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Availability and Maintainability Analysis of Buses -A Case Study at TSRTC

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Abstract— The availability and maintainability of a machine or equipment is the most important parameter in deciding the performance level of any organization. Hence, the managers would be very much interested to keep their machines or equipment available for maximum Hours without any failures. Also proper maintenance of machine or equipment and its periodic conditioning play a vital role in restoring the system after a repair. All these necessitate every manager and engineer to focus on availability and maintainability of machine or equipment. This study was taken up to evaluate the availability and maintainability of TSRTC buses to improve the profits and to minimize the customer dissatisfaction. The data regarding the bus failures for the period of one year has been collected and MTBF and MTTR have been calculated for each bus separately which are essential in finding the availability and maintainability. The results have been categorized as high, medium and low, and arranged in the matrix as a cluster based on their results. The focus on the buses which are at most extremities in the matrix may considerably maximize the availability and also the profits to the organization.

Index Terms— Availability, Maintainability, TTR, MTTR,TBF, MTBF, AMA Matrix.

I. INTRODUCTION

Transportation has become one of the major necessities of human life after food, shelter and clothing. Various transport systems include airways, railways, roadways, waterways which form major part of the country's economy. It is clearly evident from the fact that railways have a separate budget in India. In the state level, the human movements are hugely dependent on road transport i.e. public transport systems such as buses run by government/private, taxi, self-owned cars, auto- rickshaws and two wheelers particularly for moving to schools, colleges, offices and other business and personal works. Among all these, road transportation by buses run by the government is one of the major areas, where the system safety and availability are vital. In this connection availability and maintainability are two major aspects, where the system performance and its reliability can be estimated. The availability of machines or equipment is the challenging task of the Managers of any organization. It is essential to maintain the good condition of the machines or equipment in order to make the equipment availability in the field. System maintainability and availability have assumed great significance in recent years due to a competitive environment and overall operating and production costs. Performance of equipment depends on maintainability and availability of the equipment used, operating environment, maintenance efficiency, operation process and technical expertise of operators, etc. When the maintainability and availability of system are low, efforts are needed to improve them by reducing the failure rate or increasing the repair rate for each component or subsystem.

Availability is a performance criterion for repairable systems that accounts for both the reliability and maintainability properties of a component or system. Availability of any machinery or equipment in the field is essential for the progress of the work, production or service. Unavailability of equipment may incur production loss, customer dissatisfaction or financial loses.

In order to avoid these, there is a need to estimate and maximize the availability of the system. On the other hand, when a system or a machine is under repair, it should be restored in the minimal time, if not the availability will be minimized. In order to restore the system in the minimal time, the system should be in a good condition, which is possible with good maintenance policies. In practice, it is possible to define some of the maintenance policies in advance and take design decision accordingly. In other words, the maintainability of the system should be improved with timely maintenance policies. Maintainability addresses the duration of time the item is in a down state/non-operating state which in turn describes at which extent the item is repaired back to up state/operating state. This study was carried out for buses at TSRTC to evaluate the availability and maintainability. The aim of this paper is to investigate the availability of buses in a perspective of effective and efficient maintenance role for optimum availability through identifying the pattern and trend of the failures of buses.

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II. ORGANIZATION PROFILE

TSRTC is a State owned corporation that runs transport services with in the Indian state of Telangana. It was formed in 2014 by splitting the APSRTC. It serves about 89.4 lakh passengers every day, having three zones and services operating through 95 depots. TSRTC has three zones, Hyderabad, Greater Hyderabad and Karimnagar. It has 13 regions, 95 depots and 357 bus stations. TSRTC buses undertake operations on 3,687 routes, having an approximate fleet of 10,460 under its wing.

In 1932, Nizam state rail & road transport department, a wing of Nizam state railway in the erstwhile Hyderabad state was started with 27 buses and 166 employees. As department of Hyderabad state Government was established on 01-11-1951 and as A.P.S.R.T.C on 11-01-1958.

Consequent upon bifurcation of Andhra Pradesh state into Telangana, the Govt. of Telangana has subsequently established Telangana State Road Transport Corporation. TSRTC is a public transport system of Telangana state. It is the only and primary public road transport system which is governed by the govt. of Telangana which was established on 27-04-2016.

Objectives of the Present Study

The objectives of the present study are as follows

•To investigate frequent failure problems of TSRTC buses by collecting and analyzing the data.

•To figure out failure Rate of buses using the maintenance data.

•To examine and evaluate availability and maintainability of buses.

III. AVAILABILITY

If one considers both reliability (probability that the item will not fail) and maintainability the (probability that the item is successfully restored after failure), then an additional metric is needed for the probability that the component/system is operational at a given time, t (i.e. has not failed or it has been restored after failure). This metric is availability. It is defined as the capacity of a system or machine to perform its intended function when asked to do so. It is nothing but operational readiness whenever required. Availability is a performance criterion for repairable systems that accounts for both the reliability and maintainability properties of a component or system.

It can be represented as,

Availability = Total uptime/ (Total uptime + Downtime)

The availability can be maximized by the following methods.

a.Through proper design and manufacturing of the machine or equipment.

b.Proper handling of the machines while in service/production.

c.Improving the life through proper maintenance practices.

d.Zero Accidents to machines or equipment.

IV. MAINTAINABILITY

When a piece of equipment has failed, it is important to get it back into an operating condition as soon as possible; this is known as maintainability. For a given active maintenance action, the maintainability of a system is defined as the probability that it can be retained in or re-stored to a specified condition within a given time. Maintenance is any activity carried out on an asset in order to ensure that the asset continues to perform its intended functions. According to Jerry D. Kahn (2006), maintenance management is the coordination, control, planning, execution and monitoring of the right equipment maintenance activities in manufacturing and facilities operations.

It is defined as the probability that a system can be restored to predetermined level of condition in a specified period, when maintenance is carried out with pre decided procedures. In other words, maintainability measures the ease and speed with which a system can be restored to operational status after a failure occurs. This is similar to system reliability analysis except that the random variable of interest in maintainability analysis is time-to- repair rather than time-to-failure. Quantitatively it has probabilities and is measured based on the total down time for maintenance including all times for diagnosis, trouble shooting, tear-down, removal/replacement, active repair time, verification testing that the repair is adequate, delays for logistic movements and administrative maintenance delays. In a maintenance improvement program, the maintenance activities are analyzed to ensure that the correct blend of maintenance strategies is utilized.

V. BACKGROUND

Production Engineers and Managers are interested to know whether their machine or equipment is running as per the

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standard hours. At the same time the managers who have less time to involve in day to day operations would like to focus their attention on the lower efficiency areas for which they need some tools that can guide them to act. Since no machine is totally immune to breakdowns, same can be applicable in the case of public transport vehicles (buses) in TSRTC of Telangana state. Hence, it is necessary to understand the failure mode, failure rate, frequency of failure etc. so that the necessary action can be initiated to improve the availability and maintainability of the buses for better service. Also effective and efficient maintenance activities and proper management of resources will considerably minimize the downtime of buses and maximize the service availability.

VI. PRESENT MAINTENANCE SYSTEM

In order to study the maintenance strategies of TSRTC (Dilsukhnagar Bus Depot), a team has been employed for the observation. After the critical observation, it is known that the corporation follows preventive maintenance system in two levels. The regular maintenance schedules are followed at depot level for minor failures of buses, which results in minimizing the delay time. Whereas the Workshops cater to the repair/ replacement of Major parts/aggregates and act as the production units of the Corporation and help in improving the availability of buses for Depot operations. Further, about 8% of the buses of each depot strength is maintained as spares to meet the emergencies (when bus failed, spare bus is being sent to provide the service).

VII. METHODOLOGY

This paper presents the present state of availability and maintainability of the buses of the Corporation. The focus will be on the time between failures (TBF) and the time to repair (TTR).
The time between failures tell us the availability (uptime) and the time to repair (down time) tell about maintainability of buses. The time between failures (TBFs) can be (i) increasing or (ii) decreasing or(iii) can be consistent and so is the case with the time to repair (TTRs). In this paper, the various combinations of TBFs and TTRs are tabulated in a suitable matrix form and a method is developed to know what combination of TBFs and TRRs would provide High to low availability or maintainability of buses. The required data on buses is collected from one of the Bus Depots (Dilsukhnagar, Hyderabad) of the Corporation and analysis is carried out using data of few buses. Based on this information and analysis, a suitable maintenance program may be suggested to the corporation for better availability of buses and hence better profitability to the organization.

VIII. DATA COLLECTION & DATA EVALUATION

In the availability and maintainability analysis, the data collection is one of the major tasks. There are three basic steps that should be performed before the data can be analyzed to determine availability and maintainability characteristics. These are data collection from a computerized equipment maintenance system (database) or logbook, sorting of the data required for analysis and data classification in the required form for the analysis (i.e. TBF, TTR, frequency, total breakdown hours, total working hours, total maintenance hours, etc). In addition to the information generated by maintenance and production functions in the form of reports, much of the raw data upon which these reports are based must also be accessible in order to achieve successful availability and maintainability modelling. For this study, initially the higher officials of TSRTC was contacted for their approval by then the data regarding the failures and down time of buses at Dilsukhnagar Depot was collected for the period of April 2015 to March 2016. For a total of 104 buses in the depot, 21 buses are considered for the analysis, which shows the failures more than 20 per year. The failures in general are related to Engine, Gear box, Braking system, Clutch plates, c joints, Fuel pump, Electricals, Tire punctures etc. As the time taken to repair the failure of a bus varies with each problem, the average time to repair (TTR) each problem is mentioned in the table 2. The detailed failure number according to month and total failures in a year, its MTTR & MTBF are shown in the tables (1to 4).

Table 1: Month wise bus failure data (no. of failures)

Sl. No.	Bus No.	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	**Total no. of failures**
1	7162	2	7	1	2	5	1	1	2	0	6	2	3	**32**
2	3438	1	3	4	0	0	9	2	3	3	1	8	5	**39**
3	0015	0	1	0	2	5	2	2	4	1	4	2	2	**25**
4	7256	6	4	7	6	1	3	7	2	2	5	4	3	**50**
5	6758	0	5	1	6	6	3	1	2	1	1	5	4	**35**
6	7338	3	1	6	7	2	6	5	9	5	2	2	4	**52**
7	1943	3	4	0	1	4	2	2	1	1	0	1	1	**20**
8	3029	5	7	1	5	5	6	8	3	3	1	2	1	**47**

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9	4035	1	4	6	5	2	2	3	1	3	3	5	4	**39**
10	7314	0	0	8	6	1	10	8	1	5	5	3	8	**55**
11	0166	7	7	4	9	4	4	1	2	3	0	0	1	**42**
12	7295	7	2	5	2	2	7	6	1	3	7	1	1	**44**
13	7192	0	8	0	1	4	2	1	2	1	1	1	3	**24**
14	7262	5	4	3	3	4	8	2	7	1	3	3	4	**47**
15	6522	0	4	1	1	2	3	2	5	3	4	7	4	**36**
16	1943	1	7	3	4	2	7	6	4	2	2	1	2	**41**
17	7184	2	2	7	5	6	2	4	3	1	4	3	3	**42**
18	6052	6	1	4	3	0	2	8	1	7	6	4	7	**49**
19	6376	2	2	4	0	1	0	4	4	3	2	1	4	**27**
20	7140	1	2	2	5	7	4	6	7	5	2	3	3	**47**
21	0069	4	4	2	1	1	2	4	5	5	1	1	1	**31**

Table 2: Bus failure data - Problem wise

Sl. No.	Bus No.	Engine Problems	Gearbox Problems	Brake Problems	Clutch Problems	C-joint Problems	Tire Problems +Puncture	Electrical+ Other Problems	Total no. of failures
1	7162	1	1	4	2	3	2	19	**32**
2	3438	10	7	7	4	2	4	5	**39**
3	0015	4	4	2	4	3	2	4	**25**
4	7256	11	4	5	10	5	5	10	**50**
5	6758	12	4	4	6	2	3	4	**35**
6	7338	14	10	4	4	4	6	10	**52**
7	1943	4	2	2	2	2	4	4	**20**
8	3029	10	8	6	4	4	5	10	**47**
9	4035	6	6	7	5	1	6	8	**39**
10	7314	12	6	4	8	7	8	10	**55**
11	0166	4	8	8	4	2	4	12	**42**
12	7295	6	6	7	6	5	4	10	**44**
13	7192	0	0	0	1	0	14	15	**30**
14	7262	8	10	4	6	3	10	6	**47**
15	6522	4	6	6	8	2	2	8	**36**
16	1943	9	7	8	7	2	3	5	**41**
17	7184	0	1	1	1	2	15	22	**42**
18	6052	12	8	7	9	5	2	6	**49**
19	6376	3	4	6	5	2	3	4	**27**
20	7140	9	8	7	10	2	2	9	**47**
21	0069	4	6	6	4	3	4	4	**31**

Table 3: Calculation of Repair hours for each Problem

Sl. No.	Bus No.	Engine@ 8 hrs	Gearbox @6 hrs	Brakes@ 3 hrs	Clutch@ 2 hrs	C-joint @3 hrs	Tire + Puncture@ 1 hr	Electrical+ others @ 1 hr	**CTTR of each bus (Hrs.)**
1	7162	8	6	12	4	9	2	19	**60**
2	3438	80	42	21	8	6	4	5	**166**
3	0015	32	24	6	8	9	2	4	**85**
4	7256	88	24	15	20	15	5	10	**177**
5	6758	96	24	12	12	6	3	4	**157**
6	7338	112	60	12	8	12	6	10	**220**
7	1943	32	12	6	4	6	4	4	**68**
8	3029	80	48	18	8	12	5	10	**181**
9	4035	48	36	21	10	3	6	8	**132**
10	7314	96	36	12	16	21	8	10	**199**
11	0166	32	48	24	8	6	4	12	**134**
12	7295	48	36	21	12	15	4	10	**146**
13	7192	0	0	0	2	0	14	15	**31**
14	7262	64	60	12	12	9	10	6	**173**
15	6522	32	36	18	16	6	2	8	**118**
16	1943	72	42	24	14	6	3	5	**166**
17	7184	0	6	3	2	6	15	22	**54**
18	6052	96	48	21	18	15	2	6	**206**
19	6376	24	24	18	10	6	3	4	**89**
20	7140	72	48	21	20	6	2	9	**178**
21	0069	32	36	18	8	9	4	4	**111**

Table 4: Calculation of CTTR, MTTR, CTBF & MTBF

S.No	**Bus no.**	**CTTR Hrs**	**No. of failures**	**MTTR=** CTTR/no. of failures	**CTBF=4800-CTTR**	**MTBF=** CTBF/no. of failures
1	7162	60	32	1.875	4740	148.125
2	3438	166	39	4.26	4634	118.820
3	0015	85	25	3.40	4715	188.600
4	7256	177	50	3.54	4623	92.460
5	6758	157	35	4.49	4643	132.657
6	7338	220	52	4.23	4580	88.076
7	1943	68	20	3.40	4732	236.600
8	3029	181	47	3.851	4619	98.276

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9	4035	132	39	3.385	4668	119.692
10	7314	199	55	3.618	4601	83.654
11	0166	134	42	3.19	4666	111.095
12	7295	146	44	3.318	4654	105.772
13	7192	31	30	1.0333	4769	158.966
14	7262	173	47	3.68	4627	98.446
15	6522	118	36	3.278	4682	130.055
16	1943	166	41	4.049	4634	113.024
17	7184	54	42	1.2857	4746	113.000
18	6052	206	49	4.204	4594	93.755
19	6376	89	27	3.296	4711	174.481
20	7140	178	47	3.787	4622	98.340
21	0069	111	31	3.581	4689	151.258

IX. AVAILABILITY AND MAINTAINABILITY CALCULATIONS

The availability is calculated using MTBF and MTTR of the buses. The data is taken and CTTR, CTBF is calculated. Successively MTBF and MTTR is calculated. Calculation for bus no. **7162** is shown below
CTBF =4740, CTTR =60

MTBF = CTBF/no. of failures = 4740/32=148.125
MTTR = CTTR/no. of failures = 60/32= 1.875

Availability =MTBF/(MTBF+MTTR)
= 148.125 / (148.125+1.875) = **0.9875**

The maintainability index is calculated using the MTTR of the system. MTTR is calculated by taking CTTR into consideration. Calculation for bus no. **7162** is shown below.
CTTR = 60,
MTTR = CTTR/no.of failures = 60/32 = 1.875

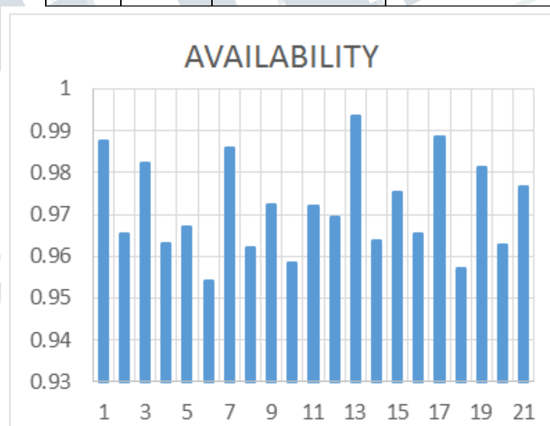
Maintainability = 1-$e^{(-1/MTTR)}$ = $1-e^{(-1/1.875)}$

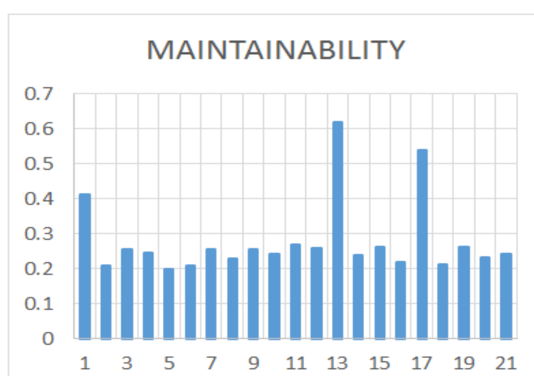
$=1-e^{-0.533}$ = **0.4132.**

Note: For all 21 buses the values are shown in Table 5.

Table 5: Availability and Maintainability values

Sl. No.	Bus No.	Availability	Maintainability
1	7162	0.9875	0.4132
2	3438	0.9653	0.2091
3	0015	0.9822	0.2547
4	7256	0.9631	0.2460
5	6758	0.9672	0.2001
6	7338	0.9541	0.2105
7	1943	0.9858	0.2548
8	3029	0.9622	0.2287
9	4035	0.9724	0.2558
10	7314	0.9585	0.2415
11	0166	0.9720	0.2691
12	7295	0.9695	0.2602
13	7192	0.9935	0.6201
14	7262	0.9639	0.2379
15	6522	0.9754	0.2629
16	1943	0.9654	0.2188
17	7184	0.9887	0.5405
18	6052	0.9570	0.2117
19	6376	0.9814	0.2617
20	7140	0.9629	0.2321
21	0069	0.9768	0.2437





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X. DATA ANALYSIS AND FITTING THE DATA

As discussed above, The time between failures (TBFs) can be (i) increasing or (ii) consistent or(iii) can be decreasing and so is the case with the time to repair (TTRs). For analysis purpose, following "AMA Matrix" is developed.

AMA MATRIX

TBF → / (TTR) ↓	Increasing *(High Availability) F1*	Consistent *(Medium Availability) F2*	Decreasing *(Low Availability) (F3)*
Increasing *(Low Maintainability) R1*	F1R1	F2R1	F3R1
Consistent *(Medium Maintainability) R2*	F1R2	F2R2	F3R2
Decreasing *(High Maintainability) R3*	F1R3	F2R3	F3R3

AMA matrix description

- Cell F1R1 represents TBF is increasing and TTR is also increasing. It shows the High availability and Low maintainability
- Cell F2R1 represents TBF is consistent and TTR is increasing. It shows the Medium availability and Low maintainability
- Cell F3R1 represents TBF is decreasing and TTR is increasing. It shows the Low availability and Low maintainability.
- Cell F1R2 represents TBF is increasing and TTR is consistent. It shows the High availability and medium maintainability.
- Cell F2R2 represents TBF is consistent and TTR is also consistent. It shows the medium availability and medium maintainability.
- Cell F3R2 represents TBF is decreasing and TTR is consistent. It shows the Low availability and medium maintainability.
- Cell F1R3 represents TBF is increasing and TTR is decreasing. It shows the high availability and high maintainability.
- Cell F2R3 represents TBF is consistent and TTR is decreasing. It shows the medium availability and medium maintainability.
- Cell F3R3 represents TBF is decreasing and TTR is decreasing. It shows the Low availability and Low maintainability.

The Criterion (Range of Values) for fitting the Data

Criterion	Availability (Range)	Maintainability (Range)
High	0.81-1.00	0.81 - 1.00
Medium	0.51-0.80	0.51 - 0.80
Low	0.0-0.50	0.0 – 0.50

From Table 5, the buses (S.nos) which fall into this criterion are marked in the AMA matrix.

Availability of Buses → / Maintainability of Buses ↓	*High Availability*	*Medium Availability*	*Low Availability*
High Maintainability	-	-	-
Medium Maintainability	13,17	-	-
Low Maintainability	1,2,3,4,7,9,11,12,15,19,21	5,6,8,10,14,16,18,20	-

XI. CONCLUSIONS

- By using AMA matrix, the condition of buses can be easily estimated.
- In the present case, the availability of almost all buses is either high or medium but all the buses are having low maintainability (except s.no13 and 17).
- It is observed that, in a rush to keep high availability of buses there is an increased sacrifice of the maintainability of buses.

- It is suggested that the management should evaluate the condition of buses using AM matrix and check for the shift of buses into better cells, else the buses in weak cells to be addressed with proper maintenance program.
- From the above, the buses falling in cell no.1 are to be operated with regular maintenance practices.
- The buses falling in cell no.9 are to be operated with utmost care i.e. close monitoring may be provided to improve the availability.
- By conducting brain storming sessions and with the suggestions from maintenance experts and based on criticality analysis, the management can devise a suitable maintenance program for each cell of AM Matrix.

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