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Availability Estimation and Maintenance Optimization for Transportations systems

Govindarajulu Eedara

Vignan's Foundation for Science, Technology and Research
govind305@gmail.com

ABSTRACT

The system performance depends on the availability, efficiency of maintenance and operating conditions. The industrial systems are designed, manufactured and tested/simulated under laboratory/ideal conditions. But the conditions in which the systems are working in real-time industries/companies are different. Due to this, the components of each system will fail well before the schedule given by the company even though the periodic maintenance is carried out as per the manufacturer's standard operating procedures (SOP). The complexity of the system will increase the failure probability and these failures will affect the performance of the system. Therefore, it is important to know the critical components of the system. In this paper, a methodology has been applied to identify the bottlenecks in the fleet as the availability estimation. Optimum maintenance intervals are calculated for each variety of systems based on the minimization of downtime.

The presented methodology is applied to on-road vehicles in Andhra Pradesh State Road Transport Corporation (APSRTC) as a case study. The transmission subsystem is identifiedas a bottleneck in transportation vehicles, availabilities and optimum maintenance intervals areestimated for TVG SML SL and EXP type buses.

1. Introduction

Many complex systems such as passenger buses, locomotives, aircraft, mining equipment, auto motives, plant machinery etc., are maintained on a regular and continuous basis to ensure a certain level of availability and safety therein. These systems are generally repaired rather than replaced on failure to serve the intended function satisfactorily through the restoration process involving any manual or automatic actions that is other than replacing the system as a whole [1]. Therefore, the task of the maintenance department concern with is to ensure that the system/fleet would meet and continue to meet its established performance goals.

It is often desirable to assess and analyse the various reliability measures, viz., expected availability characteristic, frequency of failure, downtime/number of failure, cost of maintenance or any other characteristics influenced and can be assessed by the system age, usage, and operation based on the data accumulated in the customers' use environment. Such analysis also enables to optimise the maintenance schedule tasks and plan & take action to improve the effectiveness of maintenance actions. These systems are ubiquitous in all walks of life, however, the techniques available to analyse them are not so vogue as compared to the techniques available for analysing non-repairable systems. This situation often leads to the applications of incorrect analysis approaches and decisions thereof by knowingly or unknowingly applying the terminology, which is exclusively reserved for non-repairable systems [2]

The literature on repairable system reliability is vast and most often the techniques & models applied to analyse repairable systems have been Markov models, renewal theory approach, stochastic point process models (HPP, NHPP, GRP…by ignoring the downtime), and lastly, the simulation - for the more complex cases. These techniques invariably require experience, a substantial degree of knowledge in probability and statistics, statistical sophistication, assumptions, and an iterative procedure to solve analytical equations necessitating the use of special software on the part of analysts and practitioners. Summarily, these techniques are complex and computationally cumbersome for a variety of reasons and not intuitive to an engineer/manager supporting his customers. Additionally, the inability to justify various assumptions, ideas, and results to the management while doing such analysis has further forbidden its widespread use within an organization.

Therefore, it becomes imperative to employ a simple and statistically valid approach whose results can be well explained and communicative with the management and engineers.

To our knowledge, the Literature is hardly available that considers the downtime in analysis and assesses the availability of a system/fleet except for a brief mention found in. However, one can find several other practical scenarios & examples provided and well-presented therein [3].

The purpose of this work is to apply the non-parametric method for continuously varying the performance of passenger vehicles from the maintenance data collected for about three years. Note that many models ignore the maintenance downtime due to system failure or preventive maintenance, however, in practice the downtime for the systems like buses constitutes a significant part of their operational time that may affect the decision-making process. In such cases,

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a non-parametric approach plays an important role in the performance analysing of complex repairable systems without involving infeasible assumptions. The non-parametric models are useful in tracking field failures, identifying underlying failure causes, anomalous systems, unusual behaviour, and the effect of various parameters on the performance and failure of systems at the fleet level.

The rest of the paper explains the non-parametric method for availability estimation. A Non-Parametric method is applied to a real scenario of buses used for passenger transportation. Next applied physics of failure to identify the underline causes for the frequent failures in bottlenecks and concluded with possible solutions to mitigate the failures.

2. Availability Estimation

The repairable systems use availability as a performance index and include component or system reliability and maintainability. Availability is categorized based on the types of downtimes includes in computation [4]. Inherent availability (A_{Inh}) will consider only corrective maintenance downtimes, where Achieved Availability (A_{ach}) considers only active maintenance time. But, in case of operational availability (A_{op}) considers the total down time required. This can also be termed as posterior availability based on actual events happened to the system when it had been in operation.

$$A_{op} = \frac{Actual\ Cumulative\ uptime}{Total\ time}$$

$$A_{Inh} = \frac{Actual\ Cumulative\ uptime}{CM\ time + Actual\ cumulative\ uptime}$$

$$A_{ach} = \frac{Actual\ Cumulative\ uptime}{CM\ time + PM\ time + Actual\ cumulative\ uptime}$$

In the above definitions, the efficiency and speed of the maintenance personnel will be indexed in Corrective maintenance (CM), as well as their expertise and training level. Preventive maintenance time (PM) is to prolong or mitigate failures of a component or system. But the total downtime includes Corrective Maintenance time, Preventive Maintenance time and Logistic delay time.

3. Data Collection

Buses have been used to haul both passengers, and freight on the country's road transportation. To maintain healthy and reliable systems with high availability proper maintenance is required for almost all types of its subsystems.
In this article, a problem that has not been addressed well in the literature is considered for the availability and physics of failure of Road transport systems with real-time operational data from maintenance sheds [5]. The manufacturer desires to assess the availability of its buses from the maintenance record gathered from 2018 to 2021 to assess the availability of such vehicles and to determine some of the critical areas to improve upon.

Data should preferably be collected for individual components and equipment since data can always be combined, if appropriate, but it cannot always be disaggregated. In general, maintenance data collected on a timely basis may be either discrete or continuous. Field data collection should include the relevant technical information necessary such as unit id, operation time, failure mode and type of maintenance action etcetera for conducting a target analysis. Any analysis is said to be successful only when a rigorous, proper and authentic field data collection system is in place to avoid the situation of "GIGO-garbage in-garbage out" that majority of the industries forgo. This is a major challenge faced by any analyst to pre-process the data scattered all over in a useful and meaningful form and this study is also not an exception.

Table 1. Available vehicles for analysis.

S. No	**Type of Vehicle**	**Company**	**No. Of Buses**
1	Metro	Ashok Leyland	16
2	SML	Isuzu	05
3	Express	Ashok Leyland/ TATA	07
4	Super Luxury	Ashok Leyland/ TATA/ Eicher	15
5	TVG	Ashok Leyland/ TATA	31
6	Ultra-Deluxe	Ashok Leyland/ TATA	9
7	A/C	Volva/Isuzu	5

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Table 2: Sample Data Template

S.No	Date	Vehicle No	Company Name	Type	Schedule Maintenance	Remarks
1	11/10/2018	243	TATA	SL	complaint	clutch plate, ATF oil leak, fuse issue, gear rod issue,
	11/11/2018				complaint	cabin sound, acceleration plate, gear slip

4. Data Sorting

After collecting the data from the maintenance sheds it should be sorted as per data templates used to calculate availability.

Table 3. Data template for sorting data

S.No	Date	Type	Time of failure	Time of relief arranged	Completed time	Repair time (hr)	Logistic delay (hr)	TBF (hr)	Total time (hr)	Availability
1	24.1.18	TVG	18:30:00	19:30:00	14:20:00	5.10	1.00	570.3	576.4	98.94%
2	17.10.17	SML	19:00:00	20:00:00	04:00:00	16.00	1.00	6979	6996	99.76%

5. Results and discussion

From the analysis of maintenance data obtained from APSRTC shed, TVG (class of local bus), collected in the year 2019-21, it follows that about 25% of all the failures are found in TVG vehicle transmission problems and breaks problems (27%). Each vehicle has different system failures shown in table 3, which gives detailed information like no. of failures in transmission failures, engine failures, brake failures, suspension failures, electrical failures, airlocks, oil leaks and other failures.

Table 4. Number of failures in each class of vehicles

S. No	Type of Vehicle	Engine	Trans Mission	Brakes	Suspension	Electrical Cal	Air Lock	Oil Leak	Others	Total failures
1	TVG	11	43	28	2	22	12	5	44	167
2	UD	4	8	30	0	10	0	2	13	67
3	SL	21	12	18	12	8	7	1	25	104
4	SML	5	3	0	0	4	1	1	6	20
5	ME	4	22	4	5	4	2	1	7	49
6	EXP	13	25	25	0	20	6	5	45	139
7	A/C	1	0	3	0	4	0	0	2	10
TOTAL		59	113	108	19	72	28	15	142	**556**
% of failures by each subsystem		**10.61%**	**20.32%**	**19.42%**	**3.42%**	**12.95%**	**5.04%**	**2.70%**	**25.54%**	

According to the information given in table 3, TVG vehicles have more number of failures in specific, and transmission failures are more in all vehicles. In that, Express and metro express vehicles face more no. of failures followed by TVG. Brakes failures are taking position two, for system failures in Ultra-Deluxe followed by TVG. The following pie charts give the detailed failure percentage for each class of vehicles.

Table 5. Times data for availability estimation for each vehicle

Vehicle type	Time to repair (hr)	Logistic delay (hr)	Time between failure (hr)	Total time(hr)
TVG	88.20	24.05	74519.35	74631.60

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SML	80.30	17.96	57301.65	57399.91
UD	14.60	3.90	16219.60	16238.10
SL	58.00	11.00	25224.00	25293.00
EXP	2.21	1.64	7283.00	7286.85

Table 6. Availability estimation for each vehicle

	AVAILABILITIES		
Type of Bus	**In-herent Availability (A_I) %**	**Operational Availability (Ao) %**	**Achieved Availability (A_A)%**
TVG	99	97	96
SML	99	96	99
UD	98	96	95
SL	99	97	96
EXP	99	**85**	**81**

It is observed from the data analysis and availability estimation the number of failures of express vehicles is less compared to TVG vehicles, the availability is less. This is due to either more repair time or the logistic delay.

Table 7. Code for each class of vehicle

Class of Vehicle	**Code**
Express	A
Telugu Velugu	B
SML	C
Super Luxury	D
Ultra-Deluxe	E

Table 8. Type of failure based vehicle sequence

S.No	Type of failure	Sequence
1	Transmission system failure	**A**-B-D-E-C
2	Brake failures	E-**A**-B-D-C
3	Engine failures	D-**A**-C-B-E
4	Suspension failures	D-**A**-B-E-C
5	Electrical failures	**A**-B-E-D-C
	Criticality sequence of buses	**A-B-D-E-C**

Based on the type of failures, the sequence of buses is A-B-D-E-C (Express- TVG-SL-UD-SML). The first failure system is A, i.e., an Express class vehicle facing transmission problem followed by braking system and transmission system in a class vehicle, Super Luxury, Ultra Deluxe and vehicles. This priority selection gives information regarding the maintenance and availability of the components for each type of system failure in all classes of vehicles.

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6. OPTIMAL INSPECTION FREQUENCY BASED ON MINIMIZATION OF DOWNTIME:

The goal is to present models that can be used to determine optimal inspection schedules, that is, the points in time at which the inspection action should take place.

The benefits of the inspection, such as detection and correction of minordefects before a major breakdown occurs. The primary goal addressed isto make a system more reliable through inspection.
In this paper, it considered finding the inspection interval for equipment that is in continuous operation and subject to breakdowns

To reduce the number of breakdowns, the maintenance personnel will periodically inspect the equipment and rectify any minor defects that may otherwise eventually cause a complete breakdown. These inspections cost money in terms of materials, wages, and loss of production dueto scheduled downtime. Here the aim to determine is an inspection policy that will give us the correct balance between the number of inspections and the resulting output,such that the profit per unit time in terms of availability of the equipment is maximized over a long period.

Here it is considered the inspection policy that minimizes the total downtime per unit time incurred due to breakdowns and inspections, rather than determining the policy that maximizes profit per unit time.

Construction of the Model

1. Equipment failures occur according to the exponential distribution with the meantime to failure (MTTF) = 1/λ, where λ is the mean arrival rate of failures.
2. Repair times are exponentially distributed with a mean time of 1/μ.
3. The inspection policy is to perform *n* inspections per unit time. Inspection times are exponentially distributed with a mean time of 1/*i*.
4. The objective is to choose *n* to minimize total downtime per unit time.
5. The total downtime per unit time will be a function of the inspection frequency, *n*, denoted as *D*(*n*)

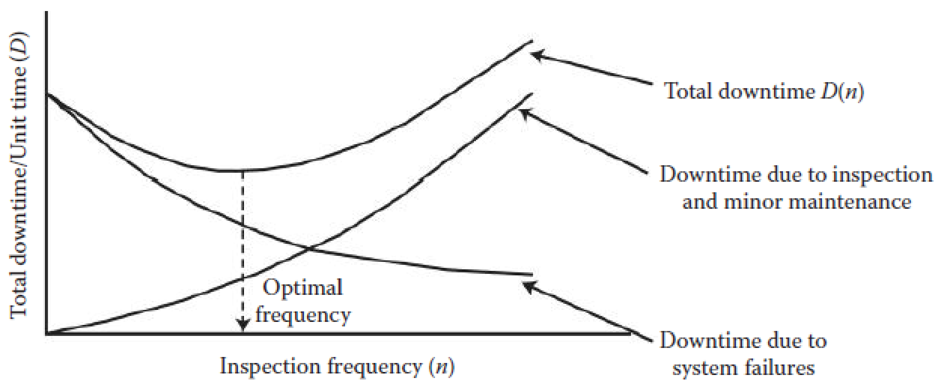

Fig 1: Optimal inspection frequency: minimizing downtime. [7]

D (n) = downtime incurred due to repairs per unit time + downtime incurred due to inspection per unit time

$$D(n) = \frac{\lambda(n)}{\mu} + \frac{n}{i}$$

Where λ(n)/μ is the proportion of unit time that a job spends being repaired.

$$n = \sqrt{\frac{ki}{\mu}}$$

Where k can be interpreted as the arrival rate of breakdowns per unit time when one inspection is made per unit time.

The equation is a model of the problem relating inspection frequency n to total downtime D (n). To calculate no. of inspections for each type of vehicle, preventive maintenance downtime is required. As per the equation, the following Table 9 gives the number of inspection for different class of buses with a different number of breakdown and also determine the downtime for each inspection category.

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Table 9. Optimum maintenance interval and downtime for buses

Downtime Minimization	TVG	SML	SL	EXP
K	1	1	1	1
N	8	9	8	5
D(N) HR/ MONTH	92.30	128.35	144.042	106.75
K	2	2	2	2
N	11	13	11	8
D(N) HR/ MONTH	97.02	136.11	136.416	113.18
K	3	3	3	3
N	14	16	14	9
D(N) HR/ MONTH	106.23	148.20	177.89	123.29
K	4	4	4	4
N	16	19	16	11
D(N) HR/ MONTH	115.002	160.40	192.58	133.43
K	5	5	5	5
N	18	21	18	12
D(N) HR/ MONTH	123.11	172.18	210.47	143.22

Conclusions

From the availability analysis, it is found that transmission failures are more frequent in the Express class of vehicles. in that also clutch problems are more. In that also Ashok Leylandclutch plate type has a heavyweight compared to the TATA vehicle clutch plate that’s why the Ashok Leyland clutch plates have the more failures. According to the analysis, it is found that brake failures are more frequent in a super-luxury class of vehicles, it is also found that SML class vehicles and Express classvehicles need to add some more maintenance to the existing maintenance schedule. The optimum maintenance intervals are determined by downtime minimization for TVG, SML, SL and EXP. This will improve the availability of the buses as well as mitigate the sudden failures of the bus.

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