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ANALYSIS OF REPAIRABLE SYSTEM RELIABILITY BASED ON LIFE DATA DISTRIBUTIONS

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Abstract

The analysis of reliability is an important parameter for ensuring the reliability of industrial systems. By understanding the individual component reliability and the overall system, engineers can take steps for improved performance of the system for cost saving and enhanced customer satisfaction. A manufacturing plant can use reliability analysis to optimize and improve schedules for product/service maintenance to minimize the unplanned downtime events. By comprehensively analyzing the dependability of such systems, organizations are enabled to implement measures aimed at enhancing both their operational efficacy and reliability, which can yield substantial advantages. The objective of this scholarly paper is to provide an extensive review of the literature concerning the reliability assessment of a maintainable industrial system. This manuscript delineates the phases ranging from data acquisition, trend analysis, and optimal distribution fitting to parameter estimation and reliability evaluation, which will serve as a resource for practitioners in reliability and maintenance engineering as well as decision-makers in their pursuit of optimal decision-making and the formulation of more effective maintenance schedules.

Keywords: Life Data Distributions, Reliability, Weibull, Repairable System etc.

1. INTRODUCTION

Reliability is the probability that the system will perform intended task whenever required [1] A measure of how likely it is that a product will work as expected over a period of time. Reliability is not the same as quality. Quality deals with complete performance of a product, while reliability refers to its ability to perform expected tasks at expected time. There are plenty of factors that can affect the reliability of product, including the materials used, manufacturing process & the environment. e.g. a product that is made with high-quality materials and is manufactured in a controlled environment is likely to be more reliable than a product that is made with low-quality materials and is manufactured in a less controlled environment. Manufacturers want reliable products for customer satisfaction which avoid recalls. Consumers also want reliable products which work as intended. Reliability assessment through rate of failure is one of the prime methods of reliability analysis. For example, a system with a 25% rate of failure has a 25% chance that it will fail in given time. Reliability analysis always starts with available life data of the system, usually failure data. Reliability Assessment is dependent on the most basic assumption that the collected data is iid (independent and identically distributed) in time or else improper interpretations can be taken as iid validation is a graphical test of trend and distribution fitting process. Finally, the best-fit can be used for parameter estimation. The graphical representation of methodology is in Figure 1.

Figure 1. Methodology for reliability estimation

2. LITERATURE REVIEW

Over the course of numerous years, a substantial body of international and national scholarly research has been dedicated to the examination of reliability facets concerning various intricate repairable industrial systems. The reliability paradigm is primarily employed for the analytical assessment of complex systems and for the formulation of strategies pertaining to their operational lifespan and maintenance. In the context of the present investigation, we have meticulously elucidated the phases of reliability analysis from an introductory standpoint, along with a review of select significant research articles present in table 01.

Table 1. Literature Review

Sr. No.	Author and Publication year	Industrial System under study	Methodologies used for study	Software Tools used
[1]	Javad Barabady (2005)	Crushing Plant of Bauxite Mine	Probability Distribution like Weibull, Exponential & Lognormal, Reliability Block Diagram	ReliaSoft's Weibull++6
[2]	Javad Barabady, Uday Kumar (2008)	Conveyor System of Bauxite Mine	Weibull Probability Plot, Probability density Function	ReliaSoft's Weibull+
[3]	S.M. Rezvanizaniani, J. Barabady, Asghari, And U. Kumar (2009)	Wheel Sets of Passenger Train	Failure Rate, Reliability Plot, Probability Density Function	Weibull++6
[4]	Vivek kumar, Saraswat (2021)	Boiler System of power plant	Anderson Darling test, Weibull Distribution using Least Square, Probability Density Function	MATLAB
[5]	Masoud Naseri, Javad Barabady (2016)	Offshore Oil & Gas Plant	RAM Approach, Probability Density Function	-
[6]	Dolas D.R., Jaybhaye M., Deshmukh S. (2014)	Diesel Engine of Compressor	Weibull Distribution, Weibull Probability Plotting,	Windchill quality solution 10.1 Tryout
[7]	Masoud Naseri, Javad Barabady (2016)	Oil & Gas Processing Plant	Expert based model, Weibull Analysis, Failure Tree	-
[8]	Ana Santose (2021)	Plastic extruder of a packaging Industry	Probability Density Function, Weibull Plot	Minitab
[9]	Sachdeva Anish (2008)	Pulping system of a paper industry	PetriNet Model, Root Cause Analysis, Reliability Plot	-

[10]	Simon Furuly, Javad Barabady, Abbas Barabadi (2014)	Convey or System on Coal Mine	Reliability Block Diagram, Weibull 3 parameter Distribution	ReliaSoft's Weibull++7
[11]	C Wu, J Ma, Y He, (2012)	Manufacturing Process	Process Reliability, Weibull Analysis, Least Square Method,	-
[12]	J. Peter, B Zberg, E Arata, (2009)	Mg-based metallic glass wires	Weibull Analysis	CAMSCAN
[13]	Milan Ambrozˇicˇ, Lovro Gorjan (2011)	Bending strength data for alumina test	Monte-Carlo simulations, Weibull 2 parameter Analysis, maximum likelihood method	-
[14]	D Dolas (2014)	Diesel Engine of Compressor	Age Replacement Model, Regression Model	MS Excel

3. IMPORTANCE OF LIFE DATA IN ANALYSIS OF RELIABILITY

Life data is used in reliability analysis to model the life of a system. By fitting a life data distribution to failure dataset, it is possible to understand the failure probability at any given time and other reliability characteristics which helps in making informed decisions about maintenance, spare parts provisioning, and other aspects. Various life data distributions that may be referred for various system reliability assessments like normal, exponential, Weibull, lognormal, and gamma distributions. The choice of which distribution to use is governed by multiple parameters. By using a life data distribution, it is possible to gain a deeper understanding of reliability. This information can help in decision making for improving the reliability. Some brief details of various life data distributions are as follows.

- **Normal Distribution:** It is often utilized to model a wide variety of data, including the lifetime of products or systems. The distribution is symmetrical, which means that mean and the median are equal. The normal distribution also has a bell-shaped curve. The normal distribution has two parameters: the mean (Shape) and the standard deviation (Scale).

- **Exponential distribution:** It is a continuous distribution suitable for systems with wear and tear. In exponential distribution the probability of failure is the same at any point in time i.e. constant rate of failure. This makes the exponential distribution a good choice for modeling products with random failures.

- **Weibull distribution:** It is a continuous distribution that is often utilized to model systems with fatigue or stress. The Weibull distribution has a shape parameter that determines the shape of the distribution. This makes the Weibull distribution a versatile choice for modeling a wide variety of products or systems.

- **Lognormal distribution:** It is often used to model systems with environmental factors. The lognormal distribution has a shape parameter that determines the shape of the distribution, and a scale parameter that determines the location of the distribution. This makes the lognormal distribution a versatile choice for modeling a wide variety of products or systems.

- **Gamma distribution:** It is a continuous distribution that is often utilized to model systems with wear and tear, fatigue, and environmental factors. This makes the gamma distribution a versatile choice for modeling a wide variety of products or systems. Apart from these, various other life data distributions are suitable for reliability analysis. The choice of which distribution to use depends on the specific characteristics of the product or system being analyzed and how best the distribution fits the life data.

4. TREND TEST AND BEST FIT DISTRIBUTION

Least Square method is one of the most important method developed for parameter estimation of given data, It's a method to find the best fit. The residuals are the differences between the observed values and the predicted values from the curve. It's a very common method for fitting data. It can be extended to fit more complex curves, but the basic principles remain the same.

$y=mx+c$

In this study, the following data is referred to as shown in table 02.[3]

Table 2. Failure Data of Water Pump

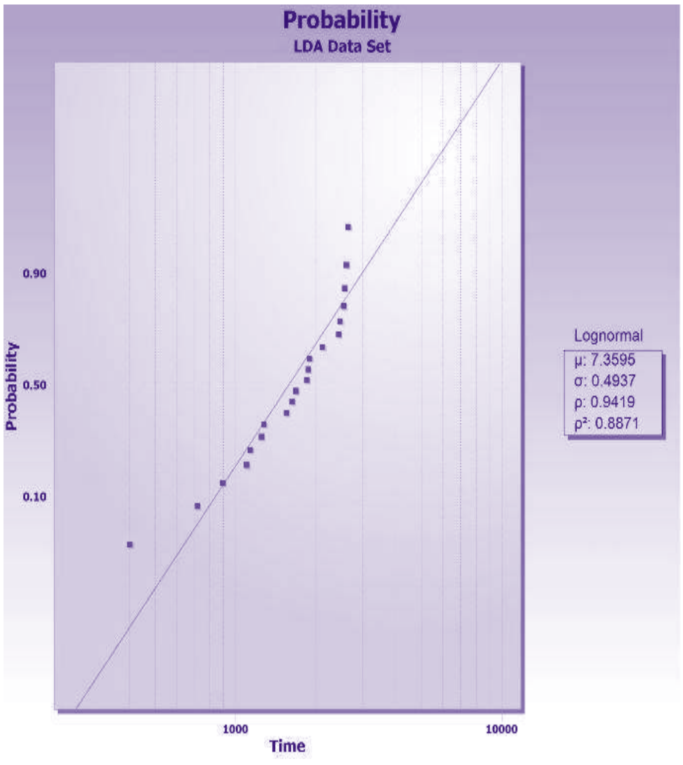
Engine No.	Time to Failure
01	1276
02	720
03	1135
04	1854
05	1687
06	2570
07	2440
08	2547
09	1100
10	2117
11	1876
12	1633
13	2646
14	1556
15	2470
16	1250
17	1895
18	2607
19	896
20	401
17	1895

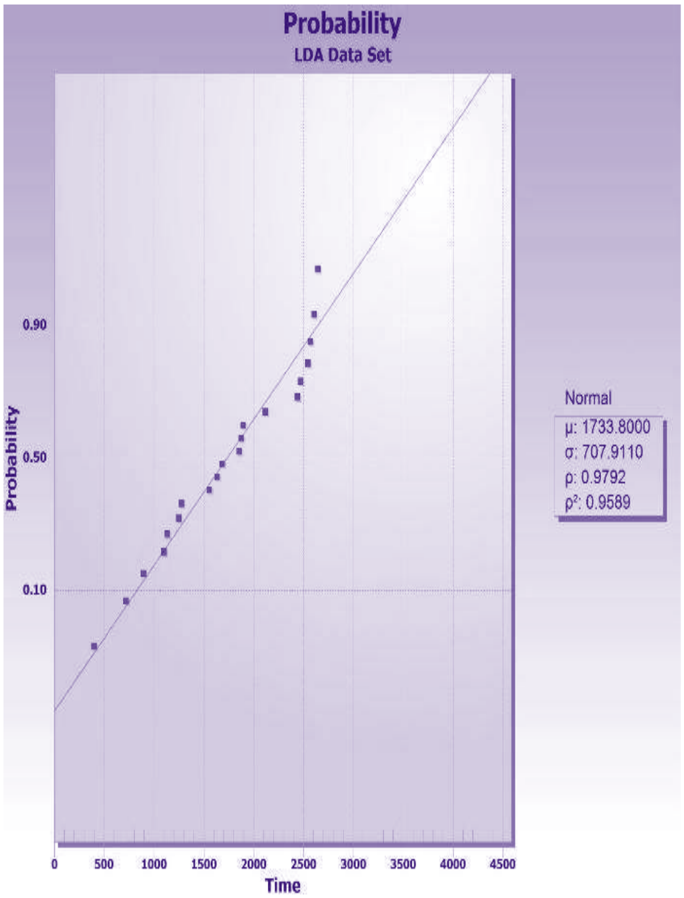
PTC Windchil quality solution tryout 10.2 is used as a software package to analyze the above data, the comparative results of various life data distributions are tabulated in Table 03 and the respective probability plots are presented below in figure 02,

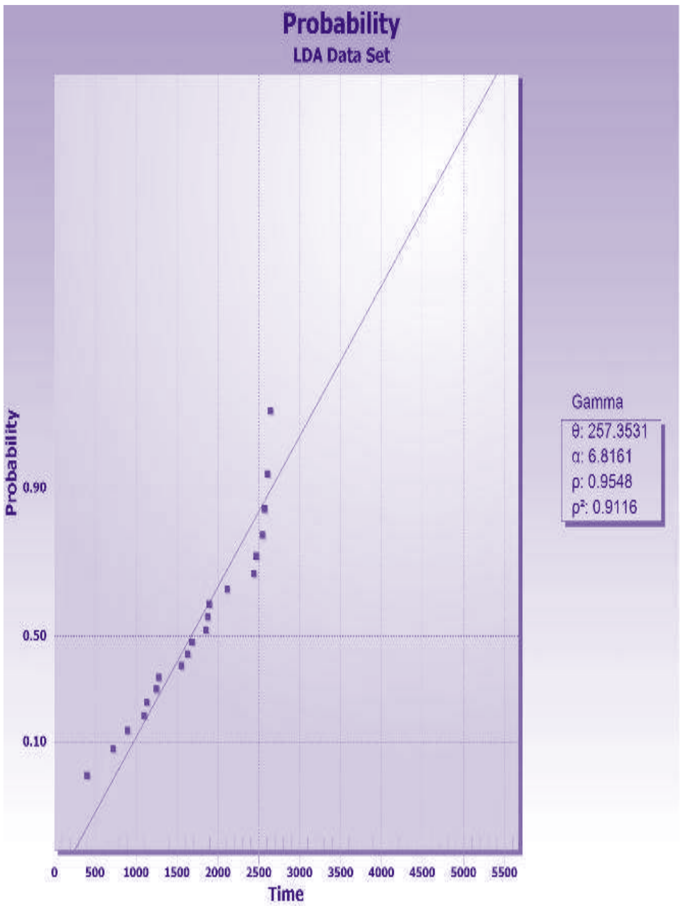
Table 03: Comparative ranking and parameter estimations of various Life data distributions

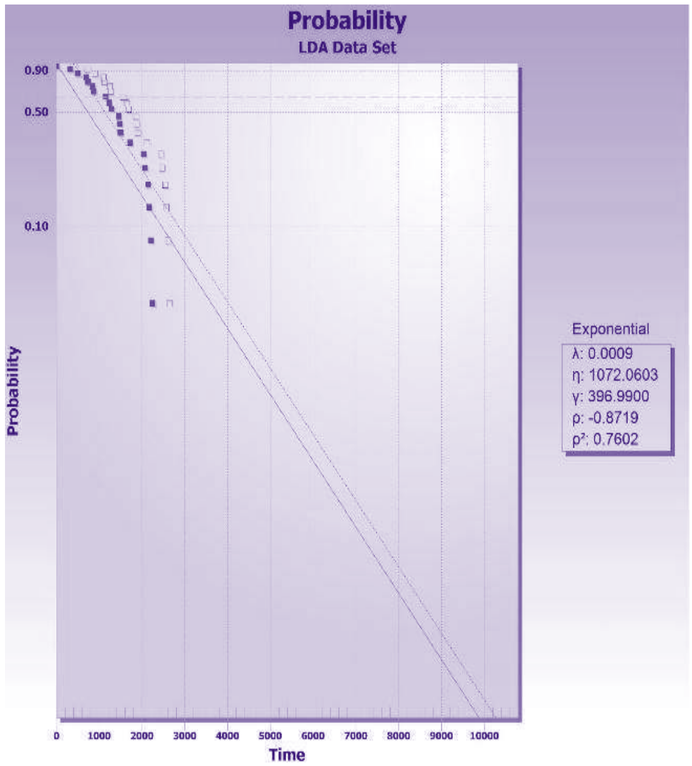
Life Data Distributions	ρ value
Weibull3Parameter β=3.6086 , η=2594.3004 γ=-604.43	*ρ=0.9906*
Weibull2Parameter β=2.3965, η=1972.5626	*ρ=0.9853*
Normal μ=1733.8000, σ=707.9110	*ρ=0.9792*
Gamma θ=257.3531, α=6.8161	*ρ=0.9548*
Lognormal μ=7.3595, σ=0.4937	*ρ=0.9419*
Exponential L=0.0009, η=1072.0603	*ρ=-0.8719*

Figure 02. Probability plots of Normal, Exponential, Lognormal, 2-parameter Weibull and Gamma distribution



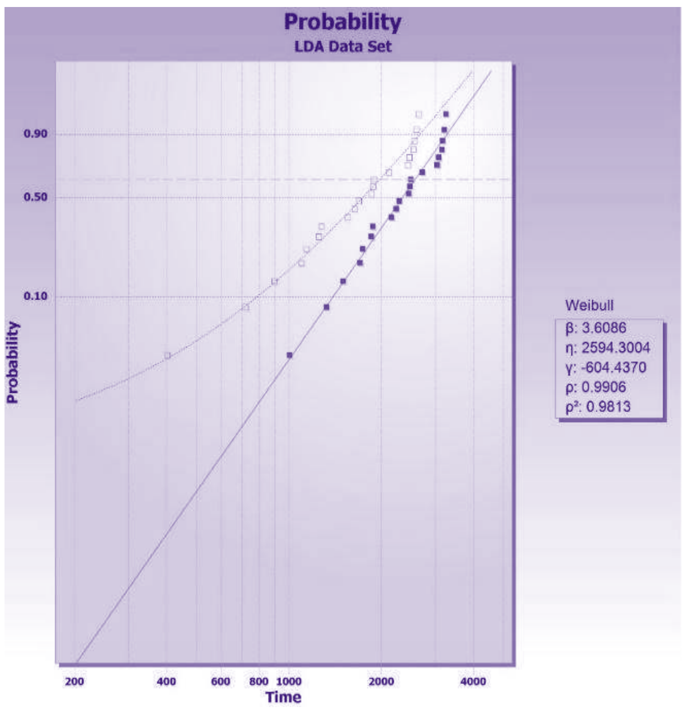






Results show Weibull distributions (2 as well as 3 parameters) fit well with the data, but because the estimation methods are different, the rank is different. The other distributions, such as normal, log-normal, gamma and exponential don't fit the data and they show a lower value of the coefficient. The distribution that better fits the data is the three parameter Weibull since the correlation coefficient is almost unity & higher than other distributions. Figure 03 shows the results,

Figure 03. Three- Parameter Weibull probability plot



5. RELIABILITY ANALYSIS OF THE REPAIRABLE SYSTEM USING 3 PARAMETER WEIBULL

The following equation i.e.

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

The cumulative density function, also noted as "unreliability" or Q (t) in various literature.

$$\mathrm{R}(t)= e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

When $\boldsymbol{\beta}$=3.6086, $\boldsymbol{\eta}$=2594.3004, $\boldsymbol{\gamma}$= -604.43

$$(t=500)=0.9551$$

$$(t=500)=95.51\%$$

6. CONCLUSION

Thisarticleoffersanexhaustive examination of the reliability estimation pertaining to a repairable industrial system. It systematically addresses the phases of reliability analysis grounded in empirical data and underscores the significance of conducting a meticulous and strategically planned analysis. The practical application of these phases is illustrated through a case study involving failure data related to a water pump. The manuscript engages in a critical comparison of an array of life distributions, including normal, lognormal, gamma, as well as 2 and 3 parameter Weibull and exponential distributions, utilizing the PTC Windchill quality solution tryout version 10.2, and systematically catalogs all relevant parameters. Additionally, probability plots

for the various distributions are graphically represented to enhance the comprehension of the audience. The findings elucidate that the optimal fitting distribution for the failure data is identified as the three parameter Weibull, given that the correlation coefficient approaches unity and exceeds that of the alternative distributions. In the subsequent section of the research article, a case study demonstrating reliability estimation via three parameter Weibull analysis is also present.

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