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A Comparison of the Fuel Economy Estimates of a Drive Cycle Developed Using the Road Load Energy Criterion and the Actual On – Road Fuel Economy

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Abstract

This study presents a comparison of the fuel economy between a drive cycle developed using the road load energy as an assessment parameter and the actual on road fuel consumption of a common rail direct injection (CRDI) passenger van. Second by second velocity as well as fuel consumption were recorded as the test vehicle traverses a 33 - kilometer pre - determined route in Quezon city, Philippines. The data were processed to generate a drive cycle using the modified Markov Chain approach. A user defined compression ratio was used to determine the length of the generated drive cycle. It was then tested on a chassis dynamometer to measure the fuel economy of the drive cycle. The road load energy, fuel economy, average speed, maximum acceleration and percent idle time were used as assessment variables to determine the quality of the drive cycles developed. Three drive cycles using different compression ratios were generated and yielded the following results: A 676 second cycle which has a 2.22% road load energy error and a 4.9% difference in fuel consumption, the 801 second cycle yielded a 3.06% energy error and 2.8% fuel consumption difference and a 901 second cycle with a 1.34% energy error and a 1.2% difference in fuel consumption. The results suggest that the road load energy criterion is a parameter that can be used to generate drive cycles that will give good on – road fuel economy estimation.

Index Terms: *compression ratio, drive cycle, road load energy*

I. INTRODUCTION

Vehicle emission is regarded as the top cause of air pollution in the Philippines. It contributes 69% to the country's air pollution. A large number of parameters that characterize engine operations under different traffic conditions must be identified to be able to come up with effective policies to mitigate air pollution. One cost effective and efficient way of performing emission studies is by using a drive cycle. A drive cycle is a speed-time sequence developed for a certain type of vehicle to represent the driving pattern in a particular environment. It aims to mimic real world driving behavior using limited duration activities with the primary purpose of simulating exhaust gas emissions and fuel economy of vehicles. Drive cycles are also used to aid in traffic management, highway engineering and vehicle design. There are readily available standard drive cycles from different cities all over the world, these drive cycles are however, developed for a particular environment. Attempts to use these existing drive cycles in a different environment often yielded poor quality results for the simple fact that different drive cycles are developed for different purposes. For emission estimation purposes, it is but logical that actual fuel consumption and the generated driving cycle fuel consumption be identical. In an attempt to develop drive cycles having fuel consumption as close to on – road fuel consumptions, the road load energy, which is defined as the energy needed by a vehicle to overcome resistive forces to put the vehicle in motion, is used as an assessment parameter.

II. METHODOLOGY

A. Instrumentation and Data gathering

The test vehicle was retro fitted with a fuel flow meter to measure the fuel consumption during on – road runs. A magnetic pick up sensor was installed on the periphery of the rear wheel to measure the vehicle's velocity. An on-board computer BC 3033 was used to process, convert and display the signals from the flow meter and magnetic sensor into a readable format. The data logger DL 4044 and Recread software were used to store the speed versus time data. After installation, the test vehicle was mounted on the chassis dynamometer for calibration of the speed sensor. The distance factor in the on – board computer was adjusted until the on – board computer and chassis dynamometer give out the same values. Data gathering was done by driving along a 33 - kilometer route with varying road types. A total of 10 round trips were made. The duration of each trip ranging from 45 to 75 minutes depending on the traffic condition.

B. Data Processing

A Matlab program was used to filter and process the gathered data. Filtering was done to remove erroneous values by computing for the maximum and minimum acceleration values obtained from the on - road runs and compared it with the test vehicle specifications. Stored data is in comma separated variable format (.CSV) and can be extracted through an excel spreadsheet. Fig. 2 shows the actual on – road data gathered from test runs.

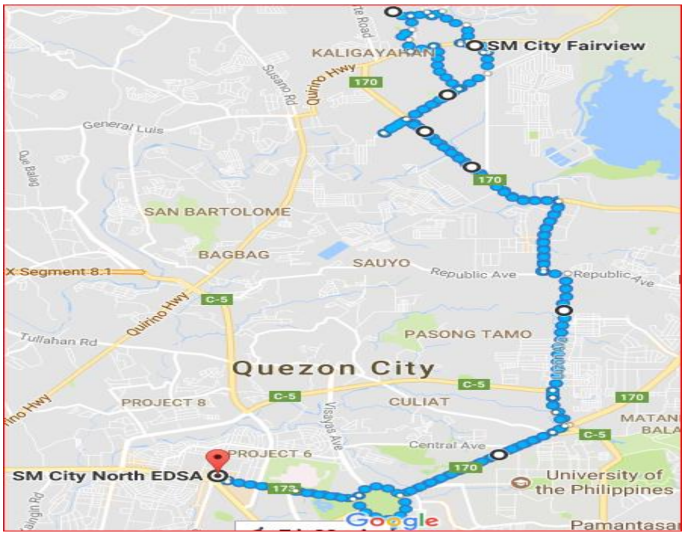

Fig. 1. SM North to SM Fairview map

	A	B	C	D	F
1	Date	Time	Diff.Consumption	Diff.Distance	Diff.Time
2	10/25/2016	2:02:43 PM	0.0005	0	1.15
3	10/25/2016	2:02:44 PM	0	0	1.149944
4	10/25/2016	2:02:45 PM	0.0005	0	1.150099
5	10/25/2016	2:02:47 PM	0	0	1.150096
6	10/25/2016	2:02:48 PM	0	0	1.390926
7	10/25/2016	2:02:49 PM	0.0005	0	1.399161
8	10/25/2016	2:02:51 PM	0.0005	0	1.399021
9	10/25/2016	2:02:52 PM	0	0	1.150058
10	10/25/2016	2:02:53 PM	0.0005	0.002128	1.150027
11	10/25/2016	2:02:54 PM	0.0005	0.002128	1.400061

Fig. 2. On – road data sample

C. Drive Cycle Construction

Drive cycle construction using the modified Markov Chain approach starts at the speed – acceleration probability distribution (SAPD). A Matlab program was developed and used to construct the candidate drive cycles. The SAPD is compressed by dividing each cell of the SAPD by a user defined integer whose value is determined depending on the desired length of the synthetic drive cycle that will be produced. After compression, all the values in the cells of the SAPD were rounded down. Cycle construction was done by stitching data points from the SAPD using a modified Markov chain approach. Every time that an event from a cell is appended into the drive cycle, the value in that cell is decremented by one. The process is done iteratively until all of the data points in the compressed SAPD are used up. If an event in the compressed SAPD could not be appended into the drive cycle being constructed, the

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program goes back to the previous event and will go on to the next most likely event to occur and check on that option. This will be done iteratively until all options are explored. While the drive cycle is being constructed, the residue error and energy error are also being computed. Residue error is the amount of unused data from the compressed data set while energy error is the difference in the road load energy between the generated drive cycle and on – road runs. The drive cycle generated with the smallest residue error will be the resulting drive cycle for that particular compression factor. A flow chart of the Matlab code used is presented in fig. 3.

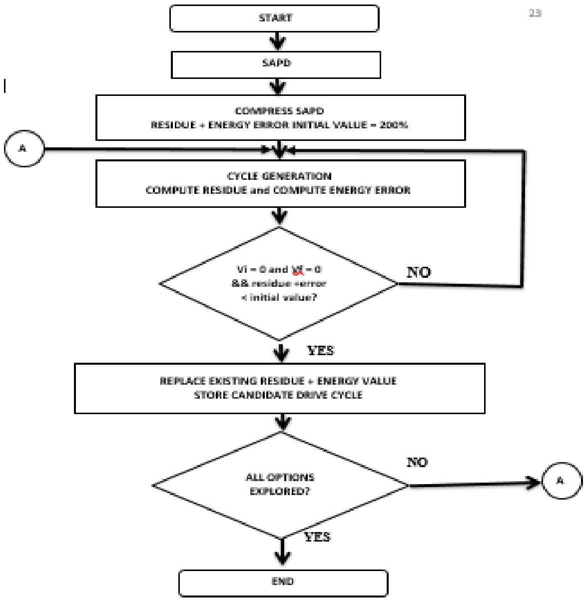

Fig. 3. Flow chart for drive cycle generation

D. Validation of the Generated Drive Cycle

In order to validate whether a generated drive cycle is a good representative of a driving pattern in a particular route, assessment parameters must be measured and compared with on – road values. These parameters were measured in the University of the Philippines Vehicle Research and Testing Laboratory (UP – VRTL). The test vehicle was mounted on the AVL AN 40720 48" Chassis Dynamometer. The hassis dynamometer was calibrated such that it mimics on – road conditoins. The test vehicle was then driven on the chassis dynamometer following the speed versus time plot of the generated drive cycles. These drive cycles are labeled DC 3, DC 4 and DC5 and are shown on figures 5, 6 and 7. Three runs were made for each drive cycle generated and the average fuel consumption of those three runs were compared to the on road fuel consumption where the tested drive cycle was derived

Fig. 4. Laboratory set – up for drive cycle validation

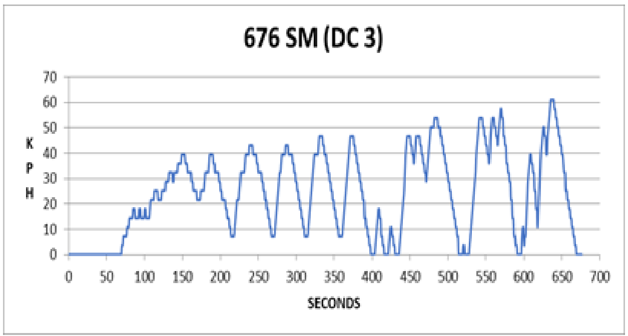

Fig. 5. Speed versus time plot of drive cycle 3

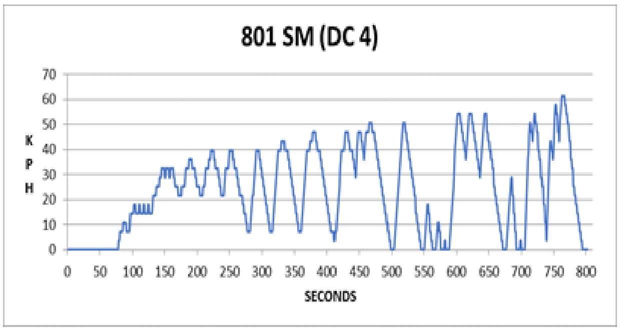

Fig. 6. Speed versus time plot of drive cycle 4

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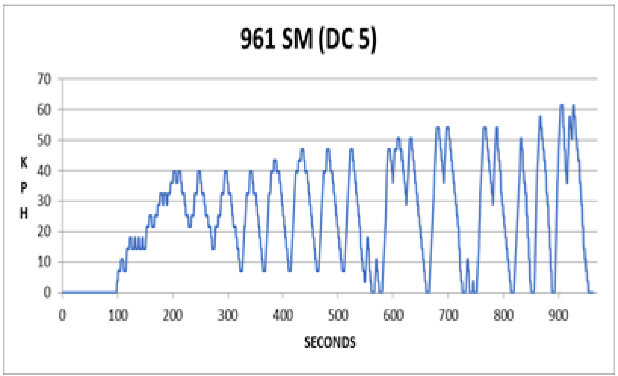

Fig. 7. Speed versus time plot of drive cycle 5

III. ROAD LOAD ENERGY CONSUMPTION ESTIMATION

Road load is defined as a force or torque which opposes the motion of a vehicle. These resistive forces are the aero dynamic drag, rolling friction and inertia forces. Figure 8 illustrates these forces as they act on a vehicle. Road load energy is the amount of energy needed to overcome these forces and can be computed using the following equations:

Road load energy = E(drag) + E(rolling) + E(inertia) (1)

E(drag) = $\frac{1}{2} \times \rho \times Cd \times A \times V^3$ (2)

E(rolling) = $W\ x\ Cr$ x V (3)

E(inertia) = $a\ x\ m\ x\ V$ (4)

Where:

ρ = air density ($\frac{kg}{m^3}$)

Cd = drag coefficient

A = frontal cross - sectional area of the vehicle (m^2)

a = acceleration ($\frac{m}{s^2}$)

V = velocity ($\frac{m}{s}$)

W = vehicle weight ($\frac{kg\,.m}{s^2}$)

Cr = rolling friction coefficient

m = vehicle mass (kg)

The road load energy is being computed as the vehicle moves and the value obtained is compared to the road load energy computed using the generated drive cycle. The ratio of the road load eneries computed must be equal to ratio of the actual driving data length and the drive cycle length.

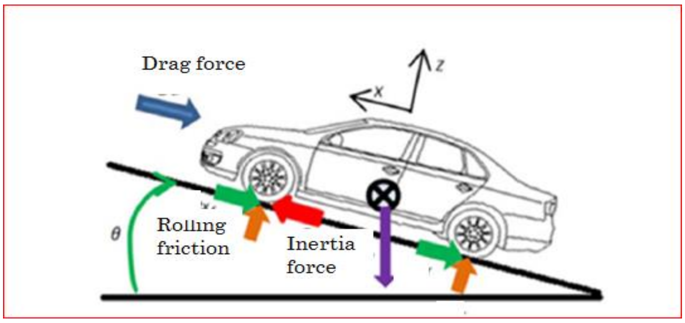

Fig. 8. Resistive road load forces acting on a vehicle

IV. RESULTS AND DISCUSSION

There were 32 drive cycles developed for this study. The compression factors used range from 40 to 200 incremented by 5. Drive cycle lengths range from 228 to 1177 seconds. Only 3 out of 32 drive cycles developed were tested on the chassis dynamometer. The assessment parameters used to evaluate the drive cycles generated are the following: residue error, energy error, fuel consumption, average velocity, maximum velocity, maximum acceleration, minimum deceleration, cycle length and percent idle time.

A comparison among the assessment parameters used in the generated drive cycles and on road values are summarized in table 1. It can be seen that the driving pattern and characteristics from on – road runs were preserved in the generated drive cycles using the road load energy criterion. Assessment parameters used have identical values for the laboratory and on – road runs. Fuel consumptions for both laboratory and on – road runs were recorded. Drive cycle 3 has the largest difference in value in terms of fuel consumption at 4% while drive cycle 5 has a 1% difference in fuel consumption compared to the on – road fuel

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consumption. It can be observed that as the compression ratio increases, the difference in fuel consumption also increases. Residue and energy errors obtained using different compression factors are very close to each other that their differences may be considered as negligible. It ranges from .99% to 3% both for residue and energy error combined. A trend line from the plot of residue versus compression factor and energy error versus compression factor suggests that as the compression factor decreases, energy error and residue also decrease. These trends are shown on figures 9 and 10.

Table 1. Assessment parameters summary

drive cycle	DC 3	DC 4	DC 5
compression factor	70	60	50
% residue	1.02	0.99	1.13
% energy error	2.22	3.06	1.34
fuel consumption (km/L)	13.1837	12.9262	12.7227
average velocity (kph)	24.1082	23.9685	24.2784
average acc (m/s2)	1.09558	1.11180	1.10769
average dec (m/s2)	-1.1037	-1.10494	-1.1191
max velocity (kph)	61.2	61.2	61.2
max acceleration (m/s2)	2	2	2
min deceleration (m/s2)	-2	-2	-2
cycle length (seconds)	676	801	961
percent idle	16.71598	16.72909	16.6493

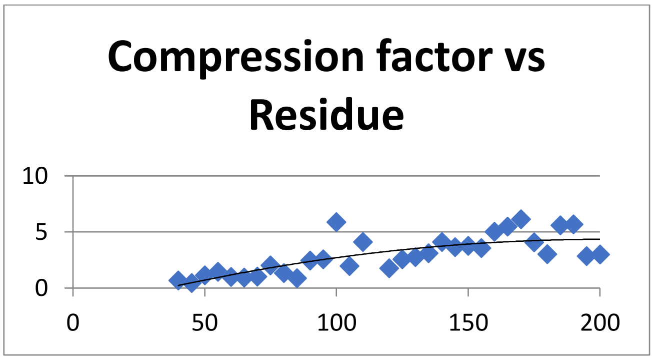

Fig. 9. Compression factor versus residue plot

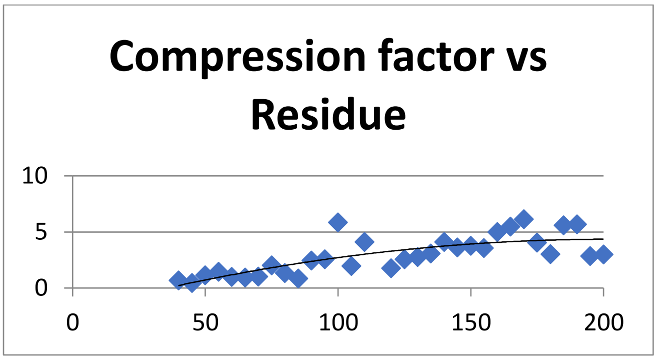

Fig. 10. Compression factor versus energy error plot

V. CONCLUSION

Based on the drive cycles tested on the chassis dynamometer, the energy based approach of drive cycle construction methodology is valid for generating drive cycles that can be used as models for fuel consumption estimations by using residue error and road load energy error as assessment measures. Using smaller compression ratios result in better representation of the real world driving pattern by the constructed drive cycle. This drive cycle construction methodology uses the road load energy to assess the quality of the developed drive cycle is valid for different types of data sets, that is, data sets with different driving patterns and velocity ranges as evidenced by the results obtained by the generated drive cycle for the SM North – SM Fairview – SM North route.

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