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Driving style analysis based on information from the vehicle's OBD system

The purpose of this study was to analyse the possibility of using information from the On Board Diagnostics (OBD) system of the vehicle to determine the characteristics of the driver's driving style. Available data from the OBD system were considered and the most useful ones were selected for further investigation. Selected zero-dimensional characteristics of vehicle velocity as well as characteristics of relative position of the accelerator pedal were proposed as criteria for the assessment of driving style. The tests were carried out in conditions of real road traffic using a passenger car with a spark-ignition engine. The car was equipped with a device for recording signals from the OBD system. The tests included two drivers traveling on routes in the urban and rural areas. The obtained results were used to analyse the driving style of both drivers separately in the considered traffic conditions. On this basis, conclusions on the suitability of information from the OBD system for the assessment of the driver's driving style were formulated.

Key words: *driving style, driving pattern, OBD, On Board Diagnostics, road tests*

1. Introduction

Driving style refers to the way a driver chooses to drive a vehicle. Driving style differs across individuals or between groups of individuals. It tends to be habitual and relatively permanent, including both automatized skills and more consciously controlled behavior, but at the same time it is determined by the actual driving conditions which create opportunities or constraints for driver's actions [13].

The study on driving style is of a great importance in various fields related to road transport. It is useful for the research on road safety, plays an important role in the construction of road infrastructure and can be applied to the optimization of driver assistance systems, so they adapt to the particular driver. In the case of vehicles with combustion engines, the most important is the influence of the driving style on fuel consumption and emission of pollutants.

Several studies have proved the relationship between driving style, vehicle fuel or energy consumption and pollutant emission [7–9, 12]. According to Gonder et al. [9], efficient driving behavior results in the reduction of fuel consumption by 5% to 10%, compared to moderate driving style, and up to 20%, compared to aggressive driving style. This is confirmed by the findings of Fonseca et al. [7], whose conclusions are that eco-driving contributes to 14% decrease in fuel consumption and carbon dioxide emission, while aggressive driving – 40% increase. The effect of the driving style is not so clear in relation to the emission of toxic substances. The aforementioned study [7] revealed that although aggressive driving brings an increase in nitrogen oxides emission by more than 40%, carbon dioxide and hydrocarbon emission show different trends, in general being increased for eco-driving. Similar conclusions have been drawn by investigators conducting vehicle tests in real driving conditions, with the use of mobile exhaust gas analyzers [8, 12].

The analysis of driving style in order to examine its impact on pollutant emission and fuel consumption requires adoption of appropriate assessment criteria. Most of previous research works focus on the statistical metrics of driving data obtain in road tests, e.g. average value, maximum value, median, standard deviation of vehicle velocity, acceleration, brake pressure and throttle position [7, 9, 15, 16]. In some papers, e.g. [1, 3, 10, 11], it was proposed to use the On Board Diagnostics (OBD) system of the vehicle to obtain necessary driving data.

Current study follows this direction, aiming at investigation whether and what signals acquired from the OBD system may be relevant for characterizing a driving style. It includes some descriptive statistical analysis of the results of experiment, in which two drivers were compared, operating the same vehicle in urban and extra-urban traffic conditions.

2. OBD parameters relevant to driving style

The OBD system, which was originally intended by its creators to facilitate vehicle monitoring and diagnostics, gives access to various information from the Engine Control Unit (ECU), sensors integrated with parts of the vehicle chassis, vehicle body and accessory devices. A complete list of standard parameters available from the current version of the system, i.e. OBD-II/EOBD, through the connection port called Data Link Connector (DLC) is defined in SAE J1979. Vehicle manufacturers can also implement their own parameters that provide extended information. Some of these additional parameters would be highly desirable to assess the impact of driving style on fuel consumption and pollutant emissions. However, most manufacturers are unwilling to reveal additional data.

By assumption, the investigation presented in this paper was limited to the standard parameters that can be obtained from the OBD system using widely available diagnostic devices. With a reference to previous research works [1, 3, 10, 11, 15] and taking into account the abovementioned limitations, the following parameters were selected as relevant to driving style:
– vehicle velocity,
– engine rotational speed,
– relative accelerator pedal position,
– relative throttle valve position,
– relative engine torque,
– intake manifold pressure.

Among them, the velocity of the vehicle and the relative position of the accelerator pedal were found to be particularly useful and effective in practice for assessing the impact of driving style on vehicle fuel consumption and pollutant emission. Therefore further investigation consisted in the analysis of OBD signals corresponding to these two parameters, recorded during vehicle road tests.

3. Experimental procedures

3.1. General approach

The empirical part of the research took place under real traffic conditions. The vehicle was driven by two drivers, marked A and B. The drivers were aware of the tests, but instructed not to adapt their driving style due to participation in the experiment. The tests were conducted in urban traffic conditions (Warsaw) and in extra-urban traffic conditions (Mazowieckie Voivodeship). While driving a vehicle, signals from the OBD system were recorded.

3.2. Test vehicle

The vehicle used for road tests was Nissan Juke, presented in Fig. 1. Its technical specifications are given in Table 1.

Fig. 1. Vehicle subject to road tests

Table 1. Technical specifications of the vehicle tested

Parameter	Data
Manufacturer	Nissan
Model	Juke
Manufacturing date	2011
Body type	5-door crossover
Number of seats	5
Curb weight	1172 kg
Drive axle	Front
Engine type	Spark-ignition
Fuel	Gasoline
Cylinder number and configuration	4, in-line
Engine displacement	1598 cm^3
Gearbox type	Manual, 5 forward gears, 1 reverse gear
Pollutant emission standard	Euro 5
Maximum useful power of the engine	86 kW at 6000 rpm
Maximum engine torque	158 N·m at 4000 rpm
Fuel supply system	Multipoint, indirect injection
Maximum velocity	178 km/h
Acceleration time from stand to 100 km/h	11 s

3.3. Apparatus

Data from vehicle's DLC port was recorded while driving using Texa OBDLog. It is the on-board logging device, which supports all OBD-II/EOBD compliant vehicles, and requires PC with software interface to collect data saved in its internal memory during vehicle testing. The technical specification of Texa OBDLog is presented in Table 2.

Table 2. Technical specifications of the apparatus [14]

Parameter	Data
Manufacturer	TEXA
Name	OBDLog
Vehicle interface	DLC port
OBD protocols supported	All included in J1850-41.6, J1850-10.4, ISO9141-2 K/L, CAN (ISO 11898)
Power supply	12 V (DLC), 5 V (USB)
Processor	ARM 32-bit Cortex-M3
Internal memory	2048 kB
Sampling frequency	1 Hz
Maximum working time	90 h
Dimensions	23 mm × 45.5 mm × 28.2 mm
Weight	19.5 g
PC interface	USB 2.0 cable
Software	OBD Log SW Suite

3.4. Data processing

As a result of road tests, 494 samples of driving data from individual trips of both drivers were obtained. Driver A made 152 trips, while driver B – 352. The data was further processed using MS Office Excel. In the first step, a minimum time limit of 180 s was set, which resulted in the rejection of 37 samples. The remaining samples were assigned to one of the three categories of vehicle traffic: urban, extra-urban and road congestion. The criteria were the average vehicle velocity and an arbitrary assessment of the driving conditions. In extra-urban traffic, the average vehicle velocity was larger than 45 km/h, in urban traffic it was in the range (10 ÷ 45) km/h, and in road congestion – less than 10 km/h. The number of samples in each category was as follows (for driver A and B, respectively): 98 and 243 in urban traffic, 42 and 63 in extra-urban traffic, 1 and 10 in road congestion traffic. For further analysis, samples from road congestion category were rejected because driving in these conditions is largely dependent on external factors, such as road capacity during peak traffic hours, thus it is difficult to conclude about driving style on this basis.

Due to the low sampling frequency (1 Hz), it was necessary to apply the filtering of recorded signals. In the case of the velocity signal, a two-stage moving average from three measuring points was used, while for acceleration – a one-stage moving average from three measuring points. The acceleration itself was calculated based on velocity value.

In the next step, the values of selected zero-dimensional characteristics of vehicle velocity as well as characteristics of relative position of the accelerator pedal were calculated (Table 3). They were examined for their effectiveness as criteria for the assessment of driving style.

4. Results and discussion

Normalized histograms of the values of characteristics listed in Table 3 are presented in Figures 2–31. They allow comparison of the results obtained for drivers A and B.

Table 3. Zero-dimensional characteristics considered as criteria for the assessment of driving style

Type	Name	Symbol	Unit
Related to vehicle velocity	Average velocity	v_{AV}	km/h
	Average velocity excluding stops	v_{DAV}	km/h
	Maximum velocity	v_{MAX}	km/h
	Average acceleration	a^{+}_{AV}	m/s^2
	Maximum acceleration	a^{+}_{MAX}	m/s^2
	Average deceleration	a^{-}_{AV}	m/s^2
	Maximum deceleration	a^{-}_{MAX}	m/s^2
	The average value of the absolute value of the velocity and acceleration product	$\lvert v \cdot a \rvert_{AV}$	m^2/s^3
	The average value of the velocity and acceleration product	$v \cdot a^{+}_{AV}$	m^2/s^3
	Relative positive acceleration	RPA	m/s^2
Related to the position of accelerator pedal	Average relative position of accelerator pedal	AP_{AV}	%
	Average relative position of accelerator pedal, excluding vehicle stops	AP_{DAV}	%
	Average relative position of accelerator pedal, excluding zero position	AP_{0AV}	%
	Average relative position of accelerator pedal, excluding stops and zero position	AP_{D0AV}	%
	Average value of the derivative of the relative position of accelerator pedal	AP_{DVAV}	%

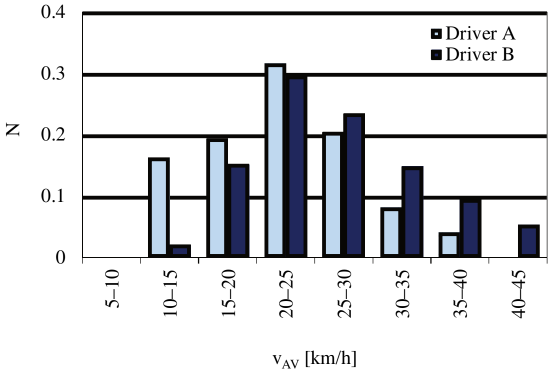

Fig. 2. Average velocity of the vehicle in urban driving conditions

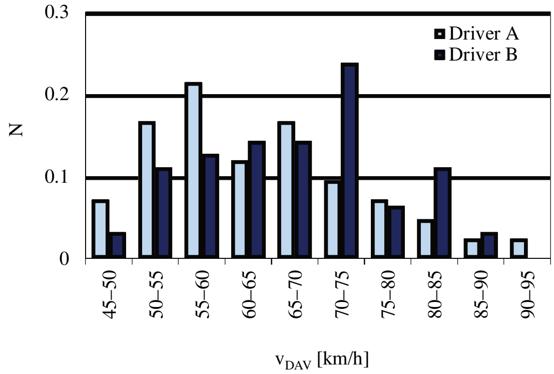

Fig. 5. Average velocity of the vehicle excluding stops in extra-urban driving conditions

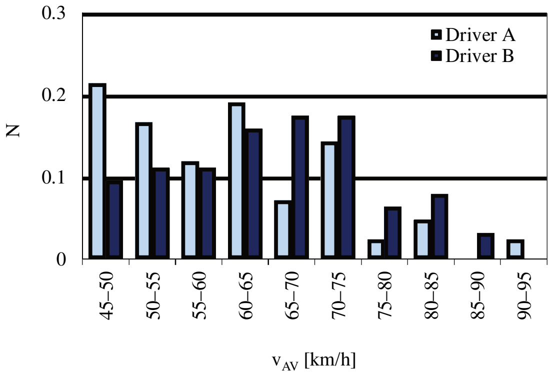

Fig. 3. Average velocity of the vehicle in extra-urban driving conditions

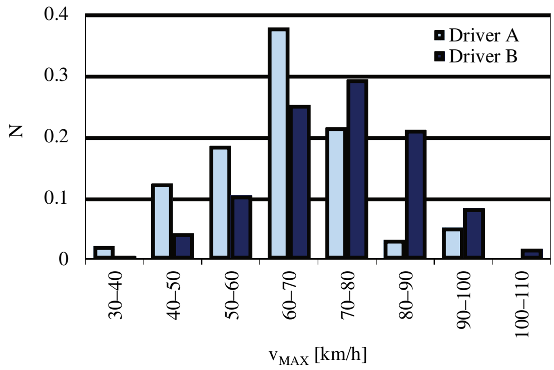

Fig. 6. Maximum velocity of the vehicle in urban driving conditions

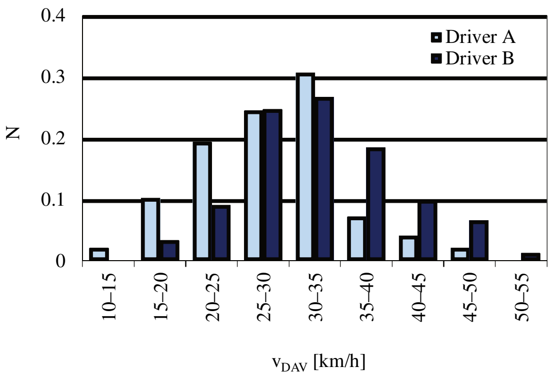

Fig. 4. Average velocity of the vehicle excluding stops in urban driving conditions

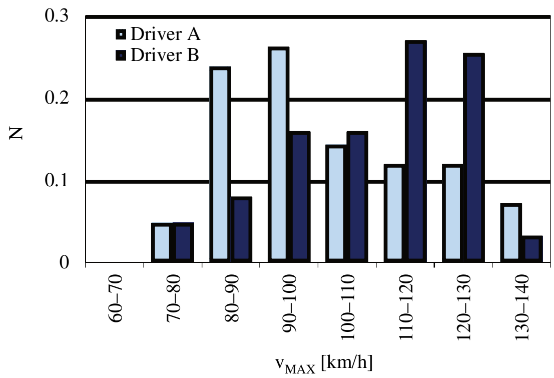

Fig. 7. Maximum velocity of the vehicle in extra-urban driving conditions

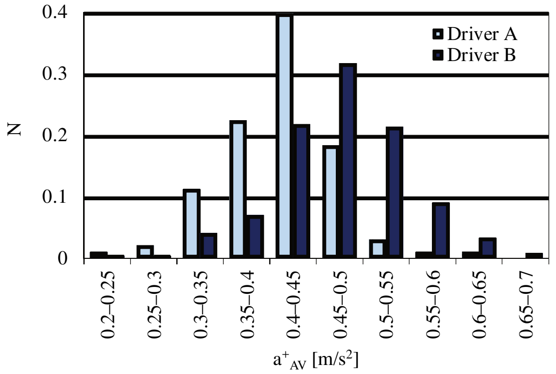

Fig. 8. Average acceleration of the vehicle in urban driving conditions

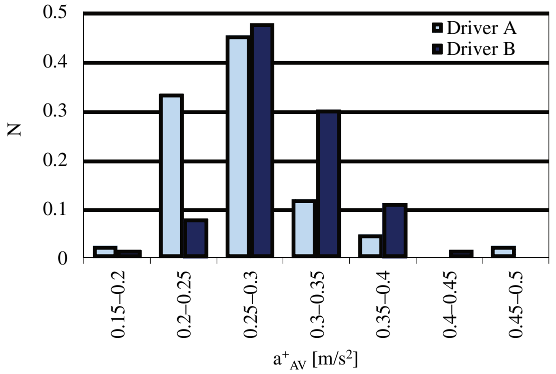

Fig. 9. Average acceleration of the vehicle in extra-urban driving conditions

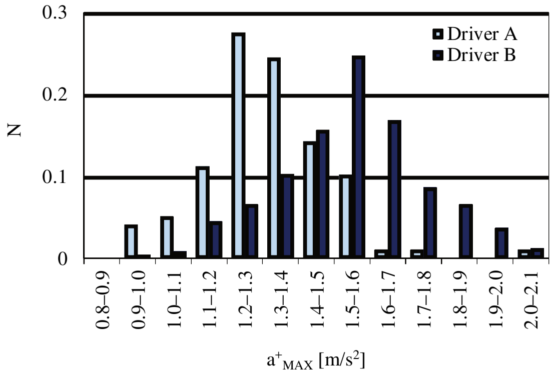

Fig. 10. Maximum acceleration of the vehicle in urban driving conditions

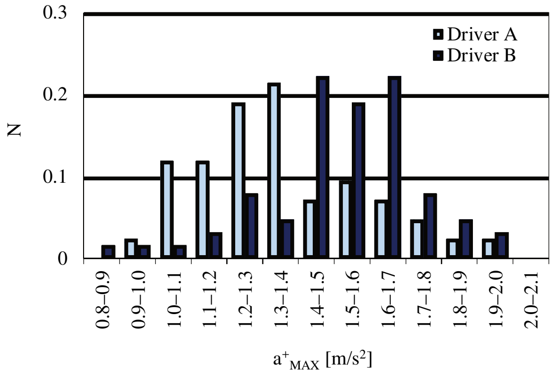

Fig. 11. Maximum acceleration of the vehicle in extra-urban driving conditions

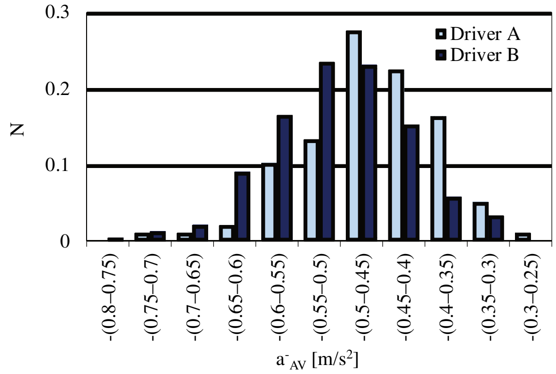

Fig. 12. Average deceleration of the vehicle in urban driving conditions

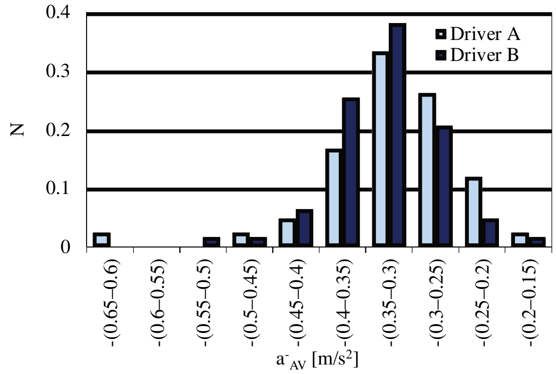

Fig. 13. Average deceleration of the vehicle in extra-urban driving conditions

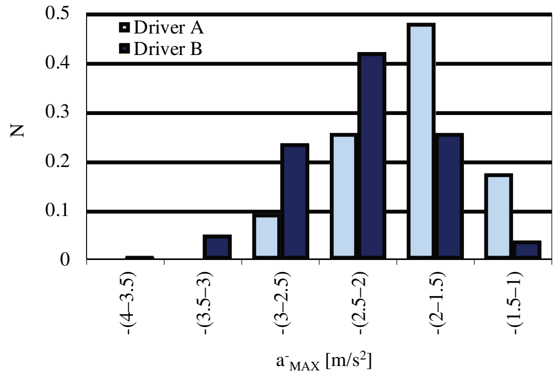

Fig. 14. Maximum deceleration of the vehicle in urban driving conditions

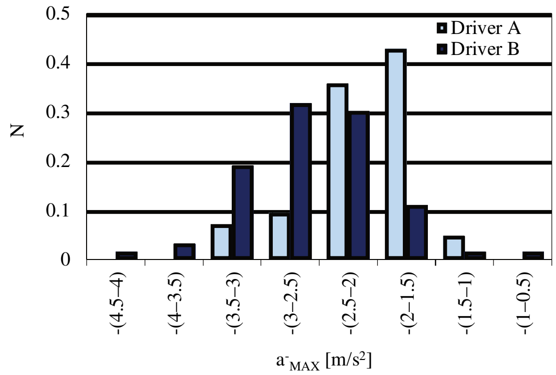

Fig. 15. Maximum deceleration of the vehicle in extra-urban driving conditions

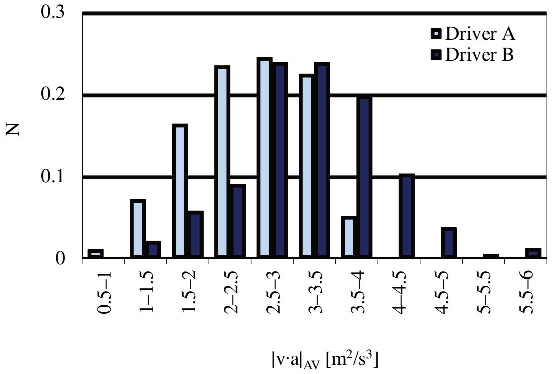

Fig. 16. The average value of the absolute value of the velocity and acceleration product in urban driving conditions

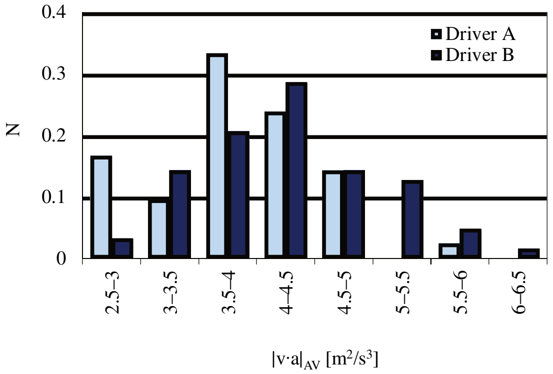

Fig. 17. The average value of the absolute value of the velocity and acceleration product in extra-urban driving conditions

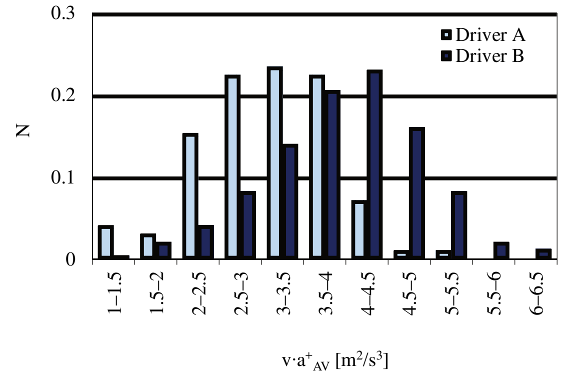

Fig. 18. The average value of the velocity and acceleration product in urban driving conditions

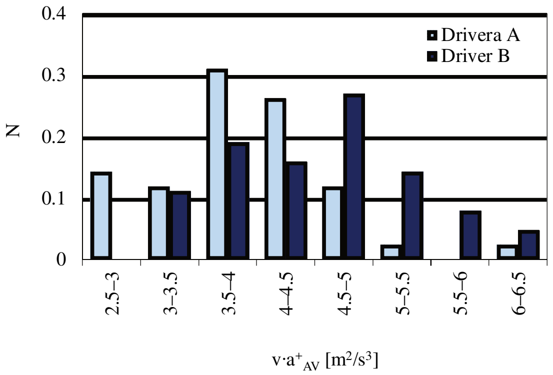

Fig. 19. The average value of the velocity and acceleration product in extra-urban driving conditions

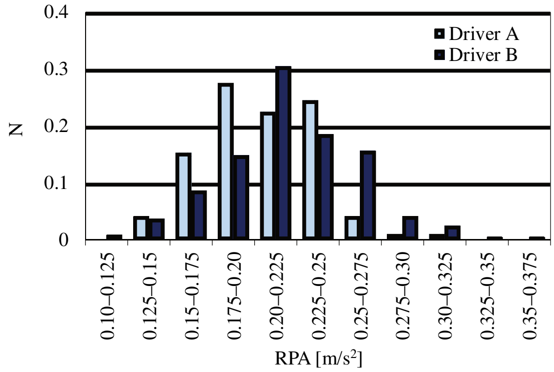

Fig. 20. Relative positive acceleration of the vehicle in urban driving conditions

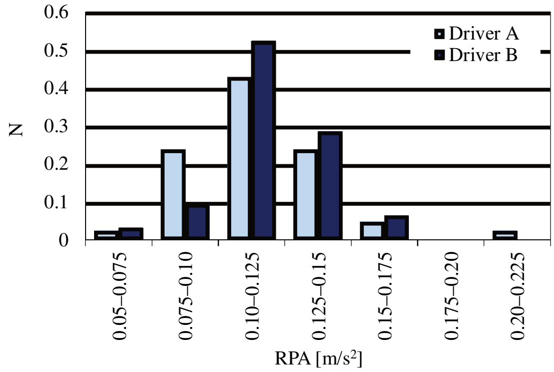

Fig. 21. Relative positive acceleration of the vehicle in extra-urban driving conditions

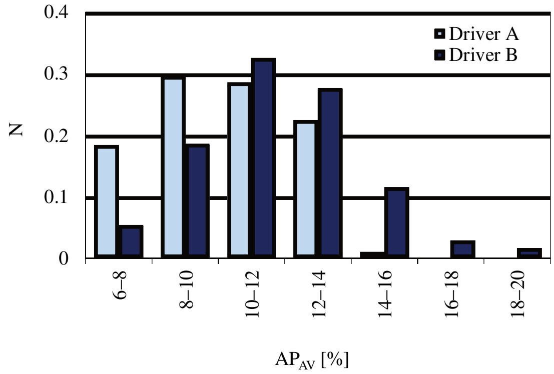

Fig. 22. Average relative position of accelerator pedal in urban driving conditions

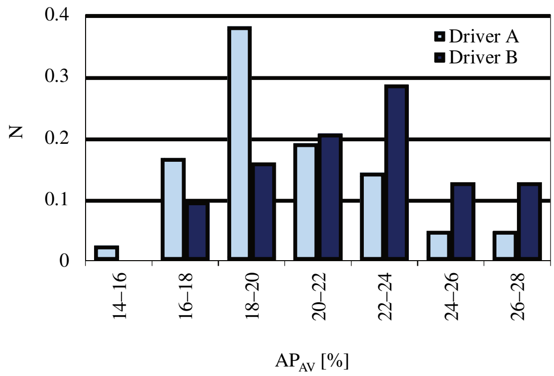

Fig. 23. Average relative position of accelerator pedal in extra-urban driving conditions

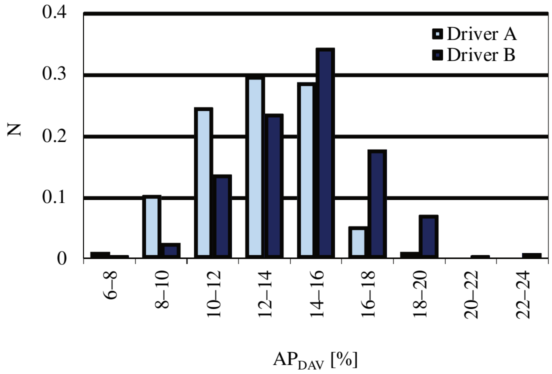

Fig. 24. Average relative position of accelerator pedal, excluding vehicle stops, in urban driving conditions

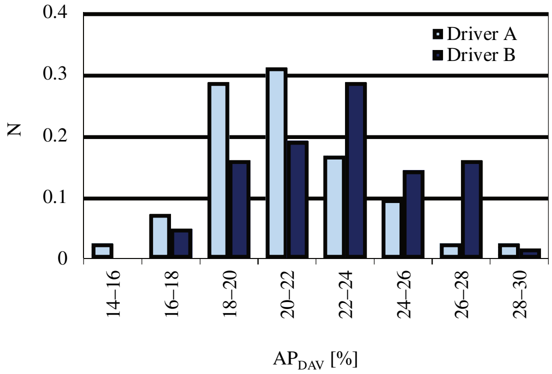

Fig. 25. Average relative position of accelerator pedal, excluding vehicle stops, in extra-urban driving conditions

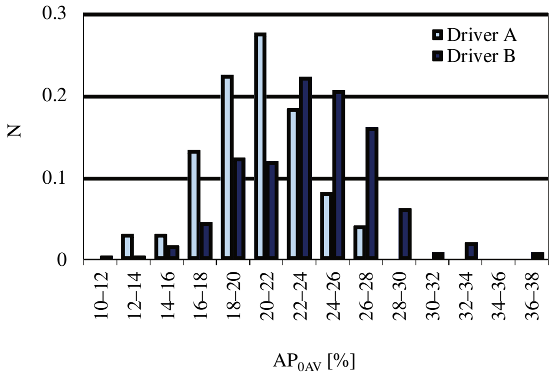

Fig. 26. Average relative position of accelerator pedal, excluding zero position, in urban driving conditions

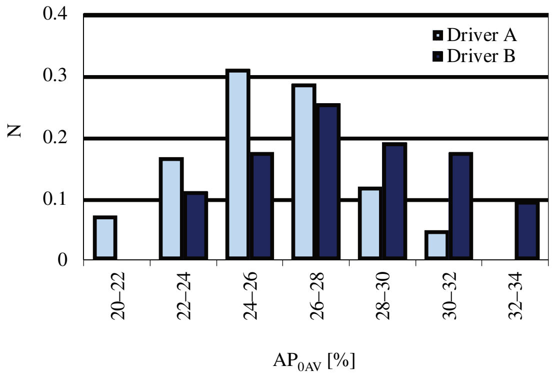

Fig. 27. Average relative position of accelerator pedal, excluding zero position, in extra-urban driving conditions

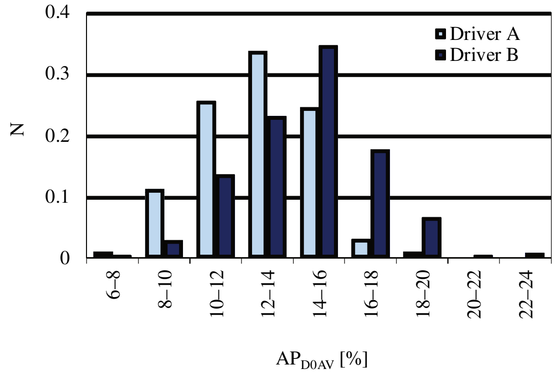

Fig. 28. Average relative position of accelerator pedal, excluding vehicle stops and zero position, in urban driving conditions

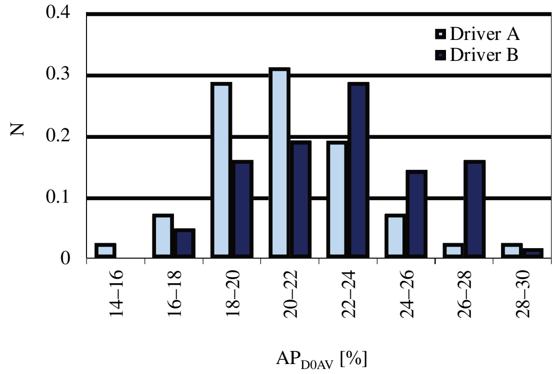

Fig. 29. Average relative position of accelerator pedal, excluding vehicle stops and zero position, in extra-urban driving conditions

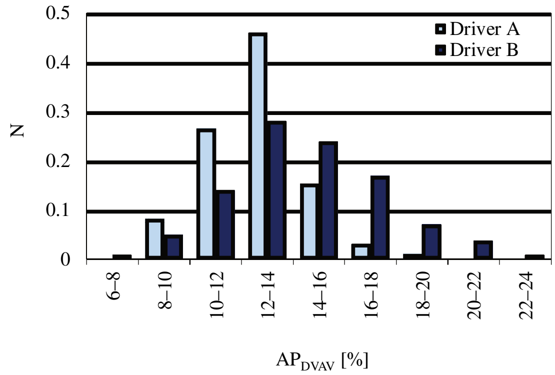

Fig. 30. Average value of the derivative of the relative position of accelerator pedal in urban driving conditions

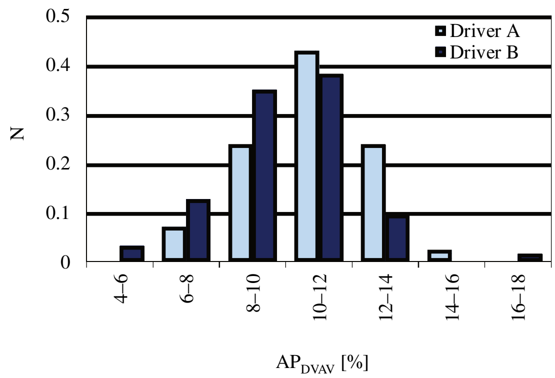

Fig. 31. Average value of the derivative of the relative position of accelerator pedal in extra-urban driving conditions

A detailed analysis of the histograms shown in Figures 2–31 reveals some trends in the obtained results.

In general, most histograms have a regular shape close to normal distribution. The exception are:

– average velocity of the vehicle, both including and excluding stops, in extra-urban driving conditions (Figures 3 and 5) – multimodal distribution;
– maximum velocity of the vehicle in extra-urban driving conditions (Fig. 7) – asymmetric distribution, for driver A moved towards moderate velocity values, and for driver B towards large velocity values;
– maximum deceleration of the vehicle in both urban and extra-urban driving conditions (Figs 14 and 15) – for driver A moved towards lower absolute values;
– the average value of the velocity and acceleration product in both urban and extra-urban driving conditions (Figs 18 and 19) – distribution that can be classified between normal and bimodal, especially for driver A.

The variability of the values of the designated characteristics is quite large, however, in the majority of cases, one clearly dominant range of values can be indicated.

Due to the purpose of this study, it is important to notice that the analysis of the histograms of the values of some characteristics allows the drivers to be distinguished. These include, above all:

– maximum velocity of the vehicle in extra-urban driving conditions (Fig. 7), which suggests that driver B has a clear tendency to drive with larger velocity than driver A;
– maximum acceleration of the vehicle in both urban and extra-urban driving conditions (Figs 10 and 11) – again, driver B has a tendency for more aggressive driving, with greater maximum acceleration;
– the average value of the velocity and acceleration product in both urban and extra-urban driving conditions (Figs 18 and 19) – the least clear difference between drivers, but still noticeable.

The above characteristics can be treated as potentially the best criteria to assess driving style. In fact they are often used to evaluate the dynamic properties vehicle velocity. The average value of absolute value of product of velocity and acceleration can be interpreted as a measure of engine power output per unit mass of the vehicle [2, 4]. The average value of the product of velocity and acceleration also takes into account engine operating conditions with a negative torque.

Characteristics related to the position of the accelerator pedal can also be used to analyze driving style and distinguish drivers. However, they are not as effective as the characteristics related to the velocity and acceleration of the vehicle. In this case, best ones seem to be:

– average relative position of accelerator pedal, especially in extra-urban driving conditions (Fig. 23), which is obviously due to the preference for driving with larger velocity by driver B than driver A;
– average relative position of accelerator pedal excluding zero position (regardless of taking into account vehicle stops), especially in urban driving conditions (Fig. 26), because in extra-urban conditions, when driving at a larger average velocity than in urban conditions, the accelerator pedal position is rarely zero.

The obtained results can be compared with results published previously by other researchers. In principle such a comparison is subject to a certain discrepancy, due to the influence of many factors on the driving style of the driver. In particular, not only the personal factors of the vehicle driver are important, but also vehicle performance, driving conditions, including weather, traffic, road infrastructure, etc. It is therefore difficult to find the results of tests that would have the same scope to current results. However, selected aspects of similar research may be compared.

Paper by Ericsson [6] presents an analysis of data collected in Sweden from five vehicles that were driven by 29 randomly chosen families for two weeks each. Comparing to present investigation, similar distribution of vehicle velocity, acceleration and deceleration can be observed. In Ericsson tests, vehicle velocity most often had a value between 50 km/h and 70 km/h when driven along two arterial roads, which corresponds to the results of current tests for extra-urban driving conditions (Fig. 3). It is also possible to indicate similarity in the case of urban driving (Fig. 2), but with less convergence, as the study of Ericsson took into account speed limits on specific roads, which affected the velocity achieved by the drivers. In the results of Ericsson's research, the most common acceleration and deceleration values were in the ranges (0–0.5) m/s^2 and (–0.5–0) m/s^2, respectively, both for urban and non-urban driving. The same value ranges were found in current study (Figs 8–13), except that under urban conditions driver B accelerated and braked more intensely.

An interesting comparison of average velocity of a vehicle is possible with a paper by Chłopek et al. [4], due to similar driving conditions. In that experimental work over 70 test drives were carried out by a single driver within the area of Mazowieckie and Łódzkie Voivodships, with the urban driving conditions tested in Warsaw. During the tests, driving parameters were recorded from the vehicle OBD system and in parallel from the device equipped with the GPS module. The following traffic conditions were distinguished in results: urban traffic congestions, urban traffic without congestions, extra-urban traffic, high-speed traffic. Under these conditions, the average velocity of the vehicle was: 8.6 km/h, 38.8 km/h, 75.8 km/h, and 123.1 km/h, respectively. In the current paper, only two categories of road conditions were distinguished: urban and extra-urban driving, with the following average vehicle velocity (respectively for the A/B driver): 22.4 km/h/ 26.7 km/h, 61.0 km/h/65.6 km/h.

When interpreting the results presented in this paper, the limitations of the study should be kept in mind. First of all, for the assessment of driving style, identical driving conditions should be created for both drivers, which of course is not possible during real traffic. In the road tests under consideration, drivers reacted to various road situations, used different, randomly selected routes, with different speed limits, and operated the vehicle in different weather and traffic conditions. On the other hand, the randomness of driving conditions has the advantage that, with a large number of samples taken, it reduces the influence of the test methods on the obtained results. Another limitation is the small range of recorded signals from the OBD system and low sampling frequency. It would be beneficial to conduct similar tests using other signals that can be extracted from the CAN bus. This can be a future direction of development of current work.

5. Conclusions

To sum up the effects of this study, the following conclusions can be drawn:

- Information derived from the OBD vehicle system can be used to characterize and evaluate the driving style.
- The most important signals that are easily accessible from the OBD system and useful for assessing the driving style, are: vehicle velocity, engine rotational speed, relative accelerator pedal position, relative throttle valve position, relative engine torque and intake manifold pressure.
- Among the analyzed zero-dimensional characteristics, it was found that the most effective to assess the driving style are: maximum velocity of the vehicle (in extra-urban driving conditions), maximum acceleration, the average value of the velocity and acceleration product and finally average relative position of accelerator pedal excluding zero position.
- The use of appropriate criteria, based on the analysis of information from the OBD system of the vehicle, allows to distinguish the driving style of two drivers of the same vehicle.
- Driving style is generally easier to evaluate in urban traffic, which is characterized by greater dynamics than extra-urban traffic, although there are exceptions to this rule (e.g. the aforementioned application of maximum vehicle velocity).

Nomenclature

a^+_{AV} Average acceleration
a^-_{AV} Average deceleration
a^+_{MAX} Maximum acceleration
a^-_{MAX} Maximum deceleration
AP_{0AV} Average relative position of accelerator pedal, excluding zero position
AP_{AV} Average relative position of accelerator pedal
AP_{D0AV} Average relative position of accelerator pedal, excluding vehicle stop and zero position
AP_{DAV} Average relative position of accelerator pedal, excluding vehicle stops
AP_{DVAV} Average value of the derivative of the relative position of accelerator pedal
DLC Data Link Connector
ECU Engine Control Unit
OBD On Board Diagnostics
RPA Relative positive acceleration
v_{AV} Average velocity
v_{DAV} Average velocity excluding stops
v_{MAX} Maximum velocity
$v \cdot a^+_{AV}$ The average value of the velocity and acceleration product
$|v \cdot a|_{AV}$ The average value of the absolute value of the velocity and acceleration product

Bibliography

[1] ANDRIEU, C., PIERRE, G. Using statistical models to characterize eco-driving style with an aggregated indicator. *Proceedings of the IEEE Intelligent Vehicle Symposium (IV 2012)*. 2012, 63-68.

[2] ANDRYCH-ZALEWSKA, M., CHŁOPEK, Z., MERKISZ, J., PIELECHA, J. Evaluation of the test drive cycle conditions impact on exhaust emissions from an internal combustion engine. *Combustion Engines*. 2018, **175**(4), 3-9.

[3] BEUSEN, B., BROEKX, S., DENYS, T. et al. Using on-board logging devices to study the longer-term impact of an eco-driving course. *Transportation research part D: Transport and Environment*. 2009, **14**(7), 514-520.

[4] CHŁOPEK, Z., BIEDRZYCKI, J., LASOCKI, J., WÓJCIK, P. Investigation of the motion of motor vehicles in Polish Conditions. *The Archives of Automotive Engineering – Archiwum Motoryzacji*. 2013, **60**(2), 3-20.

[5] CHŁOPEK, Z., LASOCKI, J., WÓJCIK, P., BADYDA, A.J. Experimental investigation and comparison of energy consumption of electric and conventional vehicles due to the driving pattern. *International Journal of Green Energy*. 2018, **15**(13), 773-779, DOI:10.1080/15435075.2018.1529571

[6] ERICSSON, E. Driving pattern in urban areas – descriptive analysis and initial prediction model.. *Traffic Planning*. Bulletin 185. Lund Institute of Technology, Lund 2000.

[7] FONSECA, N., CASANOVA, J., ESPINOSA F. Influence of driving style on fuel consumption and emissions in diesel-powered passenger car. *Proceedings 18th International Symposium Transport and Air Pollution*. Dübendorf 2010.

[8] FUĆ, P., SIEDLECKI, M., SOKOLNICKA, B., SZYMLET, N. The influence of the driving style on the exhaust emission from a passenger car with a Euro 5 diesel engine. *Journal of Mechanical and Transport Engineering*. 2017, **69**(4), 5-19.

[9] GONDER, J., EARLEYWINE, M., SPARKS, W. Final report on the fuel saving effectiveness of various driver feedback approaches. *Report NREL/MP-5400-50836*. National Renewable Energy Laboratory, Golden 2011.

[10] HADGU, R. Statistical analysis of driver behaviour and eco-driving model based on CAN bus data. Master thesis report. School of Information Science, Computer and Electrical Engineering, *Halmstad University*. 2015.

[11] LEE, M.L., PARK, Y.K., JUNG, K.K., YOO, J.J. Estimation of fuel consumption using in-vehicle parameters. *International journal of u- and e-service, science and technology*. 2011, **4**(4), 37-46.

[12] MERKISZ, J., PIELECHA, J., PIELECHA, I. Influence of behaviour driver on vehicle ecology. *Logistyka*. 2010, **2**, 1911-1920.

[13] SAGBERG, F., SELPI, PICCININI, G.F., J. ENGSTRÖM, J. A review of research on driving styles and road safety. Human Factors, *The Journal of the Human Factors and Ergonomics Society*. 2015, **57**(7), 1248-1275, DOI:10.1177/0018720815591313

[14] TEXA. Promotional materials, www.texa.com.

[15] VAITKUS, V., LENGVENIS, P., ZYLIUS, G. Driving style classification using long-term accelerometer information.

Proceedings of 19th International Conference on Methods and Models in Automation and Robotics (MMAR). IEEE, 2014, 641-644. DOI: 10.1109/MMAR.2014.6957429

[16] WANG, W., XI, J., CHONG, A., LI, L. Driving style classification using a semi-supervised support vector machine. *IEEE Transactions on Human-Machine Systems*, 2017, **47**(5), 1-11. DOI:10.1109/THMS.2017.2736948

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