TUNIS BUSINESS SCHOOL
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Bachelor Thesis in Business Administration

Major: Business Decision Making

Reliability analysis for preventive maintenance: Case study AMECAP

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Sommaire

I- INTRODUCTION

Maintenance department usually seeks to preserve the functionality of the organization equipment throughout its life cycle; however, most often prematurely ends up failing. The key is to ensure adequate maintenance programs in order to extend the availability of the equipment to improve its reliability.

Item reliability is the probability that the item performs a required function under stated conditions for a stated period of time. Equipment reliability depends on the reliability of its different parts, as well as its configuration. A measure of improving reliability needs to show improved profitability. Indeed, higher reliability reduces the cost in two ways: by increasing the production capacity and by reducing the frequency and the severity of future failures.

The empirical study concerns AMECAP, “Ateliers Mécaniques de Précision”a machining company located at Sfax. The objective of this project is to investigate the reliability of a selected machine at AMECAP and to propose a maintenance plan accordingly.

The remaining of the report is organized as follows. Section II discusses the problem. Section III provides some brief backgrounds on reliability of series systems. Section IVpresents the firm of study. Section V conducts some preliminary analyses and failure modes. Section VI carries out some reliability analyses on the chosen machine. Section VII discusses tentative schedules of preventive maintenance on the basis of the outcomes of the reliability analysis investigated in section VI. Finally, section VIII serves for conclusions.

II- THE PROBLEM

Even if machine failures do not create serious damage to other components or injury to people, they cause shutdowns; delay production and necessitate corrective maintenance, which is the most expensive and costly type of maintenance. Figure 1, below, indicates the number of failures within AMECAP during the year 2014according to different production units.

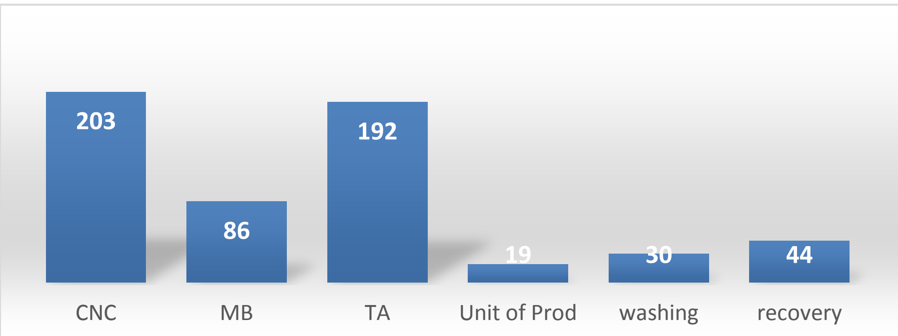

Figure 1: Number of failures per production unit within AMECAP

It appears obviously from Figure 1, that the first three production units, CNC (Computer Numeric Control machines), MB (Multi-spindle Automatic machines), and TA (Automatic single spindle cam Tours) correspond to highest failure level. AMECAP considers two types of maintenance corrective and preventive ones. The corrective maintenance is carried out in case of machine failure. However, the preventive maintenance takes steps to prevent and fix problems before failures occur. Table 1 displays some statistics recorded within the firm during 2015 for the three top breaking down machines concerning both corrective and preventive maintenance.

Table 1: Curative and preventive statistics during 2015 within AMECAP

Machine	Failure rate	Reactivity rate	Preventive compliance rate
CNC	12.9%	14.6%	50%
MB	5.6%	58.3%	100%
TA	3.9%	27.7%	100%
Total	8.24%	20.5%	92%

Based on these statistics, AMECAP has decided to adopt the following goals in its maintenance policy. Specifically, it looks for decreasing the failure rate to 6%, increasing the response rate to 30%, and improving the rate of implementation of preventive maintenance to 90%.

It appears clearly that the company needs to make more efforts in controlling both its failure rate and its response rate. It has to implement some measures to reduce its failure rate from 8.24% to at least 6% and to increase its reactivity rate from 20.5% to 30%. Nevertheless, the firm seems to be satisfied by its general preventive maintenance policy since its preventive compliance rate reaches the 92% (more than 90%).A deeper analysis of the preventive maintenance shows that CNC machines are far from receiving sufficient preventive programs in comparison to the two types of machines.

When a machine fails, it enters to repair process. The total downtimes composed by delay time and the effective repair time. The delay time is constituted by a supply delay and a maintenance delay. Supply delay consists of the necessary time to obtain spare parts or components required for the repair process. However, the maintenance delay time is the time spent waiting for maintenance resources such as personnel and test equipment especially with the increased complexity and automation of plant equipment. To a large extent these delay times are influenced by external factors. That is why; the firm may not be able to totally control its reactivity rate. Nevertheless, the firm has the possibility to improve it through some measures such as maintaining the needed replacement items available in its warehouses. Preventive maintenance, however, can be totally controllable by the firm. Furthermore, an adequate preventive maintenance may contribute to reducing the failure rate.

To sum up, we believe that AMECAP needs to reconsider its preventive maintenance program in particular for CNC machines. To accomplish this, we need to perform some reliability analyses on CNC machines in order to develop an adequate schedule of preventive maintenance. For this, we need to answer a least these two relevant questions:

- How to fit reliability function empirically?
- How to plan a preventive program based on reliability analysis outcomes?

III- BRIEF BACKGROUND ON RELIABILITY ANALYSIS OF SERIES SYSTEMS

Reliability is an important measure of performance. Many studies have been developed on reliability analysis. According to IEEE (1990) reliability is described asthe ability of a system or component to function under stated conditions for a specified period of time. Technically, the reliability is defined as the probability of a non-failure of a system or a component over time. Then reliability can be expressed as:

$$R(t) = \Pr\{T \geq t\} \text{ for } R(t) \geq 0,\ R(0) = 1 \text{ and } \lim_{t\to\infty} R(t) = 0$$

Where T denotes a positive continuous random variable measuring the time to failure of the system (component).

Three other related probability functions can be used to compute reliabilities, the cumulative distribution function, F(t),the probability density function, f(t), and the hazard rate or the failure rate function, $\lambda(t)$. Nevertheless, each of these functions characterizes the failure process from a different side.

The cumulative distribution function of the failure distribution is defined as follows:

$$F(t) = 1 - R(t) = \text{Prfor}\{T < t\}$$

The probability density function describes the shape of the failure distribution and is defined by

$$f(t) = \frac{dF(t)}{dt} = -\frac{dR(t)}{dt}$$

The hazard rate or the failure rate function provides an instantaneous (at time t) rate of failure.

$$\lambda(t) = \lim_{\Delta t \to 0} \frac{-[R(t+\Delta t) - R(t)]}{\Delta t} \frac{1}{R(t)} = \frac{f(t)}{R(t)}$$

Failure rates may be increasing, decreasing or constant function. An important form of hazard rate function is shown in Figure 2 below. Due to its shape, it is commonly referred to as the bathtub curve.

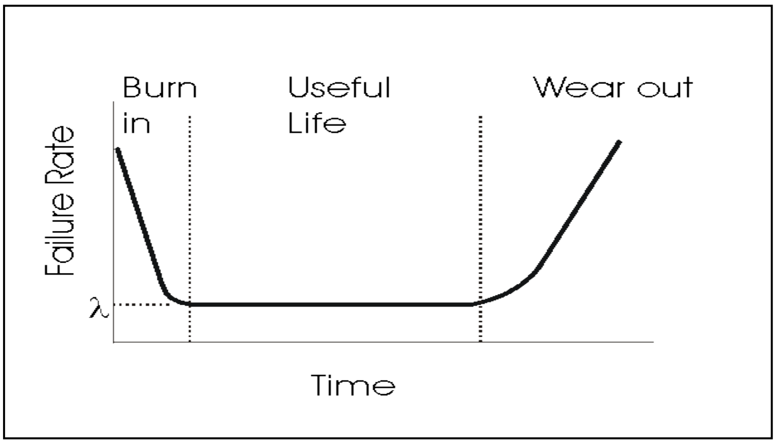

Figure 2: The bathtub curve

The curve can be broken up into three zones:

- Zone I: (the rapidly decreasing part of the curve), referred to as the Burn-in period or infant mortality stage, is characterized by failures due to manufacturing defects.
- Zone II: represents the useful life stage and is characterized by a constant failure rate due to random failures.
- Zone III: is termed the wear out period and is characterized by an increasing failure rate as a result of equipment aging and deterioration.

Complicated systems will fail through several means ensuing from different physical phenomena or different failure characteristics of individual components. Components within a system may be related to one another in a serial, a parallel, or combined series-parallel configurations. In a serial one, all components must function for the system to work. In a parallel configuration, at least one component must function for the system to work. Finally, in a combined configuration a set of components must function for the system to work.

A valuable analysis approach in reliability is to isolate the failures of a given system according to different failure modes. Failure modes are an example of a series relationship. Specifically, assuming independence among the failure modes, the reliability, R (t), of a system having independent failure modes is calculated as follows:

$$R(t) = \prod_{i=1}^{n} R_i(t)$$

Where $R_i(t)$, the reliability function for the i^{th} failure mode, indicatesthe probability that the i^{th} failure mode does not occur before time t. R(t) designates the probability that none of the n failure modes occurs before time t.

IV- PRESENTATION OF THE FIRM OF THE STUDY

Founded in 1991, the mechanical workshop precision "AMECAP" is an industrial company that is implanted in the region of Sfax in Tunisia. It is among the first companies in Tunisia, certified ISO 9002 V1994 since 1999, 9001 and 9001 since 2003 V2000 V2008 since 2009. Its main competitors, for standard products, are SOPAL, IDEAL, and those for products withcommand areSMDP, MGM. The team consists of 136 employees distributed as follows: 20 frames, 25 supervisors, and 91 workers.

AMECAP has a design office with a sale department, which plays the role of coordinator between the customer and the company. It has also a machine park that manufactures a complete line of accessories for sanitary installations and mainly the connecting parts such as the fittings, cartridges,reductions,hunting valves, tap heads, and various accessories. Furthermore, AMECAP has also the option of subcontracting products. Thecompany’s main customers areSOPAL, SAGEMCOM TUNISIA, SOFTEN, CEG GROS, STQ, SOGEC, in the local market, and ASSA ABLOY, JABIL, SMOCA PEC in the export market. The company is working towards success. Figure 3, below, displays the evolution of its turnover since 2008. Today, this latter has nearly doubled.

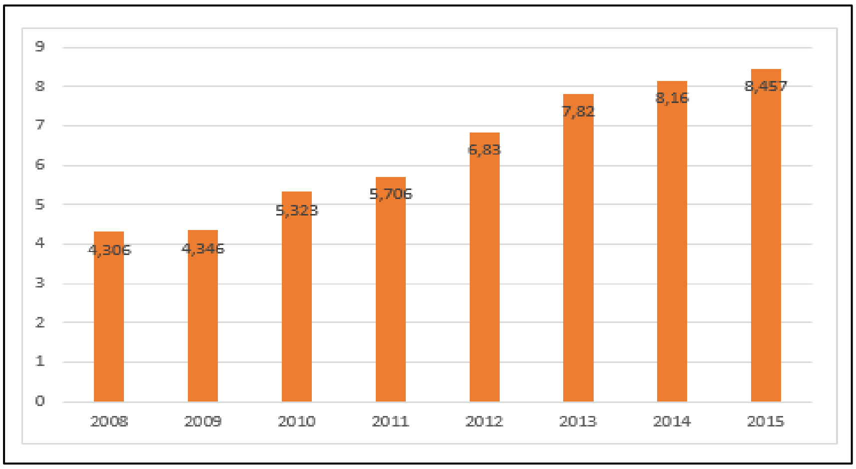

Figure 3: Turnover evolution

The company specializes in precision machining. It manufactures a full range of accessories for sanitation and makes outsourcing work of mechanical parts using raw material that comes in various forms and shapes and of different type such as steel (S300P and C45), stainless steel (303 and 316), brass, aluminum (12-21-16-25mm of diameters),copper, and polyamide.

The machine shop has team toolmakers that work in total autonomy on the realization of products with a versatile machine stock (Figure 4) consisting essentially of:

- 13 Computer numeric control machines (CNC) working 24 h/day.
- 25 Automatic single spindle cam Tours (TA)working for 14h/day. These machines are intended for the manufacture of simple parts that do not require much precision.
- 6 Tours cam multi-spindle automatic (MB), used for large series. These machines work for 14h/day and are characterized by their high rate compared to other machines.

CNC TA MB

Figure 4: Production machines of AMECAP

The production process is composed by four steps; namely, machining, washing, recovery, and assembly & packaging. Figure 5 shows the arrangement of the production workshop of the company.

The recovery concerns all finishing operations such as grinding, drilling, tapping, milling, etc. To be performed after the cutting. Washing is carried out through a degreasing machine using a product called "perchlorethylene" from per-chloric acid (HClO4).An isolation unit allows the degreasing of the chip to make it ready for recycling. Recycling is not performed in AMECAP. Finally, the assembly unit ensures weighing, metering and packaging operations and then the finished products are sent from the assembly unit, to be stored.

In order to improve its performance, AMECAP ensures a variety of controls at many levels. First, it starts by controlling the raw material and accessories at their reception. Then, it performs a control over the production process either through an auto-control performed by machine operator, or via a monitoring control made by screeners. In addition, it uses samplingtechniques to do periodical controls.

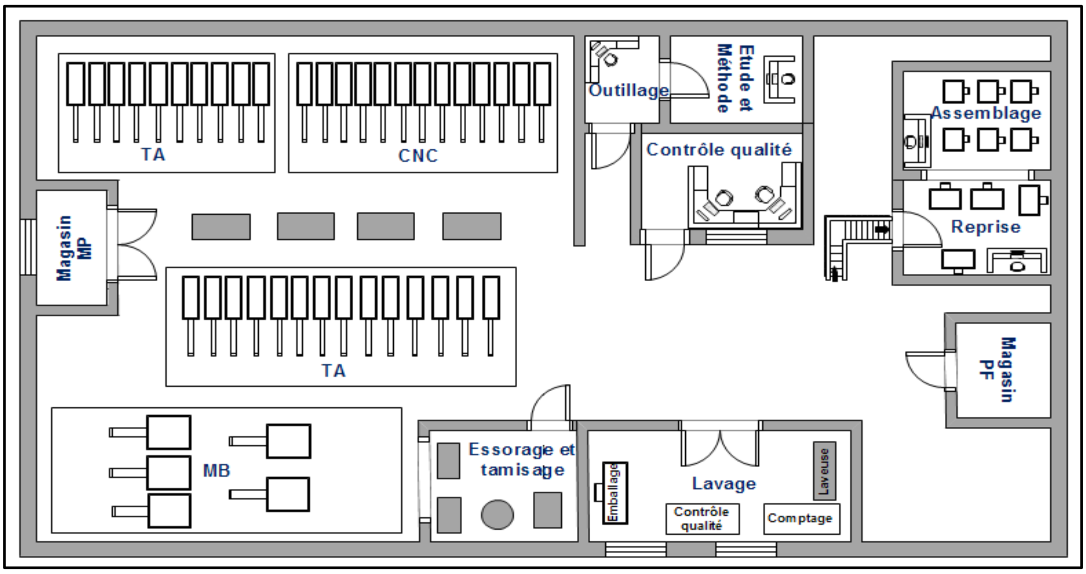

Figure 5: Production workshop of AMECAP

V- SOME PRILIMINAIRY ANALYSES AND FAILURE MODES

Complex machines fail due to various phenomena or different failure characteristics of individual components. To assess the reliability of a given machine, it is necessary to separate these failures according to the mechanics or components causing the failures.

A CNC machine includes a computer in which the program is fed for cutting a given metal as required. All the cutting processes and the final dimensions are taken into account by the computer via the program. While working, aCNC machine can be compared to a robot.You have just to feed the information needed in a program, and it follows all the provided instructions.However, even when the CNC machines are designed to meet very close accuracies, it has a near 9% failure rate, with 203 failures in 2014 alone. So, to assess and improve the reliability of these machines, field failure information where collected, then transformed throughout 12 months of the products' life and statistical analysis were performed. According to Figure 6, mechanic and electric failure modes are the most frequent for CNC machines.

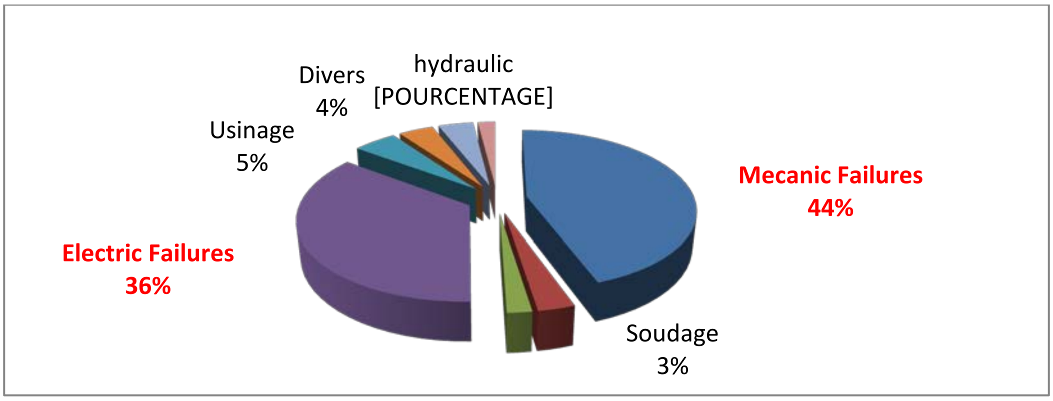

Figure 6: CNC Failures modes

Many reasons are behind mechanical failuresof a component or a system. The most recognized ones are:

- misuse or abuse,
- manufacturing defects,
- improper or inadequate maintenance,
- improper material or poor selection of materials,
- improper heat treatments,
- unforeseen operating conditions,
- Inadequate environmental protection/control.

The main difference between electric and mechanic reliability is that generally speaking electronic systems do not wear out (with some exceptions). While there are effectively some wear out mechanisms such as electro-migration and component parameter drift, electronic systems behave fundamentally in different ways than mechanic ones.

The most common causes for electronic system failure are

- excess oftemperature,
- excess of electric current or voltage,
- mechanical shock,
- Excessive stress.

Due to lack of data and time limits, we limit our study to only one CNC machine. As we consider mechanic failures mode at AMECAP, we noted that machines CNC54 and CNC55 have suffered the most from mechanical breakdowns. Figure 7, below, displays more details about mechanic failures per CNC machine. Between these two machines, the CNC54 machine has undergone more electric failures, 13 failures, in comparison to CNC55 with only 5 failures. That is why; we dedicate the remaining of the study to machine CNC54.

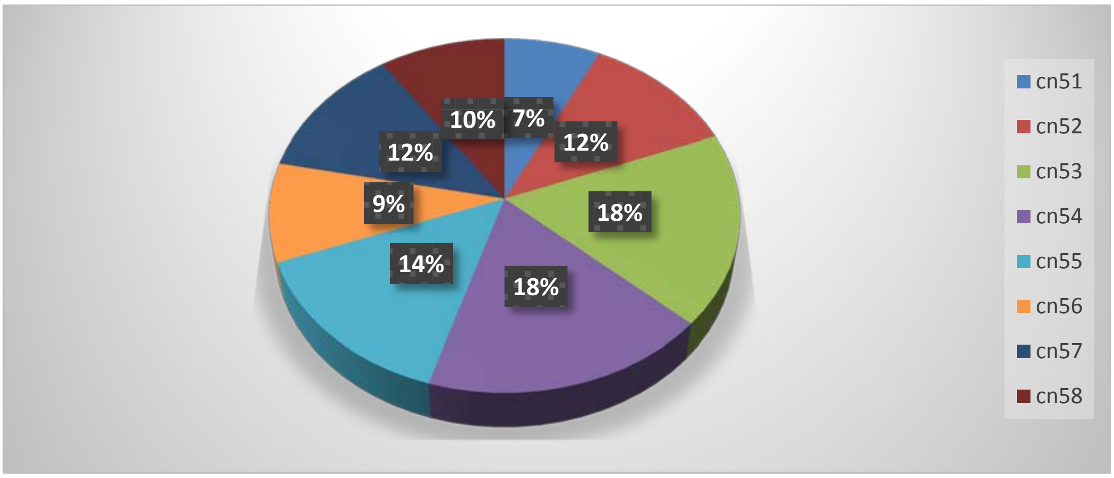

Figure 7: Mechanic failure rate per CNC machine

Moreover, based on the preliminary failures mode analysis the machine CNC54, we notice that the most recorded reasons for mechanic failures noticed in Guide bushing, spindles and feeders, were the fatigue of some parts, thermal shocks and lubrication failures, such as the one caused by the decrease of the lubricant tank oil level, or the decentralization of the lubricant system. On the other hand, the frequent seen electric failure causes are ventilation problem and a decrease of the oil sensor level.

VI- RELIABILITY ANALYSIS FOR CNC54 MACHINE

1. *Distribution fitting and validation model approach*

To assess the reliability of the CNC54 machine, we first focus on fitting failure data to a theoretical distribution such as exponential, Weibull, normal or lognormal. The exponential distribution was one of the first distributions used to model lifetime data. This distribution was widely used in reliability engineering. One of the reasons of its widespread use is its simplicity in performing analysis. It has now been superseded by the Weibull distribution, but is still used occasionally. The exponential distribution may be found from the Weibull distribution.

The Weibull distribution is named for Professor WaloddiWeibull. He demonstrated that the Weibull distribution fit many different datasets and gave good results, even for small samples. The Weibull distribution has found wide use in industrial fields where it is used to model time to failure data.

The normal distribution is one of the most commonly used in statistics. However, it is used infrequently as a lifetime distribution because it allows negative values while lifetimes are always positive.

Although the normal distribution itself does not often work well with time-to-failure data, it has been found that the logarithm of failure time often does. Hence the lognormal has become a popular distribution in reliability work. For more details see for instance Billinton et al. (2001), Billinton and Allan (1992), IEEE (1998).

After model selection, the model parameters must be estimated. Various numerical methods and graphical methods have been developed and used for parameter estimation. Based on these numerical methods, statistical software has been developed. EasyFit is one of them.

Probability plotting is a graphical method that allows a visual assessment of the model's fit. Once the model parameters have been estimated, the probability plot can be created. The accuracy of the estimation depends on the data set size and the estimation method. The validation can be carried out using the chi-square test, the Kolmogorov–Smirnov (KS) test, or the Anderson–Darling (AD) test.

The Kolmogorov-Smirnov (KS) test returns the probability that DCRIT < Dmax. A high probability value, close to 1, indicates that there is a significant difference between the theoretical distribution and the data set. The chi-squared test relies on the grouping (or binning) of the data into a number of intervals (as in histograms). It returns a p-value, provided that the data are well described by the assumed distribution. A small p-value indicates good agreement between the assumed distribution and the data set, while a p-value close to one indicates that there is a significant difference between the two.

The chi-squared test is less powerful than the KS test for any sample size. And because the AD test can avoid the grouping problem of the chi-square test, and when the sample size is small, the AD test can acquire a better recognition performance than KS test. The AD test results will be our first criteria to determine the selection of the best fitting model.

2. *Mechanic reliability assessment for CNC54 machine*

To select the best fitting distribution for our data, we use the software “easy fit». Table 2, below, presents some descriptive analysis of the mechanic failure mode data. According to Table 3, the three tests AD, Chi-Squared tests, and KS indicatethat a lognormal distribution densityfits the best our data.

Table2: Descriptive statistics for mechanic failure mode data of the CNC54 machine

Descriptive Statistics

Statistic	Value	Percentile	Value
Sample Size	40	Min	55
Range	1,6360E+5	5%	233,0
Mean	23847,0	10%	1173,0
Variance	1,5909E+9	25% (Q1)	3812,5
Std. Deviation	39887,0	50% (Median)	9747,5
Coef. of Variation	1,6726	75% (Q3)	17726,0
Std. Error	6306,6	90%	75901,0
Skewness	2,6949	95%	1,6130E+5
Excess Kurtosis	6,8651	Max	1,6365E+5

Table3: Goodness of fit according to KS, AD, and Chi-squared testsfor mechanic failure data

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Exponential	0,27282	5	4,0857	5	11,679	5
2	Exponential (2P)	0,27324	6	5,9708	6	11,855	6
3	Lognormal	0,10184	1	0,4643	2	2,5071	1
4	Lognormal (3P)	0,10441	2	0,27265	1	4,6416	3
5	Weibull	0,13399	3	0,61001	3	4,4376	2
6	Weibull (3P)	0,1439	4	1,2733	4	9,453	4

The adopted probability density function and the cumulative distribution function are plotted in Figures 8 and 9 below.

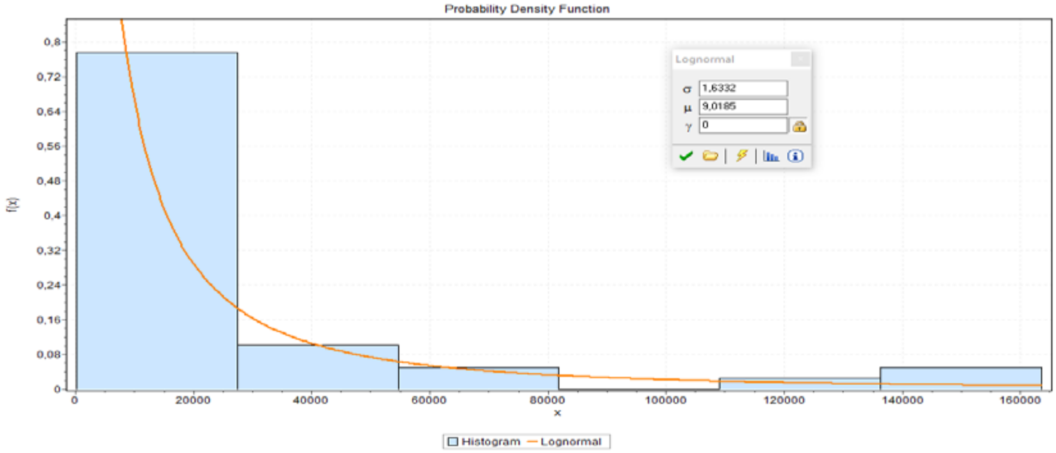

Figure 8: Mechanic failure probability density function for CNC54 machine

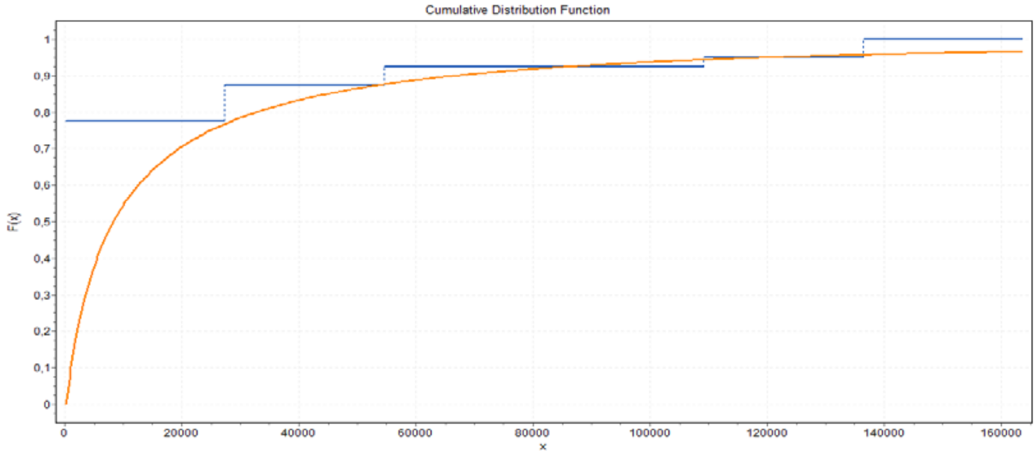

Figure 9: Mechanic failure cumulative probability function for CNC54 machine

The adopted probability density function $f(x)$is expressed as follows:

$$f(x,\mu,\sigma,\gamma)=\frac{1}{x\sigma\sqrt{2\pi}}e^{-\frac{[\ln x-\mu]^2}{2\sigma^2}}$$

Where μ=9.0189 and σ=1.6332

3. Electric reliability assessment for CNC54 machine

Adopting the same approach as that used for mechanical reliability assessment, we obtain the following results. Table 4, below, offers some descriptive analysis of the electric failure mode data.

Table4: Descriptive statistics for electric failure mode data of the CNC54 machine

Descriptive Statistics

Statistic	Value	Percentile	Value
Sample Size	13	Min	3750
Range	41880	5%	3750
Mean	21773,0	10%	4424,0
Variance	1,7508E+8	25% (Q1)	12622,0
Std. Deviation	13232,0	50% (Median)	17010
Coef. of Variation	0,60772	75% (Q3)	36038,0
Std. Error	3669,8	90%	42430,0
Skewness	0,47511	95%	45630
Excess Kurtosis	-0,94149	Max	45630

Consistent with Table 5 and considering AD test,the best fitting function is a lognormal 3P distribution density.The only difference between the lognormal and the lognormal 3P distributions is the third parameter γ called the threshold parameter. This later indicates that no failures can occur between zero andγ. When γis set to zero, we obtain the lognormal distribution.The corresponding probability density function *f*(*x*) is expressed as follows:

$$f(x,\mu,\sigma,\gamma)=\frac{1}{(x-\gamma)\sigma\sqrt{2\pi}}e^{-\frac{[\ln(x-\gamma)-\mu]^2}{2\sigma^2}}$$

Where X >γ> 0, -∞<μ< +∞, and σ> 0

μ=10.338,σ=0.39338, and γ = -11519

Table5: Goodness of fit according to KS, AD, and Chi-squared tests for electric data

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
3	Lognormal	0,15915	1	0,45625	4	0,31478	3
6	Weibull (3P)	0,16488	2	0,39956	2	0,99448	6
4	Lognormal (3P)	0,17146	3	0,37134	1	0,83162	4
5	Weibull	0,186	4	0,41757	3	0,08127	1
2	Exponential (2P)	0,22682	5	2,1552	6	0,2224	2
1	Exponential	0,27997	6	1,0133	5	0,92103	5

Since γ takes a negative value (-11519), we propose to consider the Weibull 3P as the best one since it is ranked to be the second best fitting according to both AD and KS tests.

The probability density function *f*(*x*) of the Weibull 3P is expressed as follows:

$$f(x, \beta, \theta, \gamma) = \frac{\beta}{\theta}\left(\frac{x-\gamma}{\theta}\right)e^{-\left(\frac{x-\gamma}{\theta}\right)^{\beta}}$$

Where $\theta > 0$, $\beta > 0$, $X > \gamma$, and $-\infty < \gamma < +\infty$

Empirical results indicate that $\theta = 1.429$, $\beta = 20983$, $\gamma = 2591.7$.

The adopted probability density function and the corresponding cumulative distribution function are plotted in Figures 10 and 11 below.

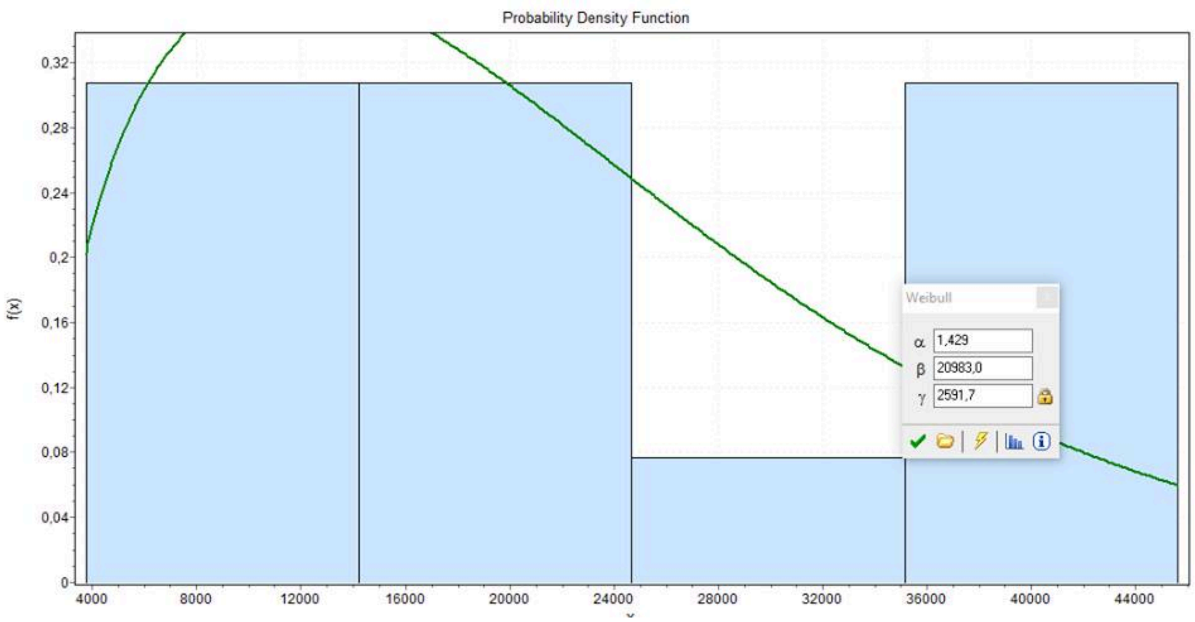

Figure 10: Electric failure probability density function for CNC54 machine

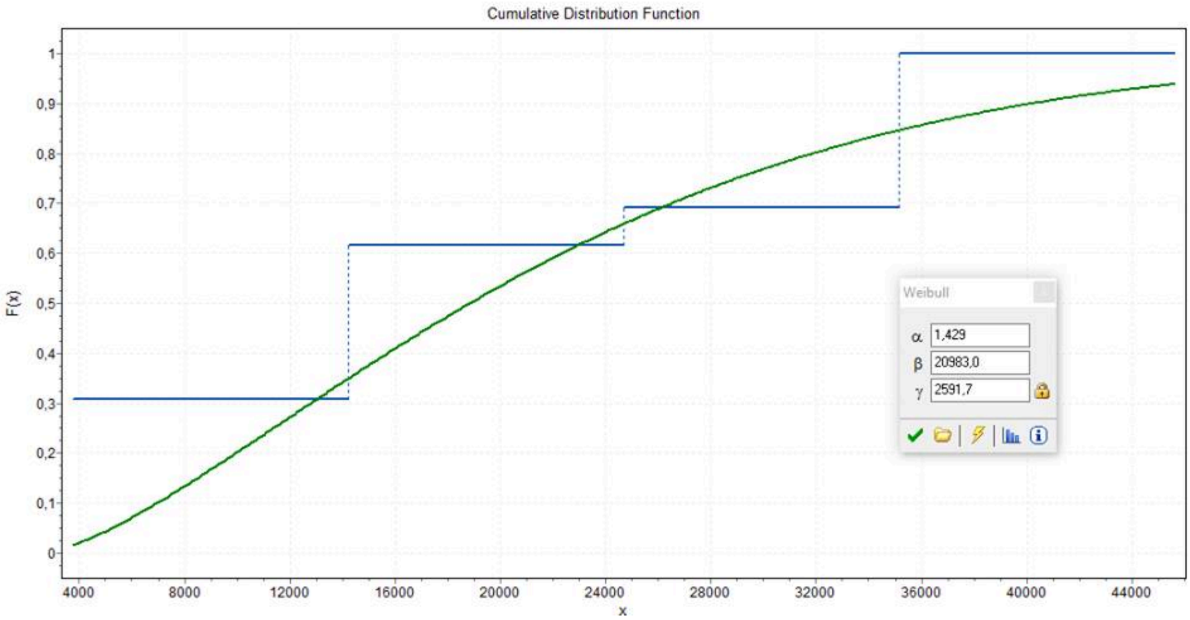

Figure 11: Electric failure cumulative probability function for CNC54 machine

a. Reliability analysis of the whole CNC54 machine

As introduced earlier in section III, the reliability of the CNC54 machine depends on both its mechanic and electric reliabilities. Furthermore, these two failure modes can be considered as independent series subsystem faults. Indeed, the machine will stop operation whichever subsystem faults.

Hence, the reliability of the whole machine can be calculated as follows:

$$R(t) = R_{mechanic}(t) \times R_{electric}(t)$$

Where $R_{mechanic}$(t) and $R_{electric}$(t) indicate respectively the mechanic and the electric reliabilities of the machine. Both these reliabilities have been already estimated in the previous two subsections. $R(t)$ designates the probability that none of the two failure modes occurs before time t.

Using the corresponding fitting functions, we can evaluate numerically the reliability o the subsystems and,hence, that of the whole machine in agiven time interval as shown in Table 6 below.

Table 6: The reliability values of the subsystems and of the whole machine for different time

Minutes	$R_{mechanic}(t)$	$R_{electric}(t)$	$R(t)$
100	0.996556498	0.99352491	0.990103708
200	0.988632206	0.99311776	0.981828199
1440	0.857494244	0.98636644	0.845803548

2000	0.807299472	0.98214124	0.792882103
2500	0.767719763	0.9776681	0.750575126
3000	0.732280082	0.97249019	0.712135198
3500	0.70032582	0.96657283	0.676915911
4000	0.671325871	0.9598892	0.64439845
5000	0.620558369	0.94415684	0.585904431
6000	0.577426054	0.92524289	0.534259352
7000	0.54019594	0.90322281	0.487917297
9000	0.478885406	0.85069906	0.407387362
10000	0.45324663	0.82081405	0.372031204
12000	0.409396594	0.75570464	0.309382904
13000	0.390465044	0.72129769	0.281641536
15000	0.357284366	0.65075852	0.232505844
17000	0.329112971	0.58025171	0.190968366
20000	0.293952879	0.47937569	0.140913865
25000	0.24872641	0.33504645	0.0833349
30000	0.214723719	0.22596081	0.048519146
35000	0.188206914	0.14887435	0.028019182
40000	0.16695109	0.09666466	0.01613827
45000	0.149541523	0.06223788	0.009307147
50000	0.135032371	0.03990885	0.005388987
60000	0.11226926	0.01639586	0.001840751
70000	0.095278405	0.00680657	0.00064852
90000	0,071759382	0,00124289	8,91887E-05
120000	0,050610951	0,00011515	5,82792E-06

As shown in Figure 12,the machine reliability decreases over time, which means that the failure risk increases as the machine continue to work.

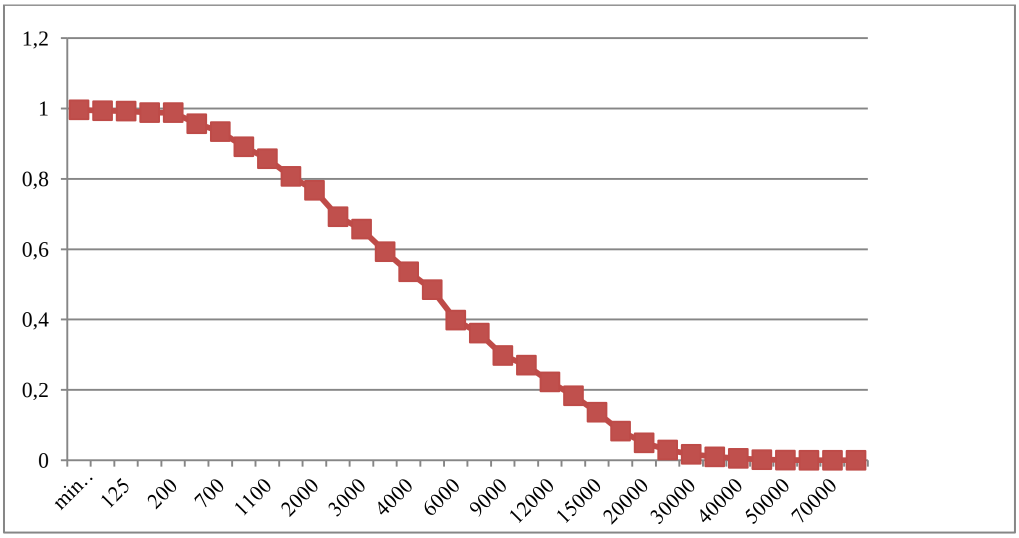

Figure 12: the plot of the reliability rate function for CNC54 machine

Furthermore, at the beginning of the operating process (for small values of time),the reliability of the whole machine is similar to that of the mechanic subsystem. For instance, when the operating time is less than 2500 minutes (around 42 hours), the reliability value of the electric subsystem is around 98%, while the reliabilities of the whole machine and the mechanic subsystem arearound75%.

The machine would work for more than 6000 minutes(4 days) to have nearly a chance over two of having a failure. As the operating time increased to 25000 minutes (17 days), the reliability value of the whole machine decreased to less than 10%.However, when the operating time becomes more than 70000 minutes (49 days), the reliability value of the whole machineturns out to be close to zero.

VII- DISCUSSION AND TENTATIVE SCHEDULES OF PREVENTIVE MAINTENANCE FOR CNC54 MACHINE

In general, machine reliability depends on its age and the maintenance policy applied. It decreases as components deteriorate. To preserve the reliability of a machine at a desired level, performing suitable maintenance schedule is essential. Maintenance may be corrective or preventive. Corrective maintenance is made after the machine breakdown. Preventive maintenance, however, corresponds to the scheduled actions that are performed while the machine is still operational. Generally, preventive maintenance is more beneficial as it may prevent serious losses due to unpredicted failures (Stephens (2004)).In this regard, determining the types and frequencies of preventive maintenance actions is a crucial planning decision. Generally, preventive maintenance actions may be of three types; namely, inspection only, low-level repair, and high-level repair.

Inspection actions consist of simple assistance such as lubricating and cleaning dust. Generally, this type of actionsneedsfewer resources and tools. These actions help to maintain the current state of the system and hence lower the degree of degradation. Low-level repair comprise changingsome simple parts such as belts and bearings. Such repair usually improves the reliability of the changed component.High-level repair is the highest resource demanding type of maintenance.It involves replacement of subsystems by new ones.

At a first glance to Table 6, it appears that the reliability of CNC54 machine is more sensitive to the mechanic subsystem than to the electric one. Therefore, AMECAP should focus in particular on the CNC54 machine mechanic reliability to improve the reliability of the whole machine. The relative high-level mechanic failures number of CNC54 machine confirms this statement; indeed, the mechanic failures account about 62% of the total failures, however, the electric failures account only about 25%.Table 7 and Table 8 display respectively the main mechanic and electric failure causes and the corresponding maintenance measures for the CNC54 machine.

Table 7: the main mechanic failure causes and the corresponding maintenance measures

Main mechanic failure causes	Maintenance measure
• Geometry of the Guide bushing with the spindle	• Adjustment
• Geometry of tool holders	• Adjustment of tool holders
• Broken slide cover	• Redress the slide cover
• Worn screws in the tool holders	• Change of worn screws
• Noise at the engine tools	• Change of bearing cannon
• Turning end-pieces broken	• Geometry of revolving-end-pieces
• Ventilator alarm	• Disassembly ventilator and Change of fixing screw
• Noise from the cannon	• Disassembly of the engine

Table 8: the main electric failure causes the corresponding maintenance measures

Main electric failure causes	Maintenance measure
• Alarm	• Broken amp
• Alarm power steering	• Checking Electrical cabinet, increased voltage
• Machine does not boot	• Rearming thermal relay, spindle clamp
• Circuit breaker broken down	• Redressing the breaker

At present, the company has implemented the following preventive maintenance program. Specifically, it has scheduled three periodic checks. The first is carried out everyday; the second is provided every two months, while the third one is performed every three months.More details of the preventive maintenance are given in Table 9 below.

Table 9: AMECAP preventive maintenance program

Every day checks	**Every two months checks**	**Every three months checks**

• Aligning of the bars • Lubricating oil level • Cleaning the twist tray • Check the safety of doors • Check the free rotation of the two spindles • The barrel adjustment • The absence of worn screws on tool holders	• Geometry of the guide bushing with spindle • Geometry of the gun belt • The rate of engine load at a speed of 300 revolutions/min (< 20%) • State of the coolant pump • Cleaning the irrigation circuit	• Full cleaning of the machine • Changing bearings of the two spindles

From Table 9, it is clear that AMECAP has implemented the three types of preventive maintenance. Indeed, everyday it performs some inspection actions. Then each two months, it ensures low-level repair for some of its components. Finally, each three months it accomplishes high-level repair actions. Nevertheless, based on reliability computations, it seems that this adopted preventive maintenance program is not totally adequate.

In fact, according to Table 6, as the operating time increased to 70000 minutes (49 days), the reliability of the whole machine turns out to be less than 0.07%. Therefore, as the operating time of the machine becomes closer to two months (the chosen interval for the low-level repair), the reliability of the machine becomes closer to zero. In other words, the risk of failure of the machine becomes almost sure before performing the low- and high-levels of maintenance.

Therefore, to improve the reliability of the CNC54 machine, AMECAP should continue performing besides its daily inspection actions, the low- and high-levels maintenance actions but in a better-chosen intervals computed based on the component deterioration state and its role in the reliability of the system.

VIII- CONCLUSIONS

This study highlights the importance of reliability concept in the planning of a preventive maintenance program for a given system. Due to the shortness period of study, we have not been able to collect more data about machines failures. That is why; we limit our study to a single machine while considering only the two major failure modes: mechanic and electric failures.

A deeper investigation on the machine key components mayhelp the decision maker finding the most adequate preventive maintenance program. Indeed, for each component, each type of preventive actions can be performed. Furthermore, the non-availability of relevant information concerning the incurred cost unable us looking for preventive maintenance optimization. Indeed, a preventive action has its own cost and resources requirement (such as manpower, spare), as well as its dissimilar effects on the component's reliability.

Moreover, we could not perform a comparison between curative and preventive maintenance in order to optimize the tradeoff between “a run until breakdown” policy and a preventive maintenance policy. However, we manage to provide the company some outlines of a preventive maintenance schedule on the basis of the outcomes of the reliability analysis.

To sum up, managers should look for avoiding the detrimental consequences of equipment failure, which can be disruptive, inconvenient, wasteful, and more importantly expensive. Maintenance and reliability is an important tool to prevent that, and to have better far-reaching effects on the firm’s operation, reputation, and profitability.

REFERENCES

Billinton, R., M. Fotuhi-Firuzabad, L. Bertling, *Bibliography on the application of probability methods in power system reliability evaluation 1996–1999*, IEEE Transactions on Power Systems 16 (2001) 595–602.

Billinton, R., N. Allan, *Reliability Evaluation of Engineering Systems: Concepts and Techniques*, Plenum Press, New York, 1992.

IEEE Std. 493-1997, *Basic Concepts of Reliability Analysis by Probability Methods*,IEEE, New York, 1998 (Chapter 8).

IEEE Standard Computer Dictionary,*A Compilation of IEEE Standard Computer Glossaries.*New York, 1990, NY ISBN 1-55937-079-3.

Stephens, M. P., *Productivity and Reliability-Based maintenance management,* Pearson, Prentice Hall, 2004.