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Fuel economy comparison of Perodua Myvi passenger vehicle on Malaysian city and highway drive cycles

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Abstract: This study generates a mathematical model of the most popular vehicle model in Malaysia (Perodua Myvi) and simulates it on the first Malaysian city and highway drive cycles. The fuel consumption results from the simulation are then compared to the experimental fuel consumption of the same vehicle run on the same drive cycle, to verify the mathematical model for Perodua Myvi that was simulated by using Matlab. The drive cycles data are gathered twice at different times of the day based on city and highway roads in the state of Kedah, Malaysia. Simulation and experimental results are comparable, with the average percentage difference of 13 %.

Key words: Vehicle simulation; Fuel economy; Drive cycle; City; Highway; Passenger vehicle

1. Introduction

Malaysia is a rapidly developing Southeast Asian country, where the demand for passenger cars increases every year. In 2014 alone, Malaysia has produced 305230 personal cars and ranked at 22nd place in the world car producer statistic (OICA, 2014). Perodua Myvi has been the best-selling car in Malaysia for eight consecutive years, between 2006 and 2013 (Tan, 2011). Like many vehicles, the vehicle performance has much room for improvements as it is not optimized to be driven in Malaysian road conditions. This paper intends to build the mathematical model for Perodua Myvi and simulate it on Malaysian city and highway drive cycles.

Every drive cycle resembles the specific road conditions of a particular place and they can vary quite widely. Thus, it is not suitable to optimize a Malaysian car using American or European drive cycles, for instance [Lin, 2003]. Unfortunately, no Malaysian drive cycle has ever been developed before. This study, therefore, intends to develop the first Malaysian's highway and city drive cycle. With the vehicle model and the Malaysian road drive cycle built, the vehicle fuel economy performance can be estimated, and further improvement can be made using simulations. This paper is divided into two parts, the simulation and the experiment. The fuel economy results from the simulation are verified by the experiment.

A vehicle must overcome four forces (inertial, air drag, road gradient and tire resistance) to move and achieve a certain speed. In the simulation, the forces are calculated from the required speed and acceleration obtained from the drive cycle. The required forces are then translated into the torque that must be provided by the wheels and the drive train components. A series of simple rule-based control strategies is employed to choose which gear ratio to use by the transmission. Next, the torque and speed at the transmission input shaft becomes the engine operating conditions. The engine operating conditions are used to estimate the fuel consumption from the engine map. The fuel consumption is then summed up for the entire drive cycle to determine the fuel economy of the vehicle.

Fig. 1: Perodua Myvi

This study simulates the vehicle using a MATLAB backward-facing discretised simulation. This means that the drive cycle is divided into discrete time steps spaced of one second apart. Each time step consists of the average speed and the average acceleration of the vehicle at that point. The simulation starts from the end point (t= n) and works its way up to the beginning of the drive cycle (t= 0), assuming that the speed and acceleration are met by the drive train at each time step. If the drive cycle speed and acceleration exceed the capabilities of the drivetrain at any time step, the simulation

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would not find the cost (fuel consumption) and the whole simulation is considered to have failed. In this study, the simulations fuel consumption results are close to the experimental ones.

For the experiment, the vehicle is driven on the same drive cycles as those in the simulations, and the fuel economy results are compared to the simulated ones. There are five drive cycles derived from driving the vehicle around the state of Kedah. Two of the drive cycles are high-speed highway type and the other three are low-speed stop-and-go city drive cycles. All of the drive cycles data are taken twice at different time of the day.

2. Simulation

The simulation reads the speed profile from a drive cycle and discretizes it into one-second time steps. At every time step, the average speed and acceleration of the vehicle from a drive cycle is fed into the vehicle model. The torque and the speed of the wheels and the flywheel are determined. The torque and the speed of the engine are then determined depending on the gear ratio selected by following a simple rule-based control strategy. The engine operating conditions (torque and speed) are used to estimate the fuel consumption by fuel consumption engine map. The fuel consumption values at each second are summed up, and the total fuel consumption of the vehicle operating on the drive cycle, is obtained.

2.1. Simulation equations

The vehicle has to overcome four forces of the driving wheels. They are the air drag force (F_{air}), the force of slope road (F_{slope}), the acceleration force ($F_{acceleration}$) and the rolling resistance ($F_{rolling}$). Thus, the total force that must be overcome during driving a vehicle should be equal to sum of the forces of the driving wheels. The total force of the driving wheel (in Newton) can be obtained by using Equation 1.

$$F_{wheel} = F_{air} + F_{slope} + F_{acceleration} + F_{rolling} \quad (1)$$

In order to calculate the total force of the driving wheel (F_{wheel}), we have to calculate every force in Equation 1. The equations for the forces are shown in Equations 2, 3, 4 and 5.

For air drag force,

$$F_{air} = 0.5\, \rho\, v^2\, C_d\, A \quad (2)$$

where, ρ is density of air (kg/m^3), v is velocity of the vehicle (m/s), C_d is air drag coefficient, and A is frontal area of the vehicle (m^2).

For the force of slope road,

$$F_{slope} = m\, g\, \sin\alpha \quad (3)$$

where m is the sum of the mass of the vehicle and the driver (kg), g is the gravity acceleration (m/s^2), and α is angle of slope road (^{o}).

For the acceleration force,

$$F_{acceleration} = m\, a \quad (4)$$

where m is the sum of the mass of the vehicle and the driver (kg) and a is the vehicle acceleration (m/s^2).

For rolling resistance,

$$F_{rolling} = C_r\, m\, g \quad (5)$$

where C_r is the coefficient of rolling resistance, m is the sum of the mass of the vehicle and the driver (kg), and g is the gravity acceleration (m/s^2).

From the total force, Equation 1, we can calculate the wheel torque, the flywheel torque and the engine torque by using Equations 6, 7 and 8.

For the wheel torque,

$$T_{wheel} = F_{wheel}\, R_{tire} \quad (6)$$

where T_{wheel} is the wheel torque (Nm), F_{wheel} is the total force of driving wheels (N) and R_{tire} is the radius of the tire (m).

For the flywheel torque,

$$T_{flywheel} = T_{wheel} \,/\, G_{ratio} \quad (7)$$

where $T_{flywheel}$ is the flywheel torque (Nm), T_{wheel} is the wheel torque (Nm) and G_{ratio} is the total gear ratio.

For the engine torque,

$$T_{engine} = T_{flywheel} \,/\, \eta_t \quad (8)$$

where T_{engine} is the engine torque (Nm), $T_{flywheel}$ is the flywheel torque (Nm) and η_t is the efficiency of transmission between the engine and the flywheel.

Next, we have to find the engine angular speed in order to read the engine map. It can be calculated by using Equation 9.

$$\omega_{engine} = \omega_{flywheel} \,/\, \eta_t \quad (9)$$

where ω_{engine} is the engine angular speed (rad/s), $\omega_{flywheel}$ is the flywheel angular speed (rad/s), and η_t is the efficiency of transmission between the engine and the flywheel.

For the flywheel angular speed,

$$\omega_{flywheel} = \omega_{wheel}\, G_{ratio} \quad (10)$$

where $\omega_{flywheel}$ is the flywheel angular speed (rad/s), ω_{wheel} is the wheel angular speed (rad/s) and G_{ratio} is the total gear ratio.

For the wheel angular speed,

$$\omega_{wheel} = v \,/\, R_{tire} \quad (11)$$

where ω_{wheel} is the wheel angular speed (RPM), v is the velocity of the vehicle (m/s) and R_{tire} is the radius of the tire (m).

Finally, we can obtain the fuel economy by using Equation 12.

$$Fuel\ Economy\ (km/L) = D_T / FC_T \quad (12)$$

Where, D_T is total distance travelled (km) and FC_T is the total volume of the fuel consumed (L). (Matej Juraj, 2013)

2.2. Vehicle parameters and gear selections

Section 2.2 shows the simulation uses many equations involving parameters that are specific to a particular vehicle, in this case, a four speed automatic transmission Perodua Myvi. The overall vehicle parameters of the vehicle are given in table 1.

The gear selection in the simulation is rule-based, selected depending on the speed range. The vehicle speed ranges are chosen such that the engine would operate at the speed below 3000 RPM. Table 2 shows the speed ranges for the gears selected. These ranges are derived from observations made while driving the car in normal city driving condition.

Table 1: Automatic Perodua Myvi parameters

Maximum engine torque	T_{engine}		116 Nm
Total gear ratio (gear ratio x final drive ratio)	G_{ratio}	1st gear	11.01
		2nd gear	6.15
		3rd gear	4.03
		4th gear	2.81
Efficiency of transmission	η_t		0.85
Tire radius	R_{tire}		0.3556 m
Frontal area	A		2306 m^2
Air drag coefficient	C_d		0.32
Air density	ρ		1.225 kg/m^3
Mass of vehicle + driver	m		1055 kg
Coefficient of rolling resistance	C_r		0.01†

Table 2: Gear selection rules

Speed (m/s)	gears
< 7.73	1
7.73 to 13.83	2
13.83 to 21.09	3
> 21.09	4

2.3. Engine fuel consumption map

The fuel consumption engine map provides information regarding how much fuel is consumed at any operating conditions (torque and speed) of the engine in the simulation. Previously, the Brake Specific Fuel Consumption (BSFC) plot in Fig. 2 was made (Ramasamy, 2014) at wide open throttle (WOT). However, the fuel consumption data are insufficient for the simulation because the engine is expected to operate at a wider range of throttle and torque. Thus, a more elaborate engine fuel consumption map has to be estimated.

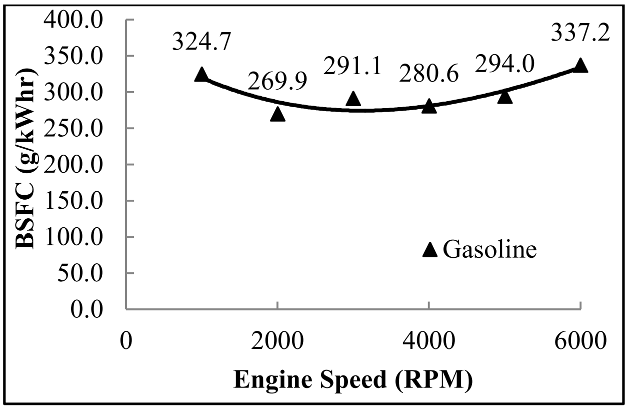

Fig. 2: BSFC curve of K3-VE engine (Ramasamy, 2014)

A study was done to estimate a full fuel consumption map, based on the limited fuel consumption data of adiesel engine (Goering, 1988).

[2]("Rolling friction and rolling resistance,")

This method is used to estimate the full fuel consumption map in this study. The estimated fuel consumption engine map for the Perodua Myvi engine (Daihatsu K3-VE) is shown in table 3 and the 3D map is in Fig. 3.

3. Experiment

The fuel economy was obtained by driving a Perodua Myvi over five designated courses derived from driving in Alor Star city, Kedah, Malaysia. One of the courses is shown in Fig. 4 and the other four are shown in appendix. The car was fuelled up and driven over the designated courses. At the end of each course, the fuel tank of the car was filled up again to determine the volume of the fuel was used. The drive cycles of five different courses were recorded by using 'My Tracks' android app.

The data of five courses are taken twice, at different time of the days. This is done to observe the effect of time of the day on the driving conditions. Drive cycles A, B and C are derived from city driving conditions and drive cycles D and E are from highways driving conditions. The five drive cycles are also used in the simulations, and the fuel consumption values obtained from the simulations are then compared to the experimental ones in the results section.

4. Results

The fuel economy results from the simulation and the experiment are shown and compared in Table 4. Based on the results, the percentages of differences for A1, B2, C1, C2, E1 and E2 are more than 10 % while those for A2, B1, D1 and D2 are less than 10 %. The worst reading difference is 29% and the best one is 2.72%. All in all, these differences averaged out at 13%. There are a few of factors that affect the results for both the experimental and the simulation parts.

For the experimental part, the amount of fuel consumed is obtained from the fuel volume readings at the fuel station. Meanwhile, the speed data are obtained from the Global Positioning System (GPS). The accuracies of these two measuring methods are unknown. The results are also affected by the fuel density especially for the experiments done in the morning (A1, C1 and E2), between 8 and 11 am. As the ambient temperature gradually increased between 8 to 11 am, the fuel density also decreased due to the expansion of the volume. Thus, the volume of fuel needed to fill up the tank until it is full is lower.

For the simulation part, the main factor affecting the results is the estimated engine fuel consumption map. The map is generated by using the diesel engine equations. Another issue is the fact that it does not consider does not consider the effect of Variable Valve Timing (VVT) used in Daihatsu K3-VE engine. VVT improves the fuel economy of the engine at high speeds. This factor may affect the results for E1 and E2 because these courses are derived from highway driving conditions, which require high engine speed. Additionally, the simulation does not take into account the accessories that are used in Perodua Myvi, such as a hydraulic power steering pump and an air conditioning system.

5. Conclusion

This study presents five newly developed Malaysian city and highway drive cycles. The drive cycles are used in Perodua Myvi vehicle simulations to obtain the vehicle estimated fuel economy. The estimated fuel economies from the simulation are compared to the experiment fuel economy of the same vehicle on the same drive cycles. The average difference between the simulation and experimental fuel consumptions was 13%.

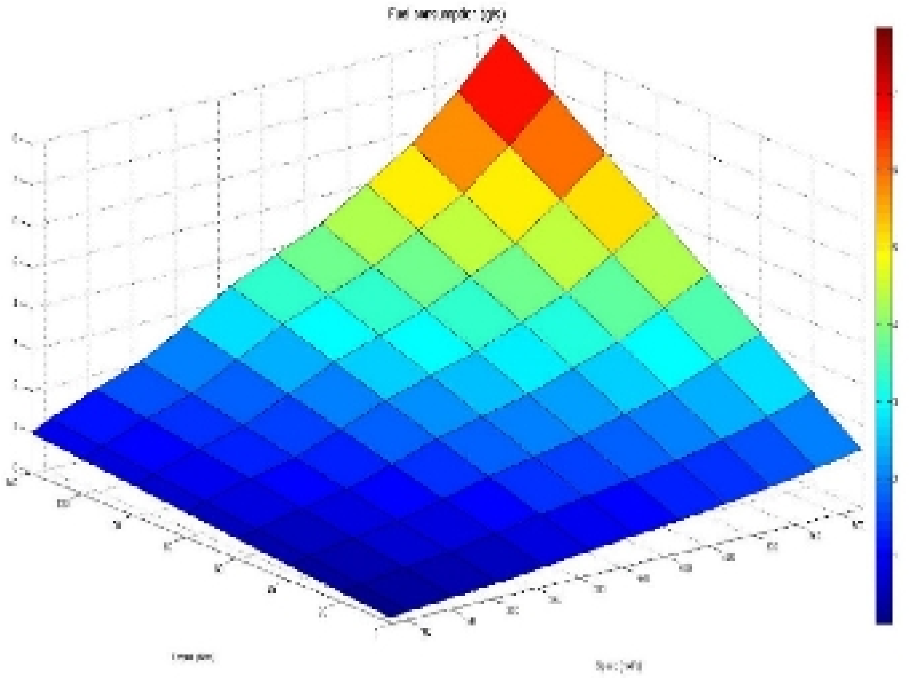

Fig. 3: Estimated fuel consumption engine map

Table 3: Fuel consumption map estimation

Torque (Nm)	Fuel rate (g/s)											
120	0.85	1.06	1.46	1.80	2.35	2.95	3.39	3.82	4.43	5.05	5.94	6.93
100	0.73	0.91	1.26	1.56	2.03	2.55	2.93	3.31	3.83	4.37	5.14	6.00
80	0.61	0.76	1.05	1.30	1.71	2.15	2.47	2.80	3.24	3.69	4.35	5.07
60	0.49	0.62	0.85	1.06	1.39	1.75	2.01	2.28	2.641	3.02	3.55	4.14
40	0.37	0.47	0.65	0.81	1.06	1.35	1.56	1.76	2.05	2.34	2.75	3.21
20	0.25	0.32	0.44	0.56	0.74	0.94	1.10	1.25	1.45	1.66	1.96	2.28
1	0.14	0.17	0.25	0.32	0.44	0.56	0.66	0.76	0.89	1.02	1.20	1.40
Engine Speed (rpm)	800	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000

Table 4: Comparison of fuel economy between the experiment and the simulation

Courses	No. of experiments	Time	Fuel consumption (L)	Distance travelled (Km)	Fuel economy (Km/L)
A	1	Morning	1.250	10.21	8.168
	2	Afternoon	1.045	10.21	9.770
B	1	Morning	1.246	12.17	9.767
	2	Afternoon	1.110	12.17	10.960
C	1	Morning	0.772	10.83	14.030
	2	Afternoon	1.447	10.83	7.480
D	1	Morning	1.125	11.45	10.180
	2	Morning	1.092	11.45	10.490
E	1	Afternoon	2.150	27.45	12.770
	2	Morning	1.610	23.72	14.740

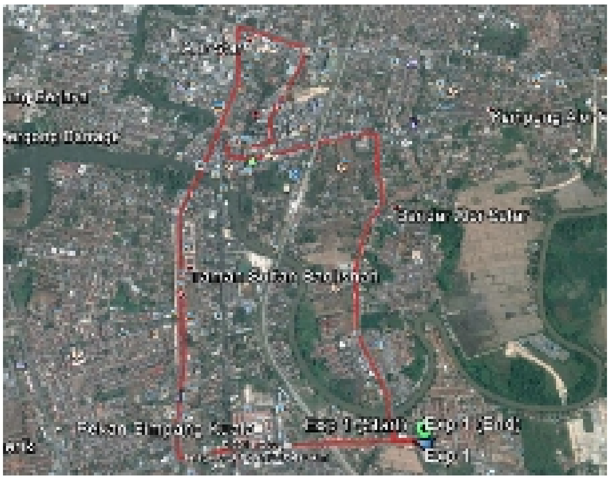

Fig. 4: Driving course A

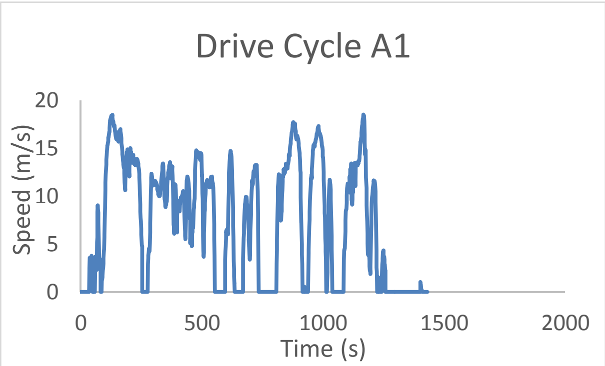

Fig. 5: Drive cycle A1

Appendix

Fig. 6: Driving Course B

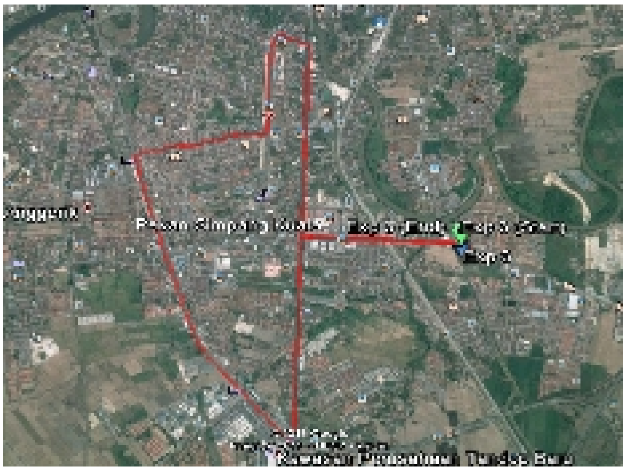

Fig. 7: Driving Course C

Fig. 8: Driving Course D

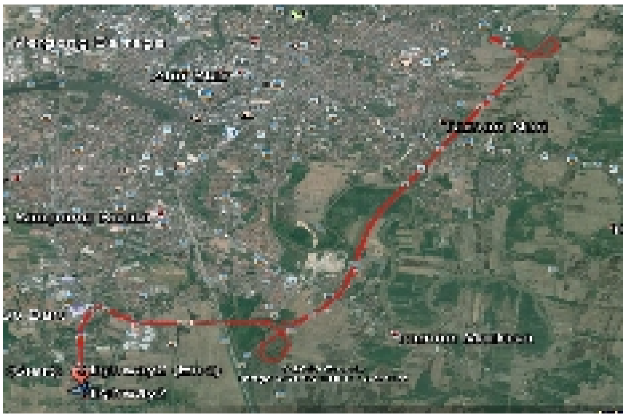

Fig. 9: Driving Course E

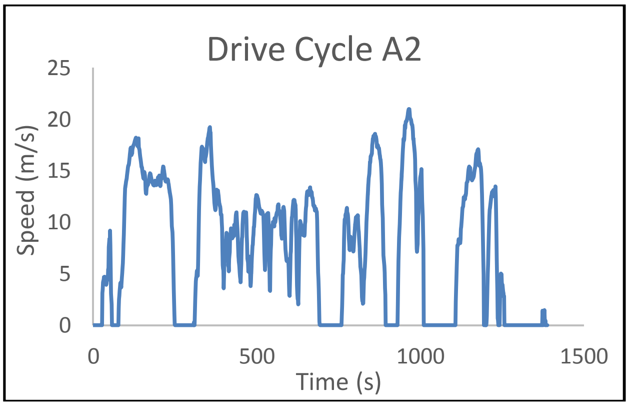

Fig. 10: Drive cycle A2

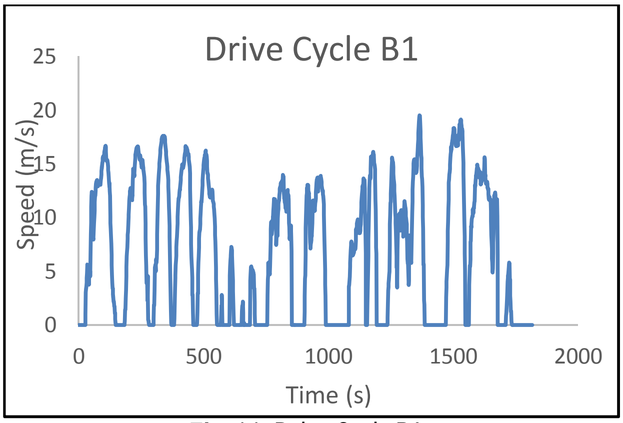

Fig. 11: Drive Cycle B1

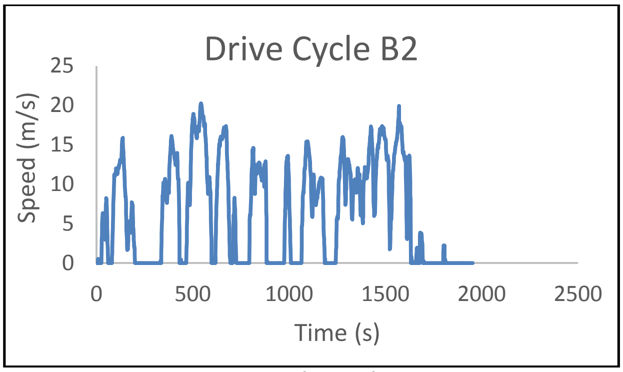

Fig. 12: Drive cycle B2

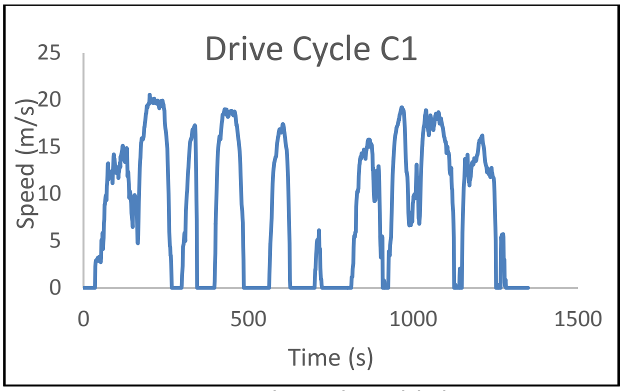

Fig. 13: Drive cycle C1 (city)

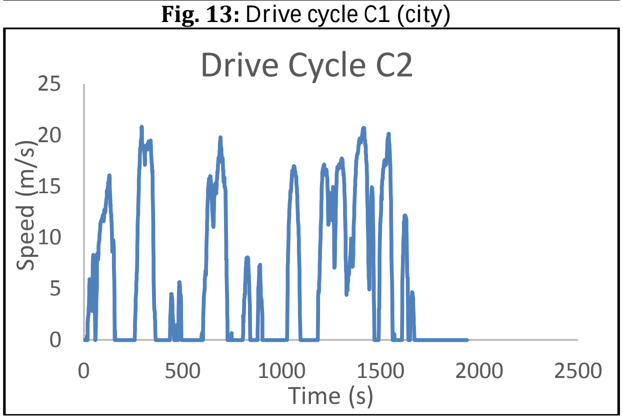

Fig. 14: Drive cycle C2 (city)

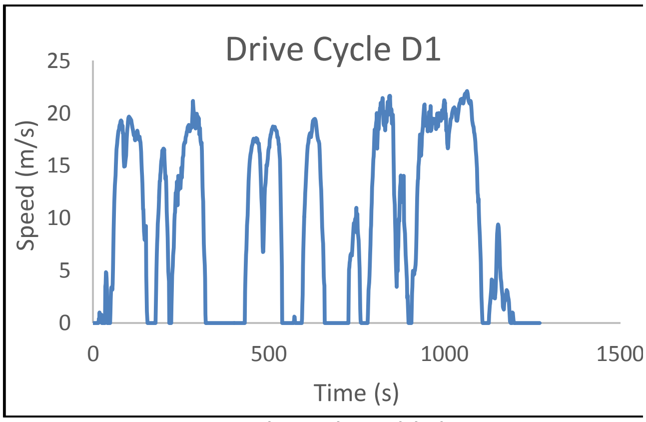

Fig. 15: Drive cycle D1 (city)

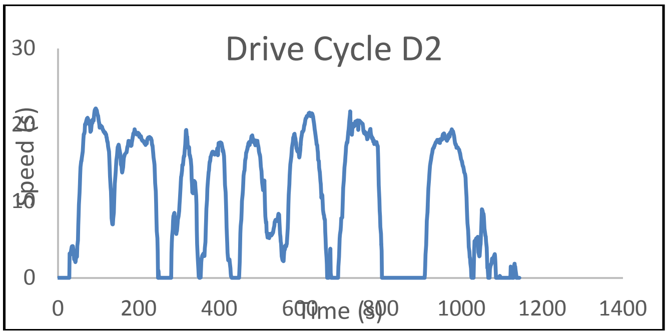

Fig. 16: Drive cycle D2 (city)

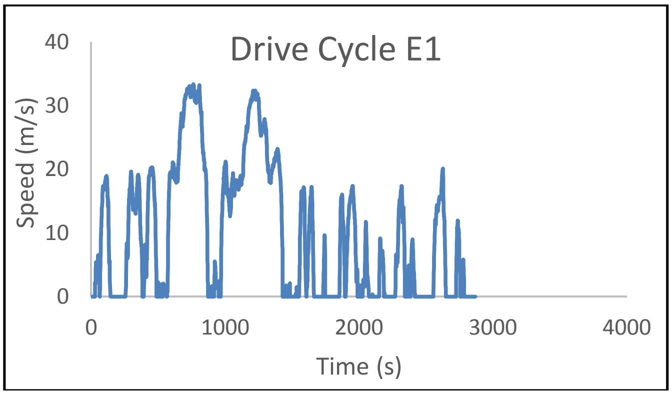

Fig. 17: Drive cycle E1 (highway)

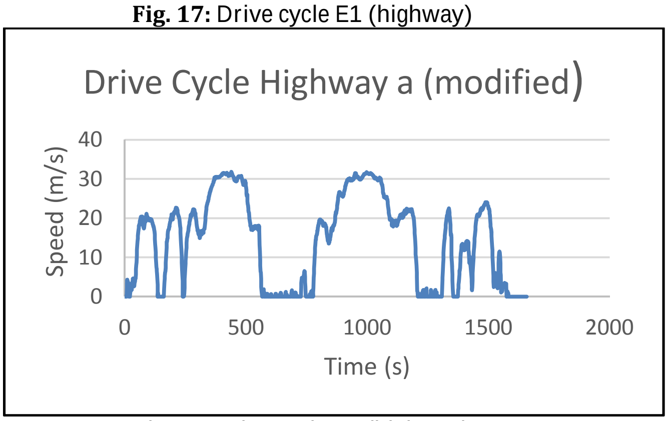

Fig. 18: Drive cycle E2 (highway)

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