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## **VEHICLE SELECTION METHODOLOGY BASED ON FUEL ECONOMY FOR THE USER'S DAILY JOURNEY**

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**Abstract.** *In this study a real driving cycle was measured and applied to a computational model in order to assess the possible fuel consumption of different vehicles in the route. The methodology proposed for the data acquisition uses the low cost ELM327 Bluetooth Scanner connected to the On-Board Diagnostic (OBD) port of the vehicle and an Android device with GPS. Based on the measured driving cycle and different vehicle powertrain data, simulations were performed. Fuel consumption results of different vehicles simulated in the real driving cycle are presented and compared with the data measured in order to validate the model. The calculated fuel consumption error between the actual vehicles and the computational models was less than 2%. The methodology developed can be applied for different routes, places and vehicles and may assist customers in choosing the most recommended car considering fuel saving at the purchase time.*

**Keywords:** *real driving cycle, vehicle longitudinal dynamics, fuel saving, ADVISOR™, ELM327.*

## **1. INTRODUCTION**

In the current automotive scenario, the focus of the industry is on meeting two major social demands: more efficient vehicles that provide lower fuel consumption and more environmentally friendly vehicles with low emissions levels. Even with all the advances made since the 19<sup>th</sup> century until the present, from the energy generated during combustion with conventional fossil fuels, approximately only 21.5% is effectively used for traction in passenger vehicles (Holmberg *et al.*, 2012) and only 34% in heavy vehicles (Holmberg *et al.*, 2014).

Laws have been established to restrict the emission of gaseous pollutants in several countries. Connected with these laws, there was a need for test procedures to compare fuel consumption and emission levels of various automobiles, then, standard driving cycles were created. Examples of these cycles are the FTP-75, used in the USA and in Brazil (called NBR 6601) and the NEDC used in Europe (Ibrahim, 2011).

However, according to Mock *et al.* (2012), fuel consumption values obtained in the laboratory using the standard cycles are increasingly distancing themselves from the values found when vehicles travel under real conditions, from 8% in 2001 to 21% in 2012. The authors cite that one possible reason for this fact may be related to the growth of sales of vehicles equipped with air conditioning.

The energy efficiency in a car is function of the powertrain technology, vehicle components technology, maintenance state, user driving style and the typical driving routes (Suarez-Bertoa *et al.*, 2015). The last mentioned parameter – typical driving routes – has a wide range of possibilities which are dependent upon the specific demand for each driver. Based in this relevance, it is interesting the development of comparative studies to verify which vehicle can offer the lowest fuel consumption for a given route, considering that a particular user often performs this track.

In this context, the present study shows a methodology to simulate different vehicles models in a driving cycle derived from real-world measurements including vehicle speed, engine speed, fuel consumption, ground level and GPS

data. The methodology validation is performed comparing the results to the fuel consumption of real vehicles in the same route. The proposed methodology can be conveniently replicated for different locations, vehicles and driving styles, allowing the creation of a database of routes. This database could help users to choose a specific car model that would be the most efficient for his/her needs prior to vehicle acquisition. This database could also be used for development of more efficient powertrain components and architectures.

## 2. METHODOLOGY

### 2.1 Real-driving data acquisition procedure

The proposed methodology is based in a low cost ELM327 Bluetooth scanner system connected to the car OBD-II communication port. The scanner system acquires data from the car and transmits it via Bluetooth to a cell phone executing Torque Pro application. The car data package is sampled at 0,5Hz and it contains the signals of vehicle velocity, engine speed, fuel consumption and engine load. The final data package is built using the car data package added to cell phone GPS signals of altitude, latitude, longitude, speed and time. The system flow diagram is presented in Fig. 1. It is highlighted that all cars manufactured since January 1, 1996 have the OBD-II port and also that the ELM327 Bluetooth scanner system costs approximately \$10 dollars.

Two conventional vehicles were used for the real driving cycle data acquisition: Nissan March 1.0 2013 (flex) and Ford Ranger 3.0 2011 (diesel - 4x2 traction mode). The data acquisition was made in a defined path covering urban and road driving. Three different trips were made with each vehicle on the planned route and a driving cycle was obtained with the measured GPS speed *versus* time.



Figure 1. Experimental ECU data acquisition procedure with ELM327™ Bluetooth Scanner.

### 2.2 Simulated model

The vehicle modeling equation is derived from the basic equation of solid-body motion - Newton's Second Law, modified with the specific forces that typically act on vehicles as shown in Eq. (1):

$$F = mgC_{rr} + \rho C_D A v^2 + ma + mgsin\theta, \quad (1)$$

where:

- $F$ : force required at the wheels of the vehicle;
- $m$ : mass of the vehicle;
- $C_{rr}$ : rolling resistance coefficient;
- $\rho$ : air density;
- $C_D$ : drag coefficient;
- $A$ : cross-sectional area of the vehicle;
- $v$ : vehicle speed in the direction of travel;
- $a$ : vehicle acceleration;
- $g$ : local gravity acceleration;
- $\theta$ : road slope.

The first term in the equation indicates the force required to overcome the rolling resistance of the wheels. This force is not dependent of the vehicle speed and tends to dominate at relatively low speeds. The second term represents the aerodynamic drag force which the vehicle must overcome at a certain speed. This force is proportional to the square of the vehicle speed, therefore, tends to be small at low speeds, but increases rapidly with velocity. The inertia of the vehicle is represented in the third equation term and has no effect under constant-speed cruising conditions. Finally, the last term represents the force required to propel the vehicle on a non-zero grade. Despite the simplicity of the resistance forces equation, it is accurate enough for most analyses, and it is the basis for almost all vehicle simulation tools, including ADVISOR<sup>TM</sup> (Senger *et al.*, 1998).

The software ADVISOR<sup>TM</sup> uses a quasi-steady approximation approach for modeling different vehicle powertrain architectures. At each discrete time step, the software estimates the required energy at the wheels of the vehicle using a pre-determined vehicle velocity profile. It then determines the amount of input energy required of each powertrain component to meet the energy demand from the wheels.

The calculation of the vehicle road load by Eq. (1) allows the calculation of the required torque ( $T$ ) at the engine as shown below:

$$T = \frac{(mgC_{rr} + \rho C_D A v^2 + ma) \cdot r + [(I_e + I_t) \cdot N_t^2 N_d^2 + I_d N_d^2 + I_w] \cdot \frac{a}{r}}{N_t N_d \eta_{td}} \quad (2)$$

The terms  $I_e$  [kg·m<sup>2</sup>] refers to the inertia of the internal combustion engine,  $N_t$  and  $I_t$  [kg·m<sup>2</sup>] the gear ratio and gearbox inertia respectively,  $N_d$  and  $I_d$  [kg·m<sup>2</sup>] the transmission ratio and the inertia of the differential,  $\eta_{td}$  the mechanical efficiency of the powertrain,  $r$  [m] the tire radius and  $I_w$  [kg·m<sup>2</sup>] represents the inertia of the vehicle wheels and tires (Gillespie, 1992). The torque demand is then compared to the available torque in the engine characteristic curve as a function of the engine speed and the maximum torque curve (full throttle). If the required torque is greater than the available torque, the performance of the vehicle will be limited by the power of the engine.

In this study, a conventional vehicle model from ADVISOR<sup>TM</sup> was used to simulate and compare different vehicles performance and fuel consumption in the driving cycle acquired and supplied to the program as a .mat file. The simulation results were compared and validated with the previously acquired experimental data. Two other vehicles were only simulated: Honda Fit LX 2015 and Volkswagen UP! 2014. The simulation results from these vehicles were also utilized for comparison purposes. The vehicles technical information used in the computational model are shown in Tab. 1.

Table 1. Vehicle data from the owner's manual.

Vehicle	Nissan March	Ford Ranger	Volkswagen UP	Honda Fit
Year	2012	2011	2014	2015
Engine displacement	998 cm <sup>3</sup>	2968 cm <sup>3</sup>	999 cm <sup>3</sup>	1497 cm <sup>3</sup>
Architecture	4 doors, 5 places, front wheel drive	4 doors, 5 places, front wheel drive	4 doors, 5 places, front wheel drive	4 doors, 5 places, front wheel drive, LX
Power	74 cv (54 kW) - 5850 rpm	163 cv (119 kW) - 3800 rpm	75 cv (55 kW) - 6250 rpm	115 cv (84 kW) - 6000 rpm
Torque	10.1 kgf.m - 4350 rpm (gasoline)	38.7 kgf.m - 1600 to 2200 rpm (diesel)	9.7 kgf.m - 3000 rpm (gasoline)	15.2 kgf.m - 4800 rpm (gasoline)
Transmission ratio	1 <sup>st</sup>	4.091	4.079	3.769
	2 <sup>nd</sup>	2.238	2.289	2.095
	3 <sup>rd</sup>	1.393	1.472	1.281
	4 <sup>th</sup>	1.029	1	0.927
	5 <sup>th</sup>	0.795	0.725	0.74
	Reverse gear	3.545	3.795	3.182
Final drive	4.5	3.54	4.929	4.625
Fuel consumption (urban)	12.3 km/l (gasoline)	9 km/l (diesel)	13.2 km/l (gasoline)	11.6 km/l (gasoline)
Fuel consumption (road)	14.5 km/l (gasoline)	13 km/l (diesel)	14.3 km/l (gasoline)	13.6 km/l (gasoline)
Tire	165/70 R14	225/70 R15	175/70 R14	185/60 R15
Weight	980 kg	1960 kg	920 kg	1060 kg
Frontal area	2.16 m <sup>2</sup>	2.66 m <sup>2</sup>	2.07 m <sup>2</sup>	2.17 m <sup>2</sup>
Drag coefficient	0.33	0.44	0.36	0.32

Several papers as Eckert *et al.* (2016b); Silva *et al.* (2009); Mashadi *et al.* (2014) use models from ADVISOR<sup>TM</sup> as reference to simulate fuel consumption and emissions. The fuel consumption in the driving cycle studied is estimated with the engine consumption map (BSFC) constructed by scaling different engine from the program database to match the engine power from the analysed vehicles, as proposed by Du *et al.* (2013). Figure 2-a shows an example from the maximum torque curve of a MWM 3.0 diesel engine from the Ford Ranger (2011). Figure 2-b shows the estimated efficiency map used in the simulation of this vehicle. The maximum engine power is 120 kW at 3800 rpm and the maximum engine torque of 380 Nm is available over a range from 1600 to 2200 rpm.

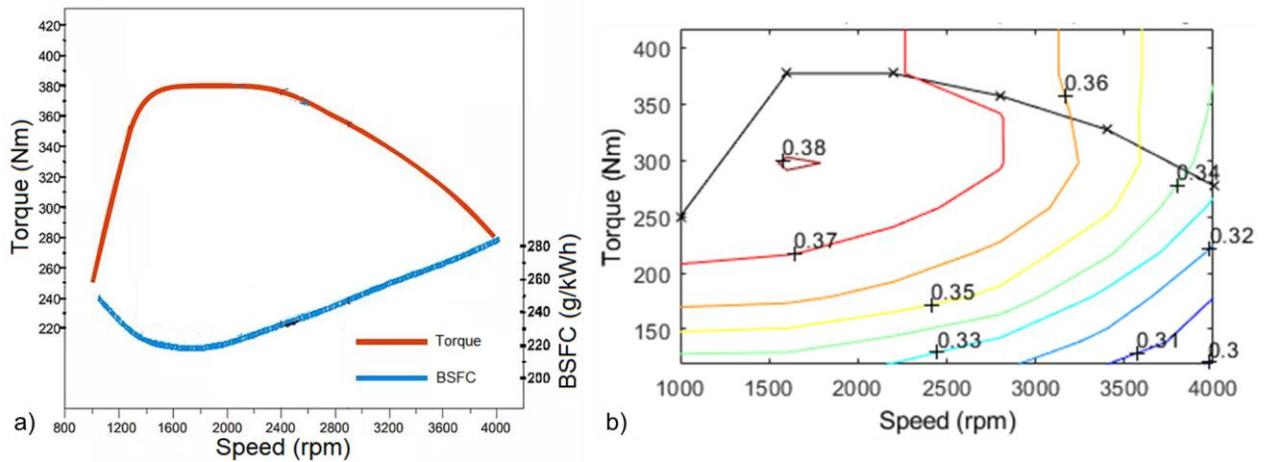


Figure 2. The maximum torque curve and its related specific fuel consumption from the Ford Ranger diesel engine (a); Ford Ranger engine efficiency map (b).

### 3. RESULTS AND DISCUSSION

The route taken in the city of Ouro Branco - MG can be visualized in Fig. 3, obtained based on GPS data acquired in one of the trips and using the Google Earth tool. Most of the time the driving is done in a highway that connects the city with the Campus Alto Paraopeba - CAP - UFSJ. The start and end of the journey were in CAP. The red arrow indicates the highest elevation point of the path.



Figure 3. The path taken to obtain the real driving cycle and the elevation profile.

Figure 4 shows a graph comparing the data obtained with the cars on the actual route in relation to the distance travelled, time and the fuel consumption in each of the three laps performed. The average distance travelled by the vehicles was  $18.43 \pm 0.41$  km, totalling approximately 111 km travelled. The fuel consumption of the gasoline vehicle - Nissan March was  $16.34 \pm 0.47$  km/l and the Ford Ranger diesel consumption was  $9.60 \pm 0.14$  km/l. Although the route was the same, each lap was performed, especially for the Nissan March, at very different times and therefore with variations of the average speed values between each trip. Such variation is responsible for the higher standard deviation value of fuel consumption observed with the gasoline vehicle. Although the route was the same for all trips, there were

slight variations of the distance travelled, especially with the pickup truck, because the Torque Pro application uses GPS position.

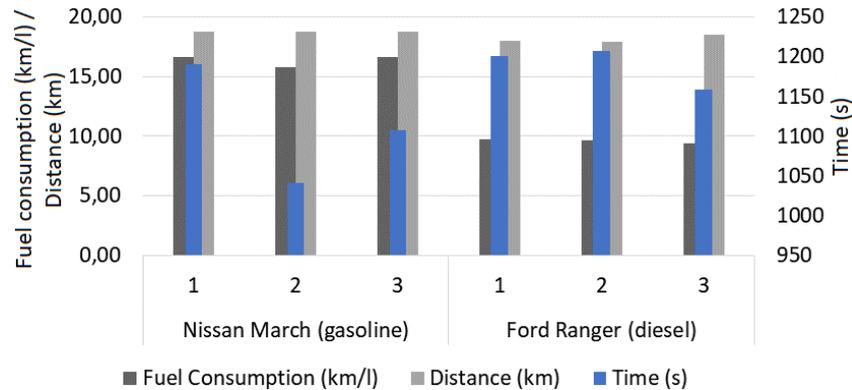


Figure 4. Data obtained in the pre-defined route in the city of Ouro Branco – 3 laps for each vehicle.

With the data obtained in the three laps made with each vehicle, a speed profile was chosen where the highest speeds in the route were reached, since it was the situation where the highest power demand of the used vehicles occurred. The adopted driving cycle data used as reference in the computational model is shown in Tab. 2.

Table 2. Real driving cycle data.

Description	Value	Unit
Minimum elevation	971	m
Maximum elevation	1081	m
Mean speed	57.85	km/h
Maximum speed	111.33	km/h
Maximum acceleration	3.76	m/s <sup>2</sup>
Maximum deceleration	-3.81	m/s <sup>2</sup>
Total distance	18.74	km
Total time	1165	s

Figure 5-a shows the speed profile of the real driving cycle. The red line is the speed profile of the ADVISOR™ model and the blue line is the reference driving cycle. The created model follows most of the time the reference velocity profile. Figure 5-b shows an example of a gear shifting strategy calculated by the software for this driving cycle based on Nissan March gears ratio. The fifth gear was the predominant gear selected for all vehicles studied in this cycle, since the majority of the path is made in a highway, as mentioned previously.

Table 3 shows the comparison between the results from the vehicles measured data and the simulated models in the real driving cycle. The calculated fuel consumption error between the actual vehicles and the computational models was less than 2%. Therefore, the methodologies adopted for the simulation with the real data of the vehicles and for the dynamic driving cycle data acquisition were considered coherent.

The Volkswagen UP only simulated in ADVISOR™ was the vehicle that presented the lowest fuel consumption (17.48 km/l) and therefore would be the recommended car for a person who lives in the region and who performs every day the route studied. The fuel cost for driving 18.68 km with the Volkswagen UP was 24% cheaper than the diesel vehicle, even with the diesel cost 36% cheaper than gasoline. Although the comparison is not fair, since the vehicles are from different classifications and for different applications, the results may help people from the location studied in the purchase of a new car.

#### 4. CONCLUSIONS

There are several applications where vehicles are used to carry out the same driving cycle daily (e.g., bus fleets, garbage trucks and delivery vehicles). The proposed methodology creates the possibility of acquiring real driving cycles for different locations with only a mobile phone and a \$10 vehicle scanner. With the known power demand of the route

where the customer intends to use the vehicle most frequently, it is possible to choose the most efficient and eventually the less pollutant vehicle for the location.

In this study, two vehicles were used for real driving data acquisition. A speed profile was created with the acquired data and used as the reference cycle in a computational simulation. Four vehicles were modelled in the software ADVISOR™ with manufacturers data and tested in the real driving cycle chose for evaluating their mean fuel consumption. The fuel consumption error between the data acquired from the actual vehicles and the modelled vehicles was less than 2%. The modelled Volkswagen UP 1.0 was the car with the lower mean fuel consumption in the route studied, performing 17.48 km/l.

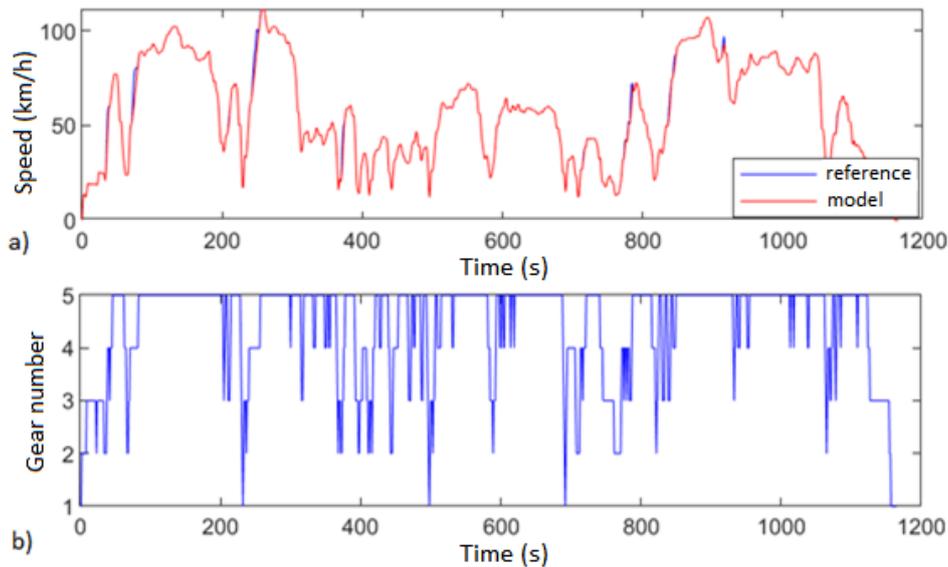


Figure 5. ADVISOR™ model simulated in the driving cycle acquired (a) and a gear shifting strategy created (b).

Table 3. Results from the vehicles measured data and the simulated models in the real driving cycle.

Data/Vehicle	Nissan March (real)	Nissan March (simulated)	Ford Ranger (real)	Ford Ranger (simulated)	Volkswagen UP (simulated)	Honda Fit (simulated)
Distance (km)	18.43	18.66	18.43	18.74	18.68	18.71
Fuel Consumption (km/l)	16.34	16.19	9.6	9.46	17.48	13.52
Fuel consumption error (%)	0.9		1.5		-	-
Cost (\$)	1.52	1.55	1.90	1.96	1.44	1.86

\*Litre price of fuel on October 5, 2018 in Ouro Branco - MG: gasoline \$1.35 and diesel \$0.99.

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