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Reliability Model of Medical Equipment in University of Port Teaching Hospital

N. P. Akpan[1] and E. R. Anyi-Akparanta[2]

[1] Department of Mathematics and Statistics, University of Port Harcourt, Nigeria
e-mail: nsipaulakpan@gmail.com

[2] Department of Mathematics and Statistics, University of Port Harcourt, Nigeria

Abstract

In this research, on medical equipment maintainability and reliability we conducted basic statistics analysis using University of Port Harcourt Teaching Hospital as the case study; the data collected covered 18 departments, namely; Anatomical Pathology, Micro Biology, Chemical Pathology Laboratory, Radiography Department, Pediatrics, Hemodialialysis, Hematology and Blood Transfusion, Physiotherapy, Dental Department, MDR-TB unit, Pharmacy, ICU, Assisted Conception Unit, Orthopedic Ward, Care for Elderly Laboratory, Family Planning Unit, Community Medicine and Labour Ward. The results of the parametric Weibull distribution percentile suggested that the reliability of the devices tends to fail every 21 days. The reliability plot of the model indicated that the devices tend to decrease its life span with age, the Weibull model was adequately fitted following the results of Anderson adjust test of goodness of fit and the probability plot. In comparison, the Probability value of goodness of fit P(0.0000) of Weibull distribution model was compared with that of exponential distribution model P(0.034), the outcome showed that Weibull distribution is better to model the data of medical equipment in University of Port Harcourt Teaching Hospital.

1. Introduction

Modern health services rely heavily on medical gadgets for patient monitoring, diagnosis, and treatment. They are gradually being implemented to improve the capacity of medical diagnostic and therapeutic services. However, most developing nations still

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have limited capacity to handle and maintain medical equipment [12]. Meeting the issues of an ever-increasing number and utilization of medical devices requires the development of powerful management strategies and practical solutions.

A medium to large-sized hospital today likely has anywhere from 5,000 to over 10,000 different types of medical devices. Hospitals and healthcare organizations must guarantee the safety, accuracy, dependability, and optimal performance of their vital medical instruments. Hospitals must create and implement a Medical Equipment Management Program (MEMP) that outlines risk management for medical equipment to accomplish these goals. A key component of such a program is inspection and preventive maintenance, which needs to be regularly examined and enhanced to meet the rising standards of healthcare organizations and the current rate of medical equipment technical advancement. Maintenance decisions that are both economical and effective can be made after a full understanding, application, and leadership of maintenance excellence in healthcare organizations. According to [2], maintenance excellence involves striking equilibrium between cost, resource inputs, performance, and risk to arrive at the best possible solution.

But in Canada, the majority of healthcare facilities, if not all of them just follow the manufacturers' advice for preventive maintenance and include all of their medical equipment in their programs. It is challenging to pinpoint specific risks and implement the best risk-reduction measures using the maintenance procedures currently used in hospitals and other healthcare facilities [6]. Furthermore, the use of reliable engineering tools in the medical industry is new, even though their use is well known. The majority of this research only makes recommendations on how to evaluate or enhance the dependability of devices during the design or production phases. The optimal maintenance plans for medical equipment within its operational environment have not yet been taken into account.

Hospitals created the Medical Equipment Management Program (MEMP) to ensure the safe and dependable operation of medical equipment and to encourage its efficient use [8]. This program lays out guidelines and rules to oversee the selection, purchase, and decommissioning of medical equipment. MEMP makes ensuring that medical equipment can function securely for patients, give physicians accurate and dependable information, and be utilized to the maximum extent possible [9]. For efficient administration, the life cycle of medical devices should be carefully taken into account. Inadequate management of each life cycle stage, particularly in the early stages, might exacerbate issues in later stages. For instance, it may be easier to overcome potential difficulties when it comes to equipment maintenance if maintenance capabilities are taken into account during the purchase stage. The stages of a typical medical equipment life cycle [3]. Each phase can benefit from the others when it is managed well.

2. Reviews of Related Work

[14] Conducted a systematic review of medical equipment reliability assessment to improve the quality of healthcare services. They noted that medical equipment plays a significant role in the effectiveness of healthcare services quality. Typically, medical equipment malfunctions or is unavailable in healthcare institutions, which impacts the provision of healthcare services to the general public. The issues are usually the result of the accountable party's poor management and upkeep of the medical equipment. To improve availability, performance, and safety during the maintenance and management of the equipment life cycle, the condition evaluation of medical equipment is a crucial task. Medical equipment criticality is evaluated by [4, 11, 7, 10]. Furthermore, by considering the various failure modes of a device and evaluating their frequency, detectability, and ramifications, the model provides a realistic estimate of the overall risk associated with it. The failure modes are examined with the risk's sub-criteria after being taken from the device's failure history which is accessible in the hospital's CMMS

A study on a reliability decision framework for multiple units was carried out by [5]. The findings provided a framework for choosing the right reliability model for large numbers of repairable units. Using the suggested framework can make it easier to choose the right dependability model when working with large, non-homogeneous numerous repairable units. This framework is system-based and is displayed as multiple sub-systems.

[13] asserts that healthcare institutions are capable of optimizing maintenance costs, enhancing monitoring activities, managing maintenance tasks with available workforces and resources, giving priority to PM and CM, determining the equipment's actual lifespan for RP, and choosing the most appropriate maintenance management strategy based on the current circumstances by consulting the output indicator.

According to [1], who conducted an investigation on Critically-based Reliability-Centered Maintenance for Healthcare, medical technology and assets are a major contributing factor to rising healthcare costs. Hospitals are now required to establish and oversee medical equipment management systems to guarantee the safety and dependability of vital devices due to the growing quantity and complexity of medical equipment. This study aims to provide an understanding of the actions associated with medical equipment maintenance management. This study suggests selecting maintenance tasks for medical equipment using a customized reliability-centered maintenance (RCM) strategy. Using this strategy will help asset management teams increase efficiency, lower risk, and expenses, and ultimately improve the health of the patients this equipment serves.

The researchers stated; and confirmed that the maintainability and reliability model of a device may be affected by internal or external factors such as operating conditions, maintenance, environmental stress, and the expertise level of operating on the device. However, it is a common belief in the HealthCare sector, that medical devices fail independent of age following the studies of the distribution of the exponential distributions [3b]. Based on that, we extend our research work to employ the method for maintenance of medical devices' statistical analysis of Exponential distribution and Weibull distribution on field data.

3. Methodology

3.1. The exponential distribution for reliability

Let define the reliability time of n devices $t_1, t_2, \dots, t_n$, and assumed it follows an exponential distribution with mean λ^{-1}, then we have the hazard function to be

$$h(t) = \lambda. \tag{3.1}$$

For $0 \le t < \infty$, then the parameter λ is a positive constant that would be estimated by fitting the model to the observed data. From the equation (3.7) the corresponding reliability function is

$$R(t) = exp\left\{-\int_0^t \lambda du\right\}$$

$$R(t) = e^{-\lambda t}. \tag{3.2}$$

That implied the probability density function of the reliability time is

$$f(t) = \lambda e^{-\lambda t}. \tag{3.3}$$

For $0 \leq t < \infty$, then equation (3.2) is the probability density function of a random variable t that has an exponential distribution with a mean λ^{-1}. Much convenient to be written as $\mu = \lambda^{-1}$, so that the hazard function can be express in form of μ^{-1}, and the reliability distribution has a mean of μ.

3.2. The Weibull distribution analysis for reliability

The practical assumption of a constant hazard function of Weibull distribution is almost equivalently to that of exponential distribution reliability times is rarely tenable. A more general form of hazard function of Weibull distribution is such that, we express as it follows;

$$h(t) = \lambda \gamma t^{r-1}. \tag{3.4}$$

For $0 \leq t < \infty$, a function that depends on two parameters λ and γ, which are both greater than zero. In the particular case where $\gamma = 1$, the hazard function takes a constant value λ and the reliability time have exponential distribution. For the values of γ, the hazard function increases or decreases monotonically, that is, it does not change direction. The shape of the hazard function depends critically on the values of γ and so γ is known as the shape parameter, while the parameter λ is the scale parameter.

So for this particular choice of hazard function, the reliability function is given as follow;

$$R(t) = exp\left\{-\int_0^t \lambda \gamma u t^{r-1} du\right\} = exp(-\lambda t^r). \tag{3.5}$$

Therefore the corresponding probability density function is as follow:

$$f(t) = \lambda \gamma t^{r-1} exp(-\lambda t^r). \tag{3.6}$$

For $0 \leq t < \infty$, which is the density of a random variable that has a Weibull distribution with scale parameter λ and shape parameterγ, the right hand tail of this distribution is longer that the left hand one, and so the distribution is positively skewed.

Knowing, the probability density function, reliability and the hazard function of a $W(\lambda, \gamma)$ distribution are given as follows;

$$f(t) = \lambda \gamma t^{r-1} exp(-\lambda t^r)$$

$$exp(-\lambda t^r)$$

and

$$h(t) = \lambda\gamma t^{r-1}$$

and so, by applying equation (3.6), the likelihood of the reliability time of Weibull distribution can be express as follow

$$\prod_{i=1}^{n} \{\lambda\gamma t_i^{r-1} exp(-\lambda t_i^r)\}^{\delta i} \{exp(-\lambda t_i^r)\}^{1-\delta}$$

where, δi is zero if the ith reliability time censored and unity otherwise, it will take a similar expression of equation, then the likelihood function can be written as

$$\prod_{i=1}^{n} \{\lambda\gamma t_i^{r-1}\}^{\delta i} \; exp(-\lambda t_i^r).$$

This is regarded as a function of λ and γ, the unknown parameters in the Weibull distribution, and so can be written $L(\lambda, \gamma)$. The corresponding log likelihood function is given as

$$log\ L(\lambda, \gamma\,) = \sum_{i=1}^{n} \delta_i \log\,(\lambda r) \,+ (r-r) \sum_{i=1}^{n} \delta_i \log\,(t_i) - \lambda \sum_{i=1}^{n} t_i^r.$$

So, the maximum likelihood estimates of λ and γ, are found by differentiating this function with respect to λ and γ, equating the derivatives to be zero, and evaluating them at $\hat{\lambda}$ and $\hat{r}$. Now the equation becomes

$$\frac{r}{\hat{\lambda}} - \sum_{i=1}^{n} t_i^r = 0 \tag{3.7}$$

and

$$\frac{r}{\hat{r}} + \sum_{i=1}^{n} \delta_i log t_i - \hat{\lambda} \sum_{i=1}^{n} t_i^r \, log t_i \, = 0. \tag{3.8}$$

From equation (3.8), we have

$$\hat{\lambda} = {}^{r}\!/_{\sum_{i=1}^{n} t_i^r} \tag{3.9}$$

And on substituting for $\hat{\lambda}$ in equation (3.9), we have

$$\frac{r}{\hat{r}} + \sum_{i=1}^{n} \delta_i log t_i - {}^{r}\!/_{\sum_{i=1}^{n} t_i^r} \sum_{i=1}^{n} t_i^r \, log t_i \, = 0. \tag{3.10}$$

4. Results and Discussion

4.1. Data

In this research, we analyzed manufactured year of devices data collected in the year 2022 December, from the University of Port Harcourt Teaching Hospital. The statistical analysis is based on the functional devices (equipment). This statistical analysis is to learn about the statistical reliability and maintainability of the devices. However, the data collected is limited to some departments, namely; Anatomical Pathology, Micro Biology, Chemical Pathology Laboratory, Radiography Department, Pediatrics, Hemodialialysis, Hematology and Blood Transfusion, Physiotherapy, Dental Department, MDR-TB unit, Pharmacy, ICU, Assisted Conception Unit, Orthopedic Ward, Care for Elderly Laboratory, Family Planning Unit, Community Medicine and Labour Ward. Hence, dealing with some did not limit the results. Therefore, this research describes how the reliability and maintainability of the device data in the above-mentioned department can be statistically analyzed.

4.2.1. Presentation of Weibull Distribution

Variable: Duration in Month (t)

Estimation Method: Maximum Likelihood

Distribution: Weibull

Table 4.1: Parameter estimates of Weibull distribution

		Standard	95.0% Normal CI	
Parameter	Estimate	Error	Lower	Upper
Shape	1.40697	0.0920863	1.23758	1.59955
Scale	93.4382	6.04044	82.3185	106.060

Log-Likelihood = -727.745

Goodness-of-Fit

Anderson-Darling (adjusted) = 6.869

P 0.000

Table 4.2: Characteristics distribution of Weibull

		Standard	95.0% Normal CI	
	Estimate	Error	Lower	Upper
Mean(MTTF)	85.0959	5.27717	75.3567	96.0938
Standard Deviation	61.3045	4.80871	52.5683	71.4925
Median	72.0098	5.19517	62.5146	82.9472
First Quartile(Q1)	38.5433	3.86146	31.6717	46.9058
Third Quartile(Q3)	17.855	7.22183	104.517	132.894
Interquartile Range (IQR)	79.3116	5.35941	69.4732	90.5432

Table 4.3: Percentiles of Weibull distribution

		Standard	95.0% Normal CI	
Percent	Percentile	Error	Lower	Upper
0.1	0.689351	0.240064	0.348348	1.36417
1	3.55289	0.864439	2.20536	5.72380
2	5.83581	1.23730	3.85151	8.84241
3	7.81328	1.51423	5.34402	11.4235
4	9.62106	1.74067	6.74872	13.7159
5	11.3163	1.93462	8.09440	15.8207
6	12.9301	2.10549	9.39710	17.7913
7	14.4815	2.25888	10.6670	19.6602
8	15.9838	2.39850	11.9110	21.4491
9	17.4461	2.52691	13.1343	23.1732
10	18.8754	2.64601	14.3408	24.8439
20	32.1761	3.53293	25.9461	39.9020
30	44.9060	4.15149	37.4638	53.8265

40	57.9669	4.67446	49.4925	67.8924
50	72.0098	5.19517	62.5146	82.9472
60	87.8091	5.80539	77.1372	99.9576
70	106.616	6.64228	94.3608	120.463
80	131.044	7.98697	116.289	147.672
90	169.032	10.7060	149.298	191.373
91	174.493	11.1563	153.942	197.788
92	180.517	11.6689	159.036	204.900
93	187.250	12.2609	164.697	212.891
94	194.901	12.9575	171.090	222.026
95	203.797	13.7975	178.472	232.715
96	214.473	14.8464	187.262	245.638
97	227.927	16.2278	198.241	262.059
98	246.361	18.2201	213.117	284.789
99	276.646	21.7181	237.192	322.662
99.9	369.045	33.7944	308.413	441.597

Weibull distribution analysis using duration in month (t), in the analysis presented above, we compute the parameter estimate, which are the scale and shape, the standard error, 95% normal confidence interval with log-likelihood value of the distribution. We also obtained the characteristics of the distribution, namely; mean, standard deviation, median, first quartile (Q_1), and Third quartile (Q_3) of the distribution.

The results, as shown in Table 4.3 at the first row of the table, at about 0.1 (percentile) indicated that every 21 days, the devices under the research tend to fail. We understand that the values in the percentile column are estimates of times at which the corresponding percent of the devices tend to fail. The table also includes standard errors and an approximate 95% confidence interval for each percentile.

In the analysis of Weibull distribution, we also conducted a test of goodness of fit, using Anderson Darling (Adjusted). The result showed that the model is of good fit.

Since AD(adj) = 6.869 with a P-value of (0.000) < 0.005. We further our test to the shape parameter, the results indicated the P-value to be p(0.000), which means the system devices are degrading with age and there is a significant difference in the devices.

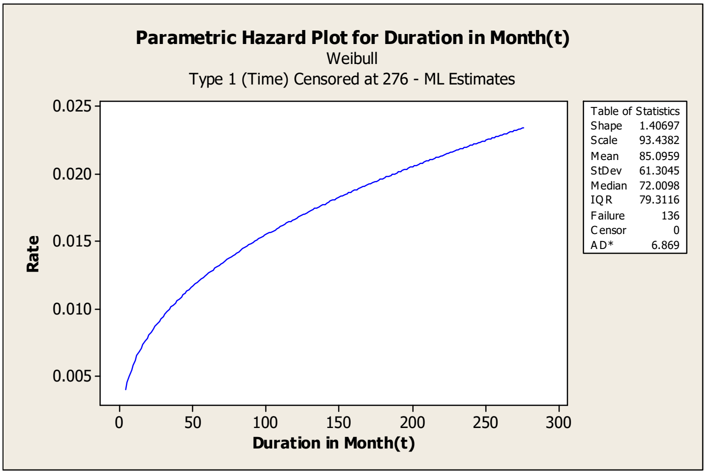

Figure 4.1: The parametric hazard plot of the devices using Weibull distribution.

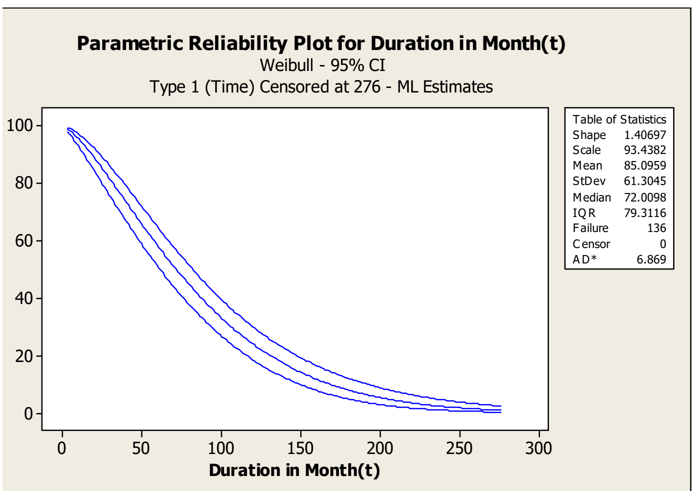

Figure 4.2: The parametric reliability plot of the devices using Weibull distribution.

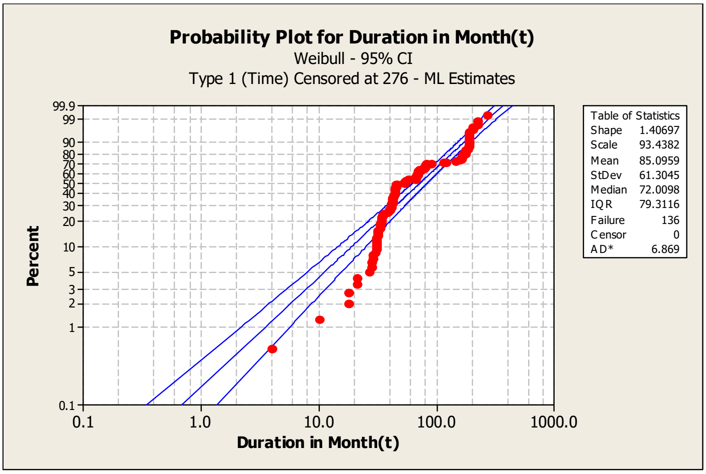

Figure 4.3: The probability plot of the devices using Weibull distribution.

The cumulative Failure plot in Figure 4.1 displays the failure probabilities versus time, and each plot point represents the cumulative percentage of the devices failing at the time. The curve is surrounded by two outer lines that have a 95% confidence interval for the curve, which provides value for the cumulative failure function. From the view and the understanding of our cumulative graph, we see that the failure rates are increasing with time.

The Reliability plot in Figure 4.2, of the Weibull distribution, is to display the reliability probability versus time (percentage). The point plot in every point represents the proportion of the device's reliability at time. The graph is always surrounded by two outer lines, which is the approximate 95% confidence interval for the curve, which provides a reasonable value for the reliability function. From our graph, we see that the device tends to decrease its life span, with age. The older the devices, the shorter the life span.

The parametric Weibull probability plot in Figure 4.3 displays failure times associated with the devices. The plot is one of the most interesting plots, and the closer the points fall into the fitted line the better the goodness of fit of the model. From our plot, we conclude that our probability plot is of good fit since most of the points are closer to the line of the fitted line.

4.3. Presentation of exponential distribution

Variable: Duration in Month (t)

Estimation Method: Maximum Likelihood

Distribution: Exponential

Table 4.4 Parameter estimates of exponential distribution

		Standard	95.0% Normal CI	
Parameter	Estimate	Error	Lower	Upper
Mean	84.4485	7.24140	71.3842	99.9038

Log-Likelihood = -739.315

Goodness-of-Fit

Anderson-Darling (adjusted) = 8.326

P 0.034

Table 4.5 Characteristics of exponential distribution

		Standard	95.0% Normal CI	
	Estimate	Error	Lower	Upper
Mean(MTTF)	84.4485	7.24140	71.3842	99.9038
Standard Deviation	84.4485	7.24140	71.3842	99.9038
Median	58.5353	5.01936	49.4798	69.2480
First Quartile(Q1)	24.2943	2.08322	20.5360	28.7405
Third Quartile(Q3)	117.071	10.0387	98.9595	138.496
Interquartile Range(IQR)	92.7762	7.95549	78.4236	109.756

Table 4.6: Percentiles of exponential distribution.

		Standard	95.0% Normal CI	
Percent	Percentile	Error	Lower	Upper
0.1	0.0844908	0.0072450	0.0714199	0.0999538
1	0.848736	0.0727785	0.717435	1.00407
2	1.70609	0.146296	1.44215	2.01833
3	2.57224	0.220567	2.17431	3.04299
4	3.44736	0.295608	2.91405	4.07827
5	4.33164	0.371435	3.66153	5.12440
6	5.22529	0.448065	4.41693	6.18159
7	6.12849	0.525514	5.18040	7.25009
8	7.04145	0.603800	5.95213	8.33014
9	7.96440	0.682942	6.73229	9.42200
10	8.89754	0.762958	7.52108	10.5259
20	18.8441	1.61587	15.9289	22.2929
30	30.1207	2.58283	25.4610	35.6332
40	43.1385	3.69909	36.4649	51.0334
50	58.5353	5.01936	49.4798	69.2480
60	77.3794	.63523	5.4087	91.5409
70	101.674	8.71845	85.9446	120.281
80	135.915	11.6546	114.888	160.789
90	194.450	16.6739	164.368	230.037
91	203.347	17.4369	171.889	240.563
92	213.294	18.2898	180.297	252.330
93	224.571	19.2568	189.829	265.670
94	237.588	20.3730	200.833	281.070

95	252.985	21.6933	213.848	299.285
96	271.829	23.3092	229.777	321.578
97	296.124	25.3924	250.313	350.318
98	330.365	28.3285	279.257	390.826
99	388.900	33.3479	328.736	460.074
99.9	583.350	50.0218	493.105	690.111

The results as shown in Table 4.6 at the first row of the table, at about 0.1 (percentile) indicated that at every 2.6 days, the devices under the research tend to fail. We also understand that the values in the percentile column are estimates of times at which the corresponding percent of the devices tend to fail. The table also includes standard errors and an approximate 95% confidence interval for each percentile.

We also conducted a test of goodness of fit, using Anderson Darling (Adjusted). The result showed that the model is not of good fit. Since AD(adj) = 8.326 with a P-value of (0.034) > 0.005.

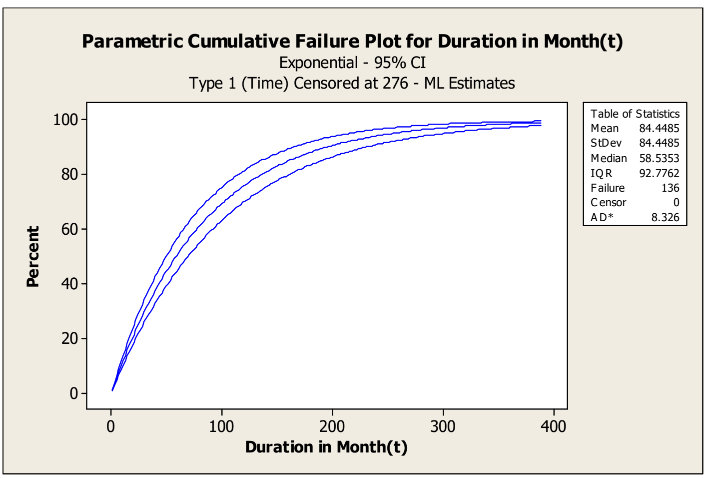

Figure 4.4: Plot of parametric cumulative failure of the devices using exponential distribution.

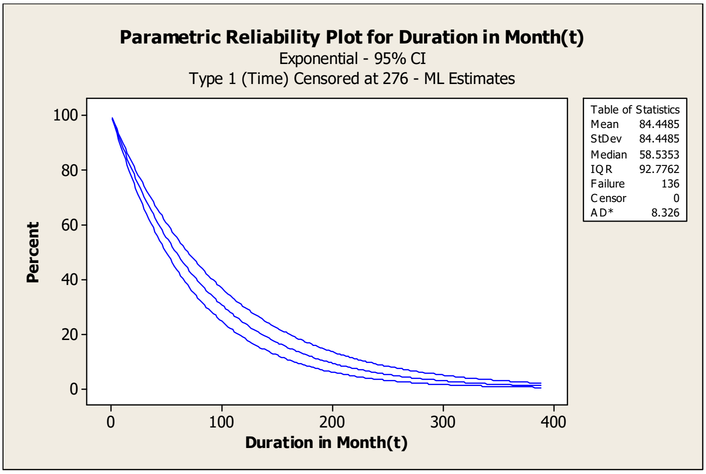

Figure 4.5: The parametric reliability plot of the devices using exponential distribution.

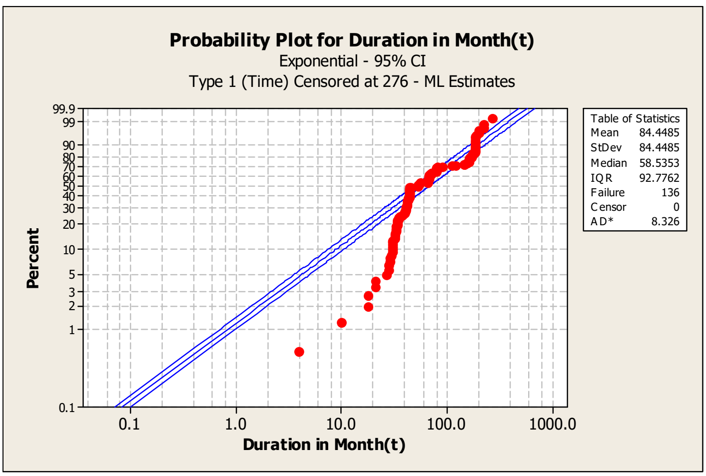

Figure 4.6: The probability plot of the devices using exponential distribution.

The graphical presentation of the exponential Cumulative Failure, the Reliability Plot, and the Probability Plot of the Model indicated that,

The cumulative Failure plot in Figure 4.4 displays the failure probabilities versus time and each plot point represents the cumulative percentage of the devices failing at time. The curve is surrounded by two outer lines which is a 95% confidence interval for the curve, which provides value for the cumulative failure function. From the view and the understanding of our cumulative graph, we see that the failure rates are increasing with time.

The Reliability plot in Figure 4.5, of the exponential distribution, is to display the reliability probability versus time (percentage). The point plot in every point represents the proportion of the device's reliability at time. The graph is always surrounded by two outer lines, which is the approximate 95% confidence interval for the curve, which provides a reasonable value for the reliability function. From our graph, we see that the device tends to decrease its life span, with age. The older the devices, the shorter the life span.

The parametric exponential probability plot in Figure 4.6 displays failure times associated with the devices. The plot is one of the most interesting plots, and the closer the points fall into the fitted line the better the goodness of fit of the model. From our plot, we conclude that our probability plot is not of good fit.

Conclusion

The data collected was correctly censored to obtain the duration (t) (that is the periods of the device's survival from the manufacture date to December 2022). The results of the parametric Weibull distribution percentile suggested that the reliability of the devices tends to fail every 21 days. This means that before 21 days maintenance for the equipment should be carried out to avoid failure during operation. The reliability plot of the model indicated that the devices tend to decrease its life span with age, the Weibull model was adequately fitted following the results of Anderson adjust test of goodness of fit and the probability plot. In comparison, the Probability value of goodness of fit P(0.0000) of Weibull distribution model was compared with that of exponential distribution model P(0.034), the outcome showed that Weibull distribution is better to model the data of medical equipment in University of Port Harcourt Teaching Hospital.

References

[1] Shamayleh, A., Awad, M., & Farhat, J. (2020). IoT based predictive maintenance management of medical equipment. *Journal of Medical Systems*, *44*, Article No. 72. https://doi.org/10.1007/s10916-020-1534-8

[2] Campbell, J. D., & Jardine, A. K. S. (2001). *Maintenance excellence: Optimizing equipment life-cycle decisions*. New York: Marcel Dekker.

[3] Cheng, M., & Dyro, J. F. (2004). Good management practice for medical equipment. In J. F. Dyro (Ed.), *Clinical engineering handbook* (pp. 108-110). San Diego: Elsevier. https://doi.org/10.1016/B978-012226570-9/50035-1

[4] Fennigkoh, L., & Smith, B. (1989). Clinical equipment management. *JCAHO Plant, Technology, and Safety Management Series*, *2*, 5-14.

[5] Garmabaki, A. H. S., Ahmadi, A., Block, J., Pham, H., & Kumar, U. (2016). A reliability decision framework for multiple repairable units. *Reliability Engineering & System Safety*, *150*, 78-88. https://doi.org/10.1016/j.ress.2016.01.020

[6] Rice, W. (2007). Medical device risk based evaluation and maintenance using fault tree analysis. *Biomedical Instrumentation and Technology*, *41*(1), 76-82.

[7] Ridgway, M. (2001). Classifying medical devices according to their maintenance sensitivity: a practical, risk-based approach to PM program management. *Biomedical Instrumentation and Technology*, 35(3), 167-176.

[8] Stiefel, R. H. (2009). *Medical equipment management manual* (7th ed.). Annapolis Junction, MD: AAMI.

[9] University of Michigan Hospitals (2010). Equipment Management Plan 2010. Retrieved from http://www.aami.org/tmcconnect/exchange/department/dept.eqtplan.doc

[10] Wang, B. (2006). Fennigkoh and Smith model for inclusion criteria: 15-year retrospective. *Journal of Clinical Engineering*, *31*(1), 26-30. https://doi.org/10.1097/00004669-200601000-00033

[11] Wang, B., & Levenson, A. (2000). Equipment inclusion criteria- a new interpretation of JCAHO's medical equipment management standard. *Journal of Clinical Engineering*, *25*(1), 26-35. https://doi.org/10.1097/00004669-200025010-00009

[12] World Health Organization (1998). District Health Facilities, Guidelines for Development and Operations. WHO Regional Publications, Western Pacific Series, No. 22.

[13] Younger (2010). Healthcare institutions are capable of optimizing maintenance costs, enhancing monitoring activities, managing maintenance tasks with available workforces and resources. Retrieved from www.ipsos.ca