

# INVESTIGATION OF THE MOTION OF MOTOR VEHICLES IN POLISH CONDITIONS

ZDZISŁAW CHŁOPEK<sup>1</sup>, JACEK BIEDRZYCKI<sup>2</sup>, JAKUB LASOCKI<sup>3</sup>, PIOTR WÓJCIK<sup>4</sup>

Warsaw University of Technology, Automotive Industry Institute (PIMOT)

## Summary

In dynamic conditions, the functional properties of internal combustion (IC) engines in steady thermal state depend on time histories of the quantities that characterize the intensity of engine operation. For the automotive engine, the most important process that determines the engine operation is the vehicle speed process. To evaluate the impact of the conditions of operation of motor vehicles on the properties of their IC engines, the investigation of passenger car speed processes in the conditions of typical vehicle use was taken up. The recorded speed vs. time curves were treated as realizations of stochastic processes and basic characteristics of the processes were determined. The vehicle motion was modelled as motion in the street congestion, urban, extra-urban, and high-speed traffic conditions. Based on empirical tests and analyses carried out, sets of passenger car speed vs. time curves have been proposed as realizations of model processes representing the vehicle motion in the conditions under consideration.

**Keywords:** motor vehicles, driving tests

## 1. Introduction

In dynamic conditions, the functional properties of internal combustion (IC) engines depend on the engine operating state defined by the quantities that characterize the intensity of engine operation and the thermal state of the engine [4]. The thermal state of an IC engine is defined by the set of temperatures of engine parts and operating fluids (engine oil and coolant, in most cases) [4]. A measure of the intensity of engine operation is the rotational speed of the engine crankshaft and a quantity characterizing the engine load, i.e. torque or mean effective pressure [4]. Hence, an assumption may be made that the functional properties of an IC engine in steady thermal state are determined by the torque and rotational speed. Naturally, these dependencies in dynamic conditions are of operational type instead of being functions with numerical values [3–5].

<sup>1</sup> Warsaw University of Technology, Institute of Vehicles, 84 Narbutta Street, 02-524 Warsaw, Poland, e-mail: zchlopek@simr.pw.edu.pl, ph.+48 22 234 85 59

<sup>2</sup> Automotive Industry Institute, Department of Environmental Protection and Use of Natural Energy, 55 Jagiellonska Street, 03-301 Warsaw, Poland, e-mail: j.biedrzycki@pimot.org.pl, ph. +48 22 777 71 91

<sup>3</sup> Automotive Industry Institute, Department of Environmental Protection and Use of Natural Energy, 55 Jagiellonska Street, 03-301 Warsaw, Poland, e-mail: j.lasocki@pimot.org.pl, ph. +48 22 777 71 92

<sup>4</sup> Automotive Industry Institute, Department of Environmental Protection and Use of Natural Energy, 55 Jagiellonska Street, 03-301 Warsaw, Poland, e-mail: p.wojcik@pimot.org.pl, ph.+48 22 777 71 92

The process that determines the operating state of a motor vehicle engine is the vehicle speed [4]. In this connection, the vehicle speed processes that take place when the vehicle is actually used are investigated in order to evaluate the impact of the conditions of operation of an automotive engine on its properties. As an example, the driving tests used to evaluate pollutant emissions and fuel consumption, including type-approval tests, are thus designed [2, 10]. It is known, however, that the actual conditions of vehicle operation often significantly differ from those taken as a basis for the type-approval tests. The functional properties of automotive engines are the more so sensitive to engine's operating conditions treated as varying at random [4, 6, 8]. Therefore, it would be useful to investigate the sensitivity of functional properties of automotive engines to their operating conditions defined by vehicle speed vs. time curves.

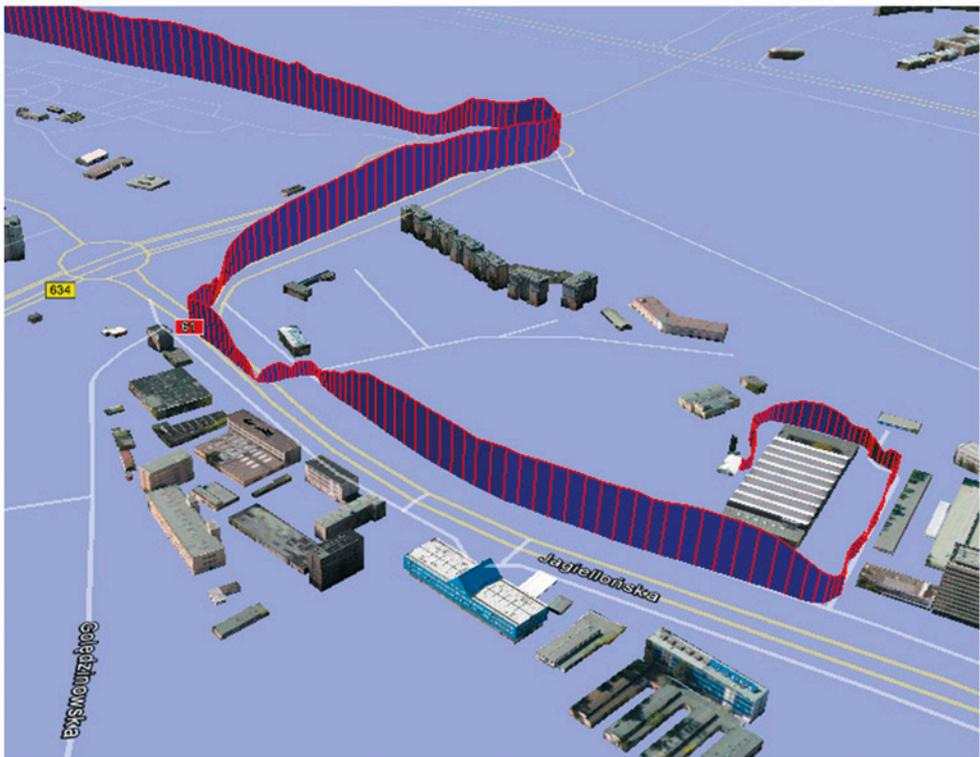
In this paper, results of empirical investigations of the motion of motor vehicles in Polish conditions have been presented. The objective of this work was to define driving tests that would adequately represent the typical use of passenger cars in the street congestion, urban, extra-urban, and high-speed traffic conditions prevailing on plain areas in Poland. The investigations were carried out within project No. N N509 556440 "Sensitivity of pollutant emissions and fuel consumption of a spark-ignition vehicle engine to its operating conditions" implemented at the Vehicle Engine and Chassis Section of the Automotive Industry Institute (PIMOT) in Warsaw and funded by the National Science Centre. In result of analyses performed, passenger car driving tests could be proposed as realizations of model stochastic processes representing the vehicle motion in the conditions under consideration. Such tests are now used for the testing of pollutant emissions and fuel consumption of passenger cars on a chassis dynamometer.

## **2. Results of empirical investigations of the motion of motor vehicles characteristics**

The test specimen was a Honda Civic car manufactured in 2000, provided with a 4 cylinder in-line spark-ignition engine of 1 400 cm<sup>3</sup> capacity. The car engine was in conformity with the requirements of the Euro 3 exhaust emission standard.

Within the tests, engine speed, engine controls operation, vehicle speed, and vehicle location were measured during actual test drives. The time histories of these quantities were recorded with a sampling frequency of 10 Hz and processed with the use of a second degree Savitzky-Golay filter [9] for nine measuring points.

The tests were carried out within the area of Mazowieckie and Łódzkie Voivodships, with the test drives in the street congestion and urban traffic conditions being performed in the city of Warsaw. A fragment of the driving route, with a graphic representation of the vehicle speed, has been schematically shown in Fig. 1.



**Fig. 1. A fragment of the vehicle driving route to PIMOT, with a graphic representation of the vehicle speed**

The vehicle motion conditions were modelled to represent the vehicle driving in the following situations:

- in urban traffic congestions;
- in urban traffic without congestions;
- in extra-urban traffic;
- in high-speed traffic.

For the individual traffic types as above, the following vehicle speed samples were taken:

- 19 samples in urban traffic congestions;
- 34 samples in urban traffic without congestions;
- 16 samples in extra-urban traffic;
- 8 samples in high-speed traffic.

The recorded realizations of the vehicle speed processes for individual models of the vehicle motion have been presented in Figs. 2 – 5.

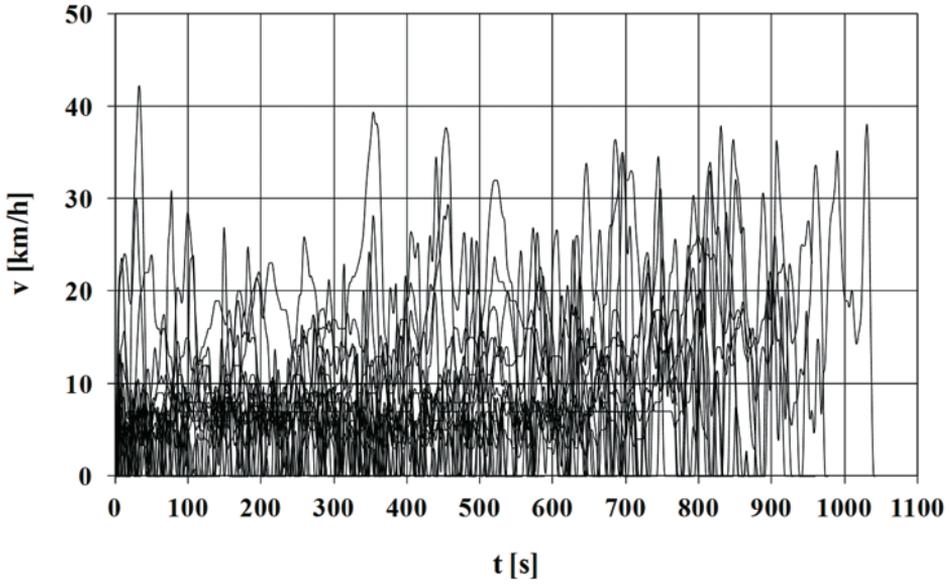


Fig. 2. Time histories of the vehicle speed recorded during test drives in urban traffic congestions

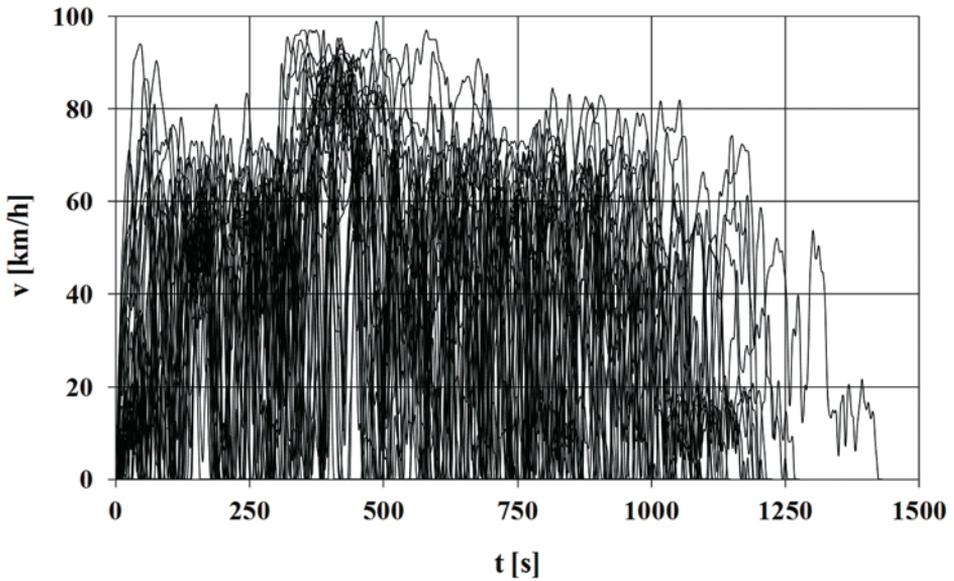


Fig. 3. Time histories of the vehicle speed recorded during test drives in urban traffic without congestions

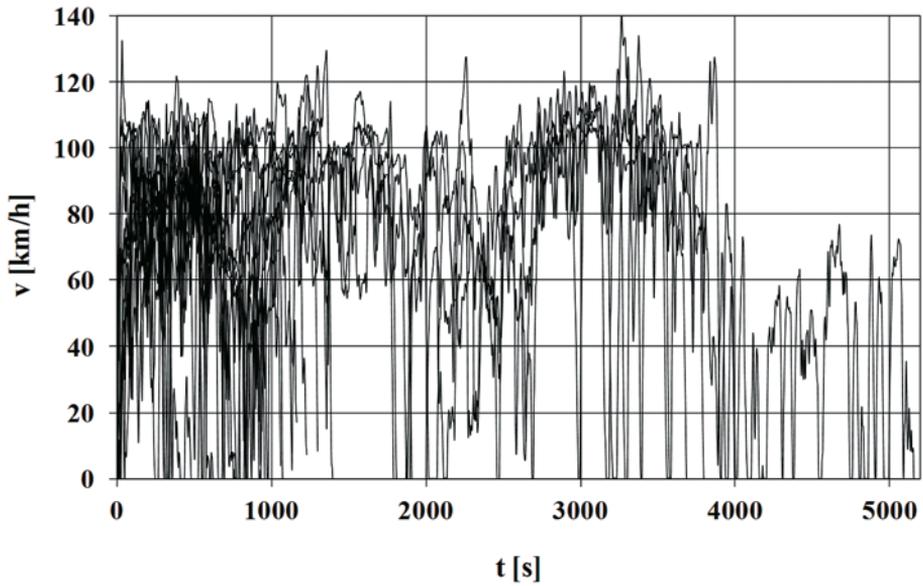


Fig. 4. Time histories of the vehicle speed recorded during test drives in extra-urban traffic

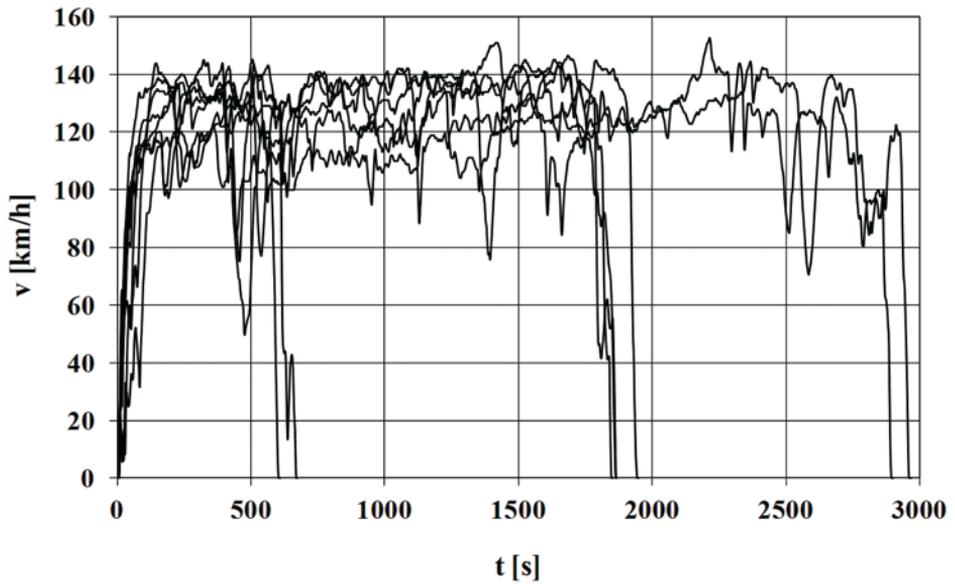


Fig. 5. Time histories of the vehicle speed recorded during test drives in high-speed traffic

The processes under investigation are characterized by diversified probability density. In most cases, the distributions are asymmetric. Significant differences can be observed in the skewness coefficient (from 3.2 to 1.9) and kurtosis (from 1.5 to 13.1).

Selected characteristics of the vehicle speed processes have been presented in Figs. 6 – 13: the average value (AV) and median (M) have been shown in Figs. 6 – 9 and the standard deviation (D) and quartile deviation (DQ, i.e. a half of the interquartile range) have been shown in Figs. 10 – 13. The maximum value (Max), minimum value (Min), average value (AV), and standard deviation (D) have also been plotted on the graphs for the characteristics presented.

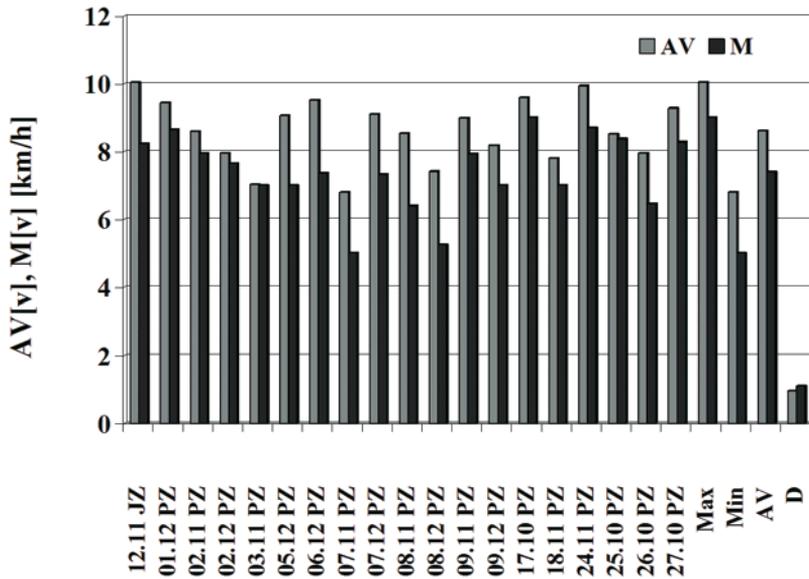


Fig. 6. Average value and median of the vehicle speed recorded during test drives in urban traffic congestions

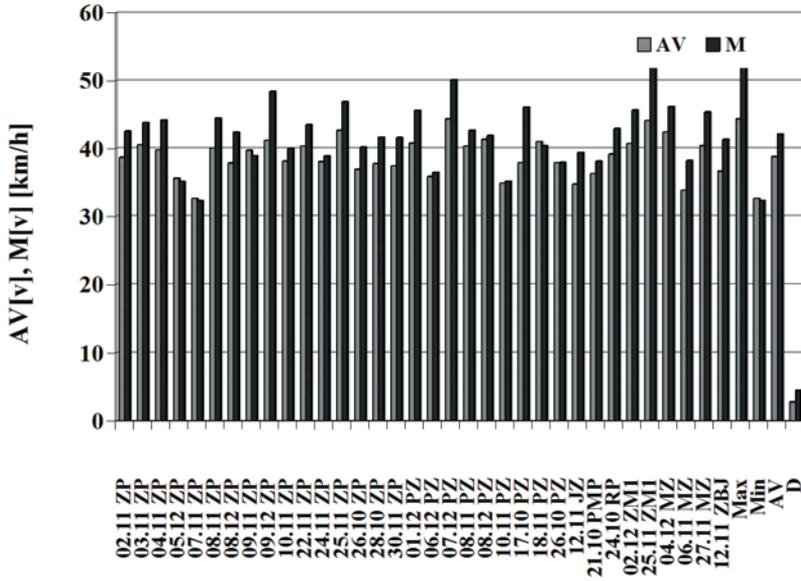


Fig. 7. Average value and median of the vehicle speed recorded during test drives in urban traffic without congestions

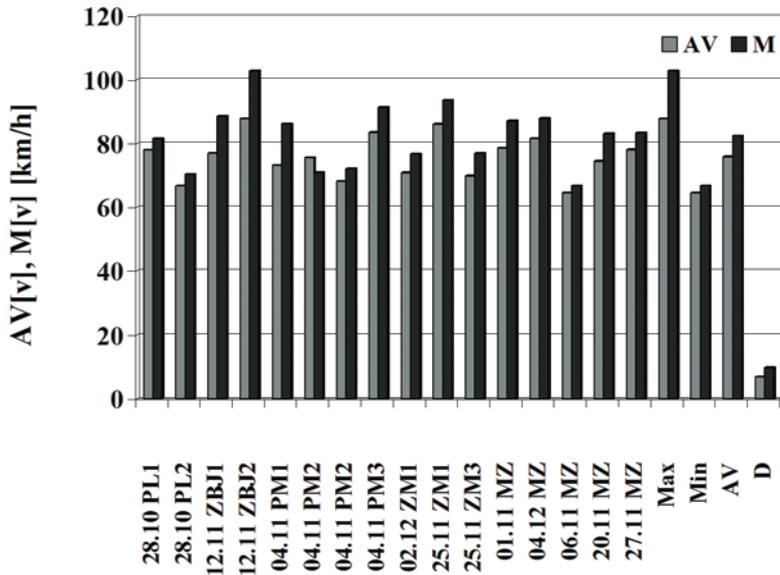


Fig. 8. Average value and median of the vehicle speed recorded during test drives in extra-urban traffic

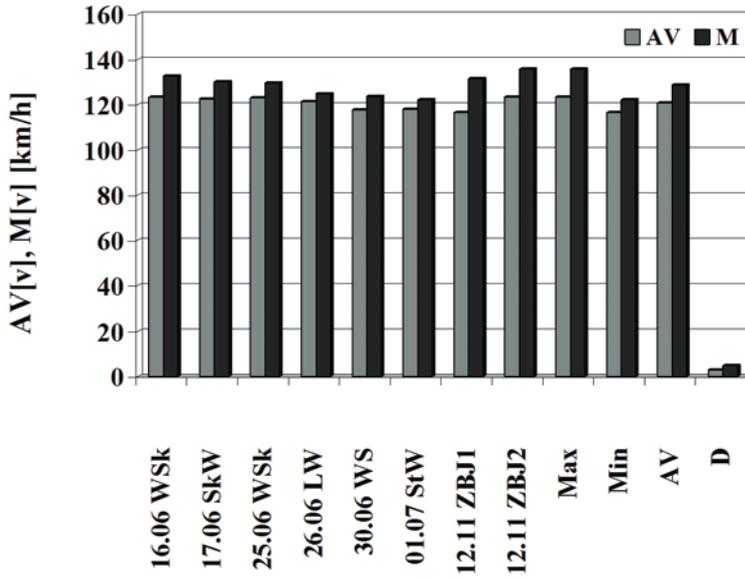


Fig. 9. Average value and median of the vehicle speed recorded during test drives in high-speed traffic

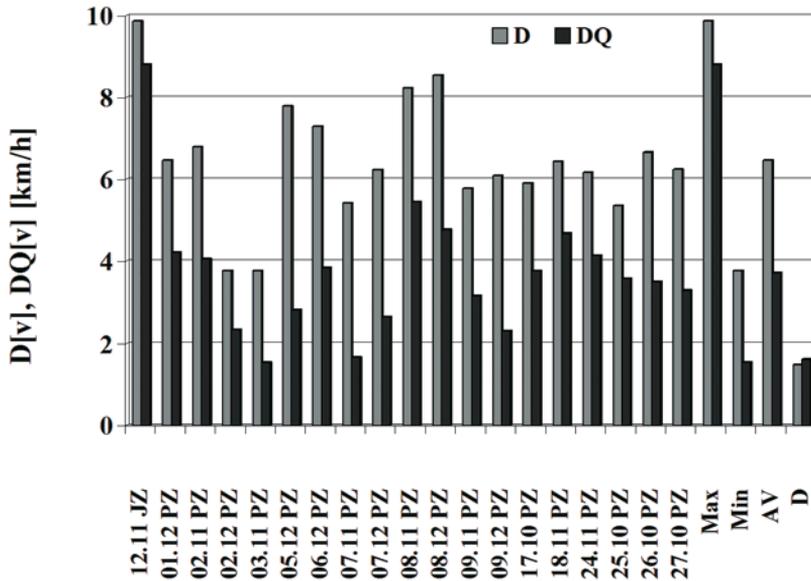


Fig. 10. Standard deviation and quartile deviation of the vehicle speed recorded during test drives in urban traffic congestions

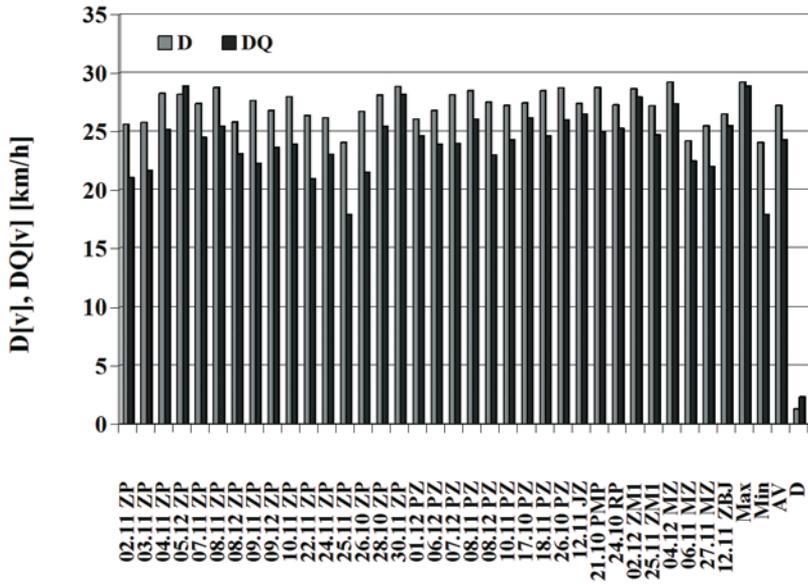


Fig. 11. Standard deviation and quartile deviation of the vehicle speed recorded during test drives in urban traffic without congestions

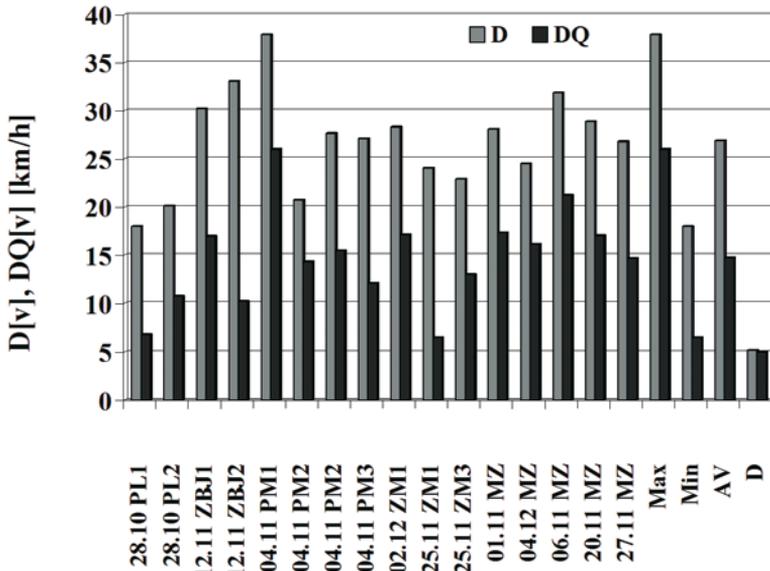


Fig. 12. Standard deviation and quartile deviation of the vehicle speed recorded during test drives in extra-urban traffic

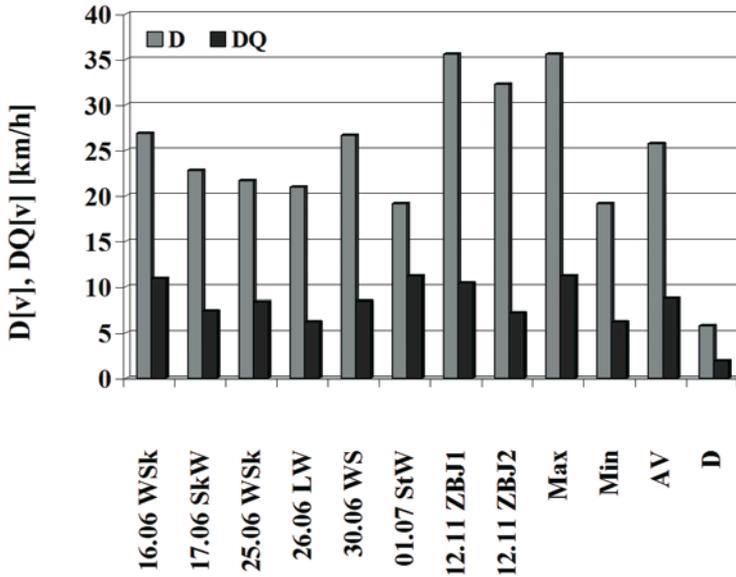


Fig. 13. Standard deviation and quartile deviation of the vehicle speed recorded during test drives in high-speed traffic

### 3. Designing of driving tests to simulate model conditions of vehicle motion

Based on results of the empirical investigations of motor vehicle speeds, driving tests were proposed for the simulation of vehicle drives in urban traffic congestions, in urban traffic without congestions, in extra-urban traffic, and in high-speed traffic. The tests were developed in conformity with the criterion of faithful simulation in the time domain [4]. From among the vehicle speed vs. time records, the fragments were separated where the average speed and standard deviation values were close to those determined for all the sets of time histories of vehicle speeds. Four tests were set for each vehicle motion model, with treating them as realizations of stochastic processes of speed for the said models. Selected time histories of the vehicle speed for individual vehicle motion models have been presented in Figs. 14 – 17.

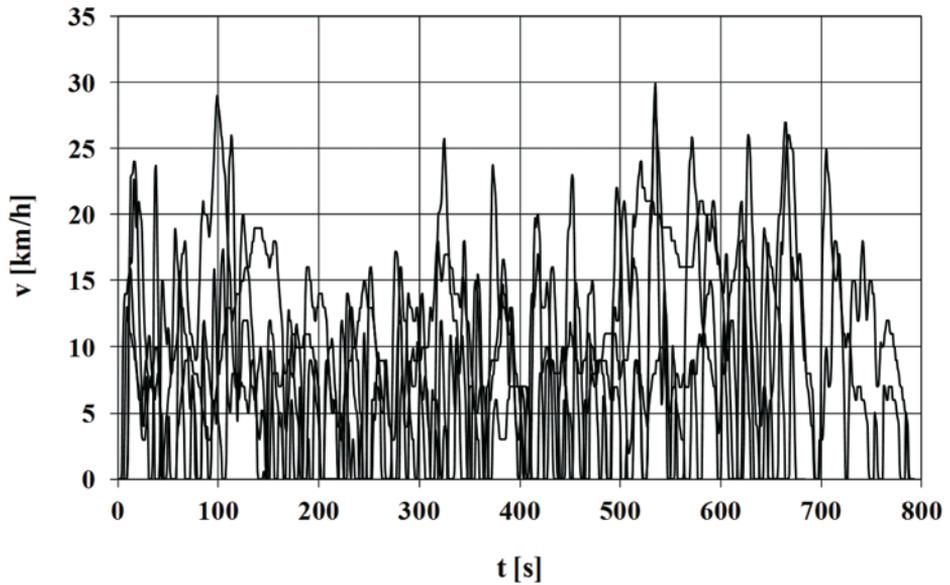


Fig. 14. Selected time histories of the vehicle speed for drives in urban traffic congestions

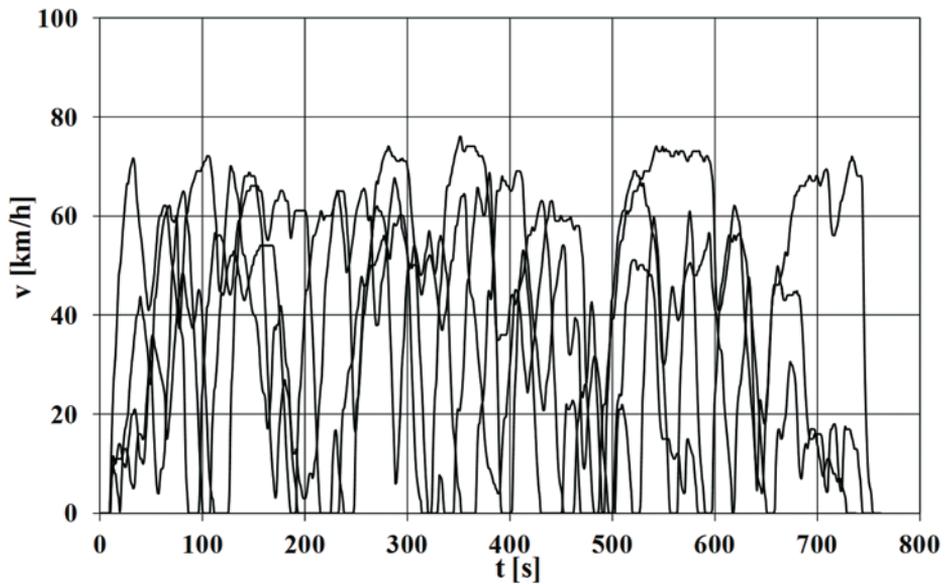


Fig. 15. Selected time histories of the vehicle speed for drives in urban traffic without congestions

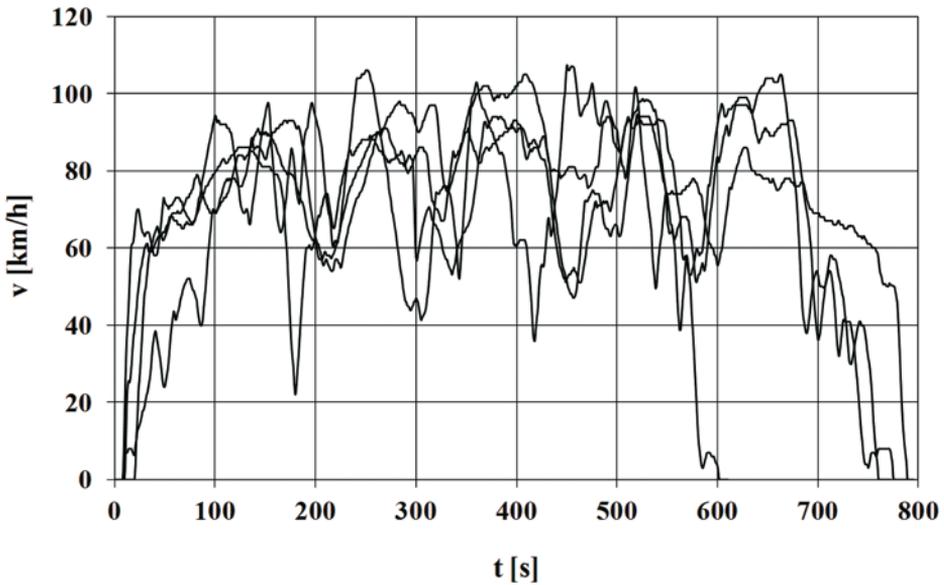


Fig. 16. Selected time histories of the vehicle speed for drives in extra-urban traffic

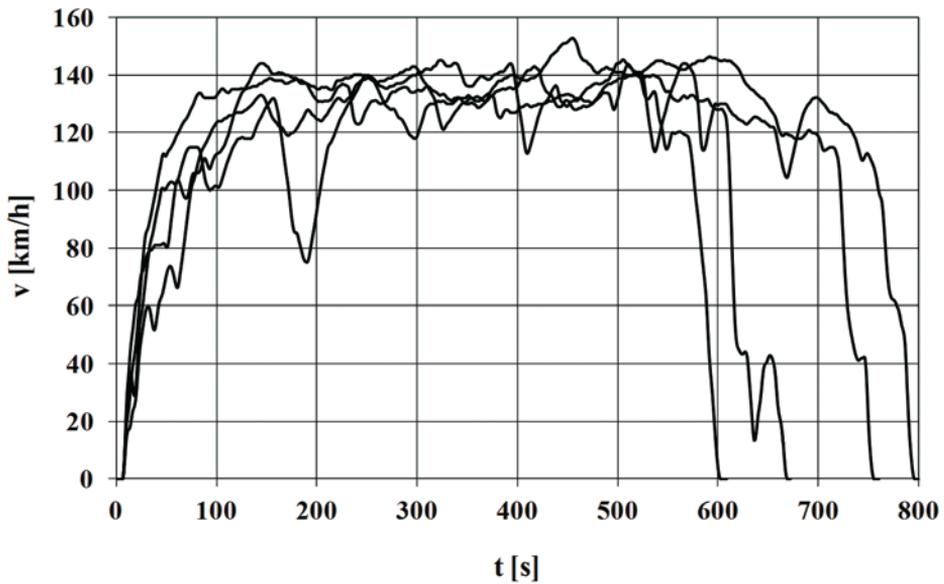


Fig. 17. Selected time histories of the vehicle speed for drives in high-speed traffic

The tests for individual models of vehicle motion have similar values of the characteristics under investigation (Ch), i.e. maximum value (Max), average value (AV), median (M), standard deviation (D), and quartile deviation (DQ). A comparison between the characteristics of individual vehicle motion models for driving tests from I to IV, for the average values for the tests (AV), and for all the recorded realizations of the processes under investigation (GAV) has been presented in Figs. 18 – 21.

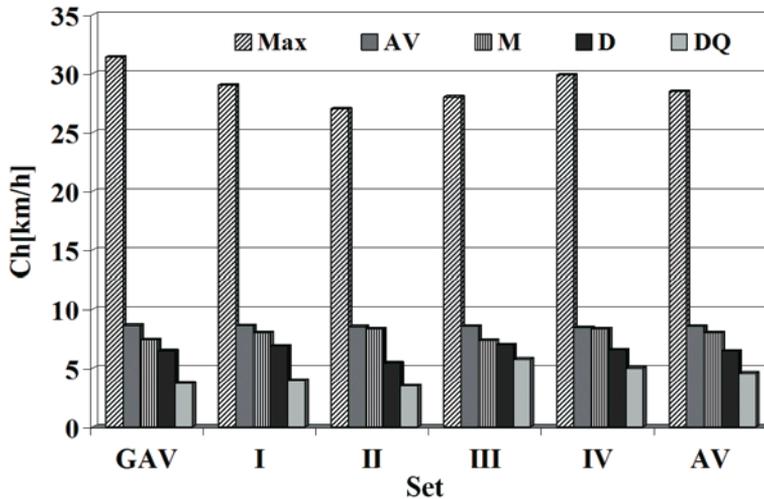


Fig. 18. Characteristics of all the time histories and tests for drives in urban traffic congestions

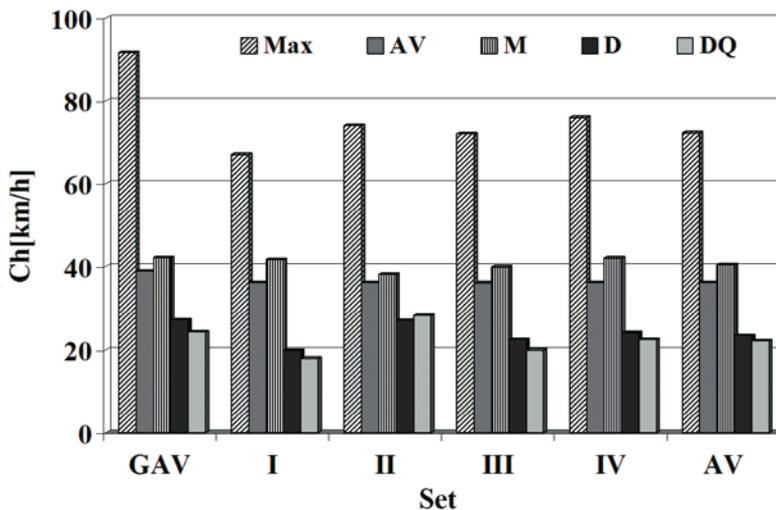


Fig. 19. Characteristics of all the time histories and tests for drives in urban traffic without congestions

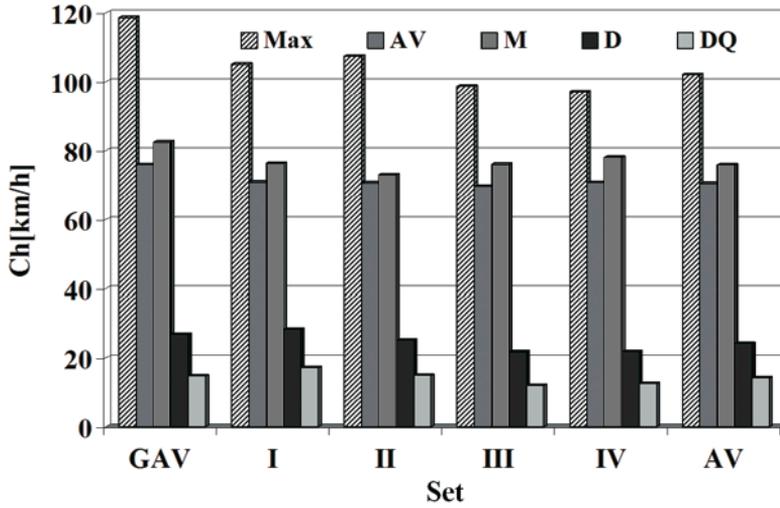


Fig. 20. Characteristics of all the time histories and tests for drives in extra-urban traffic

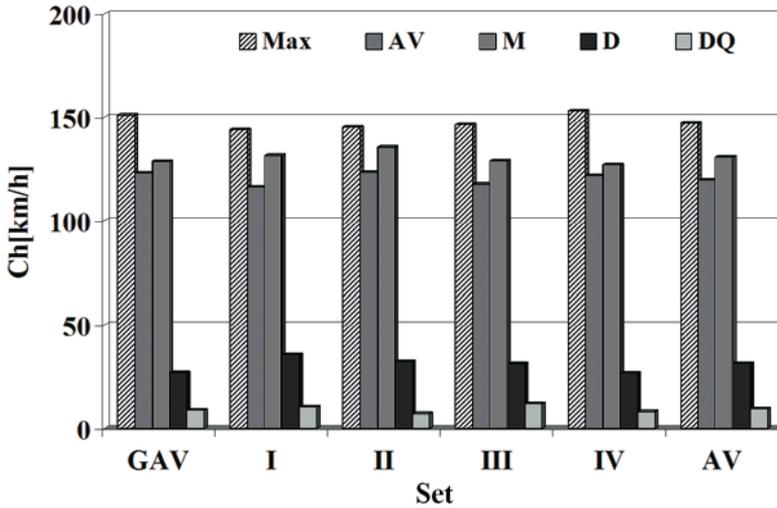


Fig. 21. Characteristics of all the time histories and tests for drives in high-speed traffic

The similarity of the characteristics under investigation to each other can be clearly seen. Differences only occur in the case of the maximum value, but the maximum value for the whole set may happen to be quite high.

Figs. 22 – 25 show a comparison between the coefficient of variation ( $W$ ) and the coefficient of interquartile range ( $WQ$ , see (1)) for individual vehicle motion models for driving tests I – IV, for the average value for the tests (AV) and for all the recorded realizations of the processes under investigation (GAV).

$$WQ = \frac{DQ}{M} \quad (1)$$

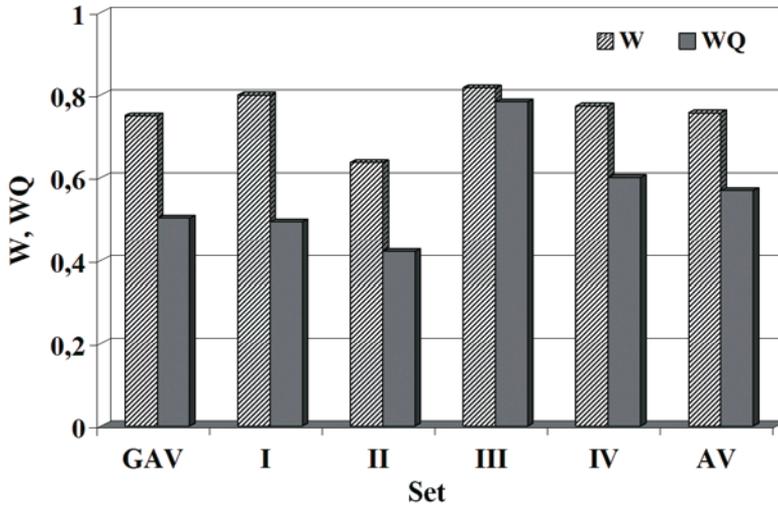


Fig. 22. Characteristics of all the time histories and tests for drives in urban traffic congestions

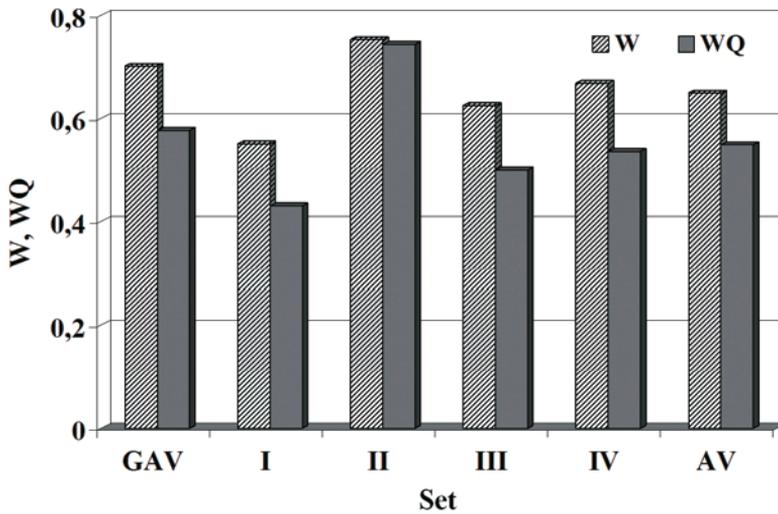


Fig. 23. Characteristics of all the time histories and tests for drives in urban traffic without congestions

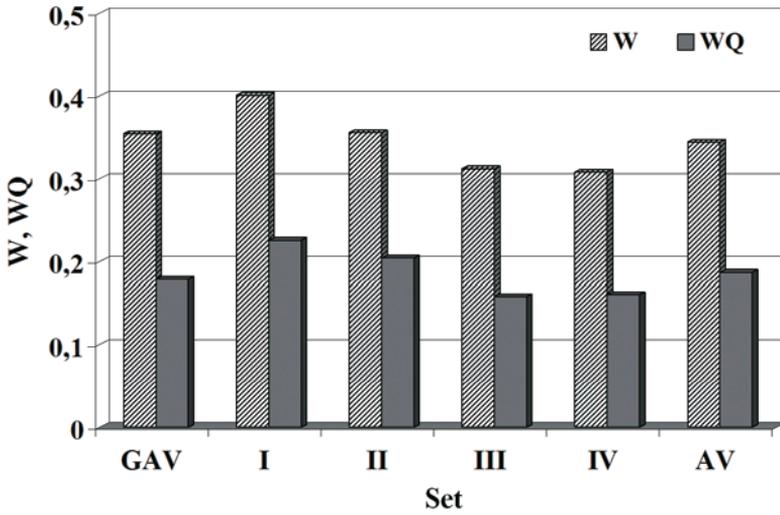


Fig. 24. Characteristics of all the time histories and tests for drives in extra-urban traffic

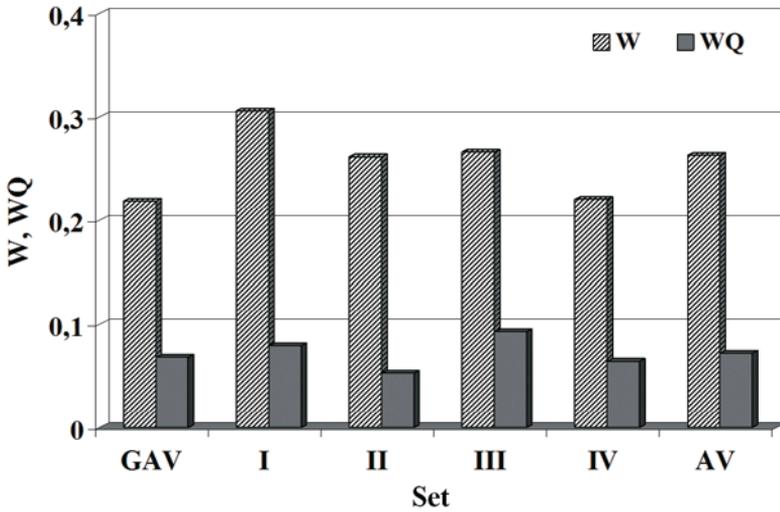


Fig. 25. Characteristics of all the time histories and tests for drives in high-speed traffic

The driving tests proposed make it possible to simulate vehicle drive conditions in pseudorandom conditions corresponding to the actual vehicle use.

## 4. Recapitulation

The empirical investigations of the speed of a passenger car in conditions corresponding to the average vehicle use made it possible to develop driving test procedures for the purposes of tests carried out on a chassis dynamometer. The investigations were aimed at the evaluation of functional properties of an automotive engine in various conditions of vehicle use, which often significantly differ from the standardized conditions of type-approval tests.

In the vehicle motion models adopted, the models of vehicle motion in urban traffic congestions and in urban traffic without congestions have been intentionally separated from each other. Thanks to this, models of vehicle motion in towns with various degrees of traffic difficulties can be built by combining together tests in different proportions of their times of duration. This method was successfully applied for different vehicle motion conditions at determining the characteristics of pollutant emissions in the emission model incorporated in the software developed by INFRAS AG [2, 7]. An important unique feature of the driving test designing method proposed in this study is the treatment of such tests as realizations of stochastic processes, thanks to which conclusions can be drawn about the sensitivity of functional properties of internal combustion engines not only to dynamic but also to random conditions of engine operation.

## Acknowledgements

This paper has been based on results of investigations carried out within project No. N N509 556440 "Sensitivity of pollutant emissions and fuel consumption of a spark-ignition vehicle engine to its operating conditions" implemented at the Vehicle Engine and Chassis Section of the Automotive Industry Institute (PIMOT) in Warsaw and funded by the National Science Centre.

## References

- [1] BENDAT J. S., PIERSOL A. G.: *Random Data: Analysis & Measurement Procedures*. Wiley New York. 1966.
- [2] BUWAL, INFRAS AG: *Luftschadstoffemissionen des Strassenverkehrs 1950 - 2010*. BUWAL-Bericht No. 255, 1995.
- [3] CHŁOPEK Z., PIASECZNY L.: *Modelling of the effect of work conditions of marine diesel engines on their ecological properties*. Maritime Transport, Technological Innovations & Research, Universitat Politècnica de Catalunya, BARCELONATECH, Barcelona 2012, 489-501.

- [4] CHŁOPEK Z.: *Modelowanie procesów emisji spalin w warunkach eksploatacji trakcyjnej silników spalinowych (Modelling of exhaust emission processes in combustion engines in the vehicle driving conditions)*. Prace Naukowe Politechniki Warszawskiej – Mechanika, vol. 173, Oficyna Wydawnicza Politechniki Warszawskiej (Publishing House of the Warsaw University of Technology), Warszawa, 1999.
- [5] CHŁOPEK Z.: *Some remarks on engine testing in dynamic states*. Silniki Spalinowe – Combustion Engines, 4/2010(143), 60–72.
- [6] CHŁOPEK Z.: *The research of the probabilistic characteristics of exhaust emissions from vehicle engines*. Silniki Spalinowe – Combustion Engines 1/2011(144), 49–56.
- [7] INFRAS AG: *Handbuch für Emissionsfaktoren des Strassenverkehrs; Version 3.1*. Bern 2010.
- [8] JANTOS J. et al.: *Driveability and fuel consumption improvement through integrated fuzzy logic control of powertrain with spark ignition engine and continuously variable transmission*. World Automotive Congress FISITA 2004, Barcelona.
- [9] SAVITZKY A., GOLAY M.J.E.: *Smoothing and differentiation of data by simplified least squares procedures*. Analytical Chemistry, 1964, 36, 1627–1639.
- [10] *Worldwide emission standards. Passenger cars and light duty vehicles*. Delphi, Innovation for the real world, 2011/2012.