and financial feasibility of the actions to be deployed.

5. WHY THE RCM APPLICATION IN A PILOT PLANT?

The year 2008 was a watershed for the business unit maintenance of a manufacturing industry mixes black with a tire plant located in the south-eastern region of Brazil, since the first half was marked by high demands of manufacturing, availability of financial resources and human capital deployed so that the goals are achieved. Instead, the second half of 2008 was marked by a demand retracted market caused by a global financial crisis, with severe reduction in production, drastic cuts in funding for maintenance, cancellation of contracts, mitigation investment and therefore collective vacation to your human capital. All actions generated from the beginning of the financial crisis converged on the need for mitigation costs and expenses, as well as to maximize results through the use of available scarce resources (human and financial). Faced with the challenge of improving the operational availability of assets, the decision was taken in September 2008 to develop and implement the RCM in a production group with 90 tons daily capacity, from the use of mapping tool processes.

This production group called Group B started its manufacturing activities in 1989 and it is considered as semi-automatic due to the manual removal of samples of products manufactured for shipment to the laboratory for analysis and by manually adding some inputs constituents early in the process. The same yields according to the precepts of production pushed with four relay teams and continuous operation of 708 hours per month, since there is still a monthly schedule of 12 hours to perform systematic preventive maintenance.

6. PROCESS MAPPING

The excellent performance of the functions that make up the manufacturing process of black mixture requires that all inter-related activities are understood and managed according to a process view. This need seeks the effectiveness of the process chain, to meet the quality requirements and exceed customer expectations and therefore deliver performance to the business through the use of limited resources.

Thus, a process has input, output, time, space, order, purpose and values that linked together logically, will result in a structure to provide products or services to the customer. Your understanding is important because it is the key to success, after all, an organization is as effective as their processes because they are responsible for what will be offered to the client.

According to Correia et *al.* (2002), process mapping is an analytical management tool and communication that aims to optimize existing processes or implementing a new and effective framework for the process. Their knowledge allows structured analysis of the production process and identifying bottlenecks, idleness, critical functions, chain of product cost and service flaws, and promotes integration between systems and eliminating steps that do not add value to the process.

7. IMPLEMENTATION OF RCM METHODOLOGY

The implementation process of Reliability Centered Maintenance using the Process Mapping tool has started in August 2008, being divided in 14 stages, as shown in "Fig. 1".

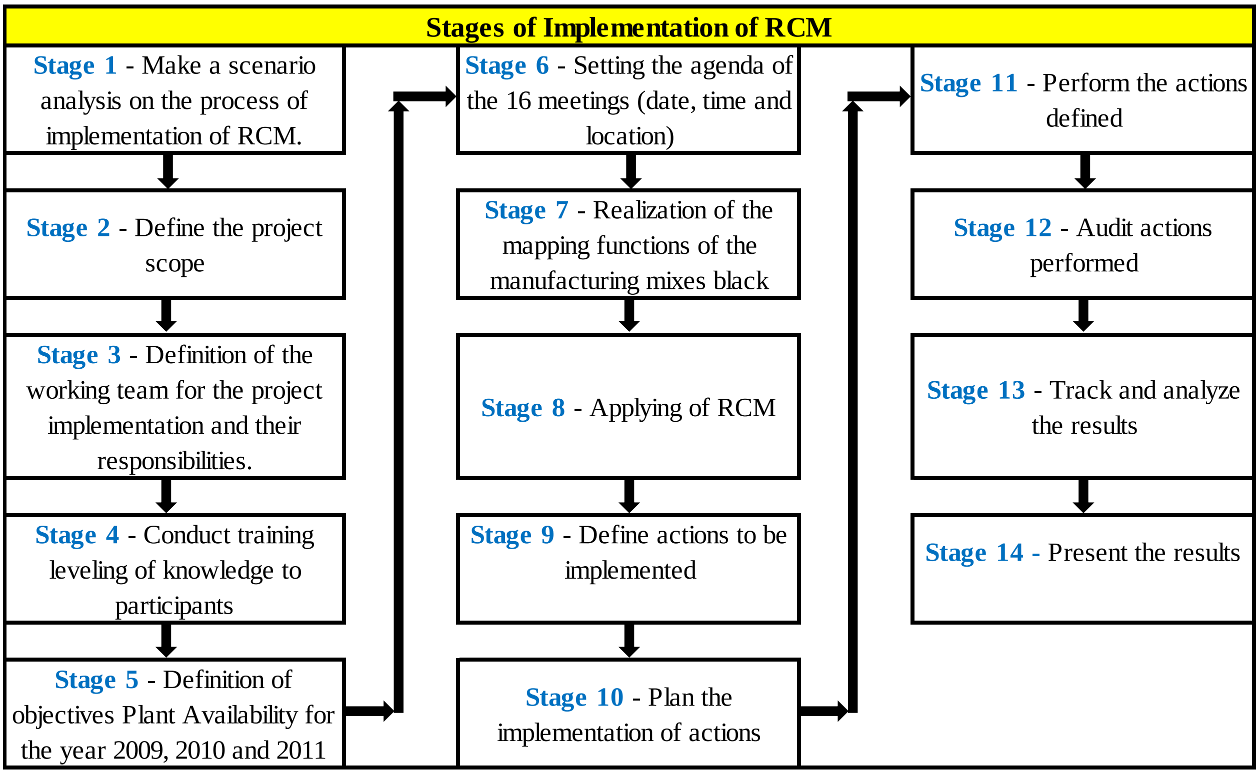
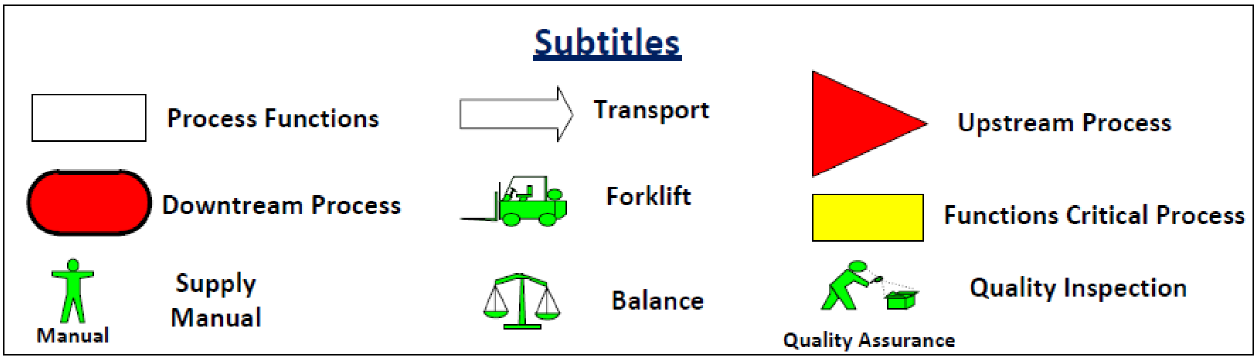


Figure 1. Diagram of RCM methodology implementation stages

The "Figure 2" presents the model used in stage 7 and the "Fig. 3" shows the matrix model RCM used in stage 8.



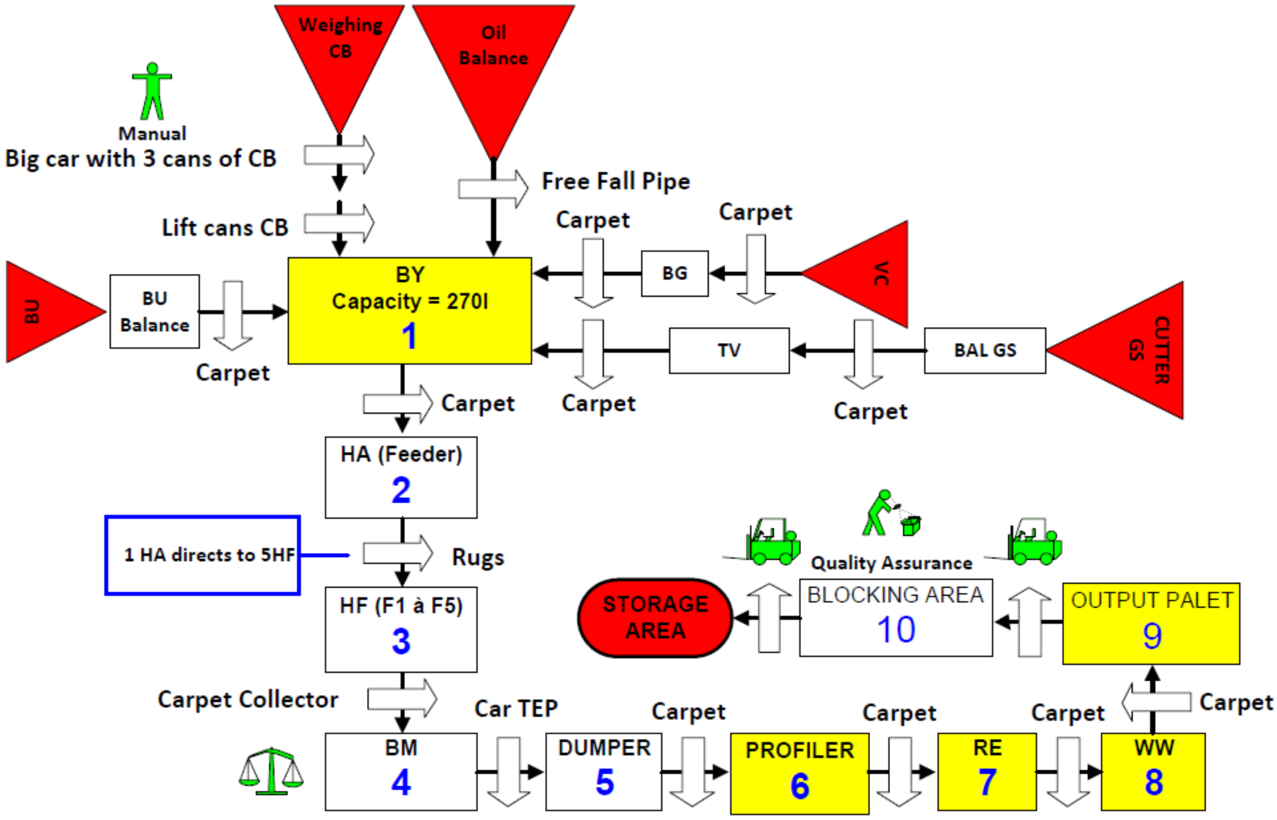
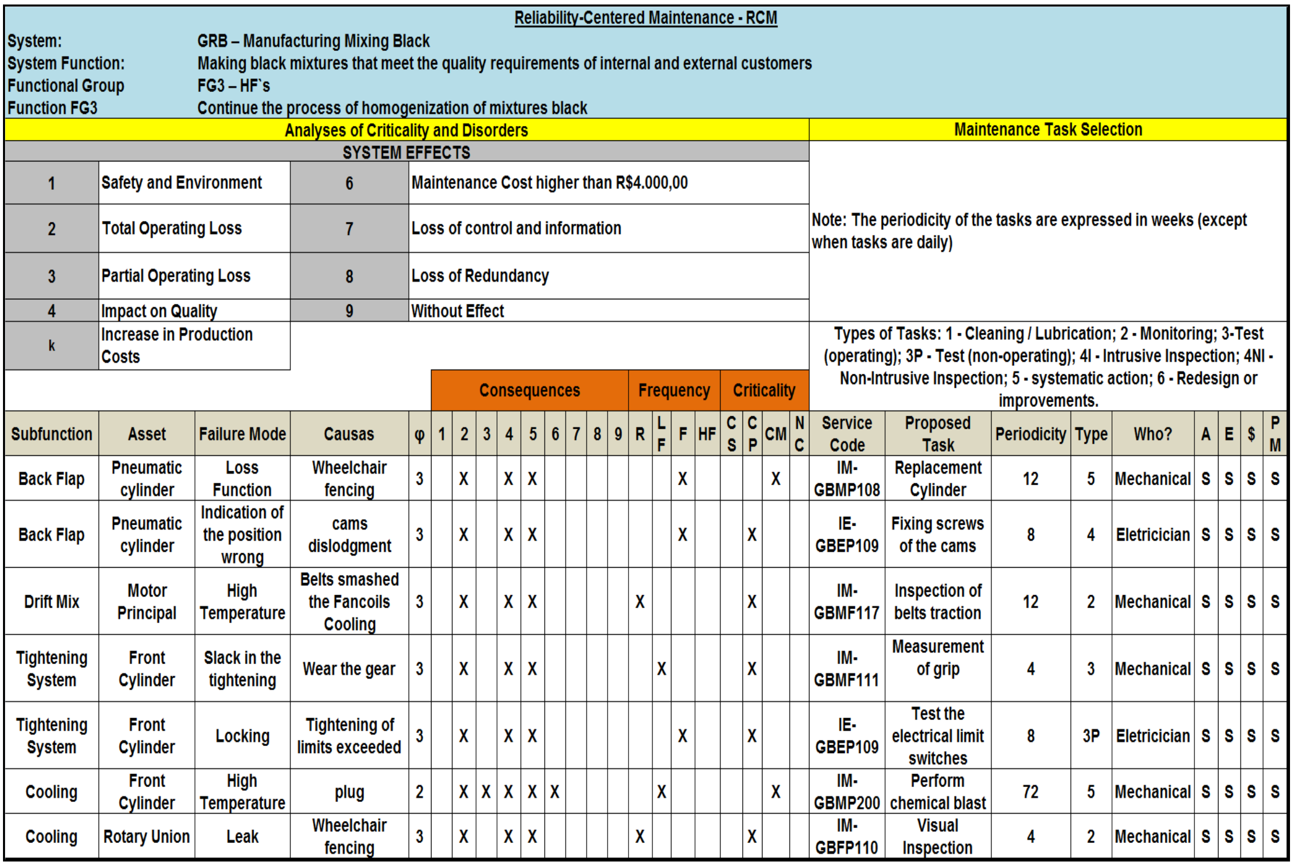


Figure 2. Model used for the mapping function manufacturing assets



Reliability-Centered Maintenance - RCM

System: GRB – Manufacturing Mixing Black
System Function: Making black mixtures that meet the quality requirements of internal and external customers
Functional Group FG3 – HF`s
Function FG3 Continue the process of homogenization of mixtures black

Analyses of Criticality and Disorders | **Maintenance Task Selection**

SYSTEM EFFECTS

1	Safety and Environment	6	Maintenance Cost higher than R$4.000,00
2	Total Operating Loss	7	Loss of control and information
3	Partial Operating Loss	8	Loss of Redundancy
4	Impact on Quality	9	Without Effect
k	Increase in Production Costs		

Note: The periodicity of the tasks are expressed in weeks (except when tasks are daily)

Types of Tasks: 1 - Cleaning / Lubrication; 2 - Monitoring; 3-Test (operating); 3P - Test (non-operating); 4I - Intrusive Inspection; 4NI - Non-Intrusive Inspection; 5 - systematic action; 6 - Redesign or improvements.

					Consequences									Frequency				Criticality												
Subfunction	Asset	Failure Mode	Causas	φ	1	2	3	4	5	6	7	8	9	R	LF	F	HF	CS	CP	CM	NC	Service Code	Proposed Task	Periodicity	Type	Who?	A	E	$	PM
Back Flap	Pneumatic cylinder	Loss Function	Wheelchair fencing	3		X		X	X							X				X		IM-GBMP108	Replacement Cylinder	12	5	Mechanical	S	S	S	S
Back Flap	Pneumatic cylinder	Indication of the position wrong	cams dislodgment	3		X		X	X							X			X			IE-GBEP109	Fixing screws of the cams	8	4	Eletricician	S	S	S	S
Drift Mix	Motor Principal	High Temperature	Belts smashed the Fancoils Cooling	3		X		X	X					X					X			IM-GBMF117	Inspection of belts traction	12	2	Mechanical	S	S	S	S
Tightening System	Front Cylinder	Slack in the tightening	Wear the gear	3		X		X	X						X				X			IM-GBMF111	Measurement of grip	4	3	Mechanical	S	S	S	S
Tightening System	Front Cylinder	Locking	Tightening of limits exceeded	3		X		X	X							X			X			IE-GBEP109	Test the electrical limit switches	8	3P	Eletricician	S	S	S	S
Cooling	Front Cylinder	High Temperature	plug	2		X	X	X	X	X					X					X		IM-GBMP200	Perform chemical blast	72	5	Mechanical	S	S	S	S
Cooling	Rotary Union	Leak	Wheelchair fencing	3		X		X	X					X					X			IM-GBFP110	Visual Inspection	4	2	Mechanical	S	S	S	S

Figure 3. RCM matrix

8. QUALITATIVE RESULTS ACHIEVED AFTER THE INPLEMENTATION OF RCM

The team formed by 11 workers from different skills (Maintenance, Maintenance Engineering, Quality, Production, Supply) analyzed all the process functions obtained by the application of the Process Mapping tool in the target production group of this paper, resulting in:

- Definition of 10 Functional Groups (FG);
- Identification of 1007 Failure Modes (FM) and its criticalities, as seen in "Fig. 4":

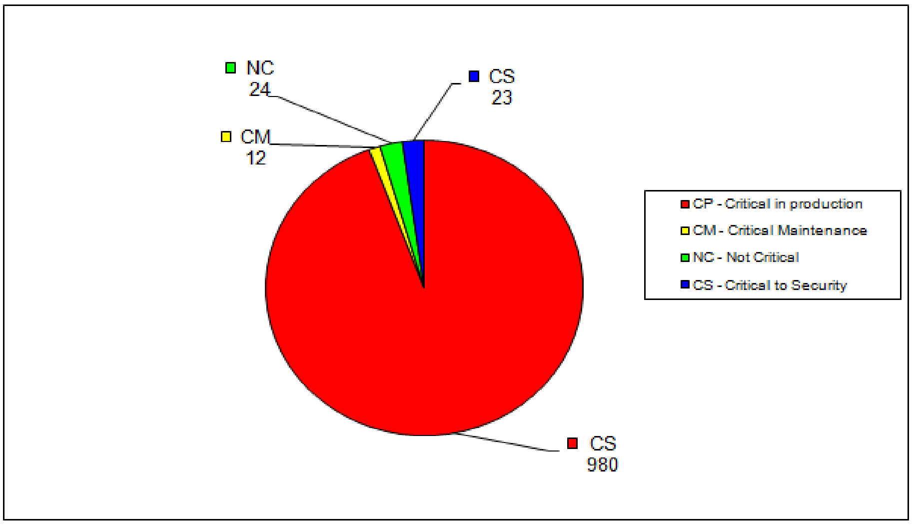


Figure 4. Criticalities and Failure Modes

The "Figure 4" graphic presents a sum of 1015 critical failure modes, being this value bigger than 1007 failure modes described previously. Such difference is given to the fact of having classified failure modes in more than one criticality and the fact of having only 24 non-critical failure modes is due to the nature of the method that is focused on the critical failure modes.

For the critical failure modes (97.8% associated to the non-planned functions stoppage), it was made by the RCM the practical actions implementation that promoted the oxygenation and expansion of the maintenance plan scope, regarding the maintenance tasks, as it can be seen in "Fig. 5".

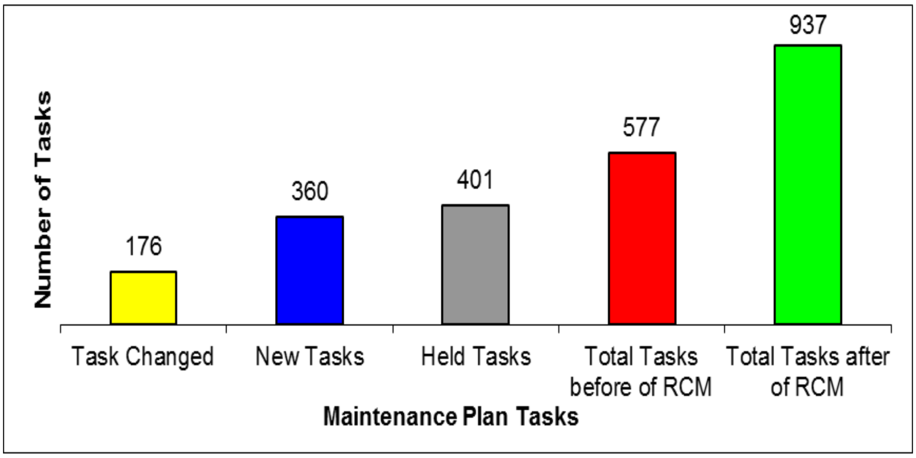


Figure 5. Existent tasks in the Maintenance Plan after the RCM implementation.

As a result of this study, the Maintenance plan had 937 tasks analyzed and the optimization global rate of the plans were 57.2%, showing the depth and relevance of the process, where:

- 43%, i.e. 401 tasks were not changed;
- 19%, i.e. 176 tasks were changed regarding their level of complexity, cost and periodicity;
- 38%, i.e. 360 tasks had actions implements, in order to avoid the critical FMs identified in the studies.

The 937 maintenance tasks were classified according to their intervention characteristics in the operational processes, as described below and outlined through the “Fig. 6”:

- Intrusive Interventions that need function stoppages of the process to be executed, like Preventive Maintenance;
- Non-Intrusive Interventions that do not necessarily need function stoppages of the process, like sensitive inspections in the assets and its functions;
- Operation interventions, which necessarily require that the process functions are in normal operation, like predictive maintenance or monitoring and performance inspections of the process functions.

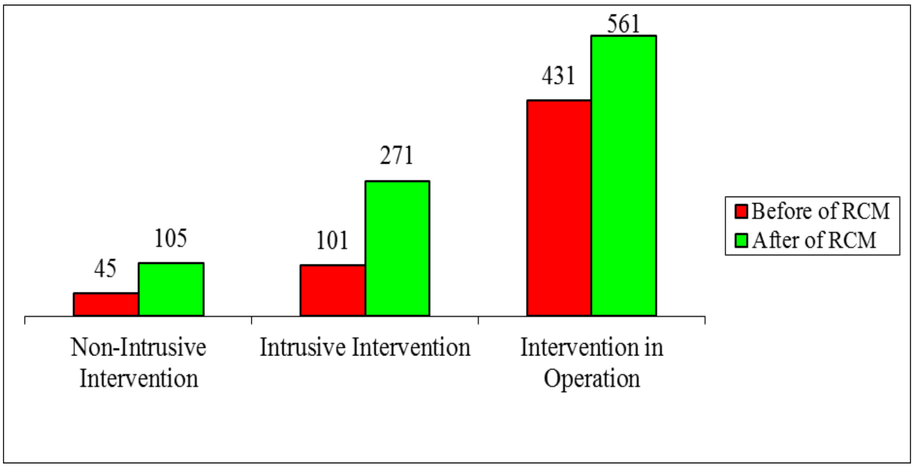
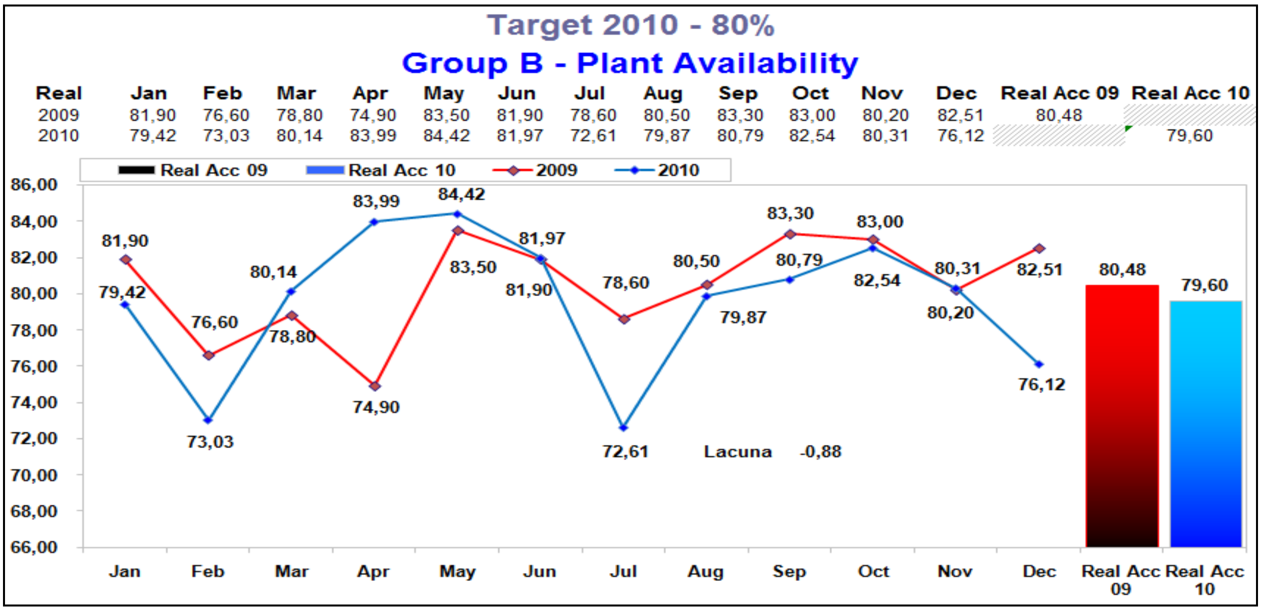


Figure 6. Maintenance Tasks Classification

Alongside the qualitative gains and balancing tasks in the maintenance plan, this work allowed the transfer of knowledge of cross-functional teams added to a database that will be used as reference for future work on the revision of the maintenance plan of the other groups of existing production.

9. QUANTITATIVE RESULTS ACHIEVED AFTER THE INPLEMENTATION OF RCM

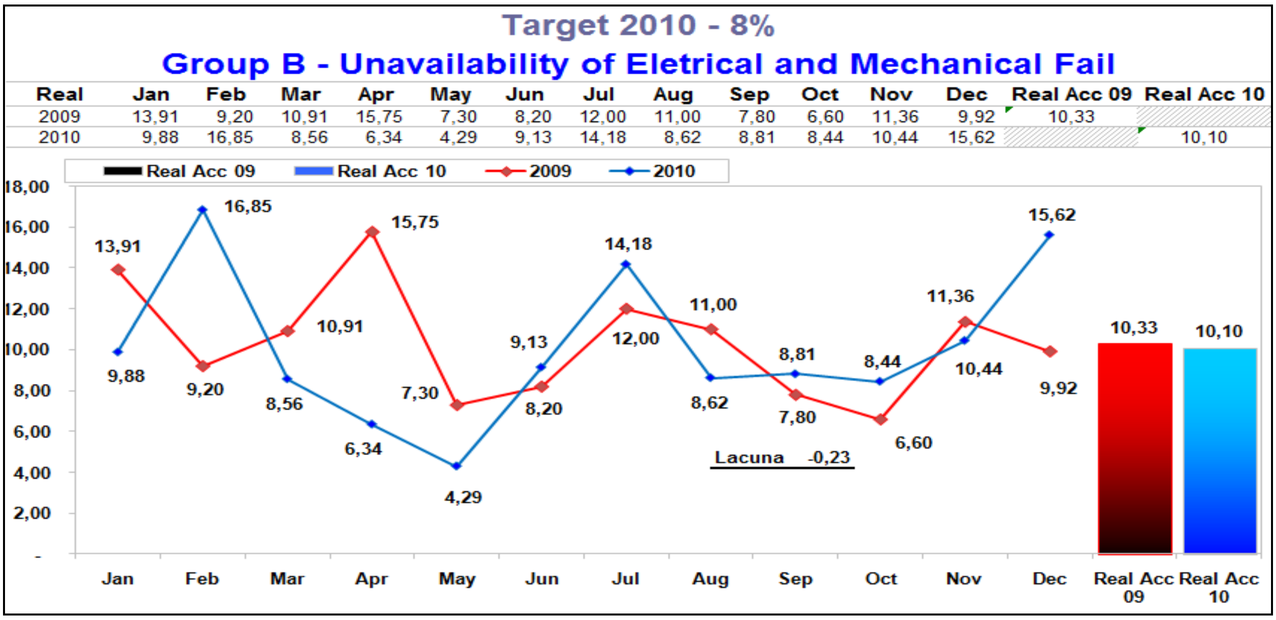
The plant availability results in group B, for the year 2009 and 2010 are shown in “Fig. 7”, and the results of unplanned electrical and mechanical origin that affected the availability results in 2010 are presented by “Fig. 8”.


Target 2010 - 80%

Group B - Plant Availability

Real	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Real Acc 09	Real Acc 10
2009	81,90	76,60	78,80	74,90	83,50	81,90	78,60	80,50	83,30	83,00	80,20	82,51	80,48	
2010	79,42	73,03	80,14	83,99	84,42	81,97	72,61	79,87	80,79	82,54	80,31	76,12		79,60

Figure 7. Result of plant availability after implementation of the RCM



Real	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Real Acc 09	Real Acc 10
2009	13,91	9,20	10,91	15,75	7,30	8,20	12,00	11,00	7,80	6,60	11,36	9,92	10,33	
2010	9,88	16,85	8,56	6,34	4,29	9,13	14,18	8,62	8,81	8,44	10,44	15,62		10,10

Figure 8. Comparison of results of plant unavailability after the implementation of the RCM

It is observed from the "Fig. 7", the results of available factory where RCM was established showed satisfactory performance in the first half of 2010, except in February when compared to the target, since the actual opening in this period was lower due to the production stop during Carnival have been five consecutive days. On the second semester, the results were primarily influenced by the availability of replacement "level 2" automation system, which occurred in the second fortnight of July, which resulted in adjustments over the months of August and the high rate of electrical power surges coming from the dealership during the month of December. The indicators that negatively impacted on the availability results in 2010 are outlined in "Fig. 8".

In the years that preceded the implementation of the RCM, there is a positive trend in real earnings after the plant availability of RCM, as can be seen from the "Fig. 9", since the results over the last six years did not outweigh to 79%.

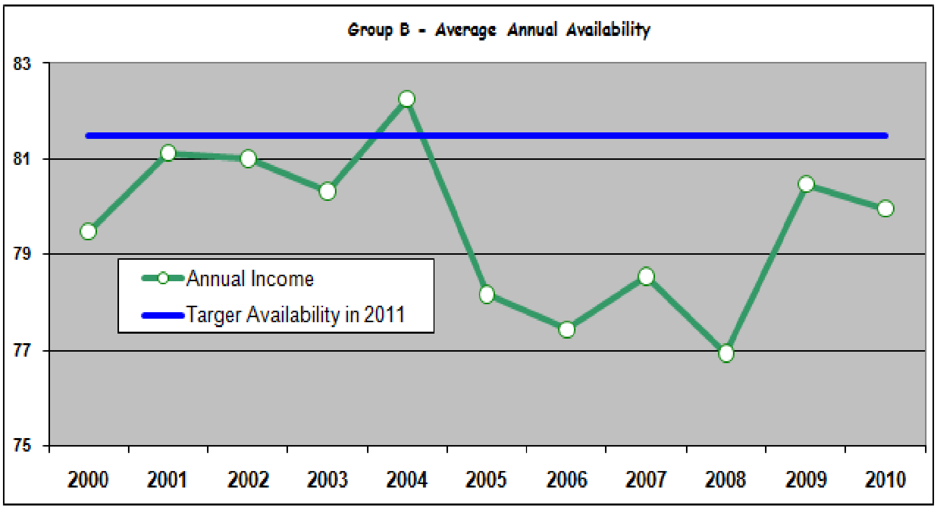
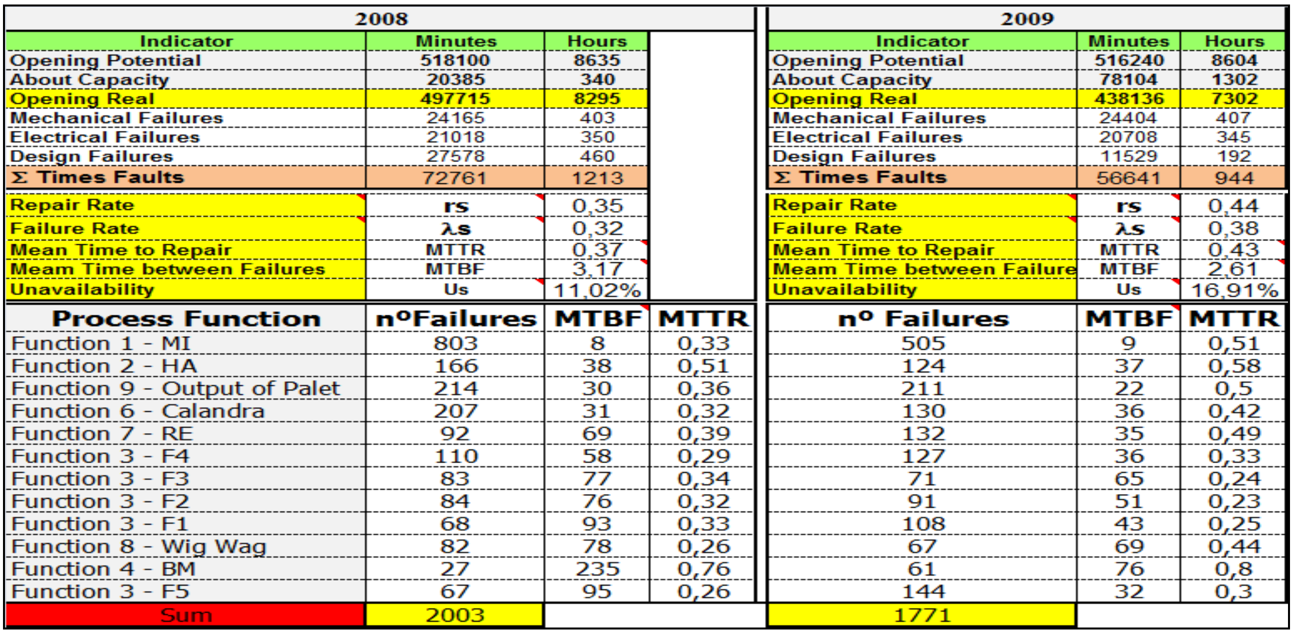


Figure 9. Plant availability results before and after implementation of the RCM

The "Table 1" shows the numeric indicators tabulated data from functional failures of electrical and mechanical origin occurred in 2008 and 2009 and the "Tab. 2" shows a comparison chart with other indicators of numerical data between the years 2009 and 2010.

Table 1. Comparative Indicators of failures that occurred between the years 2008 and 2009.



2008

Indicator	Minutes	Hours
Opening Potential	518100	8635
About Capacity	20385	340
Opening Real	497715	8295
Mechanical Failures	24165	403
Electrical Failures	21018	350
Design Failures	27578	460
Σ Times Faults	72761	1213
Repair Rate	rs	0,35
Failure Rate	λs	0,32
Mean Time to Repair	MTTR	0,37
Meam Time between Failures	MTBF	3,17
Unavailability	Us	11,02%

Process Function	nºFailures	MTBF	MTTR
Function 1 - MI	803	8	0,33
Function 2 - HA	166	38	0,51
Function 9 - Output of Palet	214	30	0,36
Function 6 - Calandra	207	31	0,32
Function 7 - RE	92	69	0,39
Function 3 - F4	110	58	0,29
Function 3 - F3	83	77	0,34
Function 3 - F2	84	76	0,32
Function 3 - F1	68	93	0,33
Function 8 - Wig Wag	82	78	0,26
Function 4 - BM	27	235	0,76
Function 3 - F5	67	95	0,26
Sum	2003		

2009

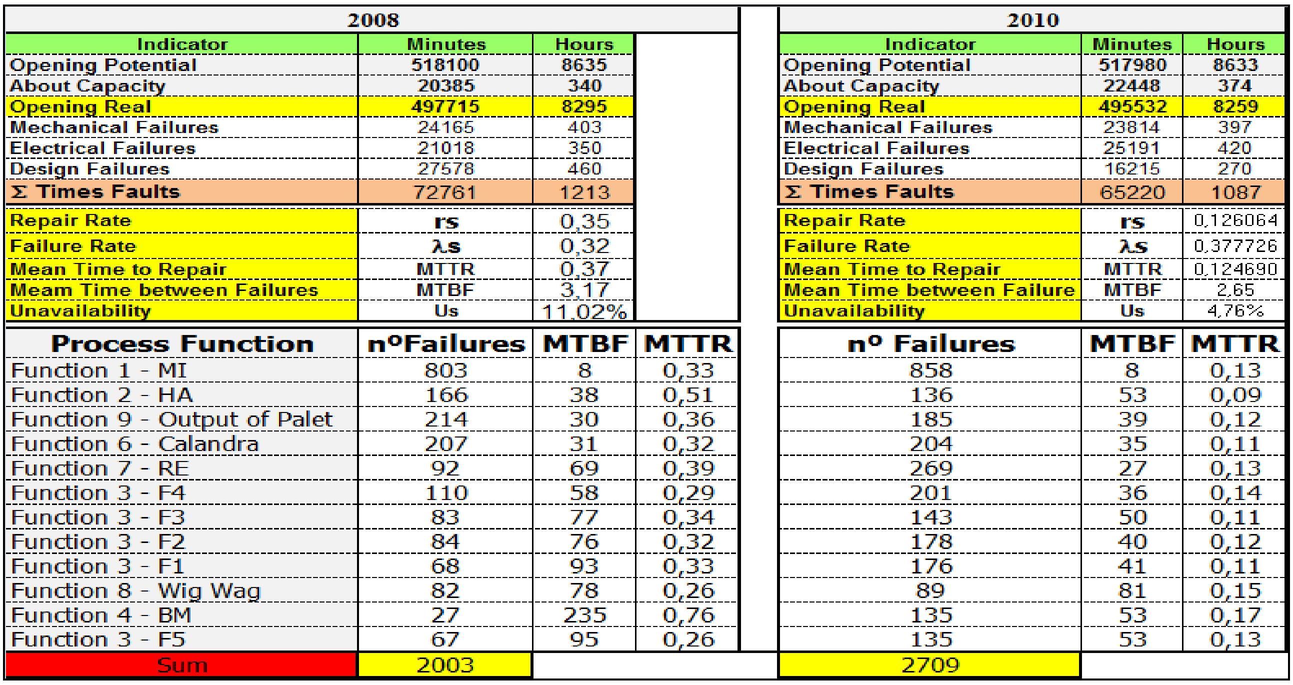
Indicator	Minutes	Hours
Opening Potential	516240	8604
About Capacity	78104	1302
Opening Real	438136	7302
Mechanical Failures	24404	407
Electrical Failures	20708	345
Design Failures	11529	192
Σ Times Faults	56641	944
Repair Rate	rs	0,44
Failure Rate	λs	0,38
Mean Time to Repair	MTTR	0,43
Meam Time between Failure	MTBF	2,61
Unavailability	Us	16,91%

Process Function	nº Failures	MTBF	MTTR
Function 1 - MI	505	9	0,51
Function 2 - HA	124	37	0,58
Function 9 - Output of Palet	211	22	0,5
Function 6 - Calandra	130	36	0,42
Function 7 - RE	132	35	0,49
Function 3 - F4	127	36	0,33
Function 3 - F3	71	65	0,24
Function 3 - F2	91	51	0,23
Function 3 - F1	108	43	0,25
Function 8 - Wig Wag	67	69	0,44
Function 4 - BM	61	76	0,8
Function 3 - F5	144	32	0,3
Sum	1771		

About the results presented in 2009, there was a high rate of Overcapacity compared to base year 2008, which is a reflection of the global financial crisis that occurred in the second half of 2008. So the results presented in 2009 have no reference results, as the production group presents a real opening lower, negatively influencing the other performance indicators.

These shutdowns Manufacturing Group, during 2009 were used to develop new operational procedures, improving existing procedures, correct period is critical tasks, develop technical standards with the use of photos and drawings, transfer the lubrication plan before in parallel to the spread sheet software maintenance and deploy the vibration analysis, as this was one of the suggested actions which would result in a return on tangible short-term reliability.

Table 2. Comparative Indicators of failures that occurred between the years 2008 and 2010.



2008

Indicator	Minutes	Hours
Opening Potential	518100	8635
About Capacity	20385	340
Opening Real	497715	8295
Mechanical Failures	24165	403
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Design Failures	27578	460
Σ Times Faults	72761	1213
Repair Rate	rs	0,35
Failure Rate	λs	0,32
Mean Time to Repair	MTTR	0,37
Meam Time between Failures	MTBF	3,17
Unavailability	Us	11,02%

Process Function	nºFailures	MTBF	MTTR
Function 1 - MI	803	8	0,33
Function 2 - HA	166	38	0,51
Function 9 - Output of Palet	214	30	0,36
Function 6 - Calandra	207	31	0,32
Function 7 - RE	92	69	0,39
Function 3 - F4	110	58	0,29
Function 3 - F3	83	77	0,34
Function 3 - F2	84	76	0,32
Function 3 - F1	68	93	0,33
Function 8 - Wig Wag	82	78	0,26
Function 4 - BM	27	235	0,76
Function 3 - F5	67	95	0,26
Sum	2003		

2010

Indicator	Minutes	Hours
Opening Potential	517980	8633
About Capacity	22448	374
Opening Real	495532	8259
Mechanical Failures	23814	397
Electrical Failures	25191	420
Design Failures	16215	270
Σ Times Faults	65220	1087
Repair Rate	rs	0,126064
Failure Rate	λs	0,377726
Mean Time to Repair	MTTR	0,124690
Mean Time between Failure	MTBF	2,65
Unavailability	Us	4,76%

Process Function	nº Failures	MTBF	MTTR
Function 1 - MI	858	8	0,13
Function 2 - HA	136	53	0,09
Function 9 - Output of Palet	185	39	0,12
Function 6 - Calandra	204	35	0,11
Function 7 - RE	269	27	0,13
Function 3 - F4	201	36	0,14
Function 3 - F3	143	50	0,11
Function 3 - F2	178	40	0,12
Function 3 - F1	176	41	0,11
Function 8 - Wig Wag	89	81	0,15
Function 4 - BM	135	53	0,17
Function 3 - F5	135	53	0,13
Sum	2709		

About the results presented in 2010, there was a considerable reduction compared to the sum of failures of electrical origin, mechanical and design when compared to base year 2008, but this result compared to the sum of the number of failures is higher about 30%. This fact is justified by the considerable increase of an electrical failure due to the replacement of the entire automation system that occurred in the second fortnight of July and the number of failures strong supply of electricity occurred between the months of November and December. So the results presented in 2010 reflect a positive trend of sustainable improvements in plant availability results for the year 2011.

10. CONCLUSION

It was verified through the difficulties found, arising opportunities, by the learning developed, by the maintenance plan balancing and by the qualitative and quantitative optimization of the maintenance plan that the adopted strategy of the Reliability-Centered Maintenance methodology implementation was positive and converge to the understanding of the perpetuation and the plant availability consistence necessity recommended in the strategic plan of 2010.

11. REFERENCES

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