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The Performance of High-power Station Based on Time Between Failures (TBF)

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Abstract: Many human activities are electricity-dependent. As major providers of electricity, the performance of high-power stations represents a vital part of any national economy. In the present study, we identified the distribution fitting to *TBF*. The distribution fitting based on failure data collection, calculated *TBF*, plotted the histogram for *TBF* and matched the plot on the continuous distributions' functions have been investigated. Then, the most valid distribution was found to be the Three-parameter Weibull distribution. Shape, scale and location parameters values were 0.75169, 32.125 and 1.9375, respectively.

Keywords: Distribution fitting, failure rate, hazard function, reliability function

INTRODUCTION

Reliability and High Power model are a necessary aspect for the prediction capacity to make sure that source sufficient electricity when required. High power systems are very difficult and it had major elements for preparation. Reliability is a primary part of product perception. Reliability is one of the most effective product qualities for buyers in making their choices among different varieties (Anbalagan and Ramachandran, 2011) Reliability usually becomes more important to consumers as failure, repair and maintenance items become more costly (Anbalagan and Ramachandran, 2011). Factory of ice cubes, for example, are especially sensitive to downtime (power cuts) during the short summer season. In 1986, the International Organization for Standardization (ISO) defines reliability as “the ability of an item to perform a required function, under given environmental and operating conditions and for a stated period of time” (ISO, 1986). Lisnianski and Jeager, they consider the time-redundant system where the system whole task is a sequence of n phases and the total task must be executed during a constrained time. There is a server for every phase, which completes the phase mission during the randomly distributed time. The server is unreliable completely and there are two types of failure are feasible ("open" and "closed"). They presented the adequate model by using a semi-Markov process as a mathematical technique and they derived the closed-form solution based on an acyclic Semi-Markov process (Lisnianski and Jeager, 2000). In 2004, Elmira, studies the structure of Bayesian group replacement policies for a parallel system of n items with exponential failure times and random failure parameter. In his study, he proofed the fact that it is optimal to observe the system only at failure times for the case of two items operating in parallel issue (Elmira, 2004). The system subject to external and internal failures was considered by Montoro-Cazorla and Pérez-Ocón, when the occurring failures following a Markovian Arrival Process (MAP) and the operational time has Phase-type distribution (PH distribution) (Montoro-Cazorla and Pérez-Ocón, 2006). Castro and Sanjuán presented a combined maintenance strategy in which the repair of the system failures is performed only in an interval of time of the operating period. The aim of the work is to exhibit the optimal interval in which the repairs can be performed (Castro and Sanjuán, 2008).

BASIC CONCEPTS AND FAILURE FUNCTIONS

There are many factors and definitions related to reliability. The most important of these are the following:

Failure: It is defined as the inability of the system (subsystem or one of its components) to perform its job (Frankel, 1988), or the "inability of the item to meet the requirements of the work" (Carter, 1997).

Availability: Most researchers define availability as the probability that an item will be available (Carter, 1986) or the probability that the system will operate satisfactorily at any point in time when operating under a specified condition (Martz and Waller, 1982).

Maintainability: It is the design quality of the system which helps the performance of various maintenance activities, in particular, inspection, repair, replacement and diagnosis. Maintainability is an important

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characteristic of life-cycle design and plays a significant role during the service period of the product (Wani and Gandhi, 1999).

Mean time between failures: MTBF is a parameter of basic reliability for the repairable components. It is the ratio of the total number of life unit for components to the total number of failures (Ying *et al*., 2011).

Mean time to failures: The expected value represents the return period of failures for equipment, when T is the time to failure is often called Mean-Time-to-Failure (*MTTF*) (Zio, 2006). It can be expressed mathematically as follows (Hamada *et al*., 2008):

$$MTTF = E(t) = \int_{-\infty}^{\infty} tf(t)dt$$

where,
E (*T*) = The expected value of *T*
MTTF = Called the expected life

There are many ways to define reliability. For example, in an electrical switch, the reliability may be defined as the probability that it successfully functions under a stipulated load and at a specific temperature. The reliability an operational definition of reliability must be precise sufficiently to allow a clear distinction between items, which are reliable and those that are not, but also must be sufficiently general to account for the complexities that arise in making this determination (Hamada *et al*., 2008).

From this definition of reliability, we see that reliability analyses often involve the analysis of binary outcomes (0, 1) (i.e., success = 1/failure data = 0) (Hamada *et al*., 2008).

Let *T* a continuous random variable, taking values on the real line. There are many ways to specify the properties of a random variable (Hamada *et al*., 2008). The first way it's the probability density function is a function (*P.d.f.*), *f* (*t*) that satisfies:

$$f(t) \geq 0 \quad -\infty < t < \infty$$

and

$$\int_{-\infty}^{\infty} \mathrm{f(t)\ dt} = 1$$

When *T* is Weibull random variable with three parameters, denote (3P), the probability density function for *T* is:

$$f\ (t;\lambda,\beta,\theta) = \lambda\beta(t-\theta)^{\beta-1}\exp\left[-\lambda(t-\theta)^{\beta}\right],\ 0 \leq \theta < t,\quad \beta > 0,\ \lambda > 0, \qquad (1)$$

where,
θ : The location
λ : The scale
β : The shape of the distribution

A second way to specify the properties of a random variable is through its reliability function, also known as the survival function (Hamada *et al*., 2008). We define the reliability function as:

$$\mathrm{R(t) = p(T >} t) = \int_{\mathrm{t}}^{\infty} \mathrm{f(s)\ ds}$$

where, *f* (*t*) is a probability density function.

The reliability function for the Weibull distribution (3P) random variable is:

$$\mathrm{R(t) = p(T >} t) = \int_{\mathrm{t}}^{\infty} \lambda\beta(s-\theta)^{\beta-1}\exp\left[-\lambda(s-\theta)^{\beta}\right] \mathrm{ds}$$

$$= \exp\left[-\lambda(t-\theta)^{\beta}\right] \qquad (2)$$

Another way to specify the properties of *T* is the cumulative distribution function. Mathematically:

$$\mathrm{F(t) = P(T \leq t)} = \int_{-\infty}^{\mathrm{t}} \mathrm{f(s)\ ds}$$

The cumulative distribution function is the complement of the reliability function, so it is also called the unreliability function (Hamada *et al*., 2008).

The cumulative distribution function for the Weibull distribution (3P) random variable is:

$$\mathrm{F(t) = P(T \leq t)} = \int_{0}^{\mathrm{t}} \lambda\beta(s-\theta)^{\beta-1}\exp\left[-\lambda(s-\theta)^{\beta}\right] \mathrm{ds}$$

$$= 1 - \exp\left[-\lambda(t-\theta)^{\beta}\right] \qquad (3)$$

where, *f* (*t*) is a probability density function for a Weibull distribution (3P) random variable. The forth way to specify the properties of a random variable is the hazard function, also called the instantaneous failure rate function (Hamada *et al*., 2008):

$$\mathrm{h(t)} = \frac{\mathrm{f(t)}}{\mathrm{R(t)}}$$

For more detailed treatment, see (Hamada *et al*., 2008). The cumulative hazard rate is also referred to as hazard function.
Mathematically (Zhao and Qin, 2007):

$$\overline{\mathrm{F(t)}} = \exp[-\mathrm{H(t)}]$$

So

$$\mathrm{H(t)} = -\log[\mathrm{R(t)}]$$

where, $h(t)$ is a hazard function. The hazard function and cumulative hazard function for the Weibull distribution (3P) random variable are:

$$\mathrm{h(t)} = \frac{\lambda\beta\left(t-\theta\right)^{\beta-1}\exp\left[-\lambda\left(t-\theta\right)^{\beta}\right]}{\exp\left[-\lambda\left(t-\theta\right)^{\beta}\right]} = \lambda\beta\left(t-\theta\right)^{\beta-1} \quad (4)$$

$$\mathrm{H(t)} = -\log[\exp(-\lambda\,(t-\theta)^{\beta})] = \lambda\left(t-\theta\right)^{\beta} \quad (5)$$

The functions $f(t)$, $F(t)$, $R(t)$ and $h(t)$ are called "failure functions."

Problem statement: The present study describes a case study of step down station transformers that transform electricity from 33000 to 11000 KV. The data were collated from the principal records of the maintenance department stations. The main problem faced was that the failure data were record manually. To deal with this, we wrote the dates of breakdowns for these stations and calculated them together with the TBF for the period under a case study. For example, the first breakdown was on 15th Jan and the second breakdown was on 24th Apr; the operation time TBF was equal to 91 days. The period was for five years.

We studied and analyzed the TBF from an electricity distribution company in Baghdad, Iraq. Where we visited the maintenance department and met with the engineers and technicians. These meetings allowed us to study the reliability of these stations and find the optimal method to maintain them. This list was also needed for further study and analysis, in light of the difficult conditions and scarcity of electric power in Iraq. Furthermore, the meetings took place for several days, accompanied by the codification of technical notes and the experiences of workers repairing these stations to aid our study of these phenomena.

The power stations under a case study included Three Transformers. Each one of these transformers had a circuit breaker with limited capacities (1200 A) that acted as the main circuit breaker for the transformers. Connected between the conduction pieces are the Bas-Bar, which are linked with a group of feeders to each of the transformers. The first, second and third transformers are separated by circuit breakers with limited capacities of 800 A, called the Bas-Section circuit breaker. Each feeder has a circuit breaker with a capacity of 400 A. The main circuit breaker should be switched ON and the Bas-Section circuit breaker should be switched OFF, if the transformers are operating. However, if one of these transformers stops due to any failure, the circuit breakers for these transformers should have to be switched OFF and the Bas-Section circuit breaker is switched ON to provide electricity to the broken transformer feeders. Through study and analysis, we created a representation of the station as described in the records of the chamber for scientific verification and analysis as shown in Fig. 1.

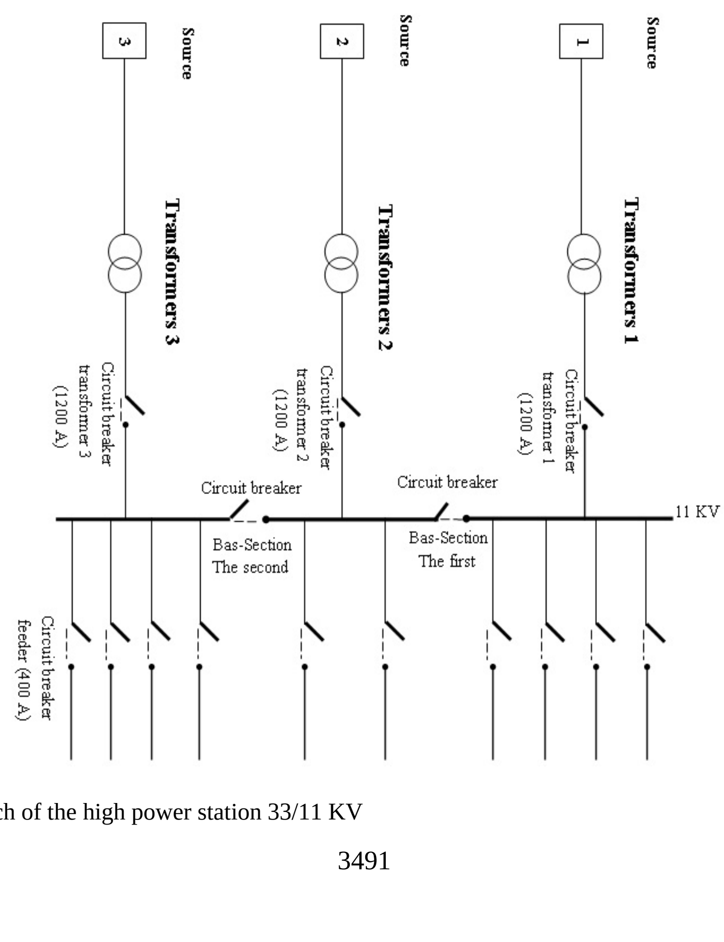


Fig. 1: The geometric sketch of the high power station 33/11 KV

RESEARCH METHODOLOGY

In the current study, the main focus is on the performance of a station component that fails randomly, i.e., the TBF is a random variable. In this case, a statistical function to identify a statistical distribution to TBF was studied. A goodness of fit for this statistical distribution was tested, including the use of the Kolmogorov-Smirnov and erson-Darling and Chi-square test. We also used the distribution fitting software "EasyFit" to display the goodness of fit reports, including the test statistics and critical values calculated for various significance levels (α = 0.2, 0.1, 0.05, 0.02, 0.01). The histogram was based on sample data. To define the number of vertical bars based on the total number of observations, we used the equation, $Q = 1 + \log_2 N$, where N is the total number of TBF and Q is the resulting number of classes. The height of each histogram bar indicates how many of the data points fall into that class. Distribution graphs are used to support the result of goodness of fit. There are several common distribution graph types that can be applied. The current study used five useful graph types: Probability Density Function (PDF) Graph, Cumulative Distribution Function (CDF) Graph, Probability-Probability (P-P) plot, Quantile-Quantile (Q-Q) plot and Probability Difference Graph (Dif).

The (PDF) Graph displays the theoretical probability density function of the fitted distribution, i.e., for continuous distributions. The PDF is formulated in terms of an integral between two points:

$$P\{a \leq X \leq b\} = \int_a^b f(x)dx$$

The (CDF) Graph displays the theoretical Cumulative Distribution Function of the fitted distributions and the empirical CDF based on the sample data. Furthermore, the PDF graph mainly shows the shape of the data. The CDF graph is useful in showing how well the distributions fit to data. The (P-P) plot is a graph of the experimental CDF values plotted against the theoretical (fitted) CDF values. It is used to determine how well the specific distribution fits the recorder data. The P-P plot will be roughly linear if the specified theoretical distribution is the correct model. The graph of the quantiles (inverse CDF values) of the fitted distribution against input data values plotted is a Quantile-Quantile plot. The analysis of the Q-Q plot is similar to that of the P-P plot: if the distribution you are testing is the correct model, the graph points will lie on a nearly upright line. The Dif graph is a scheme of the difference between the experimental cumulative distribution's function and the fitted CDF. The probability difference graph is nearer to the classical goodness of fit tests. Furthermore, the Kolmogorov-Smirnov test is based on measuring the difference of probabilities. The best fit is the less absolute value of this difference: if the maximum absolute difference is less than 0.05 (or 5%), the fit can be considered good. For very good fits, this value will be less than 1%.

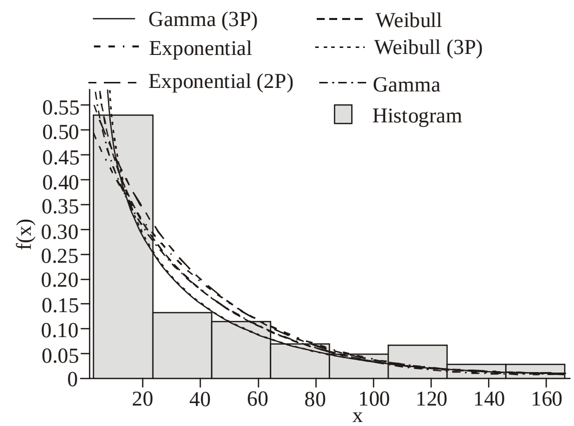


Fig. 2: Probability density function of TBF for the station

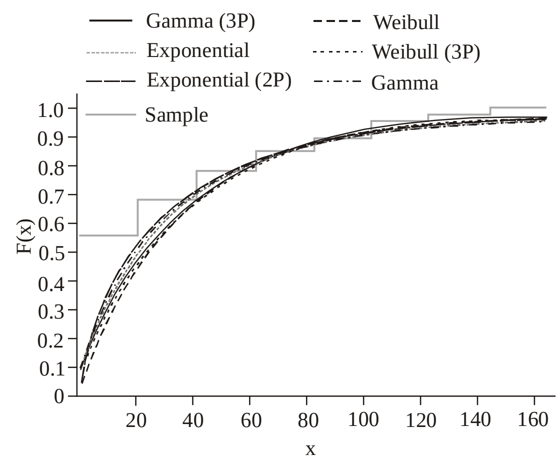


Fig. 3: Cumulative distribution function of TBF for the station

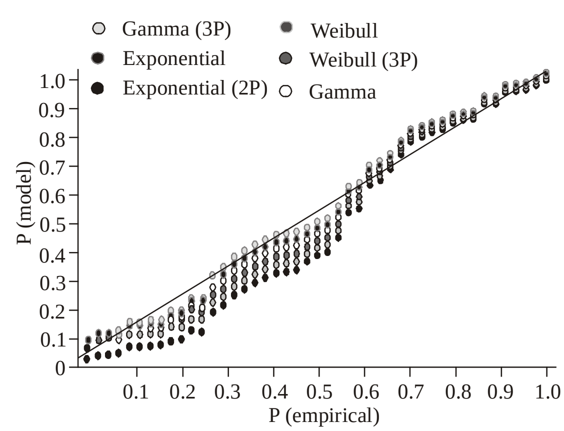


Fig. 4: Probability-probability plot for the distributions under analysis

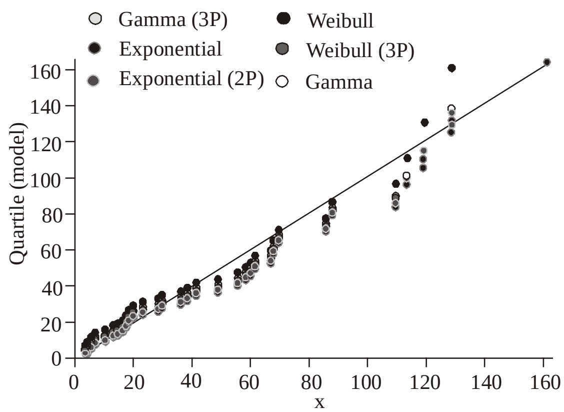


Fig. 5: Quantile-quantile plot for the distributions under analysis

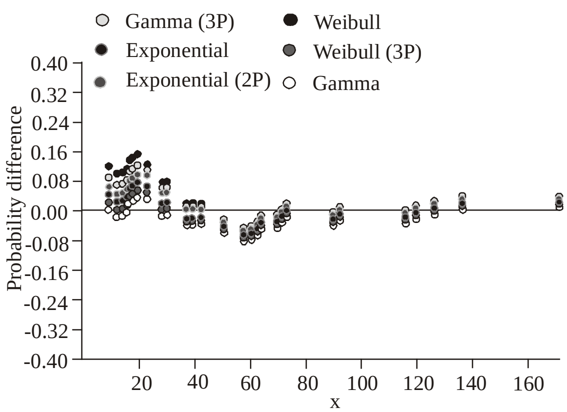


Fig. 6: Probability difference graph for the distributions under analysis

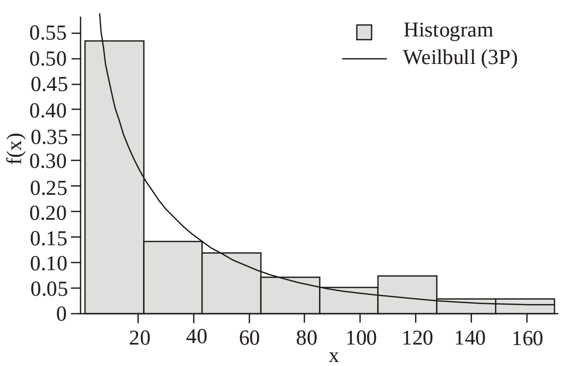


Fig. 7: PDF for the weibull distribution (3P) and TBF for the station

Data collection and analysis: Data for TBF were collected from an electricity distribution company in Baghdad, Iraq. The sample included ten stations and the study period was for 5 years. After analysis and testing the data under many distributions using EasyFit software, we found through the optimal analysis of the data that they follow the Weibull distribution (3P) (β = 0.75169, λ = 32.125, θ = 1.9375). The idea

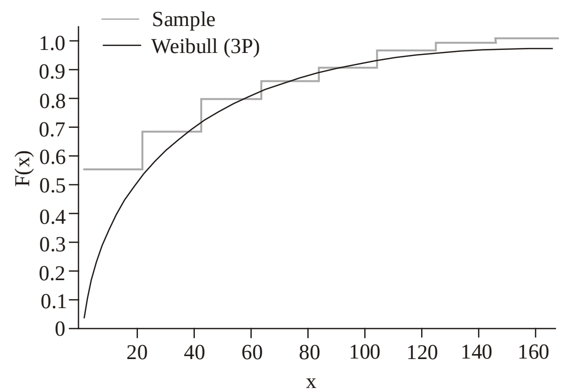


Fig. 8: CDF for the weibull distributions and TBF for the station

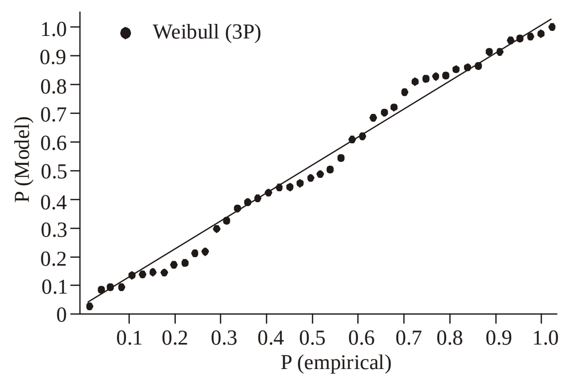


Fig. 9: Probability-probability plot for the weibull distributions (3P) and TBF for the station

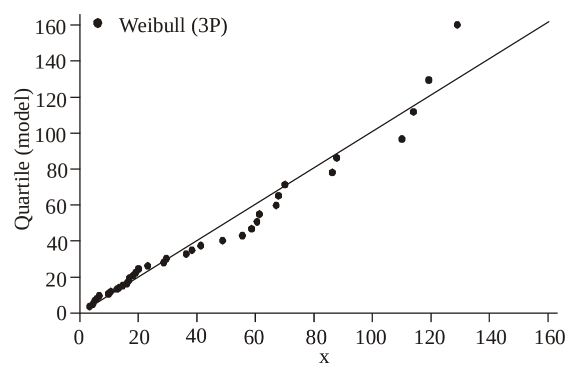


Fig. 10: Quantile-quantile plot for the weibull distributions (3P) and TBF for the station

underlying the goodness of fit tests is to measure the "distance" between the data and the distribution being tested and then comparing that distance to some threshold value. The goodness of fit reports that involve the test statistics and critical values calculated for diverse significance levels are as follows: α = 0.2, 0.1, 0.05, 0.02 and 0.01. Furthermore, if the threshold value (the critical value) is more than the distance (called the test statistic), the fit is good. Since the goodness of fit test statistics indicates the distance between the data

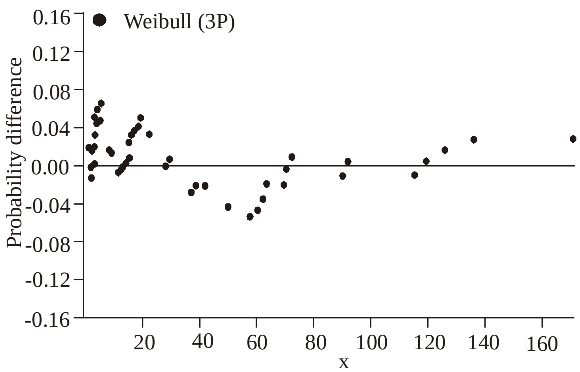


Fig. 11: Probability difference graph for the weibull distribution (3P) and TBF for the station

and the provided distributions, it is obvious that the distribution with the lowest statistic value is the best-fitting model. Based on this fact, each distribution is ranked (1 = the very best model, 2 = the next-best model and so on) as regards the highest p-value of the Kolmogorov-Smirnov test. These outcomes help us easily compare the fitted models and select the most valid one. The results of the analysis for much closer distributions are shown in Fig. 2 to 6.

The results of the good fitting for Weibull distribution (3P) are shown in Fig. 7 to 11. The results for goodness of fit for the distributions under analysis are shown in Tables 1, 2 and the results for goodness of fit for the Weibull distribution (3P) is shown in Table 3.

Table 1: The summary of goodness of fit sorted by distribution name

		Kolmogorov smirnov		Anderson darling		Chi-squared	
	Distribution	Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Exponential	0.13876	5	1.11380	4	3.6981	4
2	Exponential (2P)	0.16380	6	2.89140	5	6.7906	5
3	Gamma	0.11403	4	0.69961	2	1.6978	1
4	Gamma (3P)	0.10311	3	4.29110	6	N/A	
5	Weibull	0.09910	2	0.67700	1	2.2951	3
6	Weibull (3P)	0.08736	1	0.73276	3	2.0981	2

Table 2: The summary of goodness of fit sorted by rank resulting from the Kolmogorov-Smirnov test

		Kolmogorov smirnov		Anderson darling		Chi-squared	
	Distribution	Statistic	Rank	Statistic	Rank	Statistic	Rank
6	Weibull (3P)	0.08736	1	0.73276	3	2.0981	2
5	Weibull	0.09910	2	0.67700	1	2.2951	3
4	Gamma (3P)	0.10311	3	4.29110	6	N/A	
3	Gamma	0.11403	4	0.69961	2	1.6978	1
1	Exponential	0.13876	5	1.11380	4	3.6981	4
2	Exponential (2P)	0.16380	6	2.89140	5	6.7906	5

Table 3: The details for goodness of fit for weibull distribution (3P)

Kolmogorov-Smirnov					
Sample size	45				
Statistic	0.08736				
p-value	0.85263				
Rank	1				
α	0.2	0.1	0.05	0.02	0.01
Critical value	0.15623	0.17856	0.19837	0.22181	0.23798
Reject?	No	No	No	No	No
Anderson-darling					
Sample size	45				
Statistic	0.73276				
Rank	3				
α	0.2	0.1	0.05	0.02	0.01
Critical value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-squared					
Deg. of freedom	3				
Statistic	2.0981				
p-value	0.55231				
Rank	2				
α	0.2	0.1	0.05	0.02	0.01
Critical value	4.6416	6.2514	7.8147	9.8374	11.345
Reject?	No	No	No	No	No

CONCLUSION

In this study, the TBF has been analyzed in order to find the fitting distribution. In this analysis, we calculated the number of failures based on original failure data from the station of the company being studied. After running the software and recording the optimal distribution, we found that the Weibull distribution (3P) could be the best distribution among the others. However, it seems the data could still not lead to accurate results since quantitative tests (Chi-squared and Kolmogorov-Smirnov tests) have yet to be rejected in each distribution except Gamma (3P) and Exponential (2P) distributions (for more information see Appendix A). Looking at the qualitative tests (such as Quintile-Quintile plot, Fig. 5) it seems that Weibull distribution (3P) for whole TBF is more acceptable; therefore, we decided to focus on the top ranked element in the goodness of fit summary. The value of test statistic for Weibull distribution (3P) is 0.08736 and the critical values are 0.15623, 0.17856, 0.19837, 0.22181 and 0.23798, with significance levels $\alpha = 0.2$, 0.1, 0.05, 0.02 and 0.01, respectively. It is apparent that the statistic value is less than all critical values, which means that TBF is distributed Weibull with three parameters: shape parameter $\beta = 0.75169$, scale parameter $\lambda = 32.125$ and location parameter $\theta = 1.9375$. The Weibull distribution model, in addition to illustrating a previously unknown fault, can also be used to implement the easy matching of behavior from the data to a particular distribution. This can be applied by analyzing the shape parameter value (β) from the Weibull distribution, as shown in the figures listed in Appendix B. If the value of the shape parameter is small, it means that the station in the first stage may lead to a failure. Applying the proposed method makes it easier to reach the same result so as to extract reliability; this method derived from analyzing the Weibull distribution is called *Weibayes*.

Our future research will aim to find the reliability value for each part of the station. We will also calculate the total reliability of the station regardless of whether the station has sequential, parallel or mixed system. We will then develop a mathematical maintenance model for the station.

Appendix A: The results of goodness of fit (Kolmogorov-Smirnov, Anderson-Darling and Chi-square tests) sorted by rank of Kolmogorov-Smirnov

Table A.1: The values of two-parameter weibull distribution for goodness of fit

Weibull [#5]					
Kolmogorov-Smirnov					
Sample size	45				
Statistic	0.0991				
p-value	0.73153				
Rank	2				
α	0.2	0.1	0.05	0.02	0.01
Critical value	0.15623	0.17856	0.19837	0.22181	0.23798
Reject?	No	No	No	No	No
Anderson-Darling					
Sample size	45				
Statistic	0.677				
Rank	1				
α	0.2	0.1	0.05	0.02	0.01
Critical value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
Chi-squared					
Deg. of freedom	4				
Statistic	2.2951				
p-value	0.68167				
Rank	3				
α	0.2	0.1	0.05	0.02	0.01
Critical value	5.9886	7.7794	9.4877	11.668	13.277
Reject?	No	No	No	No	No

Table A.2: The details for goodness of fit for gamma distribution (3P)

Gamma (3P) [#4]					
Kolmogorov-Smirnov					
Sample size	45				
Statistic	0.10311				
p-value	0.68653				
Rank	3				
α	0.2	0.1	0.05	0.02	0.01
Critical value	0.15623	0.17856	0.19837	0.22181	0.23798
Reject?	No	No	No	No	No
Anderson-Darling					
Sample size	45				
Statistic	4.2911				
Rank	6				
α	0.2	0.1	0.05	0.02	0.01
Critical value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	Yes	Yes

Table A.3: The details for goodness of fit for two-parameter gamma distribution

Gamma [#3]					
Kolmogorov-Smirnov					
Sample size	45				
Statistic	0.11403				
p-value	0.56316				
Rank	4				
α	0.2	0.1	0.05	0.02	0.01
Critical value	0.15623	0.17856	0.19837	0.22181	0.23798
Reject?	No	No	No	No	No
Anderson-Darlin					
Sample size	45				
Statistic	0.69961				
Rank	2				
α	0.2	0.1	0.05	0.02	0.01
Critical value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
χ^2					
Deg. of freedom	5				
Statistic	1.6978				
p-value	0.88918				
Rank	1				
α	0.2	0.1	0.05	0.02	0.01
Critical value	7.2893	9.2364	11.07	13.388	15.086
Reject?	No	No	No	No	No

Table A.4: The details for goodness of fit for one-parameter exponential distribution

Exponential [#1]					
Kolmogorov-Smirnov					
Sample size	45				
Statistic	0.13876				
p-value	0.32136				
Rank	5				
α	0.2	0.1	0.05	0.02	0.01
Critical value	0.15623	0.17856	0.19837	0.22181	0.23798
Reject?	No	No	No	No	No
Anderson-Darling					
Sample size	45				
Statistic	1.1138				
Rank	4				
α	0.2	0.1	0.05	0.02	0.01
Critical value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No
χ^2					
Deg. of freedom	4				
Statistic	3.6981				
p-value	0.44841				
Rank	4				
α	0.2	0.1	0.05	0.02	0.01
Critical value	5.9886	7.7794	9.4877	11.668	13.277
Reject?	No	No	No	No	No

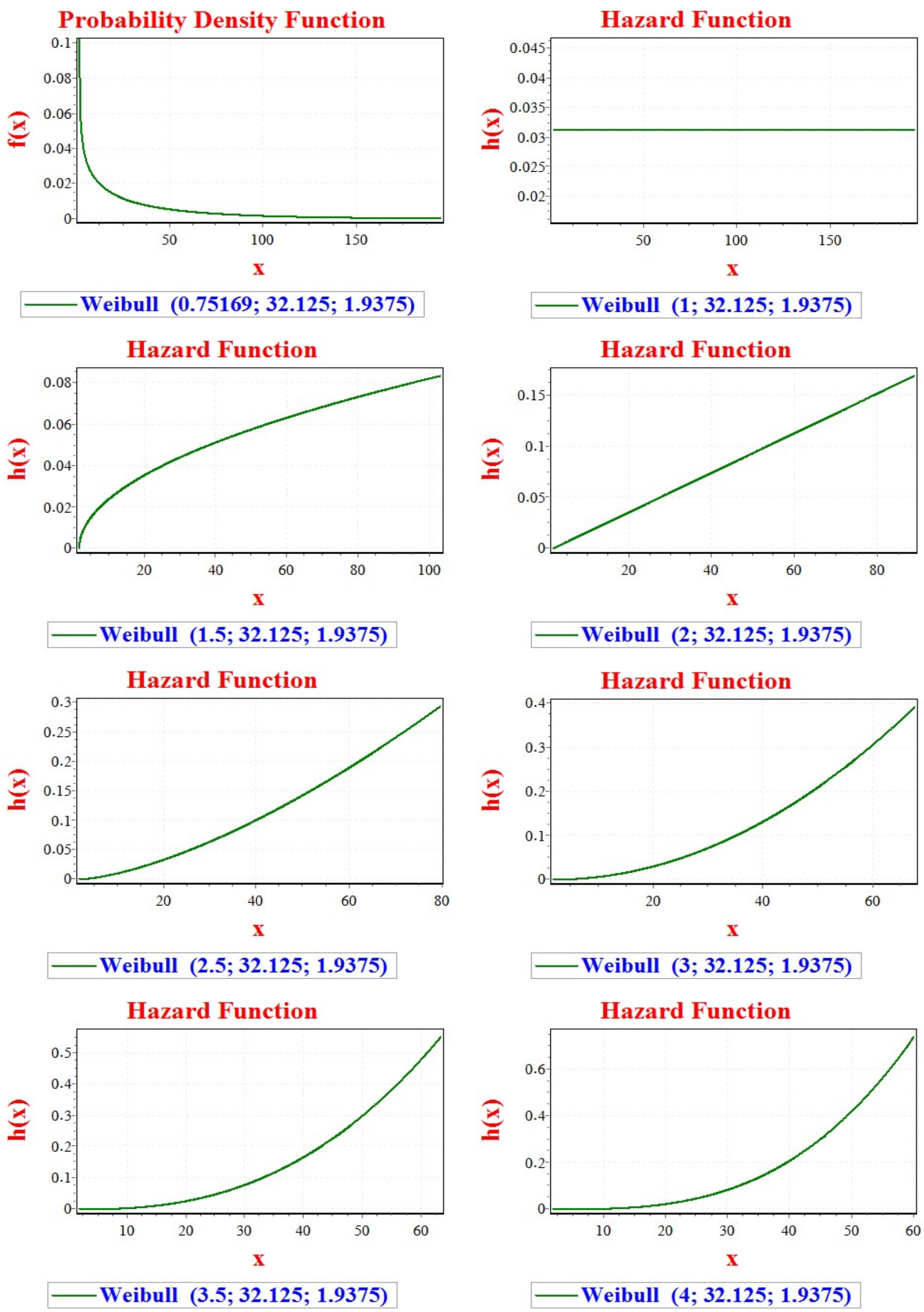
Table A.5: The details for goodness of fit for two-parameter exponential distribution

Exponential (2P) [#2]					
Kolmogorov-Smirnov					
Sample size	45				
Statistic	0.1638				
p-value	0.15973				
Rank	6				
α	0.2	0.1	0.05	0.02	0.01
Critical value	0.15623	0.17856	0.19837	0.22181	0.23798
Reject?	Yes	No	No	No	No
Anderson-Darling					
Sample size	45				
Statistic	2.8914				
Rank	5				
α	0.2	0.1	0.05	0.02	0.01
Critical value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	Yes	Yes	Yes	No	No
χ^2					

Table A.5: (Continue)

Exponential (2P) [#2]					
Deg. of freedom	4				
Statistic	6.7906				
p-value	0.14738				
Rank	5				
α	0.2	0.1	0.05	0.02	0.01
Critical value	5.9886	7.7794	9.4877	11.668	13.277
Reject?	Yes	No	No	No	No

Appendix B: The effects of changing the value of a shape parameter (α) in the mode of failure rate function



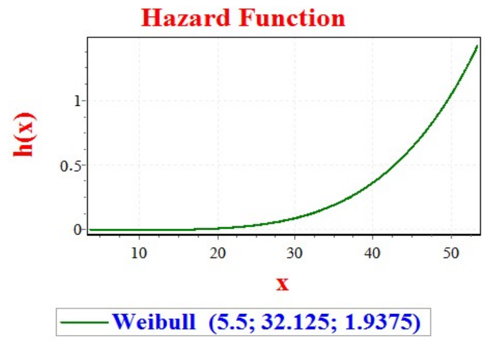


Fig. B.1: Illustration the effect on failure rate function when changing the value of a shape parameter (β)

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