Study of urban fuel consumption of a car with a petrol internal combustion engine

M Magdziak-Tokłowicz¹,2
¹ Mechanical Department, Wrocław University of Science and Technology, Poland, Wrocław, Braci Gierymskich 164
² GEO-3EM Research Center, Wrocław University of Science and Technology, Poland, Wrocław, Na Grobli 13

E-mail: monika.magdziak-toklowicz@pwr.edu.pl

Abstract. This article presents analysis and an attempt to forecast the actual fuel consumption of the vehicle in the urban cycle. The most important factors affecting fuel consumption were discussed, in particular the influence of the driver’s driving style. Each driver drove a designated, the same route in the urban area outside the rush hour. Based on the readings from the OBD on-board computer and the mobile application, the driver’s occurrence points on the universal engine characteristics were read. On the axes of torque and rotational speed, the most frequently occurring engine work fields for each driver were determined. The author divided the driving styles of the driver according to the most common occurrence on the universal characteristics of the engine and depending on the specific fuel consumption. The author’s method has shown that it is possible to point out drivers who will certainly exceed the average fuel consumption after driving a few kilometers of the road. This method shows the possibility of using the on-board computer and OBD readings to optimize fuel consumption and match each driving style to the appropriate external and universal characteristics of the vehicle engine to use as little fuel as possible, and thus contribute to reducing CO₂ emissions to the environment and consumption of fossil fuels. This method can be successfully used on all vehicles with an internal combustion engine.

1. Introduction
The development of global industry and the progressing globalization of life, as well as the increase in the mobility of people dynamically affect all aspects of automotive in the world. In 2019, the world production of passenger cars amounted to almost 92 million units. China is the undisputed leader, in which over 28% of the total was produced, followed by the USA, followed by Japan and Germany [1]. Road transport is still the leading means of transporting people and goods, but any land, sea or air transport is associated with the problem of environmental pollution caused by the use of internal combustion engines in these means of transport. In most countries on Earth, various types of ordinances have already been introduced that define the conditions for the admission of motor transport means to use, the need to test their technical condition, as well as approval methods [2-6]. In order to further reduce the emission of harmful components of exhaust gases, it is necessary to make society and the broadly understood industry aware of the catastrophic effects of environmental pollution. Possible effects of the greenhouse effect were discussed at the end of the 20th century, and then the European...
Union at the beginning of the 21st century began to consider reducing CO2 emissions by implementing stringent emission standards for harmful exhaust emissions from motor vehicles. All restrictions have a common goal to clean the air and reduce fuel consumption. To meet the limits of permissible emission standards for individual compounds, new constructs and technologies for the construction of internal combustion engines and vehicles are emerging. It is also important to check the functioning of new components and engine components so that it meets stringent standards throughout its entire life cycle. In addition to retrofit in vehicle designs, work continues in the automotive industry that aims to introduce and disseminate the idea of energy saving. First of all, the use of new fuels, hybrid and electric drives as well as hydrogen power supply or fuel cells should be mentioned [7-9].

However, despite all restrictions, combustion-powered vehicles will continue to be produced in the coming years. The total conversion of vehicle fleets into all-electric vehicles is not possible due to the insufficient energy resources of all countries and the lack of vehicle charging infrastructure. For this reason, the author focused on possible methods of reducing fuel consumption by internal combustion vehicles.

2. Fuel consumption
Fuel consumption in vehicles can be defined in two terms:

- **hourly fuel consumption (seconds)** in the unit: kg/s determines the mass of fuel consumed by the engine per unit of time. This value is determined by weight or volume measurement;
- **specific fuel consumption** in the unit: hp/h or W/s or kW/h - is a measure of the use of the fuel supplied. It determines the mass of fuel consumed by the engine per unit of power and time.

The concept of average fuel consumption in real conditions is a general and estimated parameter. At each stage of the calculation, the personal and environmental conditions of the tests should be described, the type of route and pavement should be shown, due to the fact that too many parameters affect the change in fuel consumption. The parameters affecting the increase or reduction of fuel consumption are presented in Table No. 1. An important factor is the type of engine under consideration, whether it is naturally aspirated, turbocharged, downsizing or rightsizing. It is possible to improve the usability of the combustion engine efficiency by using e.g. thermal activation of the combustion chamber of a reciprocating internal combustion engine, which returns portions of heat in one cycle, which significantly improves performance engine work and many other solutions [10-12].

| Table 1. Parameters affecting fuel consumption |
|-----------------------------------------------|
| **Constructional factors** | **Environmental factors** | **Human factors** |
| vehicle mass and inertia of rotating parts | atmospheric conditions (air temperature, density, viscosity) | driving style of the driver |
| vehicle shape (and shape changing systems) | wind direction and speed | health |
| construction of tires | terrain shape | frame of mind |
| powertrain efficiency | road surface state and art. | |
| resistance of rotational parts (bearings, brakes, etc.) | | |

It is recognized that the driver and driving style have the greatest impact on fuel consumption. Three types of drivers are defined:

- aggressive,
- moderate or optimal,
- conservative.
Driving styles can be combined depending on the parameters that are used for testing.

3. Description of research
The test object was a 2000 cc gasoline engine with a 4-cylinder in-line 16-valve engine in a D-segment vehicle shown in the figures below.

![External characteristic](image1)

**Figure 1.** External characteristic of selected car, 2.0, 203 hp, average sfc= 190 g/kWh

![Selected engine](image2)

**Figure 2.** Selected engine, 4-cylinder in-line engine 16v [13]

The study covered five drivers aged 30-40 covering almost 13 km route from point A-B-A presented on the map below. Tests were carried out outside peak hours in city. Data was read using a mobile application, while measurements were made using a device connected to OBD (On-Board Diagnostic). The following parameters were read: time [s], engine revolution speed [r/min], torque [%], fuel consumption [cc/min], vehicle speed [km/h], the throttle opening [%]. The data sampling frequency was 1 second. Data has been converted to get power [kW] and specific fuel consumption sfc [g/kWh].

![Selected route of the car in the city of Wroclaw in Poland](image3)

**Figure 3.** Selected route of the car in the city of Wroclaw in Poland.

4. Data analysis
The data analysis consisted of the implementation of the universal engine characteristics for each driver’s passes. Points corresponding to the momentary engine load have been plotted on the charts. The number of points depended on the driving time of the driver, due to the fact that the sampling frequency was 1 second.
second. The abscissa axis of each point was the engine speed, and the ordinate - the engine torque. The points marked on the charts allowed to identify the character and driving style of each driver. The first driver's chart was determined to be focused, the dispersion of points on the characteristics was insignificant. The driving style of the driver was defined as conservative. The first driver in 98% of driving time did not exceed 2300 [r/min], engine load also in the lower torque range. This location of most points on the characteristics resulted in a high specific fuel consumption of \( sfc = 203 \) [g/kWh]. The average specific fuel consumption for a given engine is around 186 [g/kWh]. The center of the points was determined by calculating the means of the coordinates of the torque and engine speed. The average point had coordinates \( T = 48.76 \) [Nm] and \( \text{RPM} = 1612.46 \) [r/min].

![Figure 4](image-url)  
**Figure 4.** 1-st driver, engine load work map for the first driver. The coordinates of the points of torque and engine revolution speed are focused on the general characteristics. The average specific fuel consumption is \( sfc = 203 \) [g/kWh].

Analysis of the data of all drivers showed the dependence of the location of the average point determining the center of points of all registered on the fuel consumption. Analyzing the fifth driver, significant points were dispersed in Figure 5. The points had greater distances from the center of the average point, which resulted in a shift to a larger range of engine revolutions, average RPM = 2054 [r/min] and significantly lower specific fuel consumption of \( sfc = 162 \) [g/kWh].

Statistical analysis showed that the correlation coefficient of the average point coordinate dependence on specific fuel consumption exists. The confidence interval estimates at 95% that the average point will be within the specified fuel consumption range. The average point has significantly lower \( T \) and RPM coordinates in the specific fuel consumption group below \( sfc = 190 \) [g/kWh].
Figure 5. 5-th driver, engine load work map for the fifth driver. The coordinates of the points of torque and engine speed are clearly dispersed on the general characteristics. The average specific fuel consumption is \( sfc = 162 \ [g/kWh] \).

The figures below present aggregate data of average points for each driver along with their fuel consumption. The relationship between the mean point location on the engine map and fuel consumption is visible.

Figure 6. Average points of the coordinates of torque and engine revolution speed for five drivers.

Figure 7. Distribution of average points on the universal engine characteristics for five drivers.
In connection with the above, an attempt was made to forecast fuel consumption based on the location of the coordinates of the universal characteristic points and the average point. Average points and specific fuel consumption were determined for each driver after 10 minutes and 15 minutes by car. This forecasting method turned out to be a simple tool for quickly determining whether a given driver after a few minutes of driving tends to exceed the average fuel consumption or not. The relationship between the location of the average fuel consumption point has been demonstrated for each driver. The presented results are presented below in Table 2.

**Table 2.** Specific fuel consumption for all drivers after 10 minutes by car, after 15 minutes and the average of the entire trip. The average coordinates of the torque points and engine speed are shown in the table.

| Driver | Average T after 10 min [Nm] | Average RPM after 10 min [r/min] | Average T | Average RPM | Specific fuel consumption sfc after 10 min [g/kWh] | Specific fuel consumption sfc after 15 min [g/kWh] | Average specific fuel consumption sfc [g/kWh] |
|--------|-----------------------------|---------------------------------|-----------|-------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| 1      | 55.88                       | 1618.45                         | 48.76     | 1612.46     | 217.43                                        | 208.83                                        | 202.91                                        |
| 2      | 37.44                       | 1357.42                         | 36.26     | 1402.14     | 204.82                                        | 209.84                                        | 206.85                                        |
| 3      | 56.65                       | 1970.32                         | 49.66     | 1759.82     | 197.62                                        | 189.47                                        | 187.98                                        |
| 4      | 38.17                       | 1899.09                         | 38.47     | 1803.36     | 190.86                                        | 176.61                                        | 176.96                                        |
| 5      | 50.94                       | 2197.23                         | 47.81     | 2054.18     | 171.42                                        | 160.31                                        | 161.61                                        |

5. Conclusion

- Based on the universal characteristics, it is possible to determine the driving styles of each driver after placing the engine load points on the charts.
- These graphs show the dispersion of points - dynamic driving or their focus - conservative driving style.
- Statistical analysis showed that there is a correlation coefficient between the mean of the point coordinate and the specific fuel consumption. The confidence interval estimates at 95% that the average point will be within the specified fuel consumption range. The average point has significantly lower T and RPM coordinates in a given fuel consumption group below $sfc = 190$ [g/kWh].
- The method of forecasting average specific fuel consumption showed which driver will almost certainly exceed fuel consumption after a few minutes of driving the vehicle.
- This method also shows that every driver drives in different speed ranges, which shows the need to adapt a person to a given vehicle and engine in the future.
- One engine is installed in millions of cars and used by different drivers, which reduces the chances of matching the driver's driving style to a given vehicle. The method can be used to convert the engine map for a specific driver.
- Autonomous vehicles, thanks to neural networks, could use good driver points distribution maps to learn the network of correct and economical driver driving styles.

Acknowledgments

Thanks to the Authorities of Wrocław University of Science and Technology for construction of the GEO-3EM Research Center, in which it was possible to carry out all kinds of experiment.
References

[1] International Organization of Motor Vehicle Manufacturers Production statistic Available: http://www.oica.net/category/production-statistics/2019-statistics/ Accessed on 10.07.2020

[2] Commission of the European Communities. Proposal for a Regulation of the European Parliament and of the Council. Setting emission performance standards for new light commercial vehicles as part of the Community’s integrated approach to reduce CO$_2$ emissions from light-duty vehicles COM (2009) 593 final 2009/0173(COD)

[3] Merkisz J, Pielecha J, Radzimirski S 2012 Emisja zanieczyszczeń motoryzacyjnych w świetle nowych przepisów Unii Europejskiej (WKŁ, Warszawa) p 220 (In Polish)

[4] Merkisz J and Radzimirski S 2009 Stan obecny i przewidywane zmiany w europejskich przepisach o emisji zanieczyszczaczy z samochodów ciężarowych i autobusów Transport Samochodowy (Wydawnictwo ITS) (In Polish)

[5] Worldwide Emissions Standards. Passenger Cars and Light Duty Vehicles Delphi 2012/2013 (www.delphi.com)

[6] Katrašnik T 2007 Hybridization of powertrain and downsizing of IC engine — A way to reduce fuel consumption and pollutant emissions — Part 1 Energy Conversion and Management (Elsevier) 48(5) pp 1411-23

[7] He Y, Chowdhury M, Pisu P, Ma Y 2012 An energy optimization strategy for power-split drivetrain plug-in hybrid electric vehicles Transportation Research Part C: Emerging Technologies (Elsevier) 22 pp 29-41

[8] Chen H et al. 2015 Modeling temporal variations in global residential energy consumption and pollutant emissions Applied Energy (Elsevier) 148 pp 820-29

[9] Chen PY, Chen ST, Hsu CS, Chen CC 2016 Modeling the global relationships among economic growth, energy consumption and CO$_2$ emissions Renewable and Sustainable Energy Reviews (Elsevier) 65 pp 420-431

[10] Sroka Z and Dziedzioch D Mechanical load of piston applied in downsized engine 2015 Archives of Civil and Mechanical Engineering (Elsevier) 15(3) pp 663-7

[11] Sroka Z 2013 Wybrane zagadnienia teorii tłokowych silników spalinowych w aspekcie zmian objętości skokowej (Oficyna Wydawnicza Politechniki Wrocławskiej) (In Polish)

[12] Sroka Z and Sadlak Z 2018 Thermal activation of the combustion chamber of a reciprocating internal combustion engine Journal of Thermal Science 27 pp 449-55

[13] https://www.netcarshow.com/volvo/2011-s60/ Accessed on 10.07.2020