Estimated fuel consumption for a vehicle with manual transmission in the highways in the city of Lima

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Abstract–Regulations aim to reduce vehicle emissions that are harmful to human health. The vehicle engine burns fuel mixed with air in a stoichiometric relation. Emissions are produced when the stoichiometric relation is not met. According to previous research work emissions can be reduced when less fuel is burned. Therefore, knowing the fuel consumption under different engine conditions can help to understand the conditions when most fuel is burned. This research analyses the fuel consumption while driving a vehicle with manual transmission in two main highways in the city of Lima. The results show when the vehicle drives at slower speeds the specific fuel consumption goes up to 10 L/100km while driving at higher speeds the consumption decreases to 8 L/100 km in average.

Keywords-- Specific Fuel Consumption, MAF Sensor, Manual Transmission, OBD-II.

I. Introduction

Emissions produced by vehicles are of great concern to human health, therefore laws to regulate emissions have become more severe [1][2]. The EURO laws [3] are good references to understand the restrictions that cars manufacturers must keep. It is necessary to guarantee that the air we breathe is cleaner, so scientists propose different techniques to reduce emissions. According to Ashok [4] spark-ignition (SI) and compression-ignition (CI), engines produce pollutants that damage the atmosphere and human health. Regarding oxides of nitrogen and particulate matter, CI engines have a more pronounced influence on human health. As indicated by Loja [5] there are several operating cycles in an internal combustion engine, producing an inevitable formation of stoichiometric mixtures. Thus, one of the stages or cycles he mentions is cold starting, where more pollutant gases are released, which is limited by the requirement to reach an adequate engine operating temperature in the shortest time. In this context it can be stated that by burning less fuel, less emissions are produced by the engine.

Every owner of a vehicle wants to use less fuel and travel long distances [6], therefore models that can predict the average fuel consumption are important. Techniques to develop models of fuel consumption fall under three categories: Physical based models, Machine learning models and Statistical models. For example, Rimpas [7] proposes a method to estimate the fuel consumed by vehicle from the data acquired from the vehicle computer. In the same way Delussu [8] uses the vehicle data to estimate fuel consumption. Toropov [9] takes a step ahead and adds an external sensor to measure the fuel consumption and compare the data with the calculated information. Additionally, Srisakda [10] describes that in heavy traffic conditions fuel consumption increases. Therefore, he's solution is to implement intelligent signals to reduce the fuel consumption. This research demonstrates that by knowing the fuel consumption vehicle designers can design strategies to alert owners to reduce the fuel consumption.

A similar solution is to use predictive models, Nier [11] describes the use of vehicle sensor data collected by the Canadian government to estimate the fuel consumption. Also, Kurganov [12] employs data from the Russian government to estimate fuel consumption of vehicles that travel different roads and combines it with the navigation data. Another method scientist propose is the use of mathematical models, like the case of Jingeun [13], that uses linear equations from technical data from vehicles. With the obtained data from vehicles in circulation he estimates the fuel consumption. Similarly, Tsiakmakis [14] employs mathematical models to calculate the fuel consumption from data of vehicle in circulation. Finally, another similar method is employed by Rivera [15] to estimate the vehicle emission in Ecuador. The described methods are centered on building predictive methods from existing information or equations that describe the vehicle engine. This demonstrates that models are required to understand the vehicle dynamics, which is not possible through thermodynamic equations.

The process of efficient fuel detection - or Eco driving - includes a series of parameters that leads to the consideration of the route chosen to drive, in the habits of passive driving and those that occur abruptly or untimely, the weight and the vehicle's aerodynamic shape, maintenance and other factors that provide comfort and entertainment, such as the air conditioning system. Other factors - internal and external - that generate a difference in the fuel consumption are traffic conditions, accumulated miles, weather, temperature, rapid acceleration and braking, the load in the vehicle, excessive use of electrical equipment, traction on the axles, the quality of fuel or the maintenance given to the motor vehicle, tires inflated correctly, dirty filters, etc. [16][17]

Through previous research [18] it has been possible to determine that vehicles have a sophisticated operation control system which is linked to the economy of fuel consumption, emissions and power developed by the vehicle, where the engine is subjected to continuous cycles as turning, acceleration and braking, mainly in urban areas. The use of built-in sensors and the obtained data by means of OBD2 CAN bus constitute a part of the methodology that makes it possible to establish fuel consumption [19]

Pepper work [20] presents a procedure for the detection of mass air flow (MAF); on the other hand, the information indicated by Rolim [21] mentions the work of Duarte [22] which indicates that, OBD-II data of mass airflow or engine load is not available, the VSP methodology (Vehicle Specific Power) is used to obtain the estimate of fuel consumption.

More recent works use the OBD2 protocol for data collection and its use with machine learning techniques, which are used for the analysis of driving behavior [23].

Because it is difficult to install a fuel meter in a particular vehicle. This article focuses on estimating fuel consumption by using data from different sensors gathered through the OBD-II port. The data acquisition was done in a RENAULT vehicle through various driving routes in the city of Lima. The estimated data shows the variation of fuel consumption compared with vehicle speed, engine speed and engine load. Finally, a relation between the gearbox ratio, engine load and estimated fuel consumption is presented. This paper is organized as follows; section II presents the methodology to estimate the fuel consumption. Section III presents the results obtained from the vehicle sensor data, and section IV discusses the obtained results.

II. Data Acquisition

A. *Fuel Consumption Estimation*

The estimation method is based on the work done by Pepper [20], who stablishes the following method for vehicles that use a MAF sensor to estimate the air entering the ignition chamber.

$$FC(ti) = (MAF(ti)*\Delta\ ti)/(AFratio*\rho\ fuel*1000ml) \qquad (1)$$

Where FC is the estimated fuel consumption in liters at time ti; MAF is the MAF sensor readings in g/s at time ti, AFratio is the air to fuel ratio at time ti; ρfuel is the fuel density in g/ml and Δti is the sampling interval. From the above variables the fuel density is constant, and its value was set to 0.713 g/ml according to [24]. For the tests a RENAULT SANDERO 2018 vehicle was used. According to the manufacturer it uses a MAF sensor to estimate air intake, which matches with the formula requirements. The vehicle technical specifications are shown in Table I.

TABLE I
RENAULT SANDERO 2018 ENGINE TECHNICAL SPECIFICATIONS

Engine Technical Characteristic	***Value***
Number of cylinders	4 cylinders in line
Engine Capacity	1600 liters
Horsepower	110 bhp
Torque	148 Nm
Fuel Type	Petrol
Transmision	Manual 6 speed

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The sensor values were obtained by using the Can Clip database through the ELM 327 scanner and using the PYREN [25] software. From all the available versions of the ELM327 scanner, the USB version proof to be the more stable. The PYREN software allows to access sensor and actuators data from RENAULT vehicles; and offer to export the collected data in a csv file. The software sampling time is around 0.2 seconds.

B. *Data Processing*

The data to estimate fuel consumption was collected after driving through two main highways in the city of Lima as shown in Fig. 1. The first drive was in the highway called “Linea Amarilla” that goes through the Rimac river covering an approximate distance of 24 km in 1 hour and 10 minutes, in this ride 14629 data points were collected and the fuel consumed was approximately 2.1 L. In the second drive the “Costa Verde” highway was selected covering a distance of approximate 24 km in 1 hour, in this drive 13339 data points were collected and the fuel consumed was approximately 3.2 L. The collected data was processed using the formula (1), the fuel consumption for each ride is shown in Fig 2 and Fig 3.

Fig. 1 Selected drive test routes to analyze fuel consumption.

The first analysis was to understand the accumulated fuel consumption. Fig. 2 shows the accumulated fuel consumption for test route 1 while Fig. 3 shows the accumulated fuel consumption for route 2.

In Fig 2 for route 1 the slope changes twice showing an increase in fuel consumption, this increase can be understand comparing the data with an increase in engine speed to gain more vehicle speed as shown in Fig 4. In this case the vehicle was running above 60 km/h in a free highway. A similar case can be observed in Fig 3 for route 2, the fuel consumption slope changes slightly at the middle. The fuel consumption is compared against the engine speed in Fig 5.

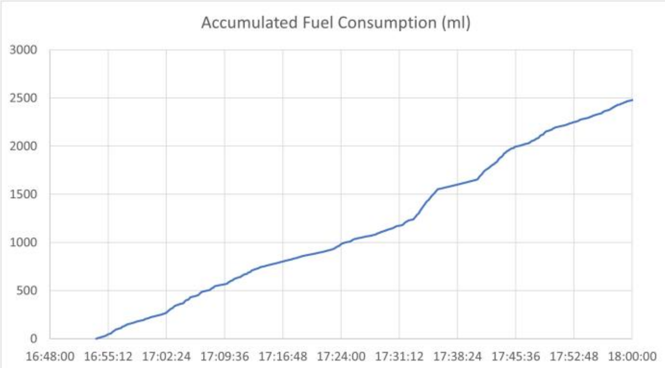

Fig. 2. Accumulated fuel consumption for route 1

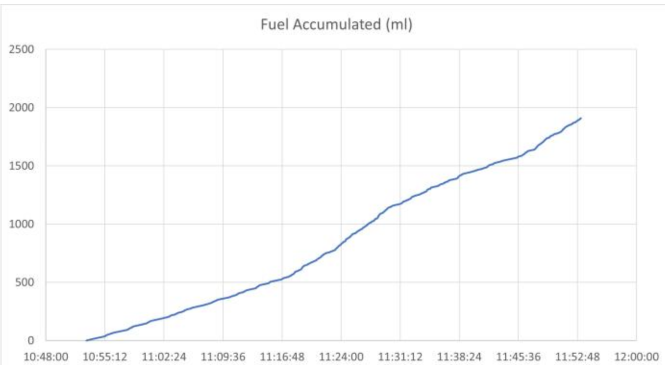

Fig. 3. Accumulated fuel consumption for route 2

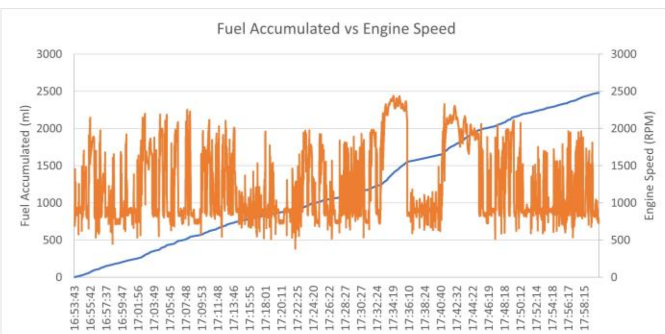

Fig. 4. Accumulated fuel consumption compared with engine speed for route 1.

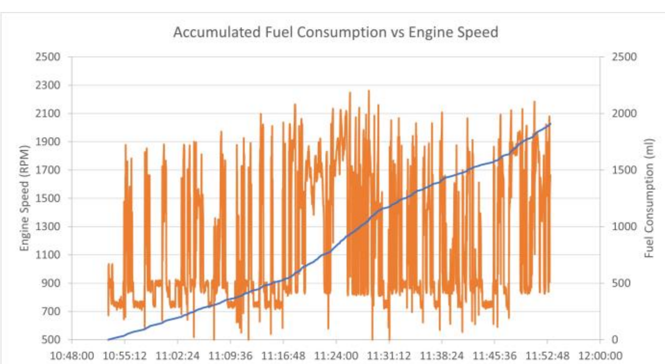

Fig. 5. Accumulated fuel consumption compared with engine speed for route 2.

C. Stadistical Analysis

The average speed for route 1 is 22 km/h where for route 2 is 26 km/h. To understand the traffic condition for each route a histogram for speed frequency was constructed. Fig 6 and Fig 7 shows the results obtained for each data set with is distribution line.

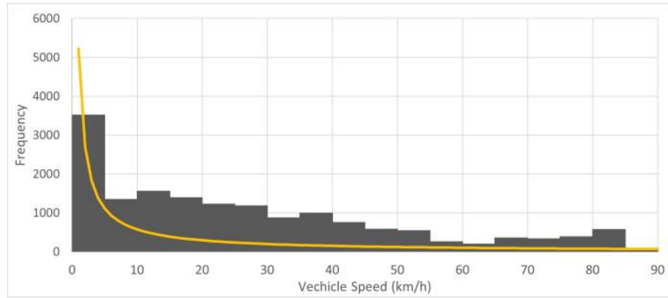

Fig. 6. Vehicle speed frequency distribution for route 1.

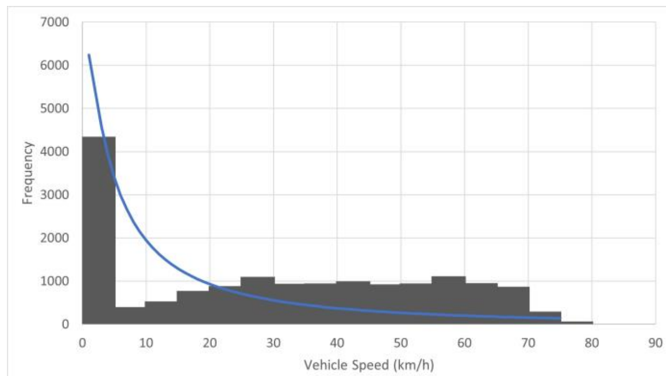

Fig. 7. Vehicle speed frequency distribution for route 2.

In Fig. 6 the vehicle was driving more time at slow speeds in route 1 than in route 2. Meaning that more distance can be covered at the same time. As mentioned before, route 1 driving span was 1 hour and 10 minutes while route 2 driving span was 1 hour.

The fuel consumption analysis is better understand converting the fuel consumed to a standard measure unit. For this case the specific fuel consumption (SFC) was calculated which is measured in liters per 100 km. The calculations were performed by obtaining the fuel consumed for one kilometer and multiplying the data by 100. The calculated data was compared with vehicle speed, engine speed and engine load. The results are plotted from Fig. 8 to Fig. 13.

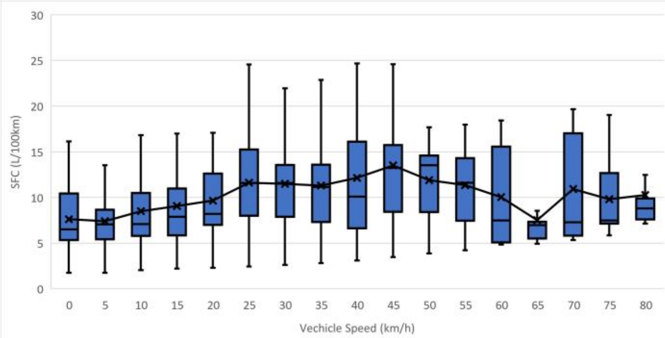

Fig. 8. SFC distribution by vehicle speed bins for route 1.

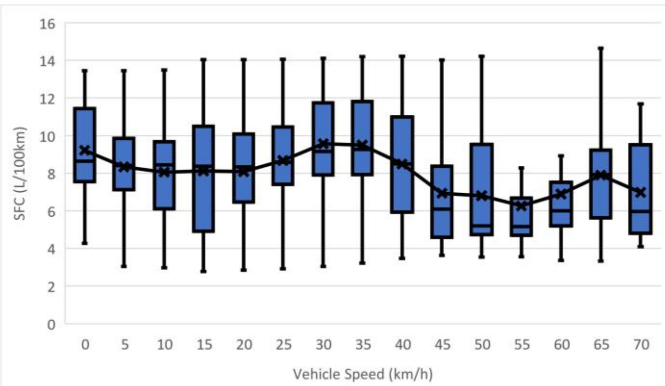

Fig. 9. SFC distribution by vehicle speed bins for route 2.

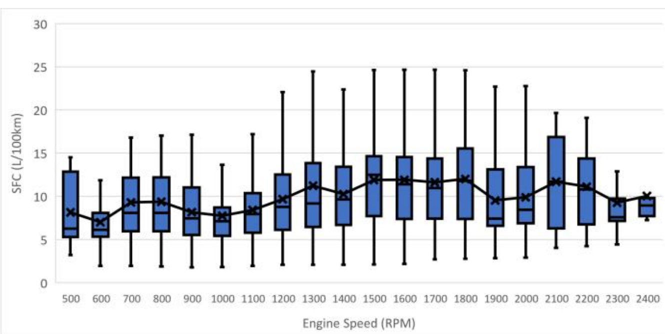

Fig. 10. SFC distribution by engine speed bins for route 1.

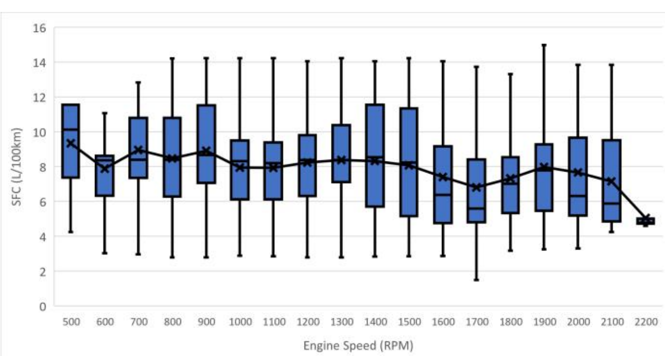

Fig. 11. SFC distribution by engine speed bins for route 2

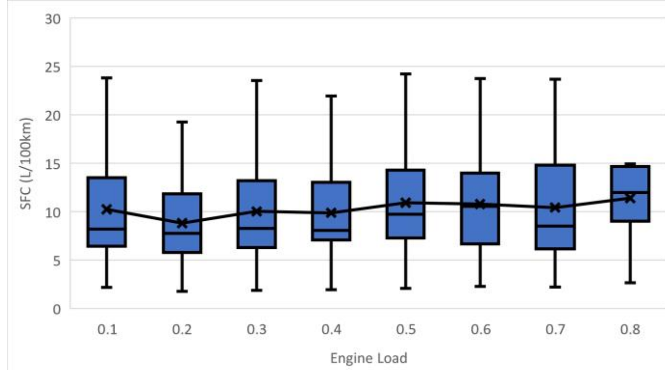

Fig. 12. SFC distribution by engine load bins for route 1

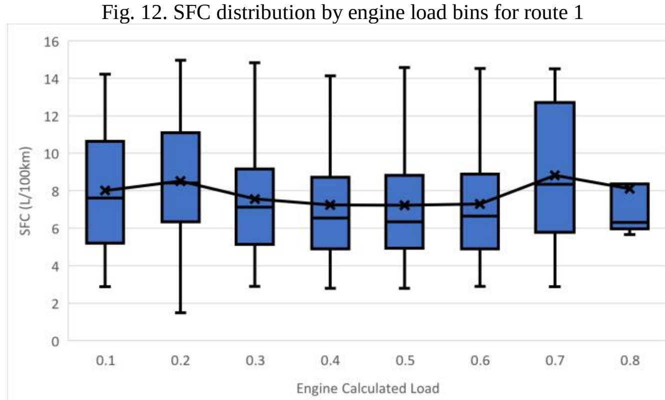

Fig. 13. SFC distribution by engine load bins for route 1.

III. DISCUSSION

As seen in Fig. 4 the fuel consumption slope increases when the driver requests more engine speed by pushing the acceleration pedal. In this case the driver was driving the vehicle at full speed in the highway without any interruption. The same happens for route 2, as shown in Fig. 5, fuel consumption rises when the engine speed increases as a demand from the driver. Although the slope change in this case is very small, this can be explained from the vehicle speed frequency distribution. Fig. 7 shows that the speed distribution is almost uniform for all speed ranges, meaning that the vehicle speed was in average higher than in route 1.

The vehicle speed frequency distribution shows that in route 1 the driving speed is slower in average than in route 2. The obtained data was approximate with a logarithmic distribution, but in both cases the decrease in vehicle speed does not follow the tendency. On the contrary the speed distribution increases for higher speeds. For the case of route 2 where the driving speed is higher, the vehicle was driving at speeds from 30 km/h to 70 km/h. For route 1 the driving speed was between 0 km/h and 40 km/h. Finally, for both cases the height bin distribution at 0 km/h means that amount of time the vehicle was stop due to traffic lights and traffic jam.

To understand the fuel consumption the SFC was calculated, this data was plotted to understand the distribution by vehicle speed bins. Fig. 8 shows that the average SFC is around 10 L/100km, while Fig. 9 shows an average SFC of 8 km/L, this average SFC is the same for all cases. Also, in both cases it can be noticed that the SFC decreases when the vehicle is driven at higher speeds that corresponds to the higher gear box. Similarly, the higher SFC is between speeds 30 km/h to 40 km/h.

For the case of engine speed the SFC is not constant in route 1; due to the fact that the vehicle was driving at slow speeds, therefore more gearbox shifts where involved. On the other hand, for route 2 the SFC is more constant because the driving speed on average was faster, meaning that less gearbox shifts were involved.

Finally, for the case of engine calculated load the SFC does not vary too much. Meaning that vehicle load for private vehicles does not impact much in SFC, the same cannot be said for trucks that manage different weights.

IV. Conclusions

As seen in the SFC distributions curves the average fuel consumption for route 1 is 10 L/100km, while for route 2 the average fuel consumption is 8 L/100km. This increase is explained by the more time the vehicle was driving at lower speeds. This fact is demonstrated in the speed frequency distributions for each route. For the case of route 1 the vehicle spent more time at speeds lower than 40 km/h. On the contrary in route 2 the vehicle speed was kept between 30 km/h and 70 km/h.

The SFC distribution varies greatly at different vehicle speeds and engine speeds, due to the fact that the vehicle has a manual transmission, and the speed shifts are done according to the driver skills. This variation can be corrected with a manual transmission, where the vehicle speed shifts are controlled by the computer ensuring optimal fuel consumption.

This work will be complemented analyzing data from other vehicles and more routes to understand the traffic speed distribution in the main corridors of the city. Additionally, the vehicle transmission configuration influences in the fuel consumption. Therefore, an analysis between a manual transmissions and automatic transmission will be performed.

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References

[1] S. Mahesh, A. McNabola, W. Smith, D. Timoney, A. Ekhtiari, B. Fowler, P. Willis, R. Rose, J. Wareham, H. Walker, B. Gosh, “On-road remote sensing of vehicles in Dublin: Measurement and emission factor estimation” Transportation Research Part D: Transport and Environment. 2023. Vol 117.

[2] S. Singh, M. Kulshrestha, N. Rani, K. Kumar, C. Sharma, D. Aswal, “An Overview of Vehicular Emission Standards”. Mapan - Journal of Metrology Society of India. 2023. Vol 138.

[3] European Comission. “European vehicle emissions standards – Euro 7 for cars, vans, lorries and buses”, https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12313-European-vehicle-emissions-standards-Euro-7-for-cars-vans-lorries-and-buses_en

[4] B. Ashok, N. Kumar, A. Jacob, R. Vignesh, “Emission formation in IC engines”. NOx Emission Control Technologies in Stationary and Automotive Internal Combustion Engines: Approaches Toward NOx Free Automobiles. 2021. 1-38 p.

[5] J. L. L. Loja, “Emisiones y temperaturas de los gases de escape de un motor durante el arranque en frío aplicando dos tipos de combustibles,” Polo del Conocimiento, vol. 7, no. 10, pp. 138–160, 2022.

[6] B. Dhanalaxmi, M. Varsha, K. Roshan, P. Mokshitha, “An Enhanced Fuel Consumption Machine Learning Model Used in Vehicles”. Journal of Physics: Conference Series. 2021.

[7] D. Rimpas, A. Papadakis, M. Samarakou, “OBD-II sensor diagnostics for monitoring vehicle operation and consumption”, Energy Reports (2019), https://doi.org/10.1016/j.egyr.2019.10.018.

[8] F. Delussu, F. Imran, C. Mattia, R. Meo, “Fuel Prediction and Reduction in Public Transportation by Sensor Monitoring and Bayesian Networks”, Sensors 2021, 21, 4733. https://doi.org/10.3390/s21144733

[9] E. Toropov, Y. Trusov, A. Vashurin, P. Moshkov, “Estimation of the accuracy of fuel consumption measurement based on data from the on-board CAN-bus”, International Conference on Actual Issues of Mechanical Engineering (AIME 2021), doi:10.1088/1742-6596/2061/1/012072

[10] N. Srisakda, P. Sumitsawan, A. Fukuda, T. Ishizaka, C. Sangsrichan, “Reduction of vehicle fuel consumption from adjustment of cycle length at a signalized intersection and promotional use of environmentally friendly vehicles”, Engineering and Applied Science Research (2022), https://doi.org/10.14456/easr.2022.2

[11] N. Hien, A. Kor, “Analysis and Prediction Model of Fuel Consumption and Carbon Dioxide Emissions of Light-Duty Vehicles”, Applied Sciences (2022), https://doi.org/10.3390/app12020803

[12] V. Kurganov, A. Dorofee, M. Gryaznov, “Rationing of fuel consumption with the use of information technology”, The Russian automobile and highway industry journal (2018), Vol. 15 N° 2, pp 237-248, https://doi.org/10.26518/2071-7296-2018-2-237-248

[13] S. Jingeun, C. Junepyo, “Development of prediction methodology for CO2 emissions and fuel economy of light duty vehicle” Energy (2022), https://doi.org/10.1016/j.energy.2022.123166

[14] S. Tsiakmakis, G. Fontaras, G. Fontaras, J. Dornoff, V. Valverde, D. Komnos, B. Ciuffo, P. Mock, Z. Samaras, “From lab-to-road & vice-versa: Using a simulation-based approach for predicting real-world CO2 emissions”, Energy (2019), https://doi.org/10.1016/j.energy.2018.12.063

[15] N. Rivera, J. Muñoz, B. Arenas, “Estimation of pollutant emissions in real driving conditions based on data from OBD and machine learning”, Sensor (2021), https://doi.org/10.3390/s21196344

[16] P. Fafoutellis, E. Mantouka, E. Vlahogianni, “Eco-Driving and Its Impacts on Fuel Efficiency: An Overview of Technologies and Data-Driven Methods”, Sustainability (2021), https://doi.org/10.3390/su13010226

[17] AECOM Ltd, “Eco-driving for HGVs Final Report” Department for Transport, December 2016.

[18] R. Isermann, “Engine modelling and control, modelling and electronic managament of internal combustion engines”, Springer, 2014.

[19] R. Jurecki, T. Stanczyk, “A Methodology for Evaluating Driving Styles in Various Road Conditions” Energies 2021, 14, 3570. https://doi.org/10.3390/en14123570

[20] G. Pepper, “Methods and System for determing consumption and fuel efficiency in vehicles” United States Patent US 7,774,130 B2, Aug. 10, 2010.

[21] C. Rolim, P. Baptist, G. Duarte, T. Farias, “Impacts of on-board devices and training on Light Duty Vehicle Driving Behavior”, IST, Universidade de Lisboa EWGT2013 - 16th Meeting of the EURO Working Group on Transportation

[22] G. O. Duarte, "A methodology to estimate real-world vehicle fuel use and emissions based on certification cycle data". Ph.D Thesis in Mechanical Engineering, Instituto Superior Técnico, Universidade Técnica de Lisboa, 2013.

[23] R. Kumar, A. Jain, “Driving behavior analysis and classification by vehicle OBD data using machine learning” The Journal of Supercomputing Springer Nature 2023 https://doi.org/10.1007/s11227-023-05364-3

[24] Petroperu. “Gasolina de 95 octanos”, Ficha de datos de seguridad. 2019.
[25] Marianpol. “Pyren”. Gitlab 2022. Avialable: https://gitlab.com/py_ren/pyren.