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Reliability Analysis of Repair Hours of RTPS through Weibull Model

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Abstract

In our earlier paper Hungund CPS and Shrikant Patil [3], the suitability of the Weibull distribution for repair hours of seven units of Raichur Thermal Power Station (RTPS) was tested using Chi-square test of Goodness of Fit (GoF). It was found that the Weibull Model best suites to the repair hours data of RTPS. In order to identify the best performing units of RTPS, further the results are need to be analyzed using Reliability theory. Hence in this paper, reliability analysis is studied using Weibull Model to identify the efficiencies of seven units of TPP. Based on reliability analysis, reliability rankings are computed to identify best performing units. Conclusions are drawn based on the results obtained.

Keywords: *Weibull Distribution, Repair hours, Reliability estimation, Reliability ranking.*

Introduction

Reliability theory is the foundation for the reliability engineering. Reliability engineers rely heavily on statistics, probability theory and reliability theory. Many statistical tools and techniques are used in reliability engineering, such as reliability prediction, Weibull analysis, thermal management, reliability life testing and accelerated life testing, and so on. Now we concentrate on discussing some fundamental concepts of reliability theory, which constitutes the methodology for the present work.

Reliability (for non-repairable items) can be defined as the probability that an item will perform a defined function without failure under stated conditions for a stated period of time. One must grasp the concept of probabilities in order to understand the concept of reliability. The numerical values of both reliability and unreliability are expressed as a probability from 0 to 1 and have no units.

Reliability is stated in another way i.e. the Reliability (Alle Sandro Birolini [1] and Kuo W et al., [4]), R(t) is defined as the probability that the component or system experiences no failures during the time interval zero to t_1 given that the component or system was repaired to a like new condition or was functioning at t_0.

Survey of Literature

In any system reliability calculation, estimation plays a vital role and hence the anlaysis is to be diverted to calculate reliabilities of units. In our earlier paper Hungund CPS et al[2]., *"Reliability analysis of Thermal Power Generating Units based on Working Hours",* the suitability of the data tested using Exponential and Weibull distributions through chi-square GoF test and the reliabilities of different units are calculated using the same distributions and conclusions are drawn.

In the following paper Hungund CPS et al[3]., entitled *"Critical Comparison of Power Units of Thermal Power Plant using Weibull Model for Production Downtimes"*, the repair hour data analyzed for seven units of TPP through Weibull distribution. The suitability of the distribution is tested by chi-square test of GoF. Two methods were used for analyzing data namely (i) combined data analysis and (ii) split data analysis. It has been observed that split data analysis is more appropriate to analyze power system of repair time data rather than combined data analysis.

Objectives

The objectives of the present paper are:

- To perform the reliability analysis of repair hours for all the units of combined and categorical data using Weibull model.
- To compare different units performances based on reliabilities at fixed time 't'.
- To identify reliable units based reliability ranking.

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Reliability Analysis of Weibull Distribution

The two-parameter Weibull distribution is used to model failures is represented by the following equation:

$$R(t) = \exp\left(-\left(\frac{t}{\alpha}\right)^{\beta}\right)$$

Where R(t) reliability at time t, t time period [h], β is Weibull distribution shape parameter and α is Weibull distribution characteristic life [h].

Estimation of Reliabilities

Estimation of reliabilities of TPP plays a very important role in predicting electricity generation. Reliabilities predictions are one of the most common forms of reliability analysis. Reliability predictions predict the failure rate of components and overall system reliability. These predictions are used to evaluate design feasibility, compare design alternatives, identify potential failure areas, trade-off system design factors, and track reliability improvement.

The estimation of reliabilities for various units of TPP located at Raichur can be done using repair hours data for both combined data and categorical data. Thus we obtain three types of reliabilities namely

1. Reliabilities for combined data
2. Reliabilities for minor repair hours (Category-I).
3. Reliabilities for major repair hours (Category-II)

As mentioned earlier in our paper Hungund CPS et al[3]., the chi-square test of GoF was carried out for both combined and categorical data to test the suitability of Weibull Distribution. The results are summarized below for ready reference.

Table 1.Summary of the Weibull distribution for Repair Hours of Combined Data

Units	n	k	Mean	Chi-Square	DF
Unit 1	84	7	3.44	27.64	4
Unit 2	100	8	2.48	59.81	5
Unit 3	60	5	3.03	29.14	2
Unit 4	60	5	1.98	47.44	2
Unit 5	56	6	3.14	17.12	3
Unit 6	51	6	3.1	2.91	3
Unit 7	82	7	3.05	41.65	4

Table 2. Summary of the Weibull distribution for Repair Hours of Categorical Data

Units	Category	n	k	Mean	Chi-Square	DF
Unit 1	Category-I	40	5	0.19	1.28	2
	Category-II	44	7	6.39	2.09	2
Unit 2	Category-I	50	6	0.17	3.87	2
	Category-II	50	6	4.78	3.44	2
Unit 3	Category-I	30	3	0.18	0.53	1
	Category-II	30	3	5.87	0.06	1
Unit 4	Category-I	29	3	0.14	0.93	1
	Category-II	31	3	3.81	0.36	1
Unit 5	Category-I	27	4	0.23	2.7	2
	Category-II	29	4	6.05	3.02	2
Unit 7	Category-I	39	4	0.24	0.24	1
	Category-II	43	4	6.32	1.89	2

Note that in Table 2, the chi-square test of GoF for Unit-6 was not applied due to insufficient data. Based on the results obtained in the Table 1 and Table 2, reliabilities are estimated for all the units of the combined and categorical data in the following sections.

Estimation of the Weibull Parameters

The method of estimating parameters of Weibull distribution using Median Rank Regression (MRR) method was discussed in the paper Hungund CPS et al [2]. Accordingly the Weibull parameters for repair hour data are estimated for both combined and categorical data and summarized below.

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Table 3.Weibull Distribution Parameters for Combined data.

Units/ Characteristics	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Mean	3.44	2.48	3.03	1.98	3.14	3.1	3.05
Alpha (α)	1.8573	1.6307	1.2455	0.9014	1.7396	1.8238	1.4652
Intercept (a) -β*Log(α)	-0.3376	-0.2732	-0.1141	0.0573	-0.3294	-0.32	-0.2004
Slope (β)	0.5452	0.5588	0.5198	0.552	0.5949	0.5325	0.5247

Table 4. Weibull Distribution Parameters for Category-I Data

Units/ Characteristics	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Mean	0.19	0.17	0.18	0.14	0.23	0.24	0.24
Alpha (α)	0.2251	0.1968	0.1997	0.1589	0.2551	0.2513	0.1942
Intercept (a) -β*Log(α)	2.5521	3.5096	5.0339	4.9816	2.6314	1.998	4.6714
Slope (β)	1.7112	2.1591	3.1246	2.7082	1.9264	1.4468	2.8501

Table 5. Weibull Distribution Parameters for Category-II Data

Units/ Characteristics	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Mean	6.39	4.78	5.87	3.81	6.05	6.32	6.32
Alpha (α)	5.6134	4.8132	3.5490	1.9369	5.0236	6.2021	4.0561
Intercept (a) -β*Log(α)	-1.3687	-1.3670	-0.8092	-0.3831	-1.3853	-1.4198	-0.8377
Slope (β)	0.7934	0.8699	0.6388	0.5795	0.8582	0.7780	0.5982

The shape parameter β also known as the Weibull slope has the distinct effect on failure rate. In Table-3, the parameter β is approximately 0.5 or less than one indicates failure rate is decreasing with time. Similarly the parameter β is closer to 1 for some of the units in Table-5 denote useful life or random failures. We see wear-out failures in case of Category-I as β>1 (Refer Table-4). These different values of β comprise the classic bathtub curve.

Reliabilities for Repair Hours

In the context for reliability for repair hours, interestingly we look for lower reliability unlike as in the case of working hours; since lesser reliability stands immediate functioning of a component or system from failed state to functioning state. Thus in the following section, reliabilities are computed for combined and categorical data and conclusions are drawn.

Reliabilities for Combined Data

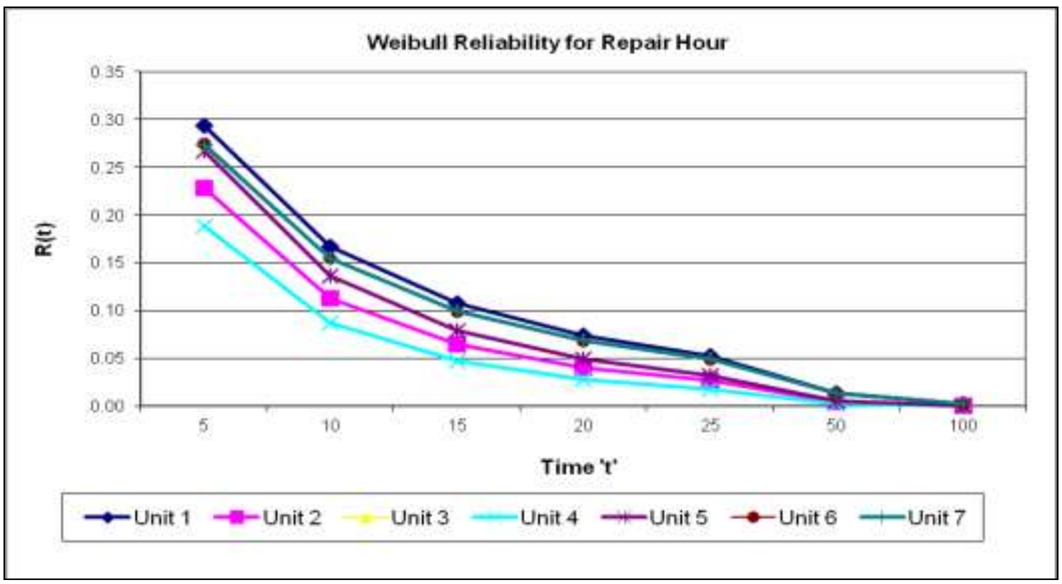
The reliabilities of Weibull distribution with different time unit 't' is given in the following table:

Table 6. Reliabilities for Repair Hours of Combined Data

Units/ Time 't'	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
5	0.2934	0.2277	0.2732	0.1887	0.2675	0.2753	0.2736
10	0.1671	0.1131	0.1557	0.0867	0.1364	0.1548	0.155
15	0.1073	0.065	0.1006	0.047	0.0792	0.0987	0.0996
20	0.0735	0.0403	0.0695	0.0277	0.0494	0.0673	0.0684
25	0.0524	0.0263	0.05	0.0173	0.0322	0.0479	0.049
50	0.0135	0.0047	0.0137	0.0026	0.0056	0.0123	0.0131
100	0.0019	0.0004	0.0021	0.0002	0.0004	0.0017	0.0019
150	0.0004	0.0001	0.0005	0	0	0.0004	0.0004
200	0.0001	0	0.0001	0	0	0.0001	0.0001
300	0	0	0	0	0	0	0

The line graph for the reliability computed for different time unit is shown below:

Figure-1



Reliabilities for Categorical Data.

In categorical data, we obtained two types of repair hours namely Category-I and Category-II. In the analysis of reliabilities for Category-I data, we have obtained zero reliabilities for all the units with time unit t=5 and onwards. Hence no table is drawn; however the reliabilities of Category-II of all the seven units are represented in the following table.

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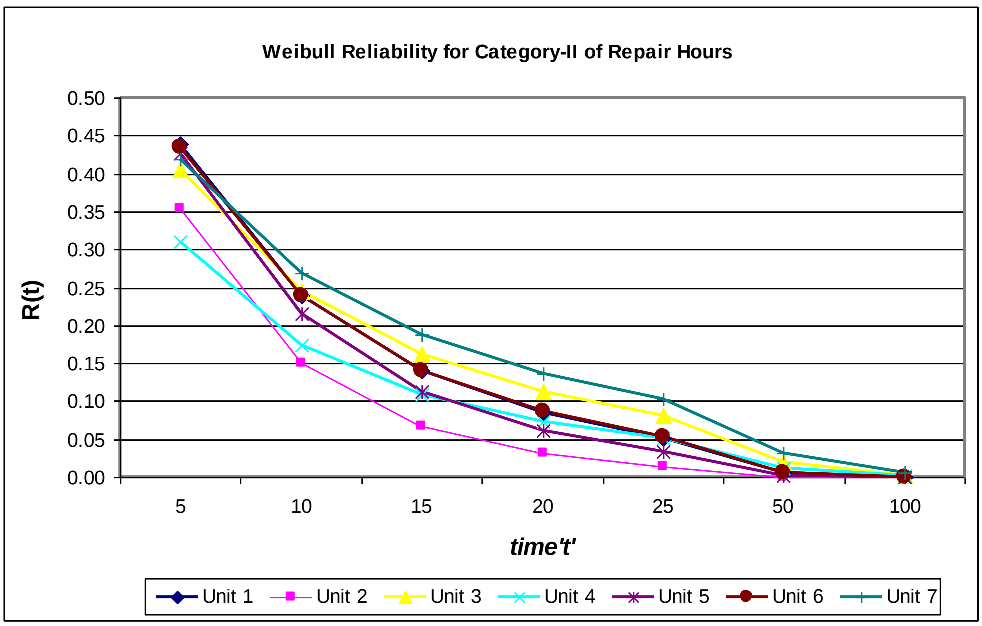
Table 7. Reliabilities for Category-II Data

Units/ Time 't'	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
5	0.4390	0.3535	0.4055	0.3102	0.4278	0.4346	0.4193
10	0.2401	0.1495	0.2453	0.1739	0.2145	0.2395	0.2682
15	0.1397	0.0669	0.1619	0.1094	0.1131	0.1410	0.1869
20	0.0844	0.0310	0.1121	0.0733	0.0614	0.0862	0.1364
25	0.0523	0.0147	0.0802	0.0511	0.0341	0.0542	0.1026
50	0.0060	0.0004	0.0197	0.0117	0.0022	0.0067	0.0319
100	0.0001	0.0000	0.0022	0.0013	0.0000	0.0002	0.0054
150	0.0000	0.0000	0.0004	0.0002	0.0000	0.0000	0.0013
200	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0004
300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

The line graph for the Category-II of repair hours is explained through following line graph:

Figure 2.



Reliability Ranking for Combined and Categorical Data

Based on the above results of reliabilities for both combined and categorical data ranking can be given for each unit and the respective ranks are given in the following table.

Table 8. Reliability Ranking for Combined Data

Units/ Time 't'	Unit1	Unit2	Unit3	Unit4	Unit5	Unit6	Unit7
5	1	6	4	7	5	2	3
10	1	6	2	7	5	4	3
15	1	6	2	7	5	4	3
20	1	6	2	7	5	4	3
25	1	6	2	7	5	4	3
50	2	6	1	7	5	4	3
Avg Ranks	***1.17***	***6***	***2.17***	***7***	***5***	***3.67***	***3***

Ranking for Category-I

Since reliability for Category-I for all the seven units with different time units are zero, therefore we did not assign average ranking for the units.

Ranking for Category-II

Table 9. Ranking for Category-II Data

Units/ Time't'	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
5	1	6	5	7	3	2	4
10	3	7	2	6	5	4	1
15	4	7	2	6	5	3	1
20	4	7	2	5	6	3	1
25	4	7	2	5	6	3	1
50	5	7	2	3	6	4	1
Avg Ranks	***3.5***	***6.83***	***2.5***	***5.33***	***5.17***	***3.17***	***1.5***

Analysis

As mentioned in of Section 6, higher ranking stands for lesser reliability which in turn termed to be efficient unit is arranged in the order Unit-4, Unit-2, Unit-5, Unit-6, Unit-7, Unit-3 and Unit-1 (Refer Table 8) for combined data. Similarly for Category-II, the rankings are Unit-2, Unit-4, Unit-5, Unit-1, Unit-6, Unit-3 and Unit-7 (Refer Table 9).

The reliability analysis is shown in the Table-6 and Table-7 and reliability ranking is shown Table-8 and Table-9, by which some conclusions are drawn:

- Reliabilities are approximately zero at time t=100 hours and onwards for the combined data and category-II data imply the reliabilities of repairs are minimal. The same is depicted in the corresponding line graphs. (Refer Figure-1 and Figure-2).
- Frequent failures are noted in case of Category-I data as $\beta>1$ for all the units (Refer Table 4)
- There is tendency of decreasing failure rate for combined data and category-II data since $\beta<1$.
- Unit-6 found to be quicker reinstallation of the repairs.
- Unit-4 found to be slower reinstallation of the repairs.

Conclusion

The reliability analysis is performed to identify the reliabilities of various units of RTPS. Some interesting results are obtained after the analyzing the repair hours data. We have obtained mixed results for the shape parameter β which comprises the perfect bathtub curve indicating the existence of thee phases of failure patterns. The

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reliability ranking gives further scope in the improvement of the performance of the unit. The minimal reliability are noted after time unit 't=100' hrs indicating precautionary measures need to taken care in the initial time period.

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