Journal of Physics: Conference Series

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To cite this article: M. S. Ibrahim *et al* 2019 *J. Phys.: Conf. Ser.* **1150** 012020

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Life-cycle Assessment on the Highway Street Lantern using Weibull Probability Approach

M. S. Ibrahim1, M. Z. Hassan*1, I. Ibrahim1, M. H. Ibrahim, M. Y. Daud1, and N. A. Bani1

1 UTM Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 KUALA LUMPUR.

*Corresponding: mzaki.kl@utm.my

Abstract. Predictive maintenance (PM) evaluates the condition of equipment by performing periodic or continuous equipment condition monitoring. This paper presents a Weibull statistical approach, in order to determine life cycle of highway street lighting. The historical data that collected from the maintenance checklist record of 250 and 400W street lighting lanterns replacement for 2 years of period were used. Than, two key performance indicators which shape factor, β and characteristic life, η were determined to perform the Weibull probability analysis. The findings show that estimation of mean time to failure (MTTF) for 250 and 400 watt bulb are 4009.30 and 5043.36 hours period of operation respectively.

1. Introduction

Currently, highly competitive in manufacturing and industry have increased the efficiency of maintenance work in order to cut the cost and increase the equipment sustainability. Maintenance is closely connected with a set of tasks with keeping the equipment in highly satisfactory condition and can work at any operating conditions [1]. Maintenance task can be extensively classified into corrective maintenance (CM) and preventive maintenance (PM) strategies [2]. Preventive maintenance (PM) is a statistical based analysis strategy that observes the performance of equipment by analysing failure rate in order to minimize failure cost, machine downtime and increases productivity [2,3].

Many attempts have been made to evaluate the failure probability for both historical service lifetime and condition monitoring variables. The Weibull distribution is a good method to simulating failure probability of products [4-6]. Jeon and Sohn analysed the reliability of the data association rule and Weibull regression analysis in order to find the significant pattern of failure for heavy duty diesel engine and excavators [7]. The warranty data obtained from 2009 to 2012. They found that this approach provides a quick analysis of the failure and proactive improvement regarding to customer management policy.

In order to investigate maintenance performance of a process system, Weibull analysis is used as a statistical tool to predict the availability and reliability of the equipment. Weibull distribution in practice is implemented in industrial processes to find the distribution of modelling lifetime. A mixture traditional Weibull and propotional hazard model were used in investigating the high-pressure water descaling pump [8]. Two major failure modes, which sealing ring wear and thrust bearing damage were obtained from this study. Results show that the Weibull proportional method is highly significant in measuring system failure prediction to the traditional Weibull approach.

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This paper is presented the applicability a Weibull statistical approach for evaluating the maintenance planning of the street lantern.

2. Methodology

2.1 Sample data of street lighting bulb maintenance

Maintenance practice at Malaysian highway is according to guidelines and standards as set out by the Malaysian Highway Authority (MHA). It has been incorporated as preventive maintenance (PM), corrective maintenance (CM) and predictive maintenance (PRM). Street lighting maintenance systems are currently following corrective maintenance work tasks were periodically repaired and inspection according to the failure of the report.

In order to produce an effective maintenance work in the effective cost manner, a proper implementation of the maintenance tasks of the systems or equipment at a certain period of time. Street lighting maintenance work is focused on replacement of malfunctioning street lantern. It has been performed for every week and the quantity of street lanterns to rectify is 20 units per week.

In this study, the data 400W SON-T street lantern that located at the centre median of the highway while 250W SON-T street lantern which placed along a slip road and ramps are tabulated in Table 1. Replacement data of the 250 W and 400 W street lighting bulbs for 2 years periods (Jan 2015 and Dec 2016) were used in this study. Historical data were collected from the maintenance checklist record.

Table 1 Collection data of samples

250 Watt			400 Watt		
No	**Period (Day)**	**Lifespan (Hour)**	**No**	**Period (Day)**	**Lifespan (Hour)**
1	490	5880	15	302	3624
2	490	5880	16	302	3624
3	492	5904	17	574	6888
4	451	5412	18	335	4020
5	306	3672	19	369	4428
6	287	3444	20	387	4644
7	287	3444	21	434	5208
8	288	3456	22	532	6384
9	245	2940	23	394	4728
10	213	2556	24	414	4968
11	189	2268	25	414	4968
12	210	2520	26	418	5016
13	491	5892	27	567	6804
14	199	2388	28	476	5712
			29	331	3972
			30	354	4248
			31	448	5376
			32	511	6132
			33	427	5124
			34	427	5124

These lanterns are mounted on 12 meters street lighting poles. In addition, at the interchange and toll plaza areas, 30 meter high masts with 400W SON-T floodlight are installed for covering a wide area. These lamps are monitored by 24 hours' time pre-setting switch from 7.00pm to 7.00am as "ON" hour. Here, the photocell switch is employed as an overriding device in the case of early darkness. Figure 1 is shown in the street lighting bulb where a total quantity of 250W and 400W is 1,339 nos and 1,575 nos respectively that install along the Hulu Langat Highway in Malaysia.

(a) (b)

Figure 1: Photo of (a) 250W and (b) 400W street lighting lantern

2.2 Weibull probability approach

Weibull distribution itself represents the useful model for determining the reliability and the failure of various systems (Taylor 1974). It's has been shown that various performance characteristics of the system can be modeled using Weibull distribution plot. For the two-parameter Weibull distribution, the cumulative density functions F(t) as following:

$$F(t) = 1 - exp - \left[\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right] \quad (1)$$

where the initial failure is only begun at a mean time to failure (MTTF), γ. The variable t represents the time, where $t-\gamma$ is equal to the characteristic life, η of an item define as the time at which 63.2% of the population has failed. The shape parameter, β is the slope of the goodness fit line through the data point on a Weibull distribution plot.

For the sample size of less than 50, the Benard's approximation factor (2) is applied to determine the median ranks.

$$F\ (t) = \frac{(i-0.3)}{(N+0.4)} \quad (2)$$

where *i*, is the rank of each data point and N is the total number of the samples.

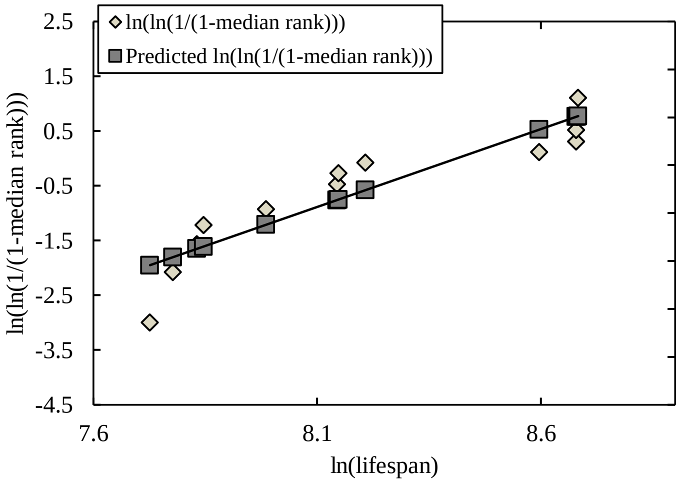
3.Result and discussion

Nowadays, many techniques have been promoted for analysing the Weibull distribution parameters from maintenance recorded data. The median ranking method is used in order to determining the two-parameter Weibull parameters which are shown in **Table 2**. Initially, the lifespan of lantern values is listed in ascending order and their respective 'rank' is placed in the second column. Then, the median ranks, which located at of each data point are computed using Eq. (2) and put in the next column. This underlying concept of Weibull probability model can be determined by a straight line with ln(ln(1/(1-median rank))) versus ln(lifespan) plots as showed in Figure 2. Therefore, the two parameters (η, β) can be calculated using a simple linear regression.

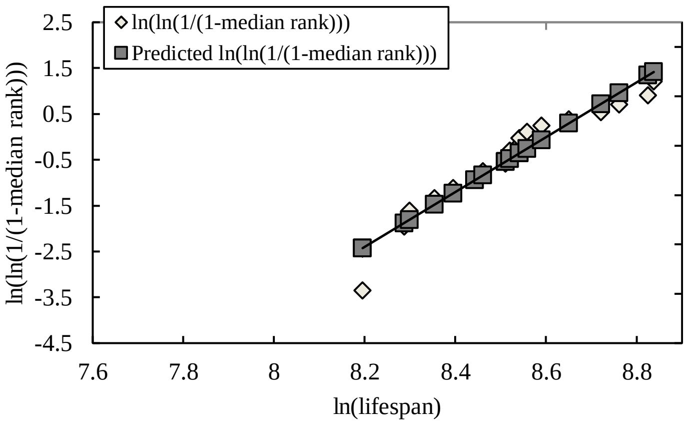
Table 2 Median ranks method of fitting a data set for 400 W bulbs to determine Weibull distribution parameters

Lifespan (Hour)	Rank	Median Ranks	1/(1-median rank)	ln(ln(1/(1-median rank)))	ln(lifespan)
3624	1	0.0343	1.0355	-3.3548	8.1953
3624	2	0.0833	1.0909	-2.4417	8.1953
3972	3	0.1324	1.1525	-1.9521	8.2870
4020	4	0.1814	1.2216	-1.6088	8.2990
4248	5	0.2304	1.2993	-1.3399	8.3542
4428	6	0.2794	1.3878	-1.1157	8.3957
4644	7	0.3284	1.4891	-0.9210	8.4433
4728	8	0.3775	1.6063	-0.7467	8.4613
4968	9	0.4265	1.7436	-0.5871	8.5108
4968	10	0.4755	1.9066	-0.4381	8.5108
5016	11	0.5245	2.1031	-0.2965	8.5204
5124	12	0.5735	2.3448	-0.1599	8.5417
5124	13	0.6226	2.6494	-0.0260	8.5417
5208	14	0.6716	3.0448	0.1074	8.5578
5376	15	0.7206	3.5790	0.2430	8.5897
5712	16	0.7696	4.3404	0.3839	8.6503
6132	17	0.8186	5.5135	0.5349	8.7213
6384	18	0.8677	7.5556	0.7042	8.7616
6804	19	0.9167	12.0000	0.9102	8.8253
6888	20	0.9657	29.1429	1.2156	8.8375

Figure 2 shows the typical ln [ln [1/[1-median rank]]] against ln[lifespan] for 200 W and 450 W of a street lantern. This "goodness-of-fit" test graph gives the straight line in the form of β parameter = m and η parameter = $e^{(t/\beta)}$. Here, the trend line for both lanterns can be suggested fit with Weibull probability distribution [9]. Following, scale and shape parameters can be determined using regression technique.



(a)



(b)

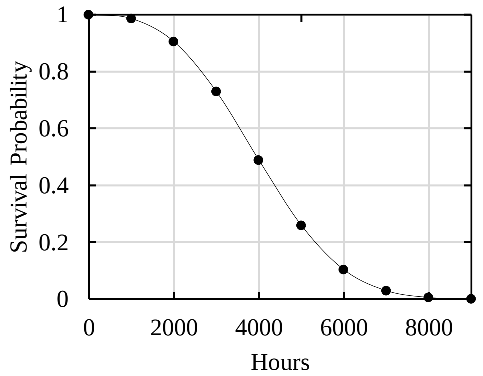
Figure 2: "Goodness of fit" test plot on the data of (a) 250 W and (b) 400 W street lanterns

Table 3 indicates the coefficient parameters for both lamps following regression analysis. Here, the shape and characteristic life (β and η) of the Weibull distribution parameter are evaluated. The β values for both lanterns are greater than 1 and indicate that the lanterns are in ware out condition. In addition, the highest η value of 400 W lanterns is recorded and suggested a high availability as compared with 200 W lanterns.

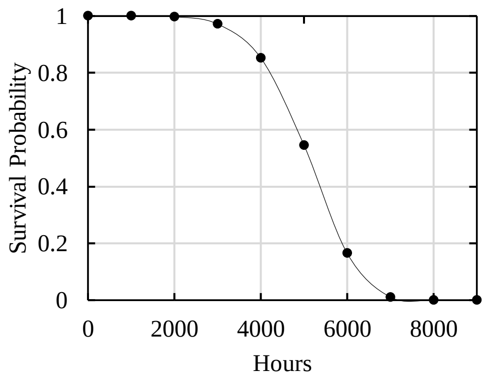
Table 3: Parameters of Weibull distributions for 250 W and 400 W lanterns

	Coefficients	
	250 W	400 W
Intercept	-23.9328	-51.4537
ln(lifespan)	2.8452	5.9823
β (or shape parameter)	2.8452	5.9823
η (or characteristic life)	4499.7614	5437.1929

Figure 3 explained the established Weibull probability requiring a performance plot. As can be seen from Figure 3, the mean time to failure (MTTF) for 250 W bulbs is 4009.30 hours, while the MTTF for 400 W bulbs is 5043.36 hours. This MTTF value is measured according to operation rate of the component before failure, *t*. On the other hand, it shows that 99 percent of the 250 W and 400 W street lighting bulbs can survive at least 893 and 2,520 hours respectively. If the operation of street lighting is 12 hours per day, the survival rates of 250 and 400 W lanterns that are obtained 2.5 and 7.0 months respectively.



(a)



(b)

Figure 3 Typical survival probability-hours plot of (a) 250 W and (b) 400 W of bulbs

4. Conclusion

The Weibull distribution is very flexible and useful to measure maintenance performance of a light bulb. Two main parameters of Weibull distribution plot are shape factor, β and characteristic life, η following goodness-of-fit plot are evaluated. It has been established that all β values exceeding 1, which mean both lanterns in ware out phase. Here, mean time to failure (MTTF) for 400 W is approximately 20% higher than those 250 W. This values are important to measure the future plan of maintenance task activities.

Acknowledgements
The appreciation is given to Universiti Teknologi Malaysia and Ministry of Higher Education under Fundamental Research Grant Scheme, R.K130000.7840.4F880 and "*Geran Universiti Penyelidik*' (GUP) Tier 1, (Q.K130000.2540.15H70) for financially support provided throughout the course of this research project.

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IOP Conf. Series: Journal of Physics: Conf. Series 1150 (2019) 012020 doi:10.1088/1742-6596/1150/1/012020

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