RELIABILITY STUDY OF COLD MILL MOTORS AT ARCELORMITTAL VEGA*

Carlos Alberto Cristofari[1]
Eliezer Thuler[2]
Ernesto Furtado de Mello Neto[3]
Claudio Vano Nunes[4]

Abstract

The Brazilian steel industry is dealing an adverse scenario with direct competition from global emerging markets. In this scenario, the need to improve asset operational performance, makes complex studies involving technical knowledge and asset life behavior, become important tools to support companies strategic accomplish. These studies allow consider performance, costs and operational risks relationship in the decision make process. The Asset Management approach support these studies in order to observe the whole asset life cycle, understand value chain through all company process and optimize the asset economic life. In this context, the present technical work has the purpose to support asset management decision making regarding ArcelorMittal Vega cold rolling drive motors, through the motors fail behavior modelling and estimated the risks involved in asset management decision. Through the Reliability, Availability and Mantenability (RAM) analysis, simulations were performed considering the failure, repair cost data and investments to build options to mitigate the operational risks.

Keywords: Reliability; Mantenability; Availability; Asset Life Cycle Analysis.

[1] *Engº Mecânico, Mestre Engenharia Produção, Especialista em Engª de Confiabilidade. Especialista em Manutenção e Gestão de Ativos na Gerência de Excelência de Performance, ArcelorMittal Vega, São Francisco do Sul/SC.*

[2] *Engº Eletricista, Especialista em Engª de Confiabilidade. Especialista em Manutenção e Gestão de Ativos na Gerência de Excelência de Performance, ArcelorMittal Vega, São Francisco do Sul/SC.*

[3] *Engº Mecânico, Especialista em Engª de Confiabilidade. Especialista em Manutenção e Gestão de Ativos na Gerência de Tecnologia e Confiabilidade de Manutenção, ArcelorMittal Tubarão, Vitória/ES.*

[4] *Engº Eletricista, Assistente Técnico em Confiabilidade da Área de Laminados à Frio da ArcelorMittal Vega, São Francisco do Sul/SC.*

1 INTRODUCTION

In the book Reliability Centered Maintenance, (MOUBRAY**,** 2001) the author constructed the evolution of Maintenance among four generation since the Second World War till the beginning of this century. Along the maintenance generations the author concluded that none other management discipline has changed as maintenance in the same period.

The maintenance major challenge is guarantee that all assets functionalities performing well taking on costs value that don't impact the business strategy. Accordingly, Kardec and Nascif (2010) this challenge has changed the maintenance focus operational to a strategic one. To assume this challenge the company must do more than correct problem and changing set, the company must look to all process involved in maintenance to understanding the asset value chain to build a systematic way to manage the asset life cycle.

The Institute of Asset Management describes asset management as a set of systematic and coordinated practices and activities that help companies manage assets life cycle balancing risk, cost and performance to accomplish the business strategy. The IAM suggested one approach with 39 knowledge area organized in six competence areas.

The Reliability Engineering knowledge area has the objective to guarantee all the asset reliability requirement and find out, as soon as possible, the assets disfunction through its life cycle. To NBR 5462 and ISO 1011 reliability is "the capability of an item performing a required function, under specific working condition during a time life". The reliability depends on asset function instead of asset capability. The Reliability Engineering concern in asset behavior understanding, using asset life data models, to predict fails and unnecessary investments.

This working paper has the propose to understand the tandem cold mill main motors failures and theirs impact. The fail analysis performed signed that the roots causes are correlated due to a similar failure mode. When a fail occurs, the spare motor is putting into operation in the failed motor place, and the failed motor starts a repair services that has a long time to repair. Considering the last events and the operational time of main motors, more events are expected. When a motor fail during the repair time a contingency plan must taking place. This plan consists in working with one motor less, restricting production plan, with direct business impact. Due to this scenario, the project has objective to main motors reliability assessment considering the motors life data, and scenarios simulation to know and assess the risks involving in motors repair.

2 MATERIAL AND METHODS

2.1 ArcelorMittal Vega

The ArcelorMittal Vega is an ArcelorMittal group company, the major steel company in world. Vega is one of most modern downstream flat carbon steel operating with pickling, cold mill and galvanizing lines. The figure 2.1 shows the ArcelorMittal Vega site.

Figure 2.1 ArcelorMittal Vega site

The company processes hot rolled coils supplied by ArcelorMittal Tubarão, located in Serra, Metropolitan Region of Grande Vitória - ES. The Vega unit produces:

- Pickled coils;
- Cold rolled coils;
- Hot dip galvanized coils, mainly for the automotive, home appliance, pipe and civil construction industries.

The coils are galvanized by the hot deep immersion process, which gives the steel specific characteristics such as high corrosion resistance, good weldability and excellent adherence to the paint to applications in the automotive industry and supply chain, civil construction, white line, pipes and profiles, among others.

ArcelorMittal Vega has the production capacity in coated coils in 0.40 to 2 mm thicknesses, with different widths depending on the grade of the steel.

ArcelorMittal Vega steels can be supplied with four types of coatings:

- Extragal®; - Zinc Pure (GI)
- Galvannealed® - Zinc Iron (GA)
- Galvalume® (GL) - Aluminum Zinc (GL)
- Alusi® - Aluminized (AS), of which stand out Usibor® and Ductibor®.

2.2 Cold Mill Process

The cold mill process has the objective of reducing the steel plate thickness to the costumer's specified values. At ArcelorMittal Vega, the cold mill is coupled in pickling process, allowing a continuous work.

The cold mill has four stands (quadruo type) in which the steel plate is subjected to controlled compressive and tensile forces, reducing thickness, according to figure 2.1.1. It also has devices and meshes of control of thickness and flatness.

Figure 2.1.1 Cold Mill

In this process the steel undergoes compression efforts up to 3,000 tons in each of the stand and tensions of up to 60 tons between them.

An emulsion of oil and water is applied into stands, with the function of cooling and lubrication the steel plate and cylinder contact. In the cold mill process, all waste is recycled or reused.

After cold mill process, the full-hard steel coils can follow two different process, depending on the final product: coated steel coils or cold rolled steel coils.

In order to process the steel plates, the cold mill has available 27.0 MW power to drive four stands and two coilers, according to the cold mill main motors layout in the figure 2.1.2.

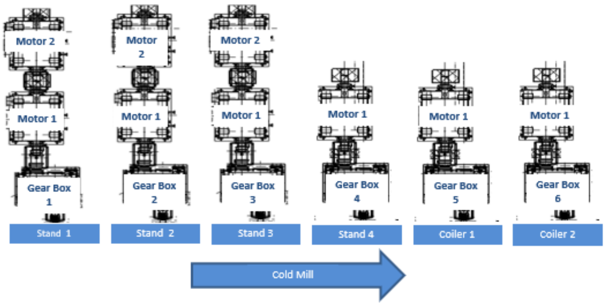


Figure 2.1.2 Cold mill main motors layout

There are 9 operational motors and one spare motor with same capacity, but 7 were commissioned in 2003 Vega startup, 2 engines commissioned and 1 motor spare in the 2010 revamp. Table 2.1.3 presents the cold mill technical data, as well as the main drive motors.

Table 2.1.3 Cold mill and main drive motor technical data

Entry Thikness	1,20 to 4,80 mm
Exity Thikness	0,37 to 2,00 mm
Width	550 to 1875 mm
Max. Weight	40 ton
Cold Mill Max Speed	900 mpm
Motor Power	3MW
Nominal Votage	3,3 Kv
Motor Type	AC (Sincronos)

2.3 Main drive motor issue

The tandem cold mill (TCM) is powered by 9 main motors and one spare motor, as figure 2.1.2 has shown. The original layout, start up 2003, had seven motors, and the 2010 revamping was added two operational (one stand 1ft position 2nd and one in coiler 2nd) and one spare. All motors have a predictive and preventive routine, following supplier technical recommendation. Some routines activities are developed by specialist partners and the others one by own staff. The motors conditions are care individually.

Since 2015 the TCM has presenting some failures in main motors. In these events the failures modes hadn't been predicted with standard maintenance routine. Towards to avoid main motors failure, the asset management team has applied specific maintenance routines to predict failure, but the actions have low assertivity.

The fail analysis has signed that the main problems are related with fatigue and aging. To mitigate failure modes impact or frequency a set of engineering improvement needs to be done by the supplier.

The main motor spare existence allows planning these activities, but the low reliability of this motors insert some risks to the repair time. In case of facing a new fail in the repair period, a contingency plan needs to be done to don't stop line production but has effect in line productivity.

The supplier mean time to repair is 4,81 months.

2.4 RCM Maintenance Strategy

In the 1997 book RCM II, wrote by Moubray, rebuild the maintenance strategy decision made algorithm. After failure modes and effects analysis, the algorithm made, through simple questions, the analysis to choose the best maintenance strategy based on risk management and the actual operation condition. For this, the algorithm suggests four maintenance strategies:

1. Condition-based maintenance;
2. Scheduled repair;
3. Scheduled exchange;
4. Run to fail.

Condition-based maintenance (CBM) are related to monitoring asset condition activities. The focus of this strategy is to identify early failure stages, in order to schedule the repair at appropriated time. The CBM definition should consider the technical feasibility, analyzing the asset availability and accessibility to data collection, and economic, analyzing the costs of monitoring the condition at a given frequency and the costs of asset replacing.

The scheduled repair (SR) are related to pre-defined frequency to restore asset's function activities. The SR is recommended where assets time to failure is known and monitoring of the condition is not technically or economically feasible. The focus of SR strategy is to repair subsets and components, without set removing to recover asset function.

The Scheduled Exchange (SE) are related to pre-defined frequency activities to component replacement. The SE strategy is recommended where the asset time to failure is known, the CBM and SR activities is not technically or economically feasible. The focus of SE strategy is to spare parts replace before failure and repair the exchanged assets an appropriate location.

And lastly, the Run to Fail (RF) strategy are related to not using any of the above strategies for certain assets. The RF strategy is recommended for assets where there is no significant impact on availability and operating cost in the event of loss of function.

Due to optimize the generated value of physical assets, Smith and Hinchcliffe (2004) recommend that all of maintenance strategies above describe must be used oriented by an appropriate asset management strategy. The asset management strategy should be updated always that the operational context and business strategy has change. To increase the asset management efficiency and effectiveness, the asset life cycle cost perspective must be considered to better asset management decisions.

2.5 Life data analysis (LDA)

Life Data Analysis consists in modeling product or equipment life data to determine the survival probability due to time life. These studies have several applications, like risk and safety analysis, quality, credit analysis, product design, asset management, among others.

In order to perform the modeling of life data, it is first necessary to carry out a life data collection and then use statistical tools to determine a statistical model that represents the sample. Fogliatto and Ribeiro (2009) made a didactic presentation of the most statistical models used in asset management.

The statistical model definition is a complex mathematical calculation that need a specialist software support. The LDA is fundamental for asset management. Life data models enable predicting and anticipating risks due to a given time and operational context.

2.6 Reliability, Availability and Mantenability (RAM)

The Reliability, Availability and Mantenability (RAM) analysis has the purpose to assess the asset or system performance through life data models. Through this assessment is possible to point out and improvement of key assets to accomplish a reliability, availability and mantenability to accomplish the business goals (CALIXTO, 2005).

To perform a RAM analysis the below phases are recommended:

1) Asset data collection (fails and maintenance);
2) Reliability blocks diagram representation;
3) Reliability system modeling and analysis.

The RAM analyzes provide an evaluation of the interaction of the reliability, availability and maintainability models of each reliability block, supporting several asset management analysis and decisions.

2.7 Life Cycle Cost (LCC)

The Life Cycle Cost (LCC) is an economic evaluation methodology where operation, maintenance and disposal asset costs are considered to make asset performance evaluation (NIST HandBook 135, 1995). For this, the LCC methodology is based on several disciplines, among them economic engineering and reliability engineering.

Farias and Fernandes (2014) presents LCC theory in a simplified equation 1.

$$LCC = Ca(t) + Cm(t) + Cd(t) \quad (1)$$

Where:
Ca (t): Acquisition cost
Cm (t): Maintenance cost
Cd (t): Disposition cost

The acquisition cost is the value that represent the implement system effort, considering the investment, commissioning and human capital values inclusive. The acquisition cost is presented in equation 2.

$$Ca(t) = Ci(t) + Cc(t) + Ch(t) \quad (2)$$

Where:
Ci(t): Asset investment cost
Cc(t): Commissioning cost
Ch(t): Human capital cost

The maintenance cost is the sum of preventive and corrective maintenance costs considering all spares and all the services involved to keep the system working during its lifetime. And the maintenance cost is presented in equation 3.

$$Cm(t) = Cmp(t) + Cmc(t) \quad (3)$$

Where:
Cmp(t): Preventive maintenance cost

Cmc(t): Corrective maintenance cost

The disposal cost, is represented by the acquisition cost of all assets (i) divided by their expected life, as presented in equation 4.

$$Cd(t)=\sum_{i=1}^{\infty}\left(\frac{Cai(t)}{Lifei}\right) \quad (4)$$

Where:
Cd(t): Disposition cost
Cai(t): Acquisition cost i
Life i: Expected asset life

All costs must be allocated in the appropriated time periods (t). To perform the LCC analysis the costs must be adjusted considering an appropriate discount rate (d) for the cash flow. Rahman and Vanier (2004) claim that LCC studies commonly use the Present Value (PV) method to consider the monetary value of costs over time. Equation 5 represents the value of PV, and equation 6 is the Yearly Uniform Cost (A).

$$PV=FV\left[\frac{1}{(1+d)^t}\right] \quad (5)$$

$$A=PV\left\{\frac{[d(1+d)^t]}{[(1+d)^t+1]}\right\} \quad (6)$$

Where:
FV: Future value;
t: Time
d: Discount rate.

Within cost values, adjusted to present value, and the reliability models is possible to perform the life cycle cost analysis and guide the most appropriate asset management decision.

3 COLD MILL MOTORS RELIABILITY STUDY

In the last three years, the failure occurrences of main cold mill motors and high maintenance time (repair) have led to alternatives maintenance strategies development to minimize failure impact. The systematic predictive and preventive inspections was not sufficient to detect the potential failure point. In this way, through LDA, RAM and LCC, was possible to build scenarios to evaluate the risks involved and to support the adequate asset management decision.

3.1 Assumptions

The relevant assumptions to this project are describe below:

- Current motors layout;
- Current motors life;
- Quantity of spare parts;
- Repair time at the supplier;
- Costs of corrective maintenance, preventive maintenance, acquisition and;
- Possible loss of revenue due to the execution of a contingency plan to support the unavailability of spare parts in the plant.

3.2 Life Data

The life data considered in this project contemplate the failure mode information related to motors short circuit. The data related to the times to failure (month) and repair time (month) are presented in Table 3.2.1. The preventive maintenances and small repairs were considered as suspensions and their costs were also considered within each simulated context.

Table 3.2.1. Life data

Year	Motor	Pos	Fail	TTF (Month)	ROP (Month)	TTR (Month)
2003	**109888**	**1.2**	fev/15	145	44	3,5
	109887	**4.1**	abr/15	144	42	6
	112525	**Out**	set/16	165	24	2,5
	109860	**1.1**	-	-	187	-
	109889	**2.1**	-	-	187	-
	109890	**2.2**	-	-	187	-
	109859	**Coiler 1**	-	-	187	-
2010	**1004668623**	**3.2**	jan/16	72	32	8
	1004668610	**Coiler 2**	-	-	101	-
	1004668612	**3.1**	ago/18	35	1	2

Attend to the motor’s life dates, noticed that 5 failures occurred up to project time, 5 motors that have not yet failed, one was being in preventive maintenance.

3.3 Life data analysis

Regarding the motors time to failure and time to repair, was possible to modeling the life model and the mantenability model. To modeling the data the Reliasoft software Weibull ++ was performed. The figure 3.3.1 shows the motors reliability and the figure 3.3.2 shows the fail probability density function.

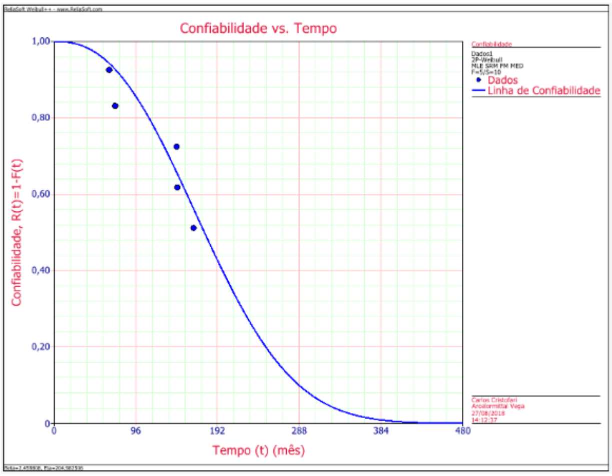


Figure 3.3.1: Motor's Reliability

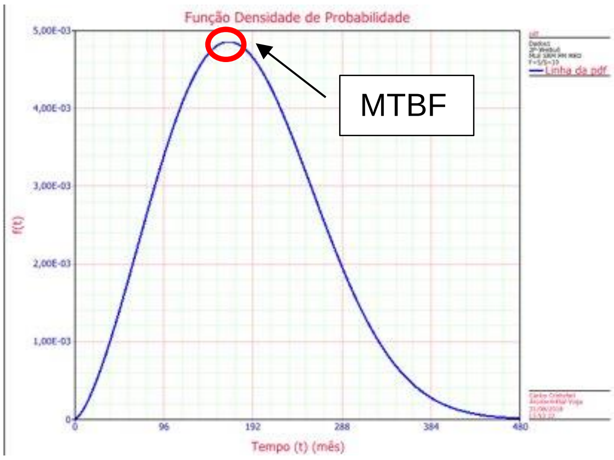


Figure 3.3.2: PDF

The model that best characterized the motors life data is a Weibull 2 parameters. This model had a shape parameter (Beta) of 2.46. This value indicates that failure modes related to failure events have a degradation and aging behavior. The scale parameter (Eta) from this model was 204 months. Eta reports that 63% of the motors will fail within 204 months, with 95% certainty. The MTBF of this model is 181 months.

The figure 3.3.3 shows the motors mantenability model and the figure 3.3.4 shows the mantenability probability density function.

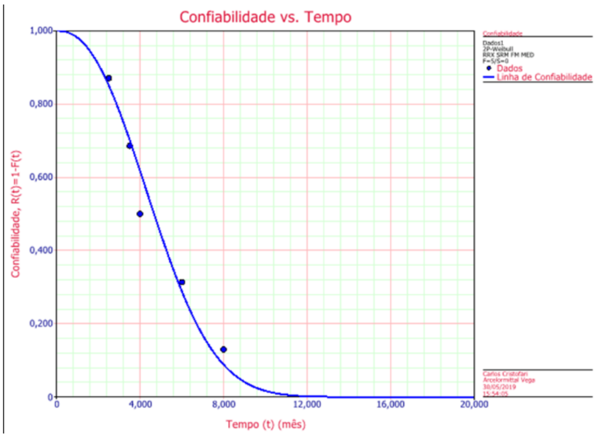


Figure 3.3.3: Motor's Mantenability

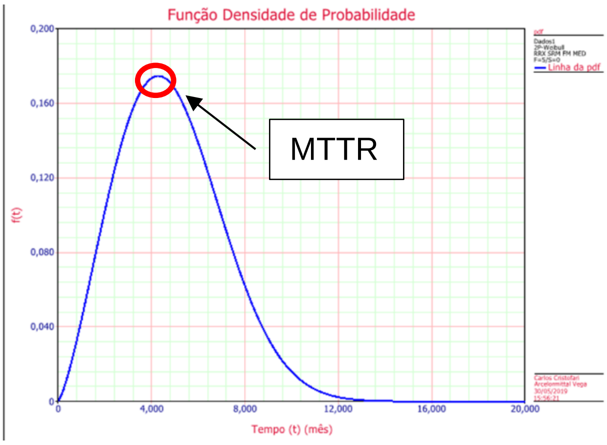


Figure 3.3.4: PDF

The model that best characterized the motors repair data is a Weibull 2 parameters. This model had a shape parameter (Beta) of 2,32. This value indicates that failure modes related to failure events have a degradation and aging behavior. The scale parameter (Eta) from this model was 5,4 months. Eta reports that 63% of the motors repair will be completed until 5,4 months, with 95% certainty. The mean time to repair is 4,81 months.

3.4 Reliability, Availability and Mantenability (RAM)

The reliability block diagram (RBD) was developed in order to represent the cold mill motors reliability interaction, as a reliability system. The figure 3.4.1 shows cold mill motors reliability layout of all four stands and two coilers. To modeling the RBD template the Reliasoft software BLOCK SIM was performed.

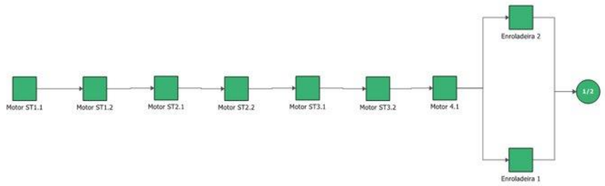
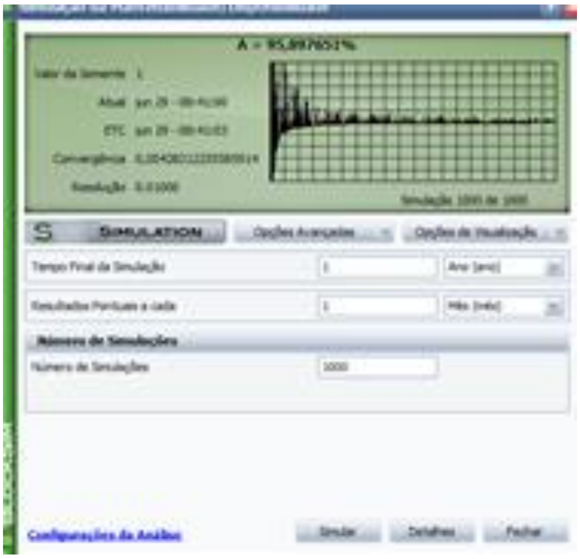


Figure 3.4.1. Reliability layout

In each reliability block is possible to consider the reliability model, mantenability model, corrective time, spare part available, spare part repair time, corrective and repair cost, and each motor current life. With this it is possible to simulate scenarios for a given time and evaluate the number of stops and system availability. Figure 3.4.2 shows the simulation example.



Tempo Final da Simulação 1 Ano (ano)

Resultados Pontuais a cada 1 Mês (mês)

Número de Simulações

Número de Simulações 1000

Figure 3.4.2. RBD simulation

Considering the motors current life, the repair performed on failed engines and engines that will be preventively maintained, simulations of three scenarios for 15 years were carried out. The first scenario was simulated for the current condition with one spare. The second scenario was simulated with two spare motors and third scenario was simulated with three spare motors. Table 3.4.1 shows the scenarios simulations.

Table 3.4.1. Scenario simulation

Table 3.4.1. Scenario simulation

Simulation Outputs	01 Spare	02 Spares	03 Spares
Avaliability (%):	98,72%	99,81%	99,85%
Available time (hours):	129721	131144	131199
Corrective Time (hours):	196	199	199
Contingency Time (hours):	1483	57	2
Total Unavailable Time (hours):	1679	256	201
Fails Expected:	8,9	9,0	9,0

The simulation permit to know how much the rolling mill availability will be affected by motors failures and absence of a health spare. Note that failures occurrence and the corrective time loss are not changed in the scenarios. The main unavailability impact is due to contingency time.

3.5 Life Cycle Cost Analysis

In order to do the life cycle cost analysis, the costs related to the asset management, the investment value of a new motor, the costs of maintenance materials and services (repair + corrective) and the production losses were considered. This information is strategic to the company, so the data used to this working paper were adapted.

Using the RAM simulation data, with the costs involved in this project were possible to evaluate scenarios in terms of total cost and unavailability. The figure 3.5.1 shows a scenarios comparison.

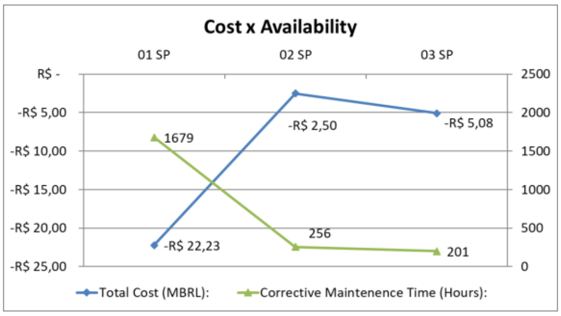


Figure 3.5.1. Scenarios comparison

3.6 Reliability Study Finds

The LDA constructed two models, reliability and mantenability. The motors reliability model indicated that the failure modes related to motors failures are associated with degradation and aging. This find is possible to corroborate looking to the fail analysis assumptions. The motors mantenability model indicated the mean time to repair to be considerate in RBD simulation.

The RAM simulated tree scenarios, one, two and tree spare motor. The number of fails and the corrective time among tree scenarios doesn’t change. The major availability impact is in contingency time, due to motors fail behavior and 4 motor with long operational time.

In the first scenario with one spare motor, the repair motors time due to a corrective implies a spare unavailability of 1679 hours and the impact of the risk due to the unavailability of MBRL 26,00. In the second scenario with two spare motors the repair motors time due a corrective implies a spare unavailability of 256 hours and the impact of the risk due to the unavailability of MBRL 9,00~~.~~ with one new motor investment. In the third scenario with three spare motor the need for maintenance of the engines implies a spare unavailability of 201 hours and the impact of the risk due to the unavailability of MBRL 12,00 and with two new motors investment. The cost of maintenance remains due to the maintenance repair time not changed with the acquisition of more spare parts.

4 CONCLUSIONS

This paper has proposed to study the main tandem cold mill motors failure data with two objectives: (1) tandem cold mill motors reliability modeling and evaluating, and (2) building scenarios to simulating and evaluating the unavailability of spare motors impact.

Considering the failure and maintenance data in the 2003 to 2018 period, were observed 5 short circuit failures and 7 preventive interventions in the period. The statistical model that best characterized the motors life data was a Weibull 2 parameters for both reliability and mantenability models. The reliability model has shown a shape parameter (Beta) of 2.46. This value indicates that failure modes related to failure events have a degradation and aging behavior. The scale parameter (Eta) from this model was 204 months. Eta reports that 63% of the motors will fail within 204 months, with 95% certainty. The model that best characterized the motors repair data is a Weibull 2 parameters. This model had a shape parameter (Beta) of 2,32. The scale parameter (Eta) from this model was 5,4 months. Eta reports that 63% of the motors repair will be completed until 5,4 months, with 95% certainty. The mean time to repair is 4,81 months.

The reliability motors model allowed to know the spare motor unavailability impact to the business and it’s not negligible. To support an asset management decision, more two scenarios was compared. The comparison the actual to the second scenario, the unavailability reduction was in order of 84% in time. The cost impact was 65% less than first scenario. The comparison the actual to the third scenario, the unavailability reduction was 88%, 20% higher than second scenario. The cost impact was 53% less than scenario one, but 25% higher than second scenario.

Although the third scenario has more positive impact in unavailability, the cost impact is not as significant than second scenario.

The study confirmed some expected assumptions but clarified the actual unavailability risk. The reliability and mantenability models, together with RAM promoted the ability to see hidden factors and must be updated as the maintenance preventive and corrective occurs. The results obtained helped to technically base the strategy of buying spare parts and preventive repairs of existing engines.

REFERENCES

1 Confiabilidade e Mantenabilidade: NBR - 5462. ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, Rio de Janeiro, 1994.

2 Comissão de Estudo Especial de Gestão de Ativos ABNT/CEE-251, 2013. Disponível em http://abraman.org.br/arquivos/325/325.pdf acessado em 08/07/2018.

3 Code of Practice for Life Cycle Costing SAS-069 RESEARCH AND TECHNOLOGY ORGANISATION and NORTH ATLANTIC TREATY ORGANISATION, 2009.

4 Statistics Reliability Engineering. Gnedenko, B.; Pavlov, I.; Ushakov, I. Wiley and Sons Inc. New York, 1999.

5 Asset Management – An Anatomy V.03. IAM. 2015. Disponível no link https://theiam.org/knowledge/Knowledge-Base/the-anatomy/ , acessado em 08/07/2018. Artigo da base de conhecimento do Institute of Asset Management, 2017. IAM. Disponível no link https://theiam.org/What-is-Asset-Management, acessado em 15/06/2018.

6 Manutenção – Função Estratégica. 4ª edição. Kardec, A. and Xavier, J. N., São Paulo, SP. 2012.

7 Life-cycle costing manual for the Federal Energy Management Program, NIST HANDBOOK, 1995.

8 Life-cycle costing manual. Capital Development Board State of Illinois, 1991.

9 Life cycle cost analysis as a decision support tool for managing municipal infrastructure, RAHMAN, S.; VANIER, D. J, 2004. Disponível em http://nparc.cisti-icist.nrc-cnrc.gc.ca/npsi/ctrl?lang=en , acessado em 15/07/2017.

10 Life Cycle Cost Analysis of Substation Automation Implementation, International Telecommunication Symposium, FARIAS, V.S.; FERNANDES, N. C São Paulo, 2014

11 Reliability Center Maintenance, Moubray, J. Industrial Press, 2ª Edição, 2001.

12 Reliasoft Corporation, Análise de Dados de Vida. Presentation Handouts, 2012.

13 ReliaSoft Corporation, Blocksim 11.0 Software Package, Tucson, AZ, www.ReliaSoft.com.

14 Reliasoft Corporation, Confiabilidade de Sistemas Avançados. Presentation Handouts, 2012

15 ReliaSoft Corporation, Weibull++ 11.0 Software Package, Tucson, AZ, www.Weibull.com.