RELIABILITY ENGINEERING IN THE IMPROVEMENT OF THE MAINTENANCE OF MILITARY SYSTEMS: CASE STUDY

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Abstract: *The amount and type of maintenance that is applied depends strongly on cost considerations, as well as the safety implications of a system failure. The challenge to be confronted is related with the opportunity of improvements in the processes used to develop maintenance actions. This paper presents the application of parametric statistical methods, supporting decision process to introduce a cost reduction maintenance strategy.*

Keywords: *Reliability, Maintainability, Maintenance and Logistics*

1. INTRODUCTION

Nowadays engineers do not have to depend a empirical style, in order to predict the future of their products. Through the use of life data analyses, reliability engineers use product life data to determine the probability and capability of parts, components, and systems to perform their required functions for desired periods of time without failure, in specified environments.

Life data can be lifetimes of products in the marketplace, such as time the product operated successfully or the time the product operated before it failed. These lifetimes can be measured in hours, miles and cycles to failure, stress cycles, or any other metric with which the life or exposure of a product can be measure. All such data of product lifetimes can be encompassed in the term life data, or more specifically, product life data.

Thus, the objective of this work is to analyze the System of Maintenance of the Brazil Marines Corps, using the technique of the reliability engineering, in order to improve all the maintenance actions used in this organization.

2. MAINTENANCE SYSTEM Of MARINES CORPS

Are used the following routines like preventive maintenance:
a) Check of Service – It correspond maintenance routine executed before drive the vehicle.
b) After-event - It take place after mission.
c) Maintenance Basic – It is the job by not special center of maintenance.
d) Advanced of Systems - It is maintenance of third step.
e) Verification - Consist in inspection actions in all systems.

3. CURRENT MAINTENANCE SYSTEM Of MARINES CORPS

There are two basic alternatives to do the maintenance: Corrective Maintenance or Preventive Maintenance.

3.1 Corrective Maintenance

As MOBLEY (2007, p. 9), the corrective maintenance represents: emergency, repair and remedial. At present, most maintenance is corrective. Repair will always be needed. Better improvement maintenance and preventive maintenance, however, can reduce the need for emergency corrections.

3.2 Preventive Maintenance

According to MOBLEY (2007, p. 9), as the name implies, preventive maintenance tasks are intended to prevent unscheduled downtime and premature equipment damage that would result in corrective or repair activities. This maintenance management approach is predominantly a time-driven schedule or recurring tasks, such as lubrification and adjustments that are designed to maintain acceptable levels of reliability and availability.

Then, considering the alternatives, maintenance corrective or preventive, the possible basic strategies to be employees are:
Strategy A: Accomplishment only of corrective maintenance;
Strategy B: Substitution of components in the times tb, 2tb..., independently of its use; or
Strategy C: substitution of the component in accordance with its use, measured in covered miles.

Analyzing the maintenance system of marines corps, it is verified that its situation corresponds to strategy B.

4. A BRIEF INTRODUTION TO RELIABILITY

Reliability engineering provides the theoretical and practical tools whereby the probability and capability of parts, components, equipment, products, and systems to perform their required functions for desired periods of time without failure, in specified environments, and with a desired confidence, can be specified, designed in, predicted, tested and demonstrated, KECCECIOGLU (1995, p. 4 e 5).

How discipline, reliability is relatively new. it is increase by several factors, which include system complexity, product design and manufacturing, Lewis (2000, p. 69).

According to LEWIS (1994, p. 139), reliability is defined as the probability that a system survives for some specified period of time. It may be expressed in terms of random variable **t,** the time to system failure.

As EBELING (2000), a process of failure can be qualified for the following four functions:

a) f(t), the probability density function (pdf) ;
b) F(t), the cumulative distribution function (cdf);
c) R(t), the reliability function ; and
d) λ(t), the hazard rate function.

LEWIS (1994, p. 139), relates f(t), F(t), R(t) and λ(t) as described in Figure 1 and equations (1) and (2).

$$f(t) = \frac{dF(t)}{dt} \tag{1}$$

$$R(t) = 1 - F(t) \tag{2}$$

$$\lambda(t) = \frac{f(t)}{R(t)} \tag{3}$$

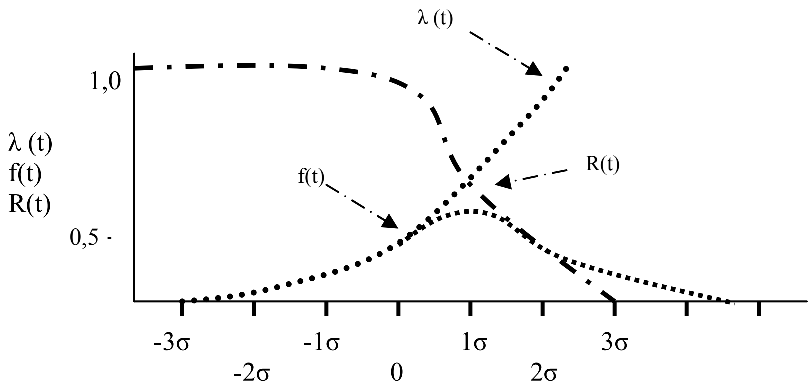


Figure 1 - The probability density function, the reliability function and the hazard rate function

According to TAVARES (1999, p.82) the reliability can be reported using the following parameters:

a) Mean Time to Failure (MTTF), used for not-repairable components;
b) Mean Time Between Failure (MTBF), used for repairable components; and
c) Mean Time to Repair (MTTR).

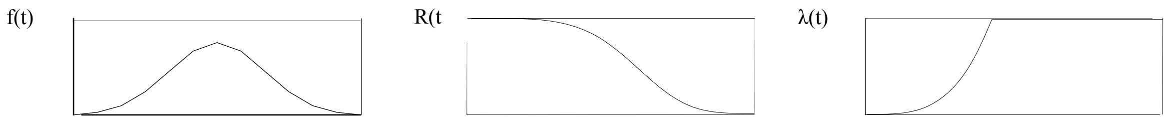
Several probability models useful in describing a failure process. These models are based upon Normal, Lognormal, Exponential and Weibull distribution.

4.1 Normal distribution

According to DHILLON (2006, p. 16), normal distribution is a widely used probability distribution and is also known as the Gaussian distribution after Carl Friedrich Gauss (1777-1855). The probability density function (pdf) is express for the equation.

$$f\left(t\right)=\frac{1}{\sqrt{2\pi\sigma}}\exp\left[-\ \frac{\left(t-\mu\right)^2}{2\sigma^2}\right] \tag{4}$$

The failure rate along with the reliability and the density probability, for times to failure are plotted in Figure 2.



(a) Density probability (b) Reliability (c) Failure rate

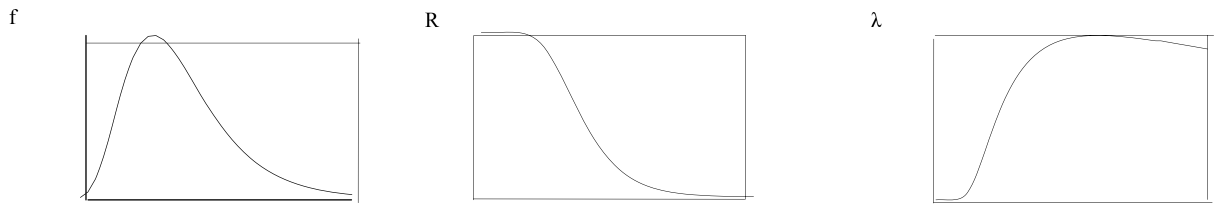
Figure 2 - The normal distribution

4.2 Log-Normal distribution

According to EBELING (2000, p.73), if the random variable T, time to failure, has a lognormal distribution, the lognormal of T has a normal distribution. The probability density function (pdf) for the lognormal is.

$$f\left(t\right)=\frac{1}{\sqrt{2\pi}st}\exp\left[-\frac{1}{2s^2}(\ln\frac{t}{t_{med}})^2\right] \qquad t\geq 0 \tag{5}$$

The density probability, reliability and failure rate for the lognormal distribution are plotted in Figure 3



(a) Density Probability (b) Reliability (c) Failure rate

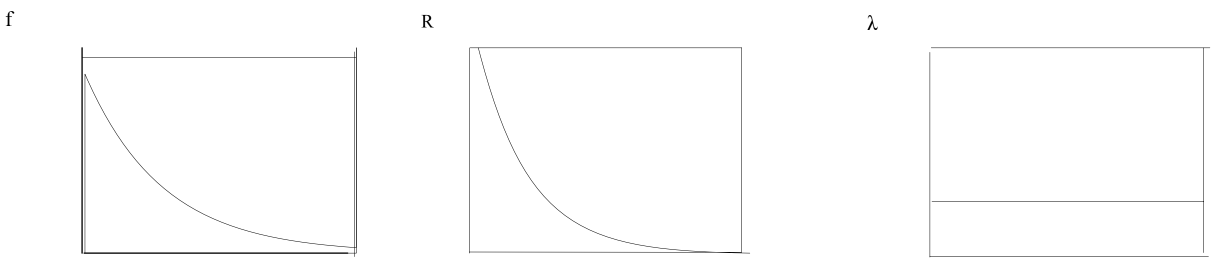
Figure 3 - The Log-Normal distribution

4.3 Exponential distribution

For the exponential distribution, the probability density function (pdf) is express for the equation.

$$f\ \left(t\right)=-\frac{dR(t)}{dt}=\lambda e^{-\lambda(t-t_0)} \qquad 0\leq t_0\ \leq t<\infty \tag{6}$$

The density probability, reliability and failure rate for the exponential distribution are plotted in Figure 4



(a) Density probability (b) Reliability (c) Failure rate

Figure 4 - The Exponential distribution

4.4 Weibull distribution

According to MONTGOMERY (2003, p. 95), the Weibull distribution is one of the most widely used lifetime distributions in reliability engineering. It is a versatile distribution that can take on the characteristics of others types of distributions, based on the value of the shape parameter β .

4.4.1 The Three Parameter Weibull Distribution

The three parameter Weibull is given by,

$$f(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}} \tag{7}$$

Where,

$f(t) \geq 0, t \geq 0 \ or \ \gamma, \beta > 0, \eta > 0, -\infty < \gamma < \infty$, and'

- η = scale parameter,
- β = shape parameter,
- γ = location parameter.

4.4.2 The Two Parameter Weibull Distribution

The two parameter Weibull is obtained setting $\gamma = 0$ and is given by,

$$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{8}$$

The value of the shape parameter β provides insight into the behavior of the failure process. Table 1 summarizes this behavior, EBELING (2000, p. 63).

Table 1 - Weibull shape parameter

VALUE	PROPERTY
$0 < \beta < 1$	Decreasing failure rate (DFR)
$\beta = 1$	Exponential distribution (CFR)
$1 < \beta < 2$	Increasing failure rate (IFR - concaves)
$\beta = 2$	Raleigh distribution (LRF)
$\beta > 2$	Increasing failure rate (IFR - convex)
$3 \leq \beta \leq 4$	Increasing failure rate, approaches normal distribution - symmetrical

4.4.3 The Two Parameter Weibull Distribution

An important form of the hazard rate function is show in Figure 5, LAFRAIA (2003, p. 74). Because of its shape, it is commonly referred to as bathtub curve. Systems having this hazard rate function experience decreasing failure rates early in their life cycle (infant mortality), followed by nearly constant failure rate (useful life), and followed by an increasing failure rate (wearout).

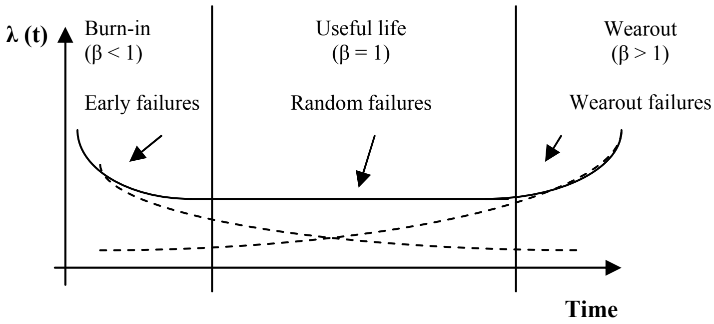


Figure 5 - Bathtub curve

The Table 2 summarizes some of the distinguishing features of the bathtub curve.

Table 2 - Features bathtub curve

CHARACTERIZED BY	CAUSED BY	REDUCED BY
Burn-in	Manufacturing defects: Welding flaws, cracks, defective parts, poor quality control, contamination, poor workmanships	Burn-in test Screening Quality control Acceptance testing
Useful life	Environment Random loads Human error Change events	Redundancy Excess strenth
Wear-out	Fatigue Corrosion Aging Friction Cyclical loading	Derating Preventive maintenance Parts replacement Technology

5. FIELD DATA

The operational failure occurs under true conditions of use, therefore, to provide precious information about the failure. For LEWIS (1994, p.366), human error is main reason which laboratory data frequently is not representative field data. EBELING (2000, p. 441) suggests the data presented in Table 3, as the basic data of the reliability engineering that must be collected to each failure. The way and the format in which the data will be registered are specific of each system.

Table 3- Reliability data elements

DATA ELEMENT	DEFINITION
Failure number	Sequential number identifying a failure record
Date and time	Date and time when the failure is recorded
Part ID	The specific component or part that hast failure
Failure time	The age of the part at the time has failed
Failure mode	The nature of the failure (short circuit, overload, breaking for impact)
Failure cause	Situation that causing the failure (vibration, overload, impact fracture, break, corrosion)
Start and stop repair	The date and the time when the maintenance began and all restoration has been completed
Action taken	The type of maintenance performed to correct the failure
Crew size	The number of individuals performing corrective maintenance

6. GOODNESS-OF-FIT TEST

The final step in selection of theoretical distribution is to perform a statistical test for goodness of fit. Such a test compares a null hypothesis (H_0) with an alternative hypothesis (H_1) having the following form:

H_0: The failure times came from the specified distribution

H_1: The failure times did not come from the specified distribution

The test consists of computing a statistic based on the sample of failure times. This statistic is then compared with a critical value obtained from a table of such values. Generally, if the test statistic is less than the critical value, the null hypothesis (H_0) is accepted; otherwise, the alternative hypothesis (H_1) is accepted.

There are two types of goodness-of-fit : general test and specific tests. A general test is applicable to fitting more than one theoretical distribution, and a specific test is tailored to a single distribution.

A goodness-of-fit test for use with the normal distribution when the parameters are estimated is a version of the Kolmogorov-Smirrnov (K-S) test. According to JARDINE (2006 p. 251), K-S test can be used for small as well as large sample size. As EBELING (2000, p.402), the K-S test, developed for H. W. Lilliefors (1967), measures in the distance maximum enters the results of a distribution to be tested and the results associates to the hypothetically the true distribution (Normal distribution). The statistics of the test it is given by D, representing the maximum difference between S_N (x) (distribution of variable X) and F(X) (theoretical distribution of variable X), in the form:

$$D = Max\left|F(X) - S_N(X)\right| \tag{9}$$

7. METHODOLOGY

The methodology for this job will follow the sequence of Figure 6.

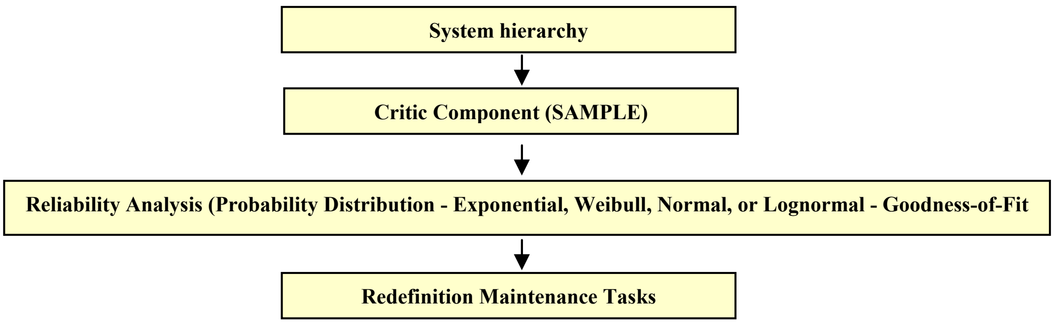


Figure 6 - Methodology

8. CASE STUDY

The case study with the critical component of tank SK 105 A2S. Figure 7 and 8.

Figure 7 - Tank SK 105 A2S

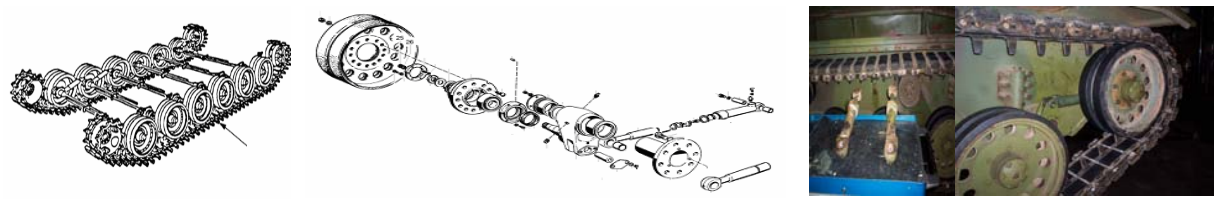
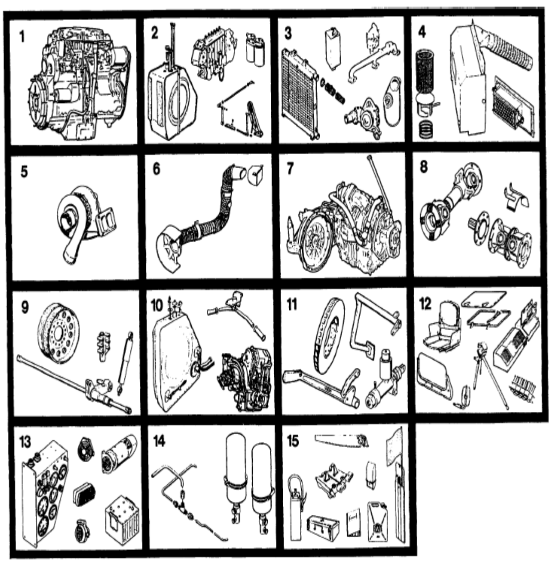


Figure 8 - CC SK 105 A2S track tensor (critical component)

8.1. Reliability Analysis

The tank CCL SK 105 A2S are composites of two groups: tower and chassis as shown in Table 4.

Table 4 - Chassis sub-groups

1. Engine	9. Tracks and Suspension	
2. Fuel System	10. Steering System	
3. Cooling System	11. Brake System	
4. Air and Cyclone Duct	12. Chassis	
5 Turbocharger	13. Electrical Equipment	
6. Exhaust System	14. Fire Warning	
7. Gearbox Unit	15. Extinguishing System	
8. Drive Train	13. Electrical Equipment	

The field data had indicated that the critical component was the tension axle and the failure data are the constant of Table 4 and 5.

Table 5 - Field data

VEHICLE	TIME (MILES)	PART ID	FAILURE CAUSE	ACTION TAKEN	CREW SIZE
SK CFN SOC	1570	Tension axle	lubrication failure	Substitution	2
SK CFN 28106030	1367	Tension axle	lubrication failure	Substitution	2
SK CFN 28106031	687	Tension axle	lubrication failure	Substitution	2
SK CFN 28106032	834	Tension axle	lubrication failure	Substitution	2
SK CFN 28106033	885	Tension axle	lubrication failure	Substitution	2
SK CFN 28106034	987	Tension axle	lubrication failure	Substitution	2
SK CFN 28106035	1589	Tension axle	lubrication failure	Substitution	2
SK CFN 28106036	1257	Tension axle	lubrication failure	Substitution	2
SK CFN 28106037	1161	Tension axle	lubrication failure	Substitution	2
SK CFN 28106038	1354	Tension axle	lubrication failure	Substitution	2
SK CFN 28106039	1111	Tension axle	lubrication failure	Substitution	2
SK CFN 28106040	1116	Tension axle	lubrication failure	Substitution	2
SK CFN 28106041	1351	Tension axle	lubrication failure	Substitution	2
SK CFN 28106042	1234	Tension axle	lubrication failure	Substitution	2
SK CFN 28106043	1278	Tension axle	lubrication failure	Substitution	2
SK CFN 28106044	1462	Tension axle	lubrication failure	Substitution	2
SK CFN 28106045	1260	Tension axle	lubrication failure	Substitution	2
SK CFN 28106046	1341	Tension axle	lubrication failure	Substitution	2

8.1.1 Empirical Method analysis

Empirical methods of analyses are also referred to as nonparametric methods or distribution free methods. The objective is to derive, directly from the failures times and reliability function. This method consist of fitting a theoretical distribution is preferred. A popular method for deriving an empirical reliability function is the Kaplan Meier product limit estimator. The equation of the estimator is given by.

$$\hat{R}(t_i) = \prod_{j=1}^{i} \left(1 - \frac{1}{n_j}\right), \quad i = 1 \ldots m \ e \ \ j = 1 \ldots i \qquad (10)$$

Where,
m = total failure number, n = total units number

Using the Reliasoft Weibull ++6 with standard configuration of the method Kaplan & Meier and the field data of Table 5, has empirical reliability. Table 6 shows the values of the empirical reliability, and Figure 9 show reliability versus time non parametric graph.

Table 6 - Empirical reliability

Miles	Reliability	Miles	Reliability
687	0.94	1260	0.44
834	0.88	1278	0.38
885	0.83	1341	0.33
987	0.77	1354	0.27
1111	0.72	1367	0.22
1116	0.66	1451	0.16
1161	0.61	1462	0.11
1234	0.55	1570	0.05
1257	0.50	1589	0.00

8.1.2 Parametric analysis

The software WEIBULL++6 was used in order to analysis the field data. The ranking of the distributions are showed in table 7.

Table 7 - Distributions ranking

DISTRIBUTION	RANKING	DISTRIBUTION	RANKING
Normal	1	Lognormal	3
Two Parameters Weibull	2	Two Parameters Exponential	4

The Figures 10 and 11 show the normal distribution, and two parameters weibull distribution.

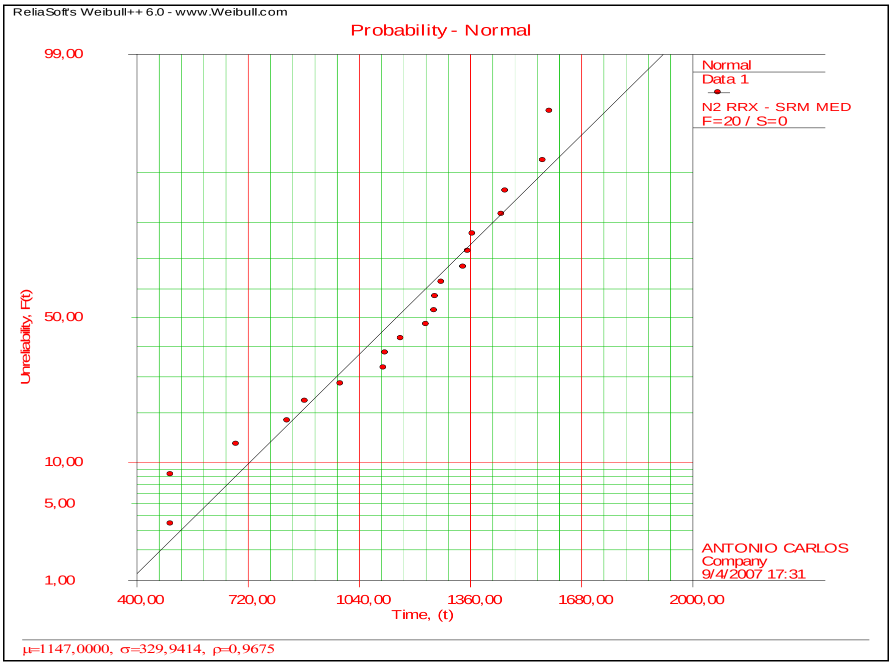


Figure 10 - Normal distribution

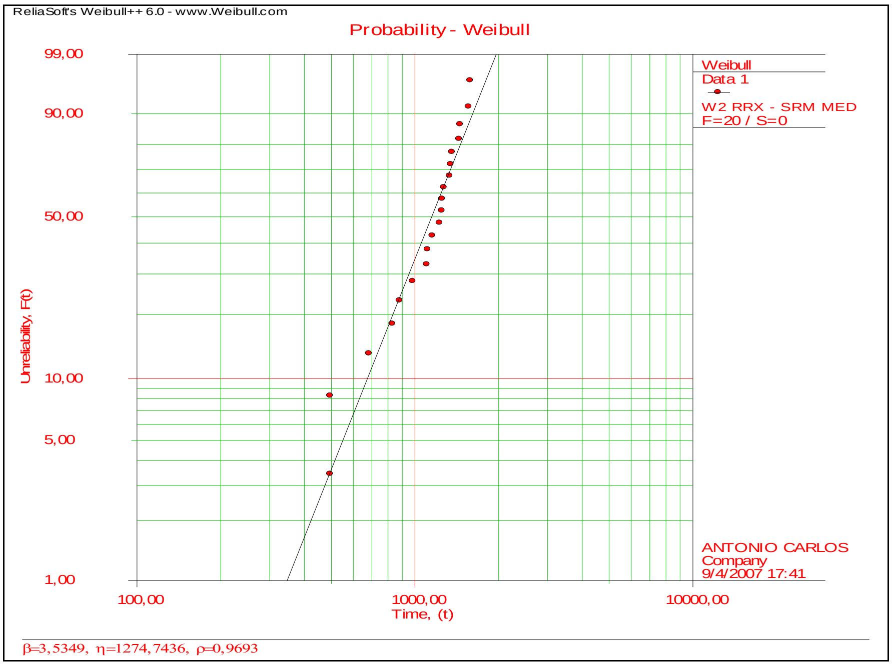


Figure 11 - Two Parameters Weibull distribution

It does not have a significant difference between the two models, normal distribution and two parameters Weibull distribution. Thus, the model adopted is two parameters Weibull distribution for analysis of the failure data. The values of the shape parameter and scale parameter are, respectively $\beta = 3.53$ e $\eta = 1274.74$. So failure rate is increasing indicating that the component reached natural degradation. Now according to KECCECIOGLU (1995), is necessary to do the hypotheses test.

H_0: distribution is two parameters Weibull distribution.

H_1: distribution is not two parameters Weibull distribution.

Thus, confidence interval of 90% ($\alpha = 0.10$). The hypothesis (**H_0**) is approved, because D_{max} (0.084) < $D_{critical}$ (Kolmogorov-Smirnov Test). From Figures 12 and 13 the failure rate of the critical component is increasing while the reliability is reducing.

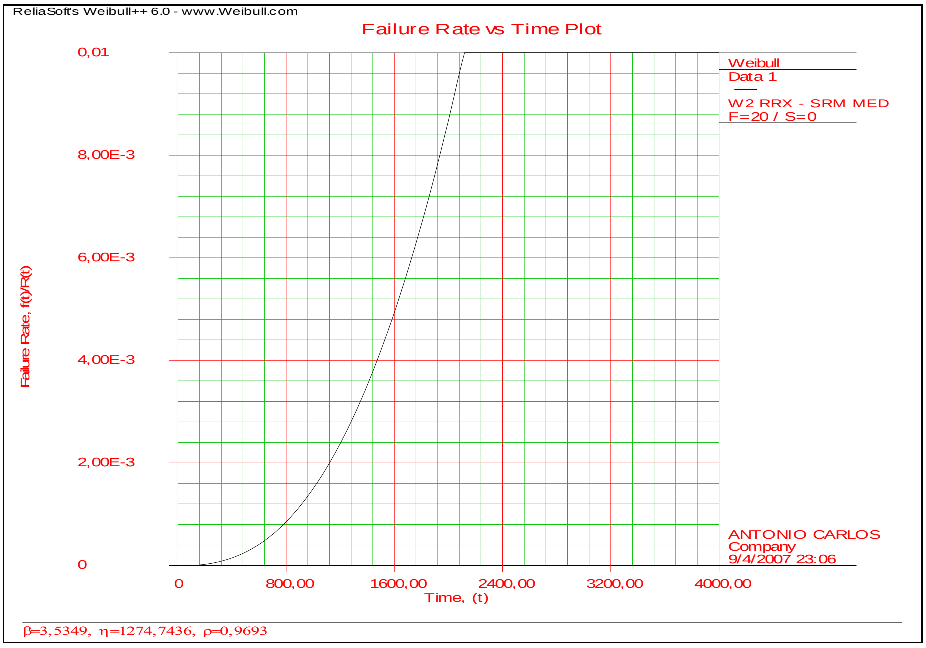


Figure 12 - Failure rate function

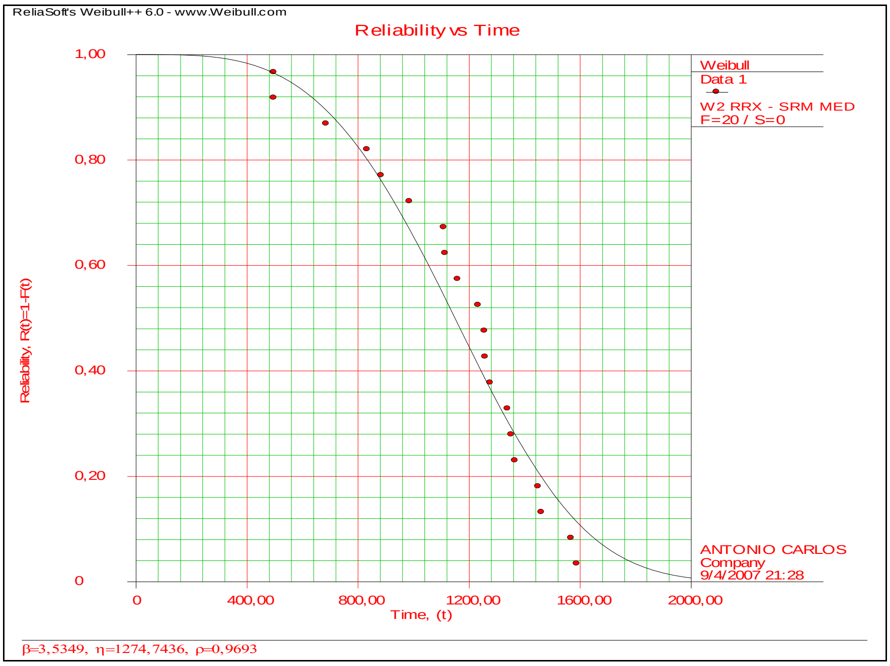


Figure 13 - Reliability function

10. CONCLUSION

There are many factors that can lead to a strategy of maintenance adequate. The importance of this job is to show the advantages of a reliability engineering program can do in order to keep the equipment running well. Reliability engineering covers all aspects of a life of the equipment, from its conception, subsequent design and production process, as well as through it is practical use lifetime, with maintenance support and availability. Reliability engineers covers:

- Reliability;
- Maintainability; and
- Availability.

All three areas are very important for the life cycle of the equipment.

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