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Fleet Maintenance Development and Analysis for a Public Transport Company in Florence -Technical and Cost Benefit Analysis

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Abstract:- Proper maintenance of components can improve the overall output of the organization by reducing the overall costs. This work presents the best strategy to develop the fleet maintenance and to recognize the severity of the component in the Mercedes bus. The data was extracted from the public transport buses of Florence city. Further the Matlab is used to detect the deviations in set values. The deviations in the suspension height, accelerometer vibration data, brake pad thickness was analyzed. The methods adopted can analyze the data in primary and secondary stages. The better brake pad replacement can be scheduled by simple methods adopted in the paper.

I. INTRODUCTION

The periodic maintenance is evaluated with reference to the past failures and the mean is calculated to define the mean time to failure. This is adopted because the maintenance may take a lot of time so, by adopting the periodic maintenance it saves the time. The actual failures data can be obtained by using different condition monitoring techniques. Performing the activities based with reference to actual situations of vehicle can improve the safety, system availability, technical maintenance costs.

II. PROBLEM FORMULATION

Optimizing the periodic maintenance is not a simple task as it requires different measuring instruments and skilled personnel and sensor data so that the accurate interval can be decided.

Before adopting the condition-based maintenance, it is important to analyze the feasibility of the capital budget and to develop a cost analysis that benefits the organization.

➢ *Main Objective*

The main objective of the thesis is to assess the entire defects of the vehicles and to determine the present conditions and to develop the systems to detect the defects easily.

➢ *Sub Objective*

The sub-objectives of this thesis are,

- Identify the common defects in the vehicles
- Assess if the defects occur after the maintenance. (i.e. if the defects occur just before the maintenance plan or just after maintenance plan)
- Develop the maintenance priority analysis
- Assess the faults individually by Weibull analysis
- Develop the methods to determine the faults in the individual component.
- Determine the cost-benefit analysis of the predictive maintenance- to check whether adopting the predictive maintenance activity is Loss/Profit for the organization.

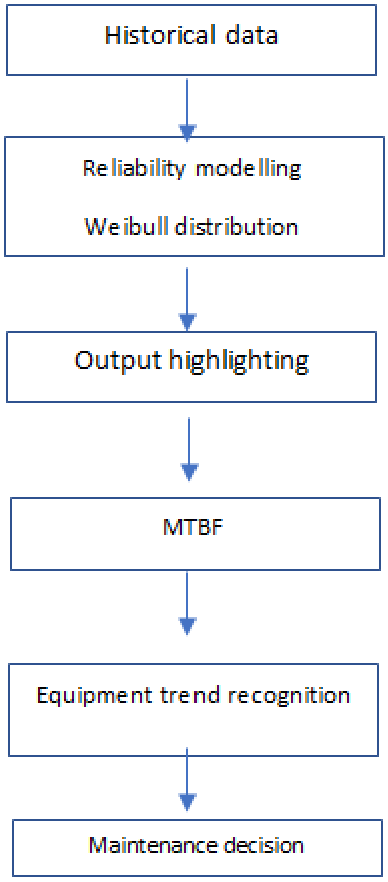

Fig 1:- Procedure for maintenance strategy

The historical data is collected, and the components maintenance priority can be analyzed based on the following formula.

$$\text{System and equipment reliability prioritization} = \frac{(A^2+B^2+C^2)^{\frac{1}{2}}}{(4)}$$

Safety is assessed based on the classification of components in vehicle divided into safety class with grade A, B and C, the quality class with rank 1-3.

- *Mileage vs Time of Historical Data*

It is found that the engine is vulnerable to fail just before and after the maintenance**.**

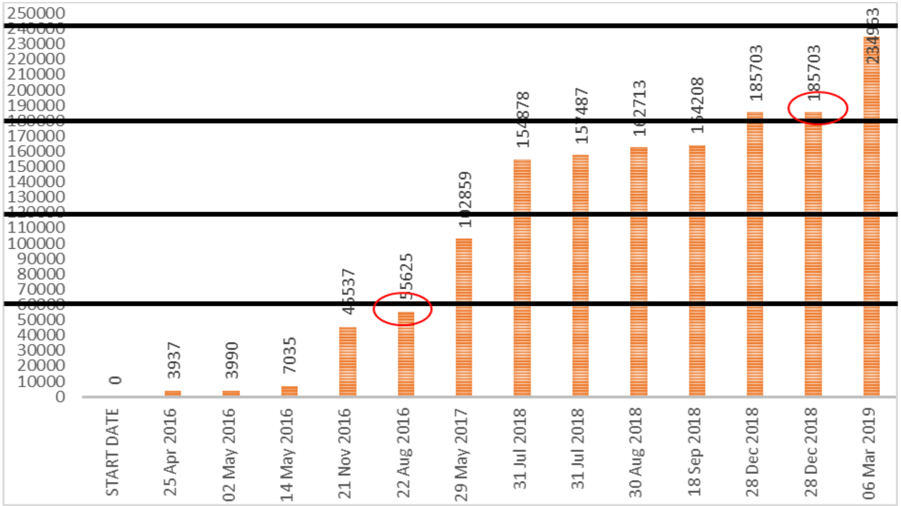

Fig 2:- Mileage vs Time Graph for Historical Data

The red color ring show that the defect occurs just before and after the scheduled maintenance plan. This is a very big problem as the periodic maintenance fails and the components may prone to big down times.

III. ENGINE-ANALYSIS

The percentile report and MTTR is calculated and the percentile report tells us that we can expect 50 percent failure rate or One – half of population will fail at 50.413, this is the median. Percentile report can also be used to determine control limits for non-normal data the lower control limit is the 0.135 percent value which is 0.244983 the upper limit is the 99.865 value, which Is 345.47.

Percentile Report:	
Percentage	**Percentile (Time)**
0.1	0.189591
0.135	0.244983
0.5	0.750237
1	1.359
5	5.462
10	10.09671209
25	23.798
50	50.413
75	91.097
90	140.48
95	175.86
99	253.84
99.5	286.11
99.865	345.47
99.9	358.82

Table 1

Distribution Characteristics:	
	Estimate
Mean (MTTF)	65.258
Standard Deviation	55.886

Table 2

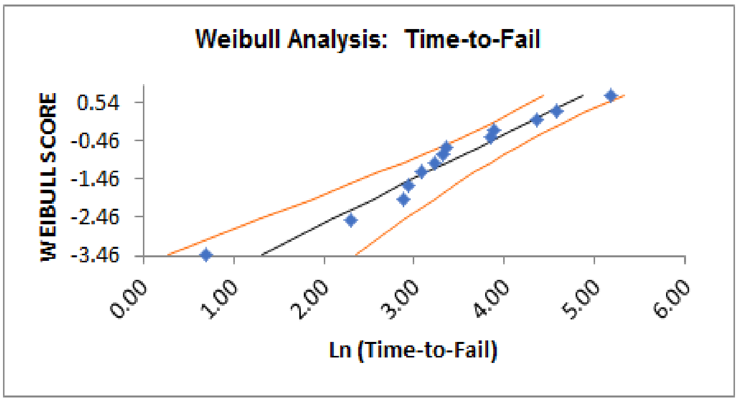

Fig 3:-Engine Weibull graph

The graph depicts that there are some fluctuations and the values deviate from the center line. In such cases a strong analysis is required. This can be solved with condition monitoring. The method uses the sensor data and measures the real time situation

➤ *Finding the internal defect in the OM936 engine from the vibration data of the engine*

The vibration data extracted, can be from the engine location will help to determine the detachments or regarding any knocks or sudden piston slaps in the engine.

The signals are sorted, and the speed vs time data is placed just above the vibration data. As the vibrations increase with respect to the speed, **if there are changes in the vibrations at the lower speed can be easily assessed and analyzed.**

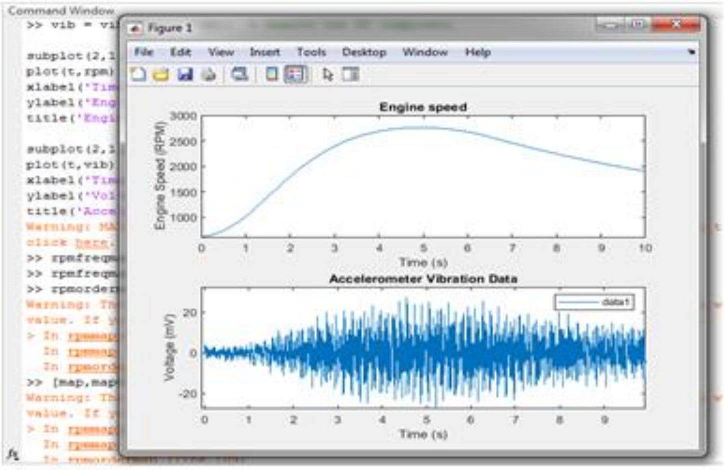

Fig 4:- Speed Vs Time Vs Vibration

- ➤ The data required for the above analysis are the change in the rpm and the changes in the vibration. A sample of 5000 intervals is taken and the analysis is carried out. The signals help to study the correlation between the varying speed with respect to time.
- ➤ There is some function like the order wave form which extract the time domain order for each wave form, and they can be compared with the previously available wave form.
- ➤ Suppose if there is a defect in the engine and it is found by the above method, one can check the fault amplitude with the corrected amplitude.
- ➤ The graph with two legends gives good understanding of the implementations done. If any of the changes are to be done can be checked and this reduces the time and effort of the staff.

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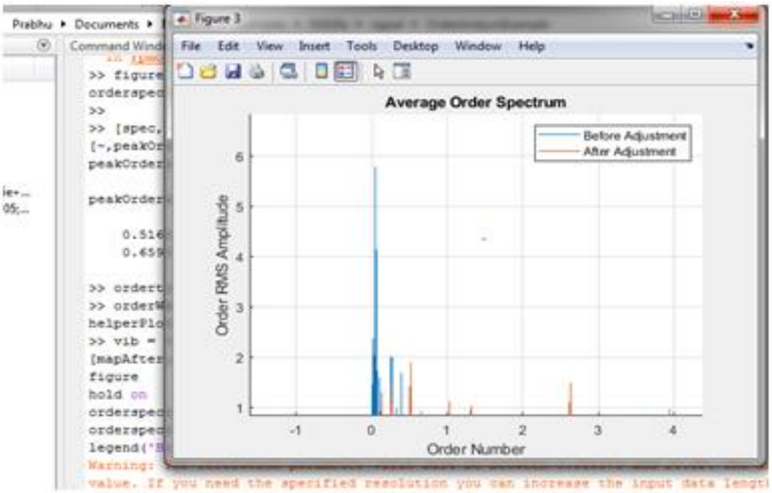

Fig 5:-Before vs after graph for vibration

The above graph can be analyzed and understood. This gives good analysis before and after the changes. Here we can see that still there is some vibration defect in the engine and it should be adjusted.

IV. SUSPENSION -ANALYSIS

The **Suspension Ride Height Sensor** is an electronic device that measures the distance between the road and a point on the vehicle's suspension, chassis or body. Based on the output of the sensor, the Electronic Control Unit (ECU) makes the compressor determine whether to fill or release air from the air bags. The ride height sensor sends signals to the ECU, which causes the suspension to react while driving over bumps or due to heavy loads on the vehicle to provide a smoother ride. It is usually fitted to the frame of the automobile or to components of the suspension system.

Similar analysis is carried for suspension and the data regarding the Percentile report and MTTR is noted and the Weibull graph is as below.

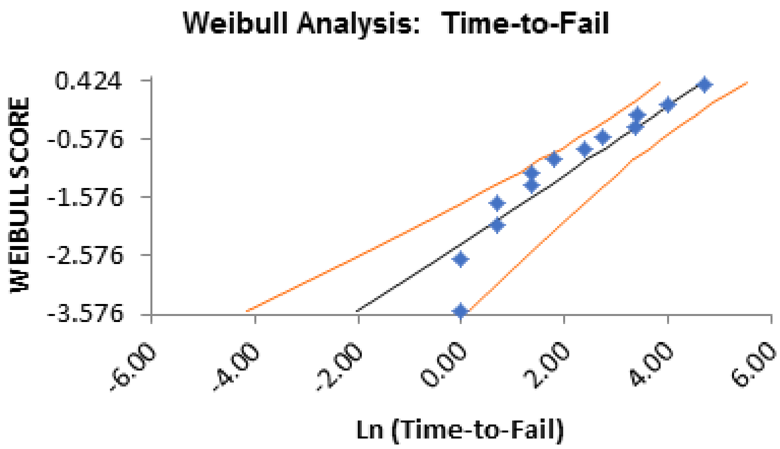

Fig 6:- Weibull Graph for Suspension

The percentile report tells us that we can expect 50 percent failure rate or One – half of population will fail at 29.717, this is the median. Percentile report can also be used to determine control limits for non-normal data the lower control limit is the 0.135 percent value which is 0.007 the upper limit is the 99.865 value, which Is 1387.0

Matlab- Remaining Useful life estimation

- The program helps to check the condition of the suspension system and the program can be run for a specific data.
- A sample data 150 intervals is taken and analyzed in Matlab.
- A limit is set and whenever the suspension violates the limits, it can be read in the graph.
- The upper bound and lower bound are designed in such a way that they get narrow with the time
- The aging factor is also taken in to consideration as any component cannot give the desired output same as initial.

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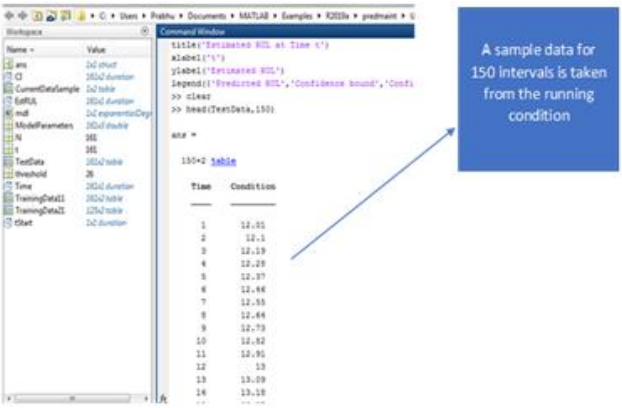

Fig 7: Matlab Loaded Data-Suspension

The output graph depicts the confidence bounds and the predicted remaining useful life can be seen not violating. As the data is for only 150 intervals the difference between upper and lower bounds is small. We can see the predicted RUL goes along the bounds without touching.

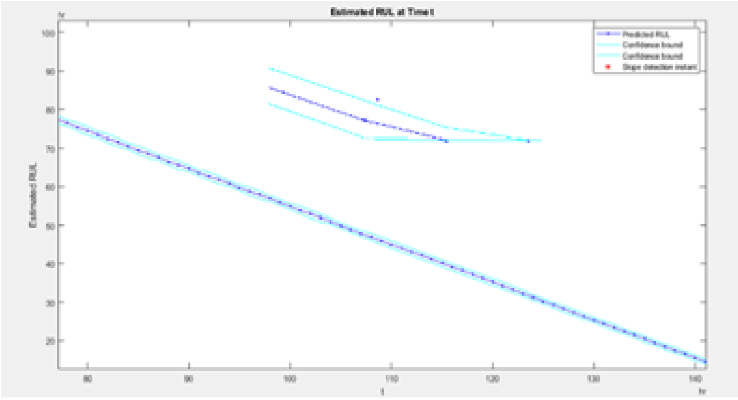

Fig 8:- RUL output graph

Here after magnifying, at some point the predicted RUL line crosses the lower confidence bound. Then the maintenance can be scheduled. But this method also gives a good estimation and helps to develop the predictive maintenance. After obtaining a large data and analyzing it will give a better view for the periodic maintenance scheduling.

V. BRAKE -ANALYSIS

The brake failures can be because of the improper pressure supplied through the valves because of the blockage. In such case the hand-brake is used which supply a large and sudden force to stop the vehicle. The hand brake usage is not always better way of avoiding the brake failures. As now a days all the brake equipment is controlled by the electrical units, there cannot be much faults as per as pressure is concerned. But the brake-pads maintenance is most vital which reduces the downtime and helps not to rupture the rotor by producing large heat.

Similar analysis can be done for the brakes like the previous components. The percentile report and the data regarding the MTTR data can be calculated.

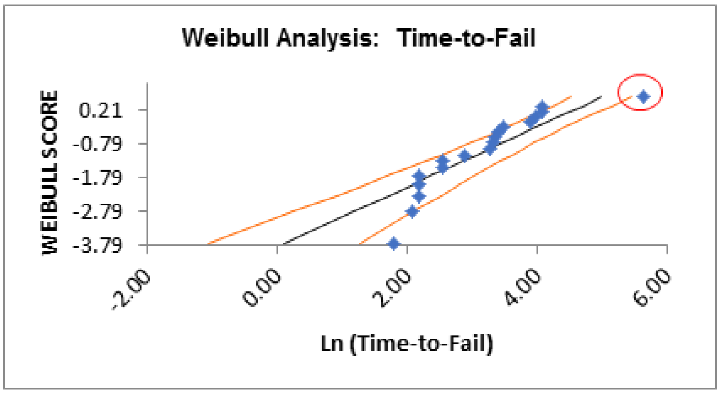

Fig 9:- Weibull Analysis-Brake

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The Weibull graph depicts that there are some uneven scatterings and fluctuation in data. A constant data for some months can give good results.

This system can be compensated by adopting the condition monitoring technique.

It can be observed that the system has violated the Weibull limits and some measures should be taken to avoid it.

We can use the regression model to correlate mileage and pad wear. Generally, the wear rate on inner pads is higher than the outer. The failure of the pad refers to the failure of whole braking system. The below equation may be used for obtaining mean service life of the brake pads and to predict the "remaining service life" during the scheduled maintenance.

$$Y = MX + C$$

X-mileage
Y-thickness
C- coefficient of intercept
M- coefficient of slope

To judge the regression model, the simplest way is to calculate coefficient of determination R^2. If the value of the coefficient of determination is equal to 1 then there is the correlation between thickness and mileage. According to the study the 95% of pads match the regression criteria.

From the below regression analysis, the coefficient of determination is 0.9233 and it is very close to 1 and this tells that the 91% of the variability in the thickness is explained by this regression line or by regression of the thickness on mileage.

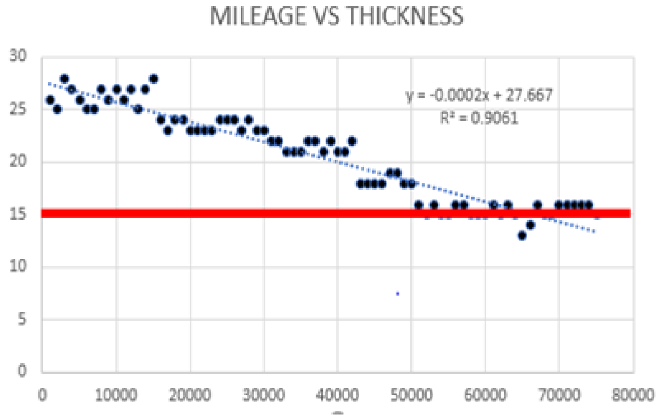

Fig 10:- Mileage vs Brake pad thickness

From the graph, around 50000kms mileage the pad thickness reaches the minimum. So, the PM schedule should be made around based on the fresh data.

VI. COST BENEFIT ANALYSIS

Preventive maintenance is adopted when the failure rate is high (where the bath tub curve shows β >1 in Weibull distribution). This area is generally called as wear out area. When failure occurs, the component should be replaced, to reduce the number of failures.

A balance should be maintained between the company's maintenance budget and replacement. The below graph can be used to estimate of the maintenance per unit time (x)

Before that we should know the following
Reliability R(t) =

$$EXP[-(t-\Upsilon/\eta)^{\beta}]$$

where:
ŋ = scale parameter; ŋ > 0,
β = shape / slope parameter; β > 0,
γ = location parameter

MTTF (Mean time to failure)
$= \gamma + \eta \Gamma(1 + 1/\beta)$

$$X = \frac{[C(pm) * R(B) + C(cm) * (1 - R(B))]}{(B + C) * R(B) + \int_0^B tf(t)dt + E * [1 - R(B)]}$$

X = total cost for one-time maintenance
C(pm) = cost for the preventive maintenance
C(cm) = cost of corrective maintenance
R(B) = reliability at time B
B= time interval for preventive maintenance
C= mean time to perform preventive maintenance
D= mean time required to conduct corrective maintenance
t= MTTF
E= mean time for corrective and preventive maintenance. (MTTR)

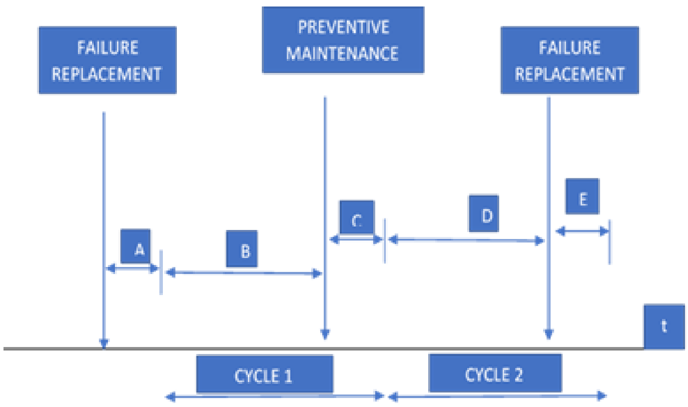

Fig 11:- Intervals in Maintenance

The investment can be the setup of required resources for implementing the maintenance of an organization. There should be some financial gains from the maintenance prediction. There will be some cost of repair for the parts that can be replaced. But lack of prediction also causes some more issues like cost of delays. There are many other aspects like wages, insurances etc. and I am not going to cover those aspects.

$$[\boldsymbol{New\ predictive\ maintenance\ cost} = \boldsymbol{Correctly\ predicted} \times \boldsymbol{New\ repair\ cost} - \boldsymbol{Wrongly\ \ predicted} \times \boldsymbol{Cost\ of\ repair} - \boldsymbol{Amount\ invested}]$$

Each correct prediction saves the additional cost and each wrong prediction adds additional cost to the budget.

VII. FUTURE WORK AND DEVELOPMENT

- *Relation between Cooling Water and Vibrations in Engine*

I have always imagined about a situation where the sensor data is minimal. In such cases the temperature changes in the system can give similar data. It was seen in many cases that changes in the water temperature affects the mean vibration values. The displacement vs temperature graph can be plotted, and it indicates that the cooling water temperature increases, the mean values of displacement are increasing, and vibrations are also increasing. The velocity and temperature graph also indicate the same i.e. vibrations in the engine are increasing with increase in temperature of cooling water. It can be interpreted that mean noise reading will increase as cooling water temperature increases. The temperature peak values are found in the starting frequency like 20Hz to 100Hz. The water temperature control is also required when investigating on the engine vibrations.

The FFT analyzer can be used to plot various spectrums and to analyze the acceleration, velocity and displacement.

- *Management/Cost Aspect:*

The investments on the maintenance is one of the very important aspect and the evaluation of investment in the corrective based maintenance is the topic I am interested to evaluate. The corrective based maintenance can be adopted in some cases where replacement or maintenance decision must be made suddenly. In such cases the net present value and the returns on investment focus on project cost benefits. Unscheduled maintenance cost and condition-based maintenance cost are the life cycle costs.

VIII. CONCLUSION

In the development of the maintenance system the thesis has found the relations of some of the parameters that define the maintenance performance. A comprehensive view of the system has been studied and proper prioritization of defects is developed for the company to easily identify the faults. The project has found some crucial parameter to predict the faults. The unbiased approach has fully focused on the detecting the major defects/faults by some good logics before their occurrence.

The thesis gives a good understanding on the cost analysis that determines whether to choose the maintenance activity or to replace the failed component.

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