IJESRT: 10(2), February, 2021 ISSN: 2277-9655

# International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

# ASPECTS REGARDING THE DYNAMICS OF VEHICLES IN THE URBAN AND EXTRA-URBAN ENVIRONMENTS

**Darie Catalin-Dumitru[1] & Copae Ion[*2]**
[1]S.A-R City Insurance, Bucharest, Romania
[*2]Department of Military Vehicles and Transportation, Military Technical Academy "Ferdinand I", Bucharest, Romania

**DOI**: https://doi.org/10.29121/ijesrt.v10.i2.2021.1

## ABSTRACT

The paper presents some functional particularities of the dynamics of vehicles when moving them in urban and extra-urban areas. There are several aspects related to the study of vehicle dynamics by applying the methods of multivariate statistics [2][3]. The study is based on experimental data tests of a Ford Focus car equipped with on-board computer, sensors and built-in actuators.

**KEYWORDS**: vehicle dynamics, multivariate statistics, spatial correlation, canonical correlation analysis.

## 1. INTRODUCTION

The approach of vehicle dynamics was one of main concern of field specialists, who constantly targeted to improve dynamical performances and fuel saving of road transport vehicles. The development of different field of study, or the advent of more developed experimental devices, as well as the on-board electronic control systems, represent the most important influence factors on the algorithms of dynamical study. Present paper aims to establish functional properties and to determine vehicles performances in urban and extra-urban environment, where traffic varies.

## 2. EXPERIMENTAL RESEARCH

Because functional properties and vehicle performances in urban and extra-urban environments can be established in a more accurate manner while driving, there have been performed several experimental tests with a Ford Focus vehicle, equipped with an electronically controlled Diesel engine. The experimental setup took benefit of Ford software and hardware. From all data obtained during tests, there have been used 40 samples from urban tests and 40 samples from extra-urban tests, with the most significance for the targeted aim.

Therefore, in fig. 1a there are presented instantaneous values of vehicle speed $V$, during urban tests, and in fig. 1b for extra-urban tests; also, the graphs show minimum and maximum values for all 40 samples [1]. From fig. 1 it is observed that vehicle speed is higher for extra-urban driving, including the extreme values, that is why the vehicle is operating within upper gears. In fig. 1c and fig. 1d there are presented instantaneous values of vehicle displacement $S$ in urban and extra-urban environment. As it was to be expected, in extra-urban environment, the distances travelled by the car are higher. Total distance for urban is 162 118 km and for extra-urban is 419 806 km.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

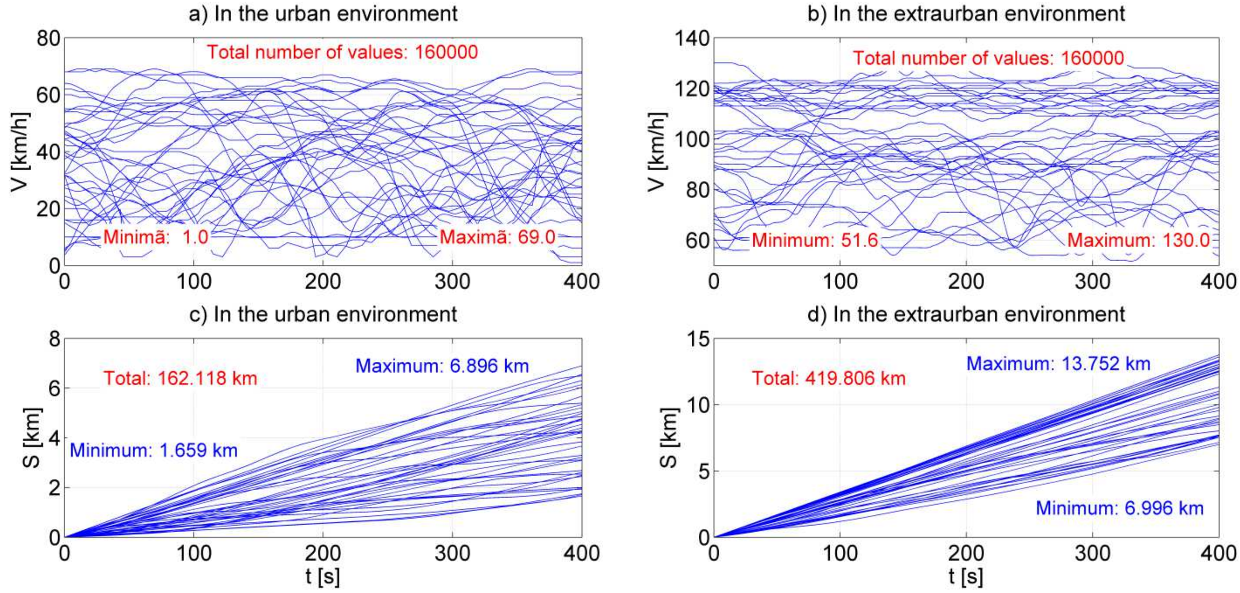


*Fig. 1. Values on tests of vehicle speed and distance travelled*

In fig. 2 there are presented average and maximum values of vehicle speed $V$, acceleration $a$, accelerator pedal's position $p$ and engine speed $n$. Similarly, in fig. 3 there are shown average and maximum values of intake air pressure measured at engine cylinders $p_a$, common rail fuel pressure $p_c$, engine power $P_e$ and travelled distance $S$. Predictably, all parameters have higher values in extra-urban environment, except accelerations, which are lower due to higher gears.

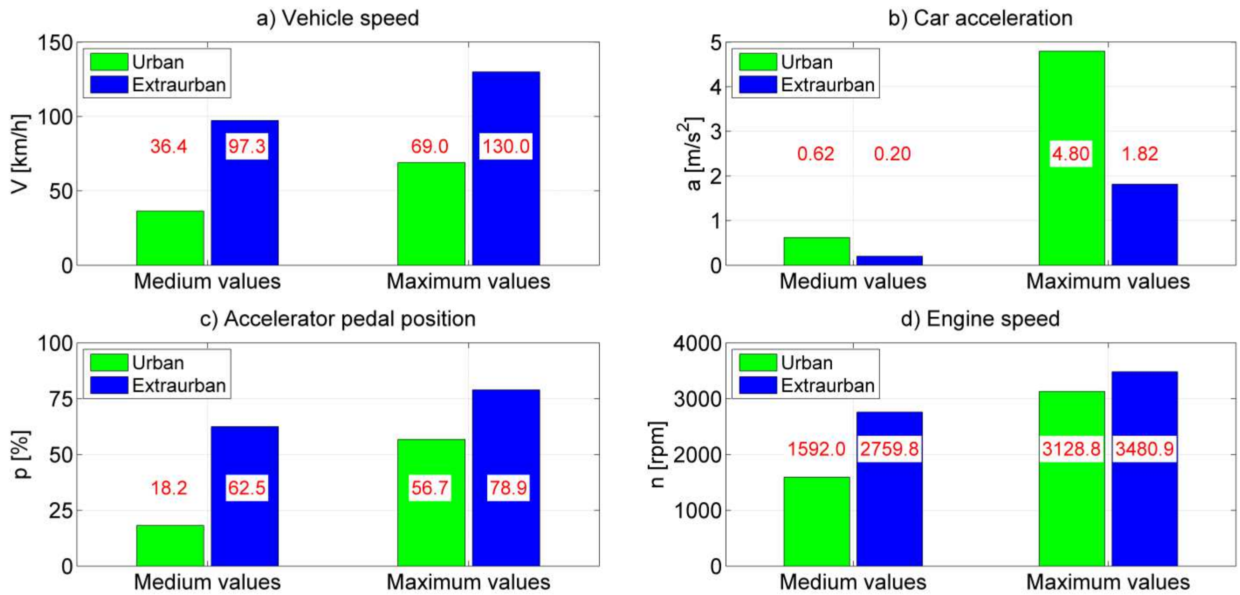


*Fig. 2. Average and maximum values on all speed, acceleration, accelerator pedal's position and engine speed tests*

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

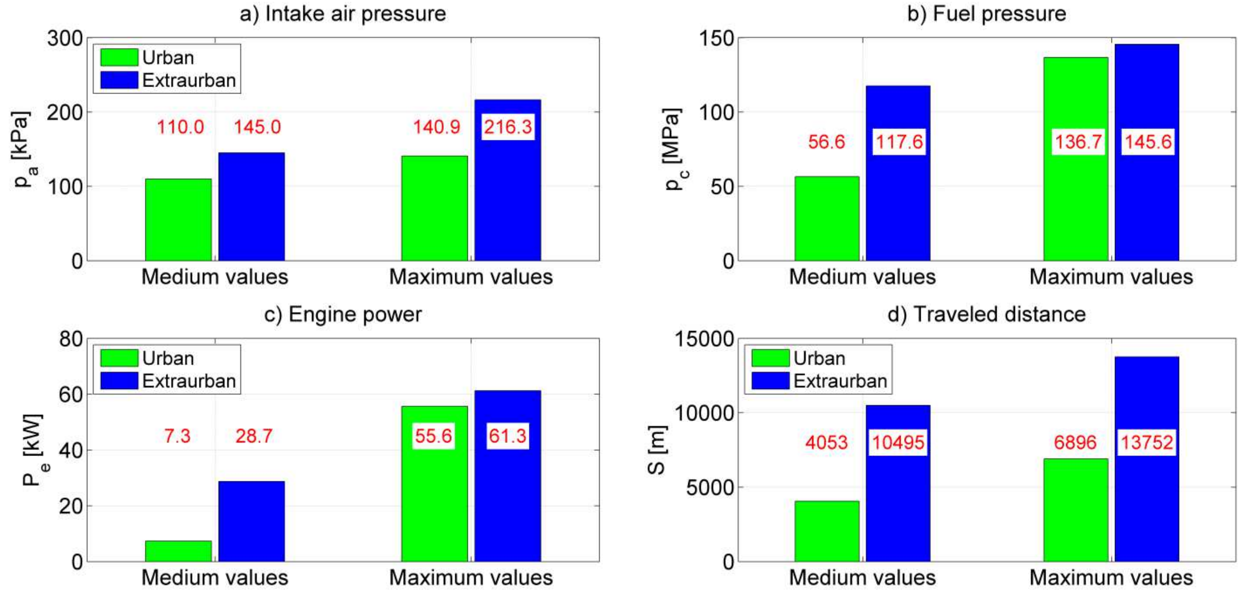


***Fig. 3. Average and maximum values on all samples of the intake air pressure, fuel pressure, engine power and traveled distance***

Starting from engine power balance, ***on a horizontal rolling track,*** it can be established a percentage of engine power, which represents the distribution of fuel consumption for 100 km, on constituents. As a result, there can be established three ratios: $k_1$ – the ratio between fuel consumption used to overcome rolling resistance forces $C_{100r}$ and total fuel consumption $C_{100}$; $k_2$ – the ratio between fuel consumption used to overcome air resistance $C_{100a}$ and total fuel consumption $C_{100}$; $k_3$ - the ratio between fuel consumption used to overcome start-up/inertia resistances $C_{100d}$ and total fuel consumption $C_{100}$:

$$k_1 = \frac{C_{100r}}{C_{100}} \cdot 100\,[\%]\,;\; k_2 = \frac{C_{100a}}{C_{100}} \cdot 100\,[\%]\,;\; k_3 = \frac{C_{100d}}{C_{100}} \cdot 100\,[\%] \qquad (1)$$

In fig. 4 there are presented average values of ratios between fuel consumption components for 100 km and total consumption, established by formula (1).

As it can be observed from upper graph, for all samples, ***during urban driving,*** the most fuel is spent to overcome start-up/inertia resistances (45.91%), obviously due to more often accelerations and decelerations; the other two components are smaller because of lower speeds.

On the other hand, from lower graph results that ***during extra-urban driving***, most of the fuel is spent to overcome aerodynamic resistances (45.17%), then the rolling resistances (37.94%), due to higher vehicle speeds. Least of the fuel (16.89%) is spent to overcome inertia, because driving speeds have smaller variations in extra-urban environment.

It is important to establish energy efficiency for both urban and extra-urban driving. To this end, it is calculated the ratio $k_4$ between volumetric fuel consumption $C_v$ and engine speed $P_e$, as well as ratio $k_5$ between volumetric fuel consumption $C_v$ and engine torque $M_e$:

$$k_4 = \frac{C_v}{P_e}\,;\; k_5 = \frac{C_v}{M_e} \qquad (2)$$

Ratio $k_4$ represents fuel consumption necessary to develop an engine power of 1 kW; average values per samples and for all samples are shown in the left side of fig. 5.

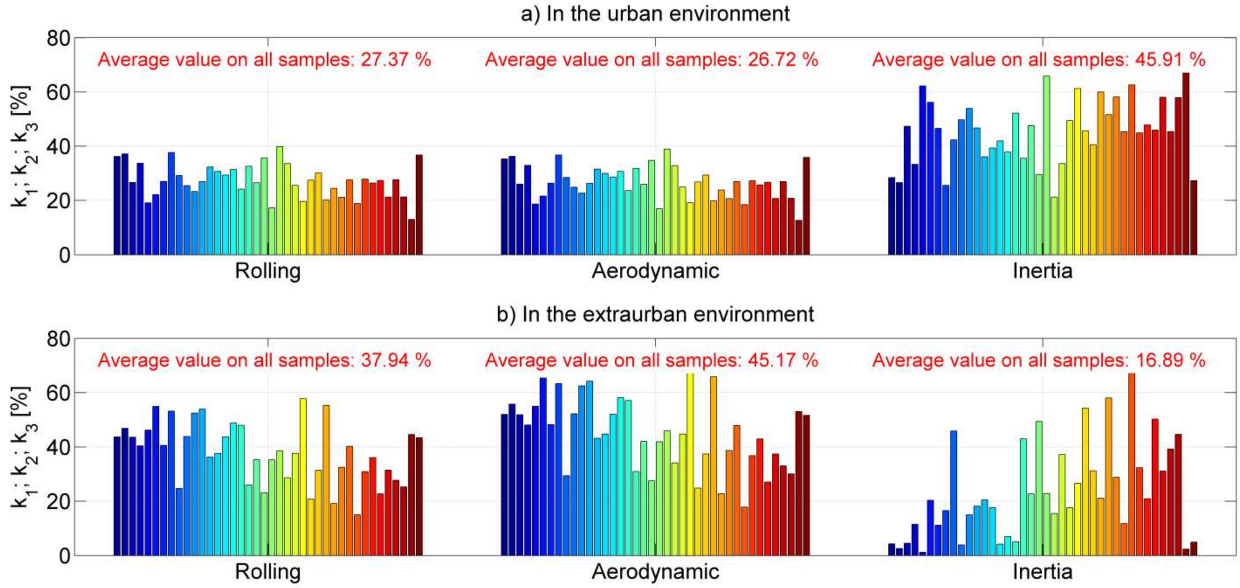


*Fig. 4. Components of vehicle fuel consumption per 100 km*

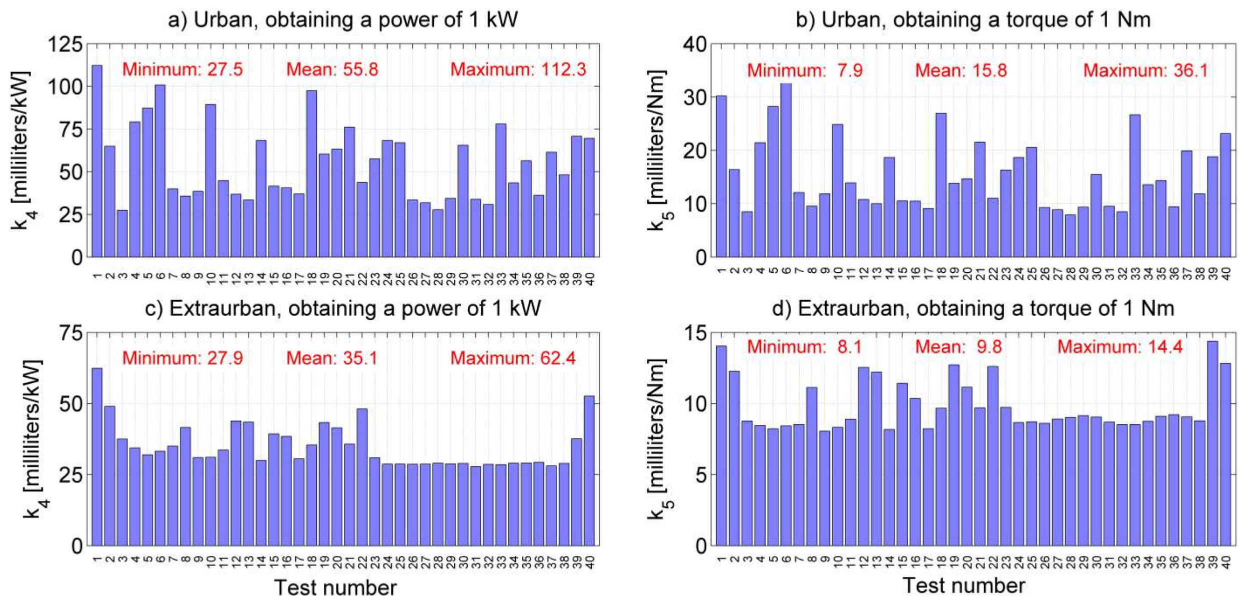


*Fig. 5. Sample average fuel consumption values per unit of power and unit of torque*

Ratio $k_5$ represents fuel consumption necessary to obtain an engine torque of 1 Nm; average values per samples and for all samples are shown in the right side of fig. 5.

The left side graphs from fig. 5 show that to obtain an engine power higher than 1 kW it involves a volumetric fuel consumption for all samples, higher by 1.59 times in case of urban driving. The right side graphs show that in order to obtain an engine torque of 1 Nm it is involved a volumetric fuel consumption for all samples, higher by 1.61 times than in case of urban driving.

Results that ***in extra-urban environment energy efficiency is higher*** than in urban environment, which is the same in case of other parameters.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

From fig. 5 also results that engine power per unit implies a higher fuel consumption than engine torque per unit, respectively, 3.53 times for urban driving (upper graphs) and 3.58 times for extra-urban driving (lower graphs).

## 3. MULTIVARIATE STATISTICAL ANALYSIS OF VEHICLE DYNAMICS

Multivariate statistics, also known as spatial or geostatical statistics, represents a component of statistics which targets large sets of data, with time variation, like in case of classical statistics, and with space variation, from which it derives the last two names; first name is due to the analysis of different types of data, meaning multiple variables [2][3][7]. Multivariate statistics can be applied in the automotive field due to the advent of engine's electronic control of functioning, where, by the existence of a group of senzorial parameters, the on-board computer operates with large sets of data, received from sensors and actuators embedded from factory.

Multivariate statistics uses analysis, concepts and specific algorithms. Therefore, plane correlation specific to classical statistics becomes spatial correlation [6][10], adding itself a third dimension, meaning the distance, which defines geostatistics. A special form represents the canonical correlation analysis [9] which is related to multivariate mathematical models. Likewise, multivariate statistics uses group analysis, defining which is common to data, as well as discriminant analysis, which targets the differences between data.

Because humans cannot detect variations within the space with more than three dimensions, geostatistics uses transformations which ensure the replacement of initial multivariate picture with equivalent ones, so that the graphical plots becomes tri-spatial, the most; this is specific to the analysis based on main components [5]. In order to conclude after data analysis, multivariate statistics also uses factor based analysis, as well as classification procedures, related to decision theory.

Follow-up, there are presented some elements specific to multivariate statistics, in order to highlight other particularities of vehicle dynamics, for urban and extra-urban environment.

**Spatial correlation analysis**

As it is known, time correlation represents a classic correlation [4]; on the other hand, spatial correlation also uses the distance, which is a parameter characteristic to multivariate statistics [6][8]. As a consequence, spatial correlation shows how much the influence on a certain point on space depends on the values of surrounding ones. In general, a positive spatial correlation shows that similar values tend to close in; a negative spatial correlation depicts a tendency of values to spread.

As it is known, time correlation is assessed based on correlation coefficient $\rho$, also called Pearson coefficient. From a quantitative point of view, spatial correlation uses two indices, of which the most used is Moran's index, calculated with formula:

$$M = \frac{n}{S} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (3)$$

In this formula there are noted: $x_i$ and $x_j$ – random variable values $x$ (with $n$ values) being in the same class at distances $i$ and $j$ of center; $\bar{x}$– average value of variable $x$; $w_{ij}$ – weight factor matrix, in which value one shows that the pair ($x_i$, $x_j$) is in the same class, and the null value indicates the opposite (that is why it is also called proximity or contingency table); $S$ – sum of elements $w_{ij}$ of the same class.

Moran's coefficient varies within $M \in [-1; +1]$; value -1 indicate a perfect negative correlation, value +1 a perfect positive correlation, and null value indicated the lack of any correlation.

For example, in fig. 6 (for urban driving) and in fig. 7 (for extra-urban driving) there are presented values of Moran's coefficient if resulting parameter is engine torque $M_e$.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

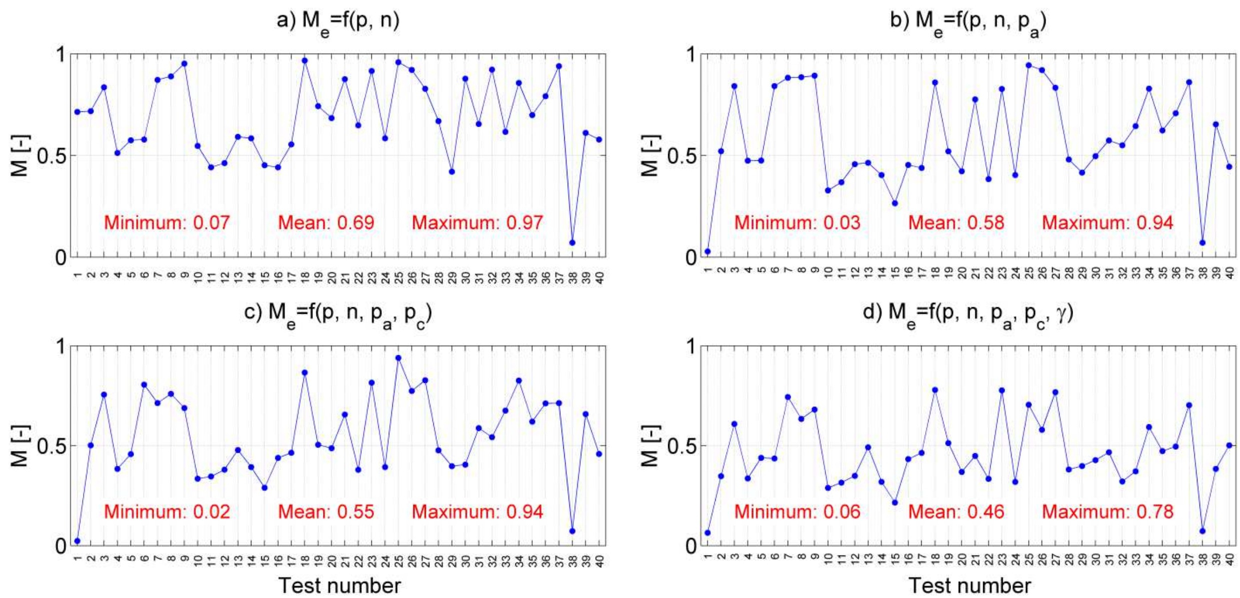


***Fig. 6. Moran's coefficient when the vehicle travels in urban areas***

First, there are adopted the accelerator pedal's position $p$ and engine speed $n$ as factorial parameters (influence factors) and then, there are consecutively added the intake air pressure $p_a$, fuel pressure $p_c$ and percentage quantity of gas recirculation $\gamma$.

Graphs from fig. 6 and fig. 7 show that all values of Moran's coefficient are positive and ***higher in extra-urban environment than in urban environment***. Therefore, for extra-urban driving, spatial correlation is more pronounced than for urban driving.

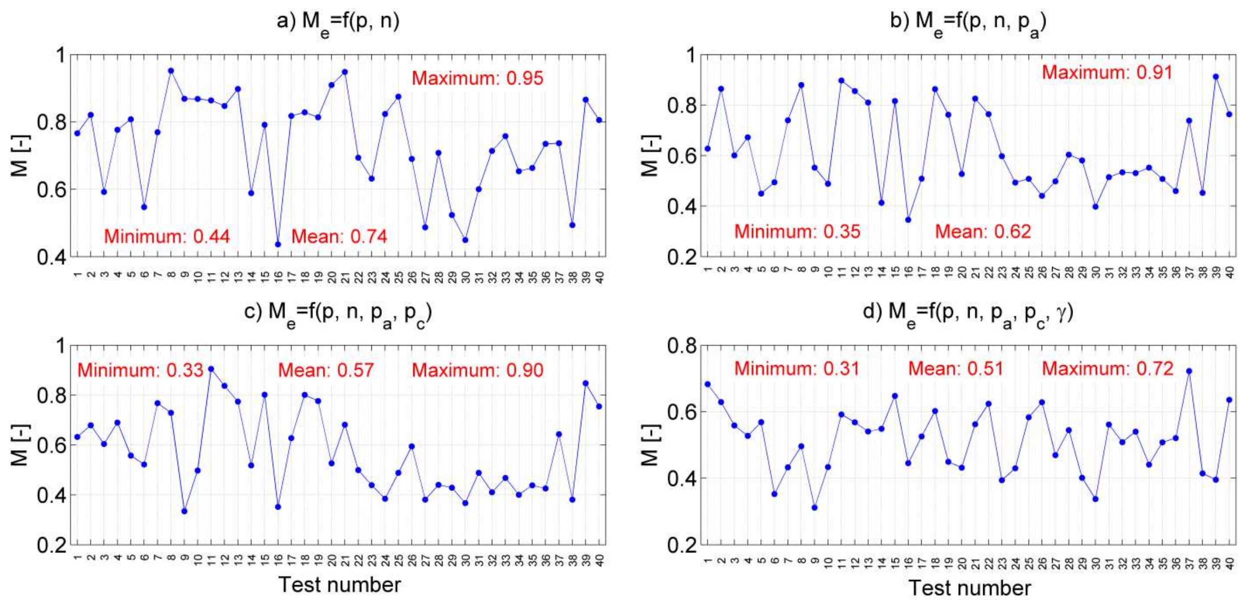


***Fig. 7. Moran's coefficient when the vehicle travels in extraurban areas***

Also, from these graphs it can be observed that by taking into account another influence factors, the values of Moran's coefficient become smaller. This shows ***the necessity to consider all functional factors*** in order to phrase probable conclusions regarding their influence on vehicle dynamics.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

**Canonical correlation analysis**

Canonical correlation analysis (CCA), proposed by H. Hotelling, represents a method to establish liniar dependency between the two sets of parameters [8]. If there are adopted two resultant parameters, the canonical correlation analysis finds two bases, one for each variable, for which the correlation matrix is maximized. Ordinarily, dimension of these new bases is smaller than the dimension of initial set of variables; accordingly, CCA ensures the reduction of data dimensions, meaning its compression.

Another property of CCA represents the invariant aspect towards multivariate parameters. This represents the difference between canonical correlation analysis and regular correlation analysis, the latter depending on the base where parameters are described, therefore it is not invariant.

There are considered two sets of vectorial parameters **x** and **y**:

$$\mathbf{x} = \begin{bmatrix} x_1 & x_2 & \dots & x_m \end{bmatrix}^T ; \mathbf{y} = \begin{bmatrix} y_1 & y_2 & \dots & y_n \end{bmatrix}^T \quad (4)$$

According to the value vectors from formula (4), there are established two new scalar sizes $x$ and $y$, representing liniar combinations based on vectors **x** and **y**:

$$\begin{cases} x = w_{x_1} x_1 + w_{x_2} x_2 + \dots + w_{x_m} x_m = \mathbf{w}_x^T \mathbf{x} \\ y = w_{y_1} y_1 + w_{y_2} y_2 + \dots + w_{y_n} y_n = \mathbf{w}_y^T \mathbf{y} \end{cases} \quad (5)$$

CCA establishes coefficients $\mathbf{w}_x$ and $\mathbf{w}_y$, which offer maximum correlation between $x$ and $y$. As a consequence, canonical correlation coefficient is expressed by formula:

$$\rho_c = \frac{\mathbf{w}_x^T C_{xy} \mathbf{w}_y}{\sqrt{(\mathbf{w}_x^T C_{xx} \mathbf{w}_x)(\mathbf{w}_y^T C_{yy} \mathbf{w}_y)}} \quad (6)$$

where $C_{xy}$ represents mutual covariance matrix between $x$ and $y$, and $C_{xx}$ and $C_{yy}$, the covariance matrices specific to sizes $x$ and $y$. For each one of the two basis, there is a canonical correlation coefficient, with the significance and values of correlation coefficient from classical statistics..

In fig. 8 is presented an example of CCA, which establishes the dependency of the data set $y = [C_{100}, C_h]$ on the set of variables $x = [p, n, p_a, p_c]$ in urban environment, meaning it is targeted the engine fuel saving (through fuel consumption at 100 km, $C_{100}$ and hourly fuel consumption $C_h$ as resultant parameters), based on four influence factors namely: accelerator pedal's position $p$, engine speed $n$, intake air pressure $p_a$ and common-rail fuel pressure $p_c$. As it can be observed from fig. 8, only the first mathematical model specific to the first invariant base ensures an acceptable error of 0.62%:

$$-1.0772C_{100} + 0.0781C_h = -0.1154p + 0.0011n + 0.001p_a - 0.0183p_c \quad (7)$$

and the canonical correlation coefficient has a high value, $\rho_c$=0.997, which confirms the reduced error for a liniar model.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

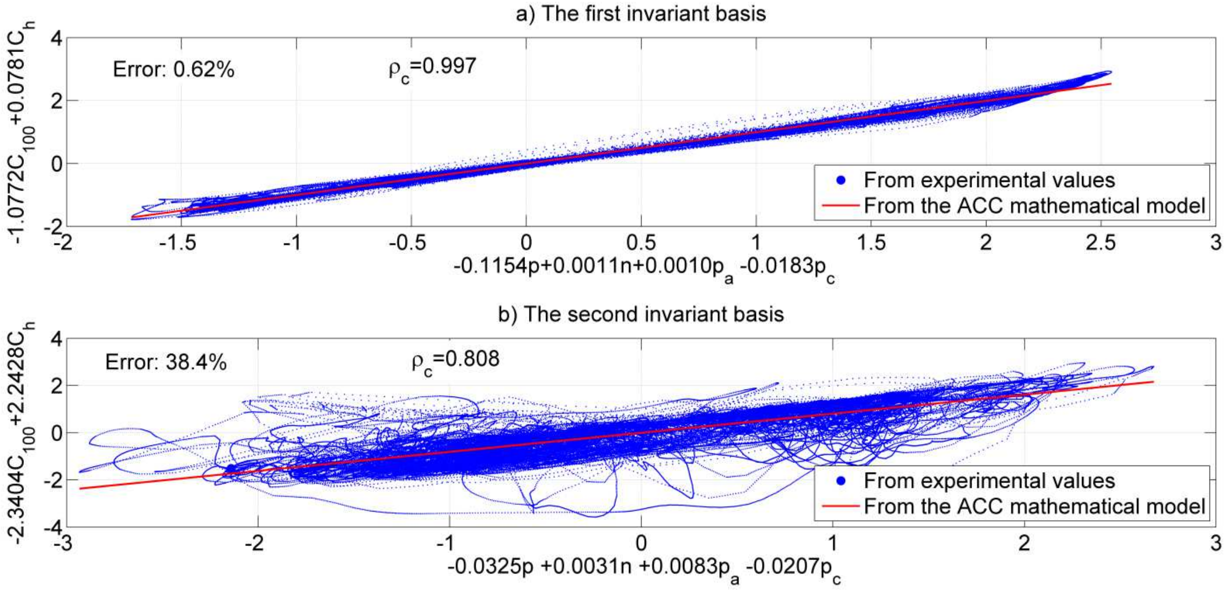


***Fig. 8. Canonical correlation analysis when moving the vehicle in the extraurban environment***

It is worth mentioning that ***multivariate mathematical models*** can be writen in any form. For example, from formula (7) it can be writen the fuel consumption at 100 km:

$$C_{100} = 0.0725C_h + 0.1071p - 0.001n - 0.00093p_a + 0.017p_c \quad (8)$$

## 4. CONCLUSION

The study has shown that in case of extra-urban driving, the speeds are higher and accelerations are lower than in case of urban driving. Likewise, in extra-urban environment, engine speed and engine load are higher, and fuel consumption is lower than in case of urban environment, therefore, engine torque and power are obtained for lower engine load and speeds. Also, energy efficiency, which has in sight vehicle dynamics and fuel saving, is higher in extra-urban environment that for urban driving.

The study of vehicle dynamics with the use of multivariate statistics, has shown that in case of extra-urban driving, spatial correlation is more pronounced than for urban driving. Yet again, spatial correlation has shown the necessity to consider all functional parameters in order to conclude about the influence on vehicle dynamics

## REFERENCES

[1] Barothi Laszlo, Voicu Daniela, Stoica Ramona-Monica, Singureanu Marius, „Recording of parameters characteristic to engine and vehicle in order to validate a simulation model for fuel consumption", 5th International Scientific Conference SEA-CONF 2019, 17–18 May 2019, Mircea cel Batran Naval Academy, Constanta, Romania, IOP Conf. Series: Journal of Physics: Conf. Series 1297 (2019) 012030 IOP Publishing, DOI:10.1088/1742-6596/1297/1/012030
[2] Hyötyniemi Heikki, "Multivariate Statistical Methods in Systems Engineering", Report 112, Helsinki University of Technology, 1998
[3] Hyötyniemi Heikki, "Multivariate Regression – Techniques and Tools", Report 125, Helsinki University of Technology, 2001
[4] Ilie Constantin-Ovidiu, Marinescu Marin, Alexa Octavian, Voicu Daniela, Barothi Laszlo, "Correlation Analysis - A Data Analysis Tool In The Vehicle Dynamics Modeling Process", Ingineria Automobilului, nr. 44/septembrie 2017, pp. 9-12
[5] Ilin Alexander, "Principal Component Analysis", AS-116.140 Schedule, Helsinki University of Technology, 2002.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[6] Savada Sara, "Global Spatial Autocorrelation Indices-Moran's I, Geary's C and the General Cross-Product Statistic", Department of Geography, University of Otawa, 2003, http://www.lpc.uottawa.ca/publications/moransi/moran.htm
[7] Stoica Ramona-Monica, Dinu Irinel, Simionescu Marius, Ciodaru Gabriel, "The study of engine vehicles functioning based on data provided by the on-board computer", MTA Review, Vol. XXV, No.1, mar. 2015, ISSN 1843-3391
[8] Unwin David, "GIS, spatial analysis and spatial statistics", University of London, 1996
[9] Zhuang Ma, "Canonical Correlation Analysis", University of Pennsilvania, 2017
[10] Zuur Julien, "Spatial autocorrelation", Academic Press, San Diego, 2000