RELIABILITY ANALYSIS OF GROUP OF BUSES- A CASE STUDY AT TSRTC

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Abstract
The managers of any organization (either private or government) shall always try to satisfy their customers by providing high quality goods and/or services without any interruption. As they have to face the tough competition from the private sector organizations, it has become more relevant and challenging task of the managers of public sector Organizations to provide uninterrupted services. The proposed work is carried out at Telangana State Road Transport Corporation (TSRTC), which is into Public bus Transportation in Telangana and neighboring states. The objective of this paper is to assess the reliability of group of buses using statistical methods (NHPP Model) from the data collected, from one of the Depots of the Corporation. This analysis will help in understanding the condition of buses i.e. whether the buses are deteriorating, improving or facing constant failure rate.

Based on this information, suitable maintenance decisions may be taken by managers to improve the reliability and hence the availability of buses for service.

Key Words: Reliability, MCRF, NHPP, repairable system, Least Replacement Assembly (LRA), Time between failures (TBF). Composites, fiber, Polymers, FRP, jute

I INTRODUCTION

In last few decades there is a lot of focus on improving the availability of the machinery and equipment and the organizations are keen on improving the reliability of their machines/equipment so that they can increase the productivity and hence the profitability. Machines /equipment or system play an important role in every organization. No machine/equipment is expected to run continuously without fail. To predict the ailures/breakdowns, graphical methods using statistical techniques are available, which provide information about their reliability of machines. The graphical method developed by Nelson [2] using Mean Cumulative Repair Function (MCRF) from the repair data of machines based on the numbers of buses put in to operation in a given period. This provides the representation of operational data and overall efficiency through graphical methods.

In this direction, a study has been conducted for a period of seven months (April 2017 to Oct. 2017) on a sample group of 40 buses of Uppal depot of TSRTC, Hyderabad, Telangana state. The present study involves a simple and informative method of estimating the reliability of group of similar buses operated in the similar environment and working conditions.

BACKGROUND

At TSRTC, there are similar or same types of buses, the maintenance department often chooses to follow the maintenance policy of interchanging by the Least Replacement Assembly (LRA) units. Suppose a bus is under breakdown due to engine failure and another due to tire failure, then the maintenance department would interchange the parts of the second bus with that of first one, if it is compatible, in the interest of improving the productivity. This production orientation will help in increasing the efficiency of production and Maintenance departments, but creates confusion in estimating the reliability of specific bus, since the failure of one bus is transferred to another bus, thus affecting the reliability of the particular bus of interest. It is therefore, the reliability studies should focus on the total group of buses of same type as one unit. Since TSRTC is adopting such LRA Maintenance policies, the study concentrates in this direction and analysis of the group reliability is done.

II RELIABILITY MODELING OF REPAIRABLE EQUIPMENT

Reliability is associated with dependability at successful operation. While modeling a system to characterize by its reliability one should first distinguish between repairable and non repairable items. Buses, which are in the interest of present discussion, are considered to be repairable equipment.

For repairable items, the equipment is expected to be renewed to "as good as new" state after every repair, thus can assume independent and identical distribution (i.i.d) and so the system is modeled in Homogeneous Poisson Process (HPP) or renewable process (RP). However, the reliability of items are dependent on several other factors such as maintenance, working conditions, dependence on parts and so forth, the repairable items cannot execute the original or new condition, therefore, it is appropriate to assume as bad as old. Thence the suitable reliability modeling is Non Homogeneous Poisson process (NHPP).

If the data sets of repairable equipment indicate presence of trend, NHPP can be used to model failure data. One of the most commonly used NHPP model is power law process (PLP) discussed by Rigdon and Basu [3].

Intensity of NHPP is the probability of failure in a short time interval, divided by length of interval.

It is given by, $U(t)\,dt = P($a failure 't' to '$(t+dt)$' … (eq..1)

The failure intensity function depends upon cumulative time 't'. Therefore the intensity function of power law process (NHPP) model is given by $U(t) = (\beta/\alpha)(t/\alpha)^{\beta-1}$ where $t > 1$ … (eq..2)

Where α and β are scale and shape parameters and 't' is the global running time.

(i) If $\beta > 1$, intensity function increases, which shows a situation where time between failures (TBF) become smaller i.e. frequent occurrence of failures. In other words, it represents the case of deterioration of the bus. (Increasing failure rate).

(ii) If $\beta < 1$, intensity function decreases, which means the bus is improving (i.e. decreasing failure rate).

(iii) If $\beta = 1$, it corresponds to constant failure rate and it can be inferred that power law process (PLP) becomes homogeneous Poisson process (HPP) with mean time between failures equal to α. It can be seen that for $\beta = 1$, NHPP also represents Renewal process. [2]

GRAPHICAL ANALYSIS FOR REPAIRABLE SYSTEM/ BUSES

A non-parametric graphical method based on Mean Cumulative Repair function (MCRF) developed by Nelson [2] is used to interpret interval data of inter arrival time for repair of repairable system i.e. Buses. The information available in breakdown register of maintenance department is used to establish the repair performance using graphical method. In NHPP, the intensity is given by power law function.

The derivative of MCRF has the same meaning of intensity function. [2]

Therefore, $d/dt\,(MCRF) = (\beta/\alpha)(t/\alpha)^{\beta-1}$ …. (eq.3)

Then from equation (3), MCRF is given by:

$MCRF = (t/\alpha)^{\beta}$ …… (eq.4)

Hence, from equation (eq.4), we get

$\text{Log}(MCRF) = \beta \log(t) - \beta \log(\alpha)$ ……. (eq.5)

The above equation (eq.5) is in the form of a straight line

$y = mx + c$ where the slope (m) directly gives the valve of β. The estimate of α can hence be obtained by the value of 't' [2].

The estimate of reliability at age 't' when the random variable is, time to first repair, can be obtained by

$R(t) = \text{Exp}\{-(t/\alpha)\}^{\beta}$ …… (eq.6)

III MEAN CUMULATIVE REPAIR FUNCTION

Repair data of vehicles is taken in the form of number of vehicles put in to operation in a period and the number of vehicles not in operation in the period and repair function is the ratio of number of vehicle not in operation to the total number planned .Thus the cumulative repair function and hence the mean cumulative repair Function (MCRF) can be estimated. This function provides useful information with engineering insight in to the system reliability. This graphical analysis presents a novel method of analysis of repair data of repairable vehicles irrespective of system age.

For this purpose, the data such as buses on role, buses working and on repair are tabulated in tables covering month wise, week wise and day wise information

(Refer Tables I to III).

Fitting the NHPP Model:

In NHPP , rate of occurrence of failure(ROCOF) is commonly modeled by a power law function, αβ tβ-1 where α and β are parameters of the NHPP model. The derivative of MCRF has the same meaning of ROCOF. Therefore if we fit NHPP to our case, we have (MCRF) /dt = α β tβ-1.

MCRF is then given by

MCRF =αTβ-1 ………….. (eq.7) hence

Log (MCRF) = β log α + β log t … (eq.8)

A straight line of the form, y = mx +c, fitted by plotting Ln(MCRF) v/s Ln (operating month), Ln (MCRF) v/s Ln (operating week) and Ln(MCRF) v/s Ln (operating day. The estimates of α and β can be obtained from the graph. The slope of the straight line gives valve of β, where as the estimate of α is exp (intercept/slope of straight line).

β logα= intercept (or) α= Exp(intercept/slope)…. ..(eq.9)

The estimate of reliability at age 't' then the random variable is time to first repair can be obtained by

R(t) = Exp[- αtβ] ……….. (eq.10). Based on this equation, the reliability value for buses is calculated.

IV DATA COLLECTION & GRAPHICAL ANALYSIS

The data of 40 buses of Uppal depot for a period of seven months is collected. After calculations, the information is tabulated in the table 1.1 to 1.3 and the three graphs (For month, week and Day wise) are drawn between *log MCRF v/s log operating period*, to show the trend and a straight line equation is obtained after fitting the data. The slope of the curve gives the shape parameter β.

Table I : Mean Cumulative Repair Function of buses (Month -wise)

S.no.	Month	Available Hours	Break down Hours	Mean Repair Function	MCRF	LN month	LN MCRF
1	Apr-17	19200	17	0.00089	0.00089	0.00000	-7.02950
2	May-17	19840	15	0.00076	0.00164	0.69314	-7.18747
3	Jun-17	19200	25	0.00130	0.00294	1.09861	-6.64379
4	Jul-17	19840	15	0.00076	0.00370	1.38629	-7.18742
5	Aug-17	19840	20	0.00101	0.00471	1.60944	-6.89972
6	Sep-17	19200	20	0.00104	0.00575	1.79176	-6.86693
7	Oct-17	19840	40	0.00202	0.00777	1.94591	-6.20657

Graph 1

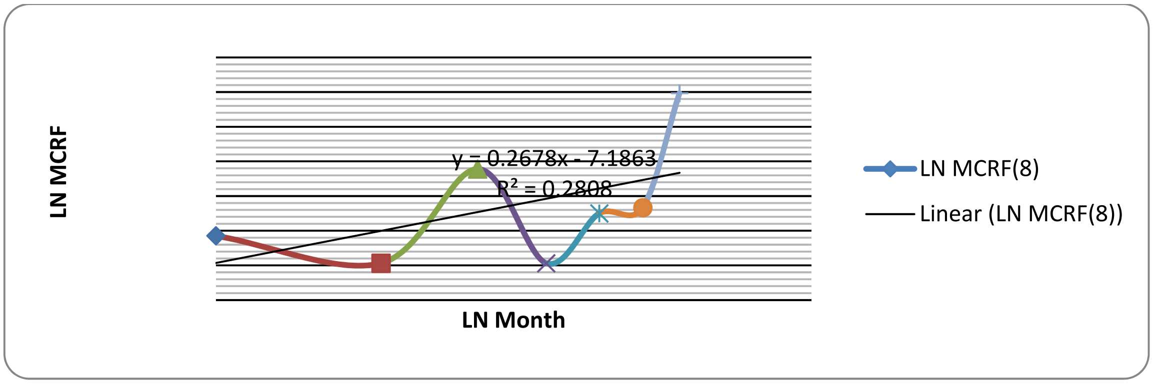


Table II : Mean Cumulative Repair Function of buses (Week -wise)

week no	Available Hours	Breakdown hours	Mean repair Function	MCRF	LN month	LN MCRF
1	4480	6	0.00134	0.00134	0.00000	-6.61562
2	4480	3	0.00067	0.00201	0.69315	-6.21015
3	4480	4	0.00089	0.00290	1.09861	-5.84243
4	4480	4	0.00089	0.00379	1.38629	-5.57416
5	4480	4	0.00089	0.00469	1.60944	-5.36286
6	4480	3	0.00067	0.00536	1.79176	-5.22932
7	4480	5	0.00112	0.00647	1.94591	-5.04008
8	4480	1	0.00022	0.00670	2.07944	-5.00618
9	4480	3	0.00067	0.00737	2.19722	-4.91087
10	4480	2	0.00045	0.00781	2.30259	-4.85203
11	4480	13	0.00290	0.01071	2.39790	-4.53618
12	4480	4	0.00089	0.01161	2.48491	-4.45613
13	4480	3	0.00067	0.01228	2.56495	-4.40005
14	4480	9	0.00201	0.01429	2.63906	-4.24850
15	4480	3	0.00067	0.01496	2.70805	-4.20269
16	4480	12	0.00268	0.01763	2.77259	-4.03793
17	4480	1	0.00022	0.01786	2.83321	-4.02535
18	4480	1	0.00022	0.01808	2.89037	-4.01293
19	4480	5	0.00112	0.01920	2.94444	-3.95303

20	4480	1	0.00022	0.01942	2.99573	-3.94147
21	4480	2	0.00045	0.01987	3.04452	-3.91874
22	4480	2	0.00045	0.02031	3.09104	-3.89652
23	4480	6	0.00134	0.02165	3.13549	-3.83267
24	4480	8	0.00179	0.02344	3.17805	-3.75342

Graph 2

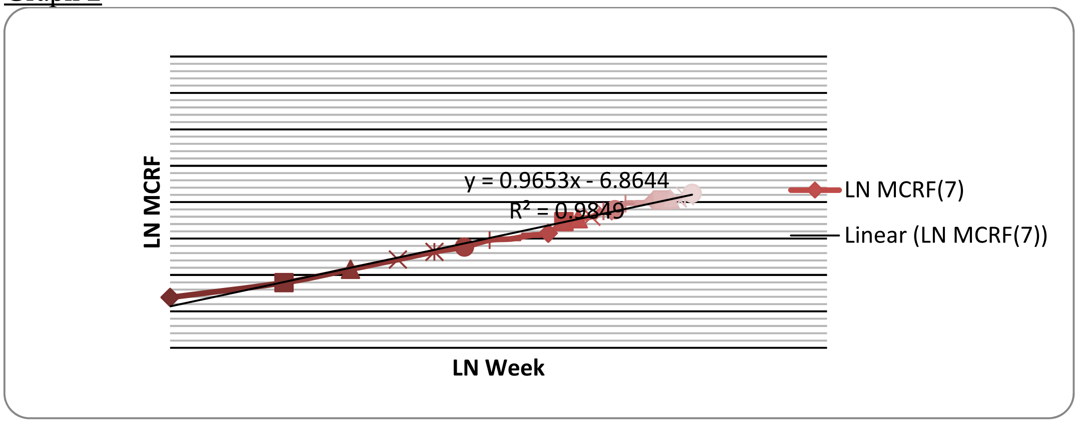


Table III: Mean Cumulative Repair Function of buses (Day -wise)

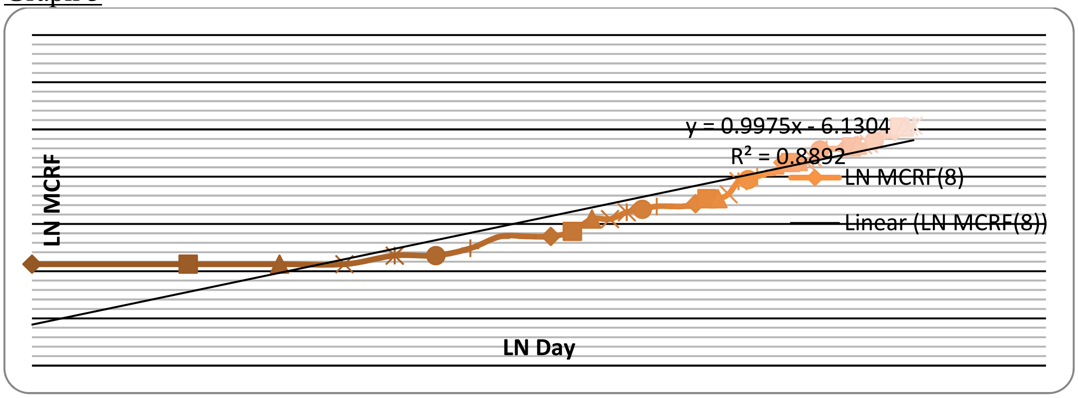
Day no	Date	Available Hours	Breakdown hours	Mean repair Function	MCRF	LN Day	LN MCRF
1	4/1/2017	640	5	0.00781	0.00781	0.00000	-4.85203
2	4/2/2017	640	0	0.00000	0.00781	0.69315	-4.85203
3	4/3/2017	640	0	0.00000	0.00781	1.09861	-4.85203
4	4/4/2017	640	0	0.00000	0.00781	1.38629	-4.85203
5	4/5/2017	640	1	0.00156	0.00938	1.60944	-4.66971
6	4/6/2017	640	0	0.00000	0.00938	1.79176	-4.66971
7	4/7/2017	640	1	0.00156	0.01094	1.94591	-4.51556
8	4/8/2017	640	2	0.00313	0.01406	2.07944	-4.26424
9	4/9/2017	640	0	0.00000	0.01406	2.19722	-4.26424

10	4/10/2017	640	0	0.00000	0.01406	2.30259	-4.26424
11	4/15/2017	640	1	0.00156	0.01563	2.39790	-4.15888
12	4/20/2017	640	3	0.00469	0.02031	2.48491	-3.89652
13	4/30/2017	640	0	0.00000	0.02031	2.56495	-3.89652
14	5/5/2017	640	2	0.00313	0.02344	2.63906	-3.75342
15	5/10/2017	640	1	0.00156	0.02500	2.70805	-3.68888
16	5/15/2017	640	1	0.00156	0.02656	2.77259	-3.62825
17	5/20/2017	640	0	0.00000	0.02656	2.83321	-3.62825
18	5/25/2017	640	0	0.00000	0.02656	2.89037	-3.62825
19	5/30/2017	640	1	0.00156	0.02813	2.94444	-3.57110
20	6/4/2017	640	2	0.00313	0.03125	2.99573	-3.46574
21	6/9/2017	640	0	0.00000	0.03125	3.04452	-3.46574
22	6/14/2017	640	2	0.00313	0.03438	3.09104	-3.37043
23	6/19/2017	640	7	0.01094	0.04531	3.13549	-3.09417
24	6/24/2017	640	1	0.00156	0.04688	3.17805	-3.06027
25	6/29/2017	640	2	0.00313	0.05000	3.21888	-2.99573
26	7/4/2017	640	2	0.00313	0.05313	3.25810	-2.93511
27	7/9/2017	640	1	0.00156	0.05469	3.29584	-2.90612
28	7/14/2017	640	8	0.01250	0.06719	3.33220	-2.70027

29	7/19/2017	640	0	0.00000	0.06719	3.36730	-2.70027
30	7/24/2017	640	1	0.00156	0.06875	3.40120	-2.67728
31	7/29/2017	640	0	0.00000	0.06875	3.43399	-2.67728
32	8/3/2017	640	3	0.00469	0.07344	3.46574	-2.61132
33	8/8/2017	640	9	0.01406	0.08750	3.49651	-2.43612
34	8/13/2017	640	1	0.00156	0.08906	3.52636	-2.41842
35	8/18/2017	640	0	0.00000	0.08906	3.55535	-2.41842
36	8/23/2017	640	1	0.00156	0.09063	3.58352	-2.40103
37	8/28/2017	640	1	0.00156	0.09219	3.61092	-2.38393
38	9/2/2017	640	1	0.00156	0.09375	3.63759	-2.36712
39	9/7/2017	640	2	0.00313	0.09688	3.66356	-2.33433
40	9/12/2017	640	0	0.00000	0.09688	3.68888	-2.33433
41	9/17/2017	640	2	0.00313	0.10000	3.71357	-2.30259
42	9/22/2017	640	4	0.00625	0.10625	3.73767	-2.24196
43	9/27/2017	640	4	0.00625	0.11250	3.76120	-2.18480
44	10/2/2017	640	3	0.00469	0.11719	3.78419	-2.14398
45	10/7/2017	640	5	0.00781	0.12500	3.80666	-2.07944
46	10/12/2017	640	3	0.00469	0.12969	3.82864	-2.04263
47	10/17/2017	640	8	0.01250	0.14219	3.85015	-1.95061

48	10/22/2017	640	0	0.00000	0.14219	3.87120	-1.95061
49	10/27/2017	640	1	0.00156	0.14375	3.89182	-1.93968
50	11/1/2017	640	2	0.00313	0.14688	3.91202	-1.91817

Graph 3



DISCUSSION, CALCULATIONS & RELIABILITY ESTIMATION:

(i) From the above graphs, the following is obtained:

From the Graph 1

Regression line equation:

y=0.267x -7.186 --eq 1

Sample size:7, Intercept (c):-7.186,Slope (m): 0.26

From the Graph 2

Regression line equation:

y=0.965x-6.864 ----eq 2

Sample size:24, Intercept(c):-6.864, Slope (m): 0.965

From the Graph 3

Regression line equation:

y=0.997x-6.130 ---eq 3

Sample size: 50, Intercept (c): - 6.130,

Slope (m): 0.997

(ii)From the above three equations, the values of intercept, α and β are found for three time periods :

(a) y = 0.267x -7.186 (Straight line)-For Month wise data :

The slope (m) = 0.267(i.e. β value) and the intercept (c) = -7.186

The value of α can be calculated using formula

β Log α = intercept or α = Exp(intercept /slope)

i.e. **α** = Exp **(**-7.186/0.267) = 2.0565E-12

(b) y=0.965x-6.864 (Straight line)-For Week wise data :

The slope (m) = 0.965 (i.e. β value) and the intercept

(c) = - 6.864

The value of α using above formula

i.e. **α** = Exp **(**-6.864/0.965) = exp(-7.113) = 0.000814

(c) y=0.997x-6.130 (Straight line)- For Day wise data :

The slope (m) = 0.997 (i.e. β value) and

the intercept (c) = -6.130

The value of **α** = Exp **(**-6.130/0.997) = 0.002136.

Summary of α and β values

Period	**α value**	**β value (slope)**
Month wise data	2.0565E-12	0.267
Week wise data	0.000814	0.965
Day wise data	0.002136	0.997

(iii) Reliability Estimation:

The estimate of reliability at age 't' when the random variable is time 't' to first repair can be calculated using formula, R(t) = Exp[- α t^{β}].

(i) For t=7 months, the reliability before the 1st repair is R(7) = Exp (-2.0565E-12*7 $^{0.2673}$) = 1.0, for t=12 months, the R(12)=1.0 and for t=24 months, the R(24) = 1.0

(ii) For t=24 week, the reliability before the 1st repair is R(24) = Exp(-0.000814*24 $^{0.965}$) = 1.0, and for t=(60) weeks, the R(60)= 0.9586

(iii) For t=50 day, the reliability before the 1st repair is R(50) = Exp(-0.002136*50 $^{0.997}$) = 0.90, for t=60 days, the R(60)= 0.88, for t=120 days, the R(120)= 0.77 and for t=200 days, the R(200) = 0.65

Summary of Reliability values

Period	**Reliability values**		
Month	R(7) = 1.00	R(12) = 1.00	R(24) = 1.00
Week	R(24) = 1.00	R(36) = 0.97	R(60) = 0.96
Day	R(50) = 0.90	R(120) = 0.77	R(200) = 0.65

V. RESULTS AND CONCLUSIONS

1. Form the graphical analysis using MCRF, the system is found to be have three different values **(**0.267, 0.965 and 0.997**)** of **β** for three periods**.** All the values are less than 1, which means the buses are improving (i.e. decreasing failure rate)
2. β value (Weekly & Daily) near to 1 may show constant failure rate of buses, but it does not mean that all the vehicles have identical behavior. So, there is a need to analyze further using Trend tests and TTT plots to find the unreliable buses.
3. From reliability calculations, for monthly data, the group of buses is reliable to an extent of 1.00. But for weekly and daily data showing there is decreasing trend in reliability (r = 0.65, for 200th day), indicating failures are increasing as the time elapses, which also shows the necessity of improved maintenance practices.
4. Hence, it is advised to reschedule monthly and quarterly schedules to fortnightly and bi-monthly with better facilities and observed for some period to know if there is any decrease in failures and improvement in the availability and reliability.

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