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Availability Assessment of the Centrifugal Pump of Afam VI Gas Plant using Lognormal Distribution

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ABSTRACT

This study investigated the availability of centrifugal pumps in Afam VI Gas Plant, using lognormal distribution. The lognormal distribution as a more effective and tested means of determining the appropriate time for maintenance or parts replacement was used in this study to establish a maintenance technique that will minimize system downtime, forecast maintenance requirements and reduce maintenance cost and time. The lognormal distribution parameters were obtained from the probability plot in Minitab software. The value for scale parameter obtained as 7.618 gives an idea of the scale on the horizontal axis; the shape parameter was 0.4324, and the total number of technical systems was 20. The Weibull shape parameter was 2.802 which imply that failure rate is increasing with time. The scale parameter was 2485 which gives the idea of the scale on the horizontal axis. The probability value (p-value) of the distributions are greater than 0.05, this concludes that the data followed both lognormal and Weibull distributions. The study proved that lognormal distribution is more reliable than the Weibull distribution between 200 hours and 2600 hours. The decrease in reliability with increase in time could be as a result of friction and wear of the engineering members of the pump, which was not appropriate by the operating environment. The availability of the technical system at 2600 hours with lognormal distribution was observed to be 0.7, while that of Weibull was 0.6. It was observed that the availability of the system with both lognormal and Weibull distributions decreased with increase in time. Hence, lognormal distribution can be used to estimate the availability of the centrifugal pump and other engineering systems with parts or components that fail primarily due to stress, corrosion or fatigue.

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***Keywords*:** Gas plant, Availability, Lognormal, Weibull, Centrifugal-Pumps

1. INTRODUCTION

Centrifugal pump is a rotating mechanical device where pressure is obtained dynamically. In centrifugal pump, the inlet is not walled off from the outlet as observed in the positive displacement pump [7]. Instead, it brings up vital energy to the pumpage with the help of velocity variations that occur as a result of fluid flow by the help of the impeller and all related fixed movements of the pump. The S200 series centrifugal pump is widely used for agricultural, domestic, and industrial purposes. Mechanical elements fail primarily as a result of a decrease in its property or an increase in load acting on it [11]. Mechanical component failure impedes the output of the pump, leading to a decrease in efficiency or a total seizure.

When seizure or failure occurs, the whole system is turned off, till a point where the pump is restored back to normalcy. To avert large economic losses encountered as a result of a shutdown, the pump expected to perform reliably under some specified operating environments [5].

The major objective of this study is to predict the life span of the equipment and frequency of failure recorded in the centrifugal pump. Information concerning the failure of the pump will be gathered by conducting a survey among pump, then components vulnerable to failure will be identified by analyzing the survey result.

The fundamental requirement of the availability of the S200 Series Centrifugal Pumps refers to the number of hours it will not breakdown or undergo a repair when needed to carry out its function. The S200 Series Pump was built in a way that it will be very much durable in service. The back plate, casing, and shaft in the centrifugal pump S200 series are made of steel to ensure better mechanical property that will enable it be resistance and corrosion free [3].

Pump components fail as a result of cyclic loading, over-loading, and deterioration in the strength of components, erosive and corrosive environment, and very poor finishing [4]. In this research, the failure data was obtained from both the manufacturers and users, and analyzed so as to identify weaker component parts, and constantly occurring issues. Strengthening the component parts, and improving availability of the centrifugal pump, requires suitable and well-designed modifications, which could be achieved through experiment or simulation.

Considering the importance of centrifugal pump in the transfer of fluids, it is important to estimate its availability to ensure it operates properly when it is requested for use. Hence, lognormal distribution been a life distribution model for many technology based applications was used to obtain the availability of the pump. Lognormal distribution which depends on the multiplicative growth model implies that at any given period, the process undergoes a random increase of degradation that is directly proportional to its current state [8]. The multiplicative effect of all these random independent growths accumulates to trigger failure. Therefore, the distribution is often used to model parts or components that fail primarily due to stress, corrosion or fatigue.

Lognormal distribution as a flexible distribution is closely related to the normal distribution. It can be used to model data that is symmetric or skewed to the right. It is a simple life distribution model for numerous technology processes [10].

The distribution is based on the multiplicative growth model, which means that at any instant of time, the process undergoes a random increase of degradation that is proportional to its current state. The multiplicative effect of all these random independent growths accumulates to trigger failure. Therefore, the distribution is often used to model parts or components that fail primarily due to stress or fatigue, including the following applications. In this research, the lognormal distribution was used to examine the availability of the centrifugal pumps in Afam VI gas plant.

2. MATERIALS AND METHODS

2. 1. Source of Data Collection

The source of data for the calculations of the availability assessment of the centrifugal pumps in Afam VI gas plant include:

i. company's corrective maintenance log books
ii. company's annual report sheets
iii. manufacture's data sheets
iv. demographic data of pump users

2. 2. Methods

The methods employed in this study are as follows:

2. 2. 1. Availability for Lognormal Distribution

Availability for Lognormal Distribution = uptime/operating cycle = uptime/uptime + downtime where uptime for Lognormal Distribution = $e^{\mu+{}^{1}/_{2}\sigma^{2}}$ (1)

2. 2. 2. Availability for Weibull Distribution

Availability for Weibull Distribution = uptime/operating cycle = uptime/uptime + downtime where uptime for Weibull Distribution = $\eta.\Gamma\left(\frac{1}{\beta}+1\right)$ (2)

where: σ = shape parameter; μ = scale parameter

2. 2. 3. Failure Rate (λ) with Lognormal Distributions

Failure rate is the frequency with which an engineered system or component fails, expressed in failures per unit of time. It is usually denoted by the Greek letter λ (lambda) and is often used in reliability engineering. The failure rate of a system usually depends on time, with the rate varying over the life cycle of the system.

$$\lambda(t) = \frac{1}{t\sigma\sqrt{2\pi}} \quad (3)$$

2. 2. 4. Failure Rate (λ) with Weibull Distributions

$$\lambda(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} \quad (4)$$

where: η = Characteristic life ; β = Shape factor

2. 2. 5. Probability Density Function (PDF)

In probability theory, a probability density function, or density of a continuous random variable, is a function whose value at any given sample in the sample space can be interpreted as providing a relative likelihood that the value of the random variable would equal that sample (Ahsanullah, 2016).

$$F(t) = \frac{1}{\sigma t\sqrt{2\pi}} . e^{-1/2(\frac{\ln t-\mu}{\sigma})^2} \quad (5)$$

$$F(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \quad (6)$$

3. RESULTS AND DISCUSSION

3. 1. Uptime of a Centrifugal Pump

The uptime of the technical systems of a centrifugal pump as collected from the four major sources are in Table 1.

Table 1. Uptime of a Centrifugal Pump

Technical System	Time to Failure (h)	Technical System	Time to Failure (h)
1	2200	11	2190
2	3010	12	2300
3	1460	13	2000
4	2000	14	2400
5	2500	15	3300
6	1100	16	3200
7	1500	17	4220
8	730	18	3220
9	1300	19	1800
10	1260	20	2500

Source: Manufacture's data sheets

Table 1 is the table for the time to failure of the component parts that make up the centrifugal pump as collected from the three major sources stated in chapter three.

3. 2. Probability Plots of Failure Times of Lognormal Distribution

The lognormal probability plots of failure times were generated by putting in the uptime of the centrifugal pump in the worksheet of the Minitab software by choosing graph > probability plot > distribution > lognormal.

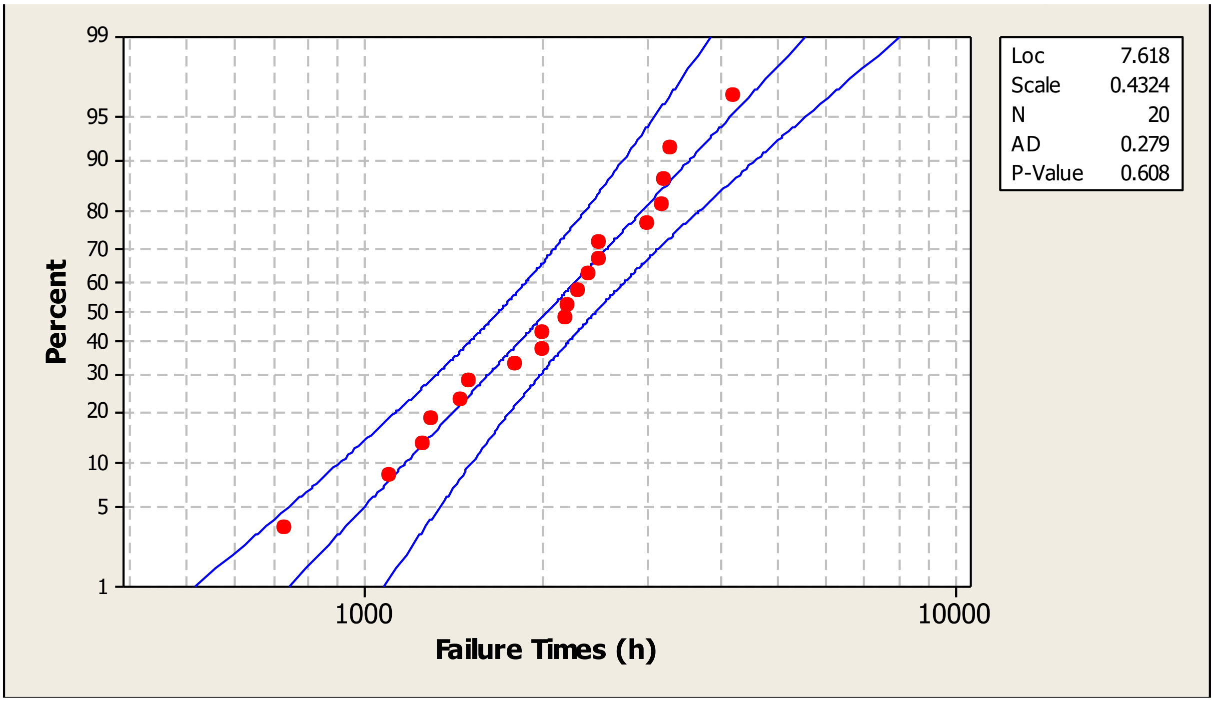

Fig. 1. Probability plot of Lognormal Distribution

Fig. 1 is the probability plot of failure times of the component parts of the pump, this figure been generated in Minitab software, estimates the lognormal parameters. It can be observed from the top right hand side of the Figure 2 is the scale parameter = 7.618 gives you an idea of the scale on the horizontal axis, the shape parameter = 0.4324, and the total number of technical systems = 20. This proves that the software can be used to estimate the lognormal parameters [2].

3. 3. Probability Plots of Failure Times of Weibull Distribution

The Weibull probability plots of failure times were generated by putting in the uptime of the centrifugal pump in the worksheet of the Minitab software by choosing graph > probability plot > distribution > Weibull. Fig. 2 is the probability plot of failure times of the sections of the centrifugal pump, this figure been generated in minitab software, estimates the weibull parameters. As can be observed from the top right hand side of the figure is the shape parameter = 2.802 this implies that failure rate is increasing, the scale parameter = 2485, gives you an idea of the scale on the horizontal axis and the total number of technical systems = 20. This proves that software can be used to estimate the weibull parameters [2].

3. 4. Failure Rates with Lognormal and Weibull Distributions

Figure 3 below shows the comparative analysis of lognormal, Weibull and the operating pumps failure rates. Where Log/F is the failure rate with lognomal, Weib/F is the failure rate with weibull and pump A and pump B are the failure rates of the studied pumps respectively [20].

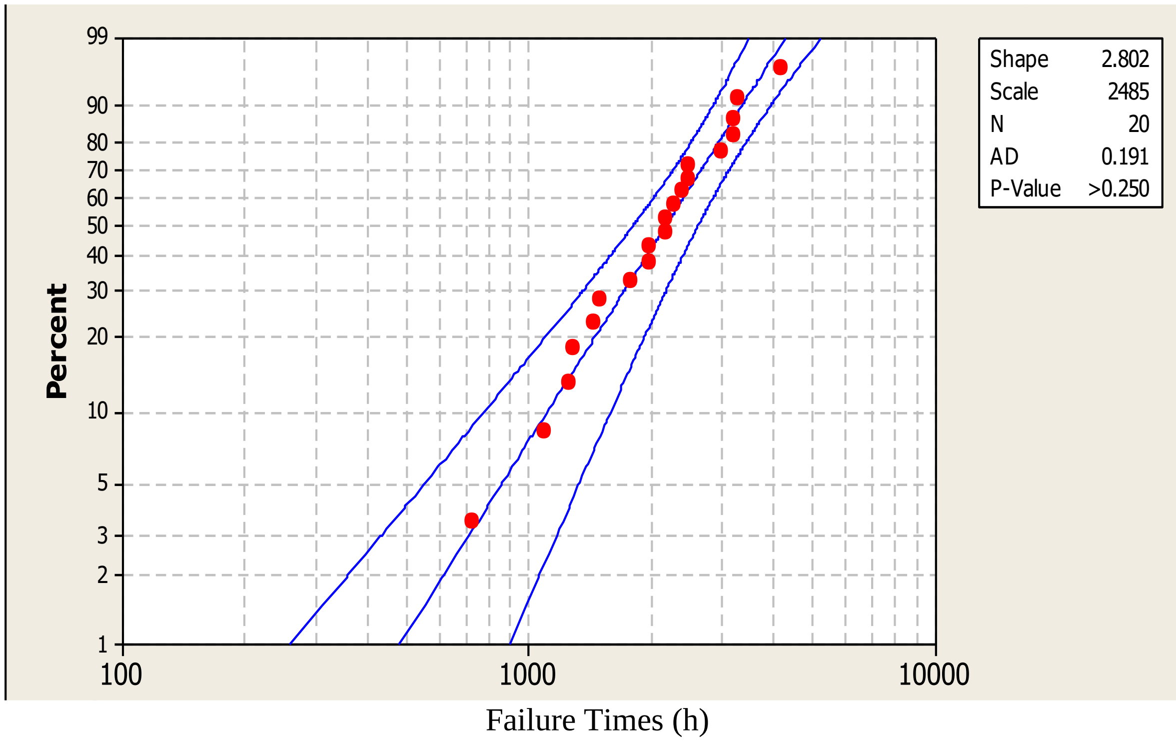

Fig. 2. Probability plot of Weibull Distribution

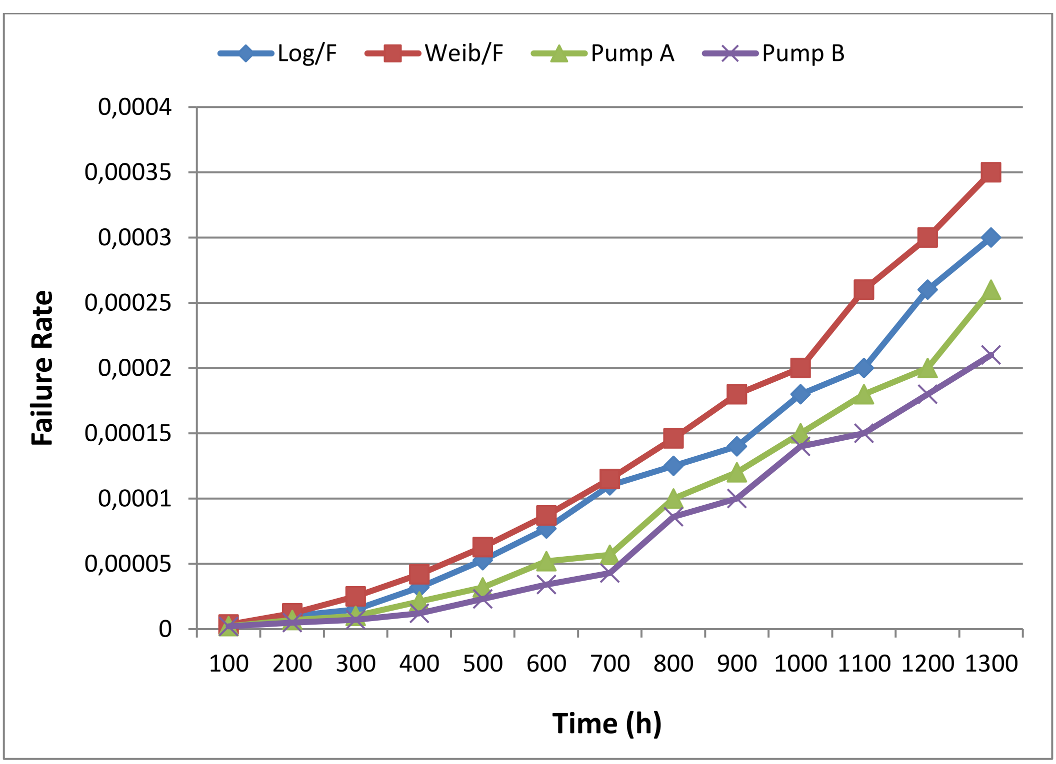

Fig. 3. Comparative Analysis of Lognormal, Weibull and the Operating Pumps Failure Rates

3. 5. Availability Comparative Analysis of Lognormal and Weibull Distributions

Figure 4 below presents the availability comparative analysis of lognormal distribution and weibull in comparison with the operation of two studied pumps. Where avail/W is the availability of the pump with weilbull, avail/L is the availability of the pump with lognormal, pump A and pump B are the studied pumps A and B respectively [19].

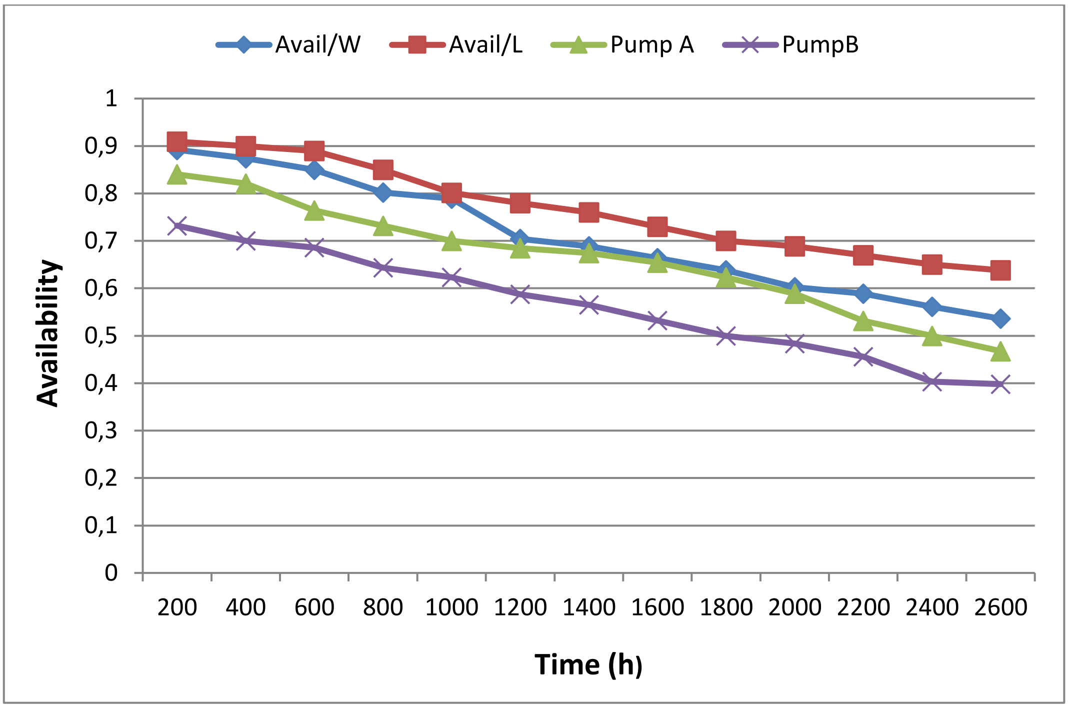

Fig. 4. Availability Comparative Analysis of Lognormal, Weibull, and the Operating Pumps

The Availability comparative analysis of Lognormal distribution and Weibull distributions show some degree of agreement between the two distributions. It is observed that at 2600 hours, the availability of the pump with lognormal is 0.7 while for Weibull, the pump is 0.6 available [17]. For every 168 hours, there is 24 hours downtime, that is one day per week, so, for the 2234 hours uptime, there is 312 hours downtime. Substituting into (1) and (2) above, Availability = uptime/operating cycle = uptime/uptime + downtime, availability becomes 0.9 which is 90% availability. For Figure 4 below, uptime of 200, 400, 800, 1000, 1200, 1400, 1600, 1800. 2000, 2200 2400 and 2600 hours were considered [18]. The comparative analysis of the Lognormal distribution and Weibull as presented in Fig. 4 shows clearly that the Lognormal technique is more efficient than the Weibull distribution. It shows greater availability than the Weibull distributions. Hence the Lognormal distribution can completely replace Weibull [6].

3. 6. Probability Density Function (PDF)

In probability theory, a probability density function, or density of a continuous random variable, is a function whose value at any given sample in the sample space can be interpreted as providing a relative likelihood that the value of the random variable would equal that sample [16].

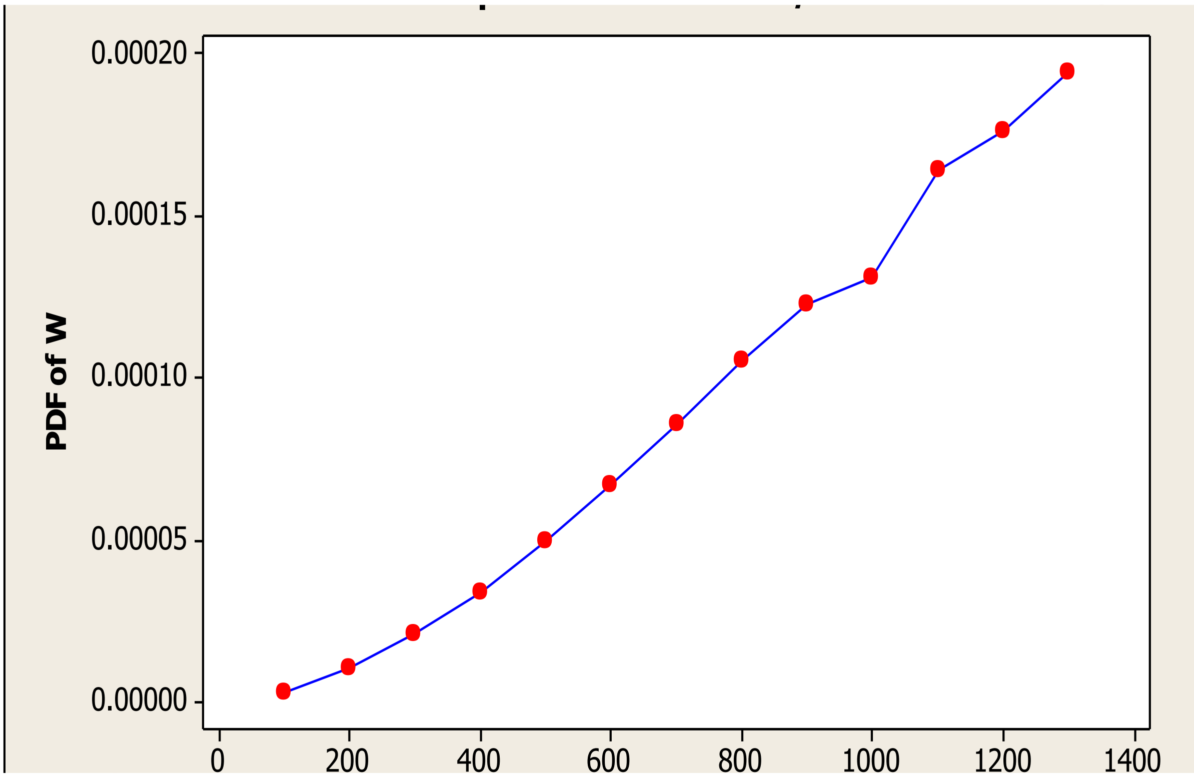

Figure 5. Probability Density Function of Lognormal Versus Time

Figure 5 shows the comparison of the probability density function of lognormal and weibull with increase in time, the result shows a slight variation when comparing the probability density function of lognormal with the weibull [15]. The result demonstrates a good match in using either the weibull. Increase in probability density lognormal and weibull was observed with increase in time, the variation in probability density function of lognormal and Weibull can be attributed to variation in time [14].

3. 7. Probability Distribution Plot

Figure 6 (a and b) presents the probability distribution plot with weilbull and lognormal distributions respectively as obtained from the Minitab 17 software.

Figure 6a shows the probability distribution plot with Weibull, which can be observed to be symmetric, because it looks the same to the left and right of the center point. The probability distribution is a statistical function that describes all the possible values and likelihoods that a random variable can take within a given range [13].

It is observed from Figure 6b that the distribution is a positive skew because it is skewed to the right, indicating that the mean is greater than (to the right of) the median [12].

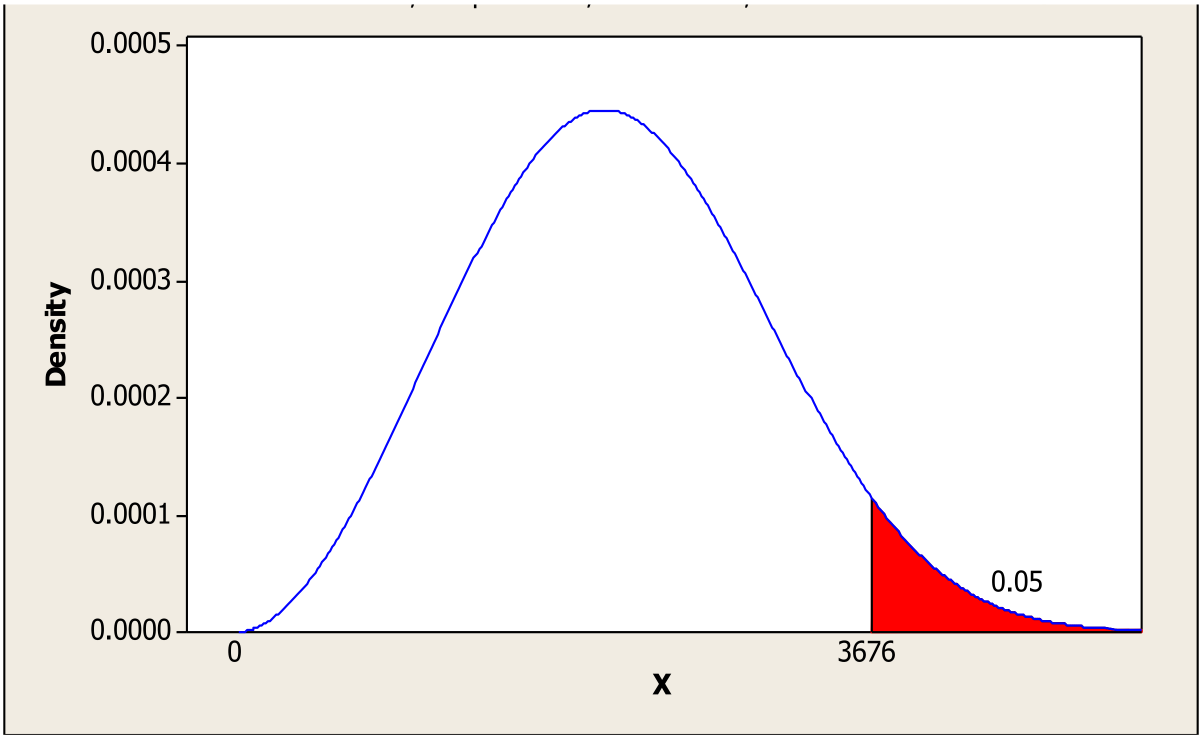

Figure 6a. Probability Distribution Plot with Weibull

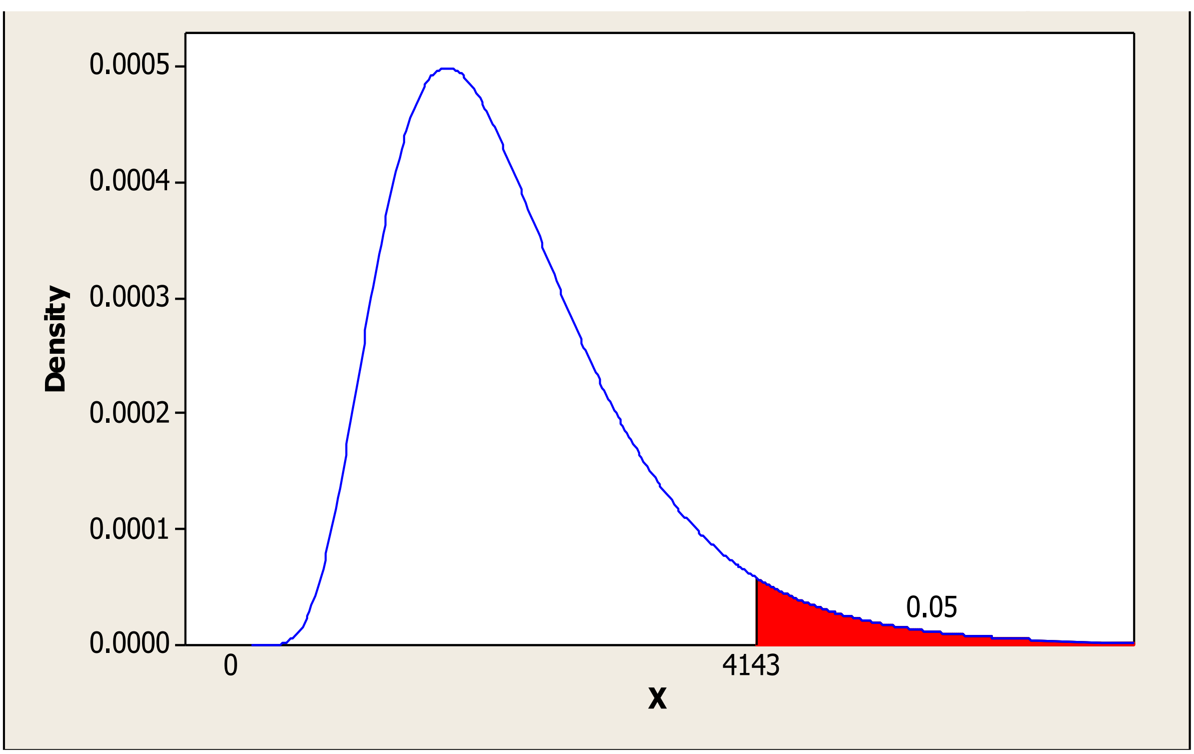

Figure 6b. Probability Distribution Plot with Lognormal

4. CONCLUSIONS

Studies were performed to examine the Availability of the Centrifugal Pumps in Eleme Petrochemicals, using Lognormal distribution. From the investigations undertaken, the following conclusions can be drawn in line with the achieved objectives:

(i) The lognormal distribution parameters were obtained from the probability plot in Minitab software which is a graphical technique for comparing two data sets, either two sets of empirical observations, one empirical set against a theoretical set, or two theoretical sets against each other. The values for lognormal are scale parameter = 7.618 gives you an idea of the scale on the horizontal axis, the shape parameter = 0.4324, and the total number of technical systems = 20. While for Weibull we have the shape parameter = 2.802 this implies that failure rate is increasing, the scale parameter = 2485, which gives the idea of the scale on the horizontal axis and the total number of technical systems = 20

(ii) Mean Time Before Failure of the centrifugal pump was calculated using the lognormal distribution, and results proved that the MTBF is 2234 hours.

(iii) It is observed that failure rate increases with increase in time; this is because the fatigue strength of the shafts reduces with increase in time of operation. The Lognormal is also comparatively better than the Weibull distribution. As such, the Lognormal is more efficient technique of predicting failure rate.

(iv) The Availability analysis with both Lognormal and Weibull distributions showed the degree of agreement between the two distributions. It is observed that at 2600 hours, the availability of the pump with lognormal is 0.7, while for Weibull, the pump is 0.6 available. It is observed that availability decreased with increase in time.

4. 1. Recommendations

The following recommendations are made for future studies:

(i) Researchers should explore other means of analyzing the reliability and availability of engineering systems, other than lognormal distribution distributions in any statistical software.

(ii) Many other distributions should also be tested in comparison with the lognormal other than weibull distribution.

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