International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:8, No:10, 2014

Slope Effect in Emission Evaluation to Assess Real Pollutant Factors

G. Meccariello, L. Della Ragione

***Abstract*—**The exposure to outdoor air pollution causes lung cancer and increases the risk of bladder cancer. Because air pollution in urban areas is mainly caused by transportation, it is necessary to evaluate pollutant exhaust emissions from vehicles during their real-world use. Nevertheless their evaluation and reduction is a key problem, especially in the cities, that account for more than 50% of world population.

A particular attention was given to the slope variability along the streets during each journey performed by the instrumented vehicle.

In this paper we dealt with the problem of describing a quantitatively approach for the reconstruction of GPS coordinates and altitude, in the context of correlation study between driving cycles / emission / geographical location, during an experimental campaign realized with some instrumented cars.

Finally the slope analysis can be correlated to the emission and consumption values in a specific road position, and it could be evaluated its influence on their behaviour.

***Keywords*—**Air pollution, Driving cycles, GPS signal, Slope, Emission factor, fuel consumption.

I. Introduction

The evaluation of emission produced by vehicles in correspondence of determined traffic situation in a specific road with specified traffic management rules is generally carried out by multiplying emission factors per vehicle activity, obviously considering different vehicle types.

The problem is thus, in principle, defined when the following information is available:

- Road characteristics (number of lanes, type of pavements, crossing…)
- Traffic management rules (traffic lights, parking, speed limits..)
- Vehicle composition (fleet composition, vehicle age distribution,…) and activity.
- Vehicle flow and density, congestion level of road.

In recent years we are seeing positive results, but on a national scale we are still far from achieving this goal. In the case of Italy, factors that are yet contributing negatively to this situation are so different. To obtain emission factors consolidated methods make reference to vehicle mean velocity, which can be easily obtained by vehicle flow and density in the road. In this framework a new statistical approach has been proposed capable to consider more attributes than the simple speed to characterize driving behaviour, not only in the determination of driving cycles but also in the emission modelling. In Naples many research programs have been carried out on this subject, whose aim was to determine driving behaviour and emission trends. Preliminary results show that if we consider a specific road driving behaviour changes and so driving cycles of different characteristics always occur. In this context, it could be interesting to suggest paths based not only on the minimum distance, but on the minimization of fuel consumption as a function of the geomorphological features of the territory. For this purpose, the activities will be aimed at integrating automatically, the commercial digital maps with geomorphological data relating to the real three-dimensional pattern of the road network.

During the development of a research project, an experimental campaign is realized and some results relative to tests performed on road with a Fiat Panda Bipower, (CNG and gasoline powered), and a New Panda Twin Air with auto Start & Stop system, are compared. Gaseous emissions are measured with Portable Emission Measurement Systems (PEMS) on two different urban routes, in terms of traffic and slope characteristics during in use experiments.

The aim of this paper is to synthesize some considerations about the problem of GPS signal reconstruction, especially for altimetry coordinate, to better analyze and to outline the behavior of low environmental impact vehicles in city traffic situations and in a precise location. Also it could be desirable to perform a quantitative analysis of altimetry to evaluate the slope variability during a path, so this variable can contribute to correlate kinematic behavior with emissions.

II. Background and Motivation

In a general approach for the determination of emission factors, the development and updating of emission factors is one of the main activities. To this aim, on road tests have to be performed in different geographical areas to collect experimental data on driving behaviour relative to different street networks, traffic conditions and specific features of each geographical areas, with vehicles of different segment and technology. On road data have to be analyzed by statistical methods to determine typical and statistical representative groups of driving cycles and engine operating conditions. So far, emission modelling is based on measurements performed with vehicles on dynamometer chassis performing driving cycles statically representative of the behaviour, considering and simulating engine operating conditions. Applying regression techniques to pollutant data, emission models can

Giovanni Meccariello is with the Istituto Motori National Research Council, Napoli, 80125 Italy (phone: 39-081-7177114; fax: 39-081-2396097; e-mail: g.meccariello@im.cnr.it).

Livia Della Ragione is with the Istituto Motori National Research Council, Napoli, 80125 Italy (phone: 39-081-7177175; fax: 39-081-2396097; e-mail: l.dellaragione@im.cnr.it).

be obtained to determine functions relating these data with relevant characteristics of driving cycles, which produce higher and statistically significant effects on environment. In this way, from the experimental work performed on the road it is possible to create a data base of driving cycles and operating conditions. Also from laboratory and on road data acquisition, emission data base is built. Combining these two activities determines the emission factors. Obviously, the experimental work has to be performed continuously to update driving and emission data respect to the upgrading of vehicle technology, considering also other factors affecting emissions as deterioration of used vehicles [1]-[5].

The link between traffic-road characteristics and driving behaviour-emission factors can be built by setting same quantities to cluster driving cycles and to build emission modelling. But to give an added value in terms of the precise geographic position, a problem that cannot be overlooked is the reconstruction of the GPS signal. Today this signal is widely acquired on board during car trip and therefore the correct geolocation of a driving cycle both in terms of latitude and longitude than altimetry is a very interesting issue to be investigated.

Following the general approach, driving cycles have been determined without any conditioning of data respect to road network, but keeping the information on which road the driving data have been detected, when applicable.

Therefore it could be plausible and it must be investigated that the weight of the variables in creating and grouping driving cycles is different depending on their geographical location, especially when realized paths have frequent slope variations that is made up by hills and plains.

So in our approach we define and calculate all the variables, and then we use the most appropriate in the statistical analysis also depending on the path achieved in the experimental phase.

On road tests will be performed in the Naples area with an instrumented car capable to detect and record, car velocity and position, engine parameters and other parameters. Also pollutant exhaust emissions are sampled by a SEMTECH portable analyzer. They are carbon oxide, nitro oxides, hydrocarbons and carbon dioxide (CO, NOx, HC and CO_2 respectively). Driving cycles have been obtained by cutting velocity profile recorded on the road by a heuristic rule based on multivariate statistical analysis of kinematic sequences. Driving cycles are clustered into groups to determine typical and statistical car performance in different roads with different experienced traffic conditions. From each group the most representative cycle is determined by Discriminant Analysis. The selection of the representative driving cycles is a very important issue because emissions measurements in the lab are performed on these cycles.

III. The Experimental Campaign

A Panda Natural Power and the New Fiat Panda Twin Air have been instrumented with a complete Portable Emission Measurement System (PEMs) [6] comprised of gas analyzers, to measure the concentrations of regulated gaseous pollutants in the exhaust gas, an exhaust mass flow meter, a Global Positioning System, sensors to measure the ambient temperature and pressure and a connection with the vehicle ECU.

The main components of the PEM system used in this work are:

- a Semtech gas analyzer produced by Sensor to measure at 1Hz CO, NOx and CO2 emissions. This analyzer uses NDIR cell (Non-Dispersive Infrared) for CO and CO2 measurements, NDUV cell for NO/NO2 and separate electrochemical sensor for oxygen. The analyzer is calibrated on a regular basis and zeroes itself on start-up using outside air.
- a Semtech-EFM (Exhaust Flow Meter) by Sensor.
- an OBD interface and logging computer running proprietary software (EDS) to acquire engine operating parameters (speed, rpm, engine air flow).
- a GPS receiver by Racelogic Ltd to acquire the spatial position (for distance: resolution = 1cm; accuracy = 0.05% - for altitude: 10 m 95% Circle of Error Probable).
- a video camera to record traffic situations.

The measured emissions, the kinematics and GPS data are filtered, synchronized and analyzed using statistical methods. During the experimental campaign, instrumented car performed some missions in the city of Naples, along a traffic busy route. The chosen route is the hilly area of Naples, with varied terrain and sudden changes of slope of about 6 km, as shown in Fig. 1.

Fig. 1 Experimental route: the hilly area of Naples (Google Earth); track with latitude, longitude and elevation profile

Overall, 4 road tests have been performed:

- N° 2 tests with Panda Natural Power;
- N° 2 tests with New Panda Twin air.

IV. Methodology to Analyze Elevation and GPS Profiles

The following Fig. 2 illustrates the general layout of the overall approach. The core of the paper principally concerns the central block, which refers to the reconstruction of the GPS signal with the aim to solve the frequently problems that can arise from the acquisition of this signal in real time [7]-[10]. Also the third block is partially analyzed and described the statistical approach to correlate the emission and consumption values in a specific road position [11]-[13].

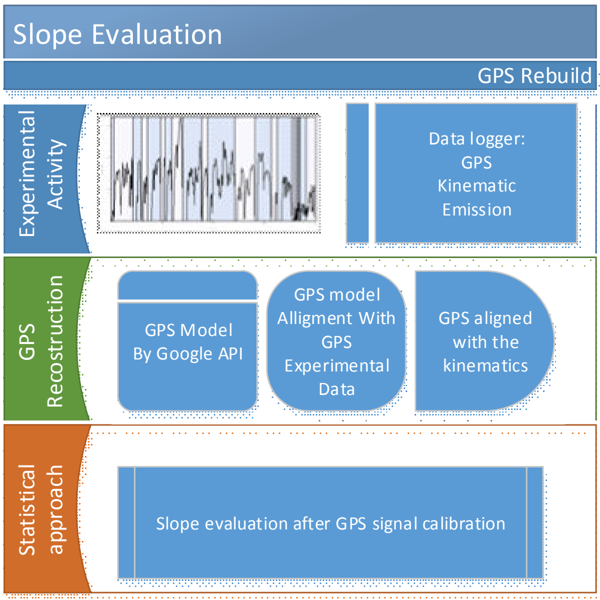


Fig. 2 General layout of the approach

During the review of the data of the GPS signal, the vehicles are equipped with a GPS instrument that returns the values of position and elevation of the path with a 10 Hz frequency. The data for altimetry varies in a range of +/- 10 ms, this change makes it not completely accurate analysis of the slope on the way.

Such errors, for what concerns the coordinates, have occurred in the form of:

- position values sometimes missing;
- misplacement of the vehicle, for example, in areas that are not followed during the journey;
- drift of the position values with the vehicle stationary.

For what concerns instead the elevation errors, they were found:

- changes in short strokes, with slope values are incompatible with reality;
- discrepancies in absolute terms, by comparison with ordinary topographic maps and Google Maps.

So the logical process defined to individuate an algorithm to perform in a mathematical and in an automatic way the signal reconstruction consists of the steps described below. On the first phase, through the Google API (Application Program Interface), we can get the correct map data DTM (Digital Terrain Model) of the theoretical path, on which we performed the real tests. A second phase is to reconstruct accurate geolocation and slope of the vehicle respect to the GPS signal recorded in real use. To this end, a software solution has been implemented in C# .NET, which should facilitate the correction and the filling of the data set of coordinates.

The following part describes the implementation of the approach for the analysis of the identified path as shown in Fig. 3. In the fig. 3 the range of the elevation profile is about between 50 m and 190m.

Fig. 3 Experimental route: Path B: the hilly area of Naples

Figs. 4 and 5 show the graph of Experimental Path (EP) and the Model Path (MP) imported through the realized software. In particular Fig. 4 shows the EP on a latitude and longitude graph. In the analysis of this path problems can be arise due to continuous changes of elevation, signal drift and the presence of tall buildings leading to the loss of the GPS signal.

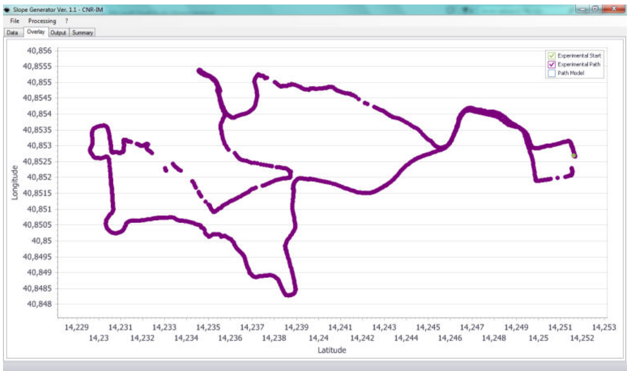


Fig. 4 Lat. vs Long. of the Experimental Path

Fig. 5 shows the graph of the corresponding Model Path used to match and aligns the GPS data of the EP.

Fig. 5 Lat. vs Long. of the Model Path

Fig. 6 shows the elevation profile of the MP obtained through the Google API.

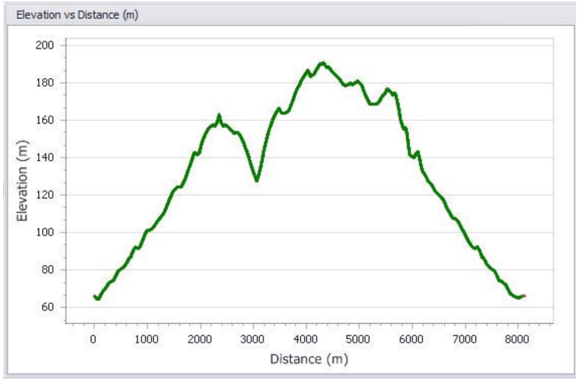


Fig. 6 Elevation profile of the Model Path

We have to take in mind that the elevation profile obtained by Google API, shown in Fig. 6, is speed independent and consequently also the distance calculated. Instead the distance calculated from the real profile is obviously dependent on the speed recorded. Moreover, in the reconstruction phases we must consider that the recorded distance is different from the real one, due to the error of the recorded velocity signal especially in the speed range close to 0. In the data processing we must keep in mind that gap. In fact as shown in Fig. 7 the cumulative distance of EP (red line) is lower than the MP (green line).

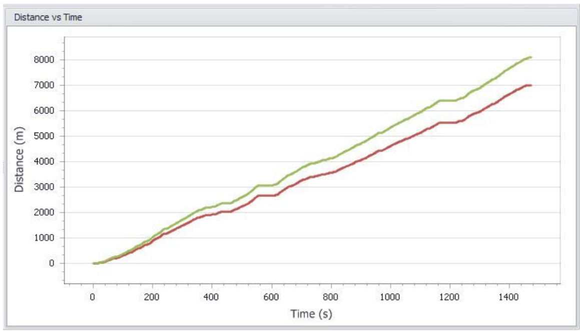


Fig. 7 Elevation profile of the Model Path

Applying the algorithm identified, on the experimental data registered in different days, we can reconstruct automatically, for each trip, all the profiles of the elevations perfectly aligned with the kinematic.

After data processing, which globally consists in several steps based on the identification of the beginning and the end of the EP and MP, scale and realign the EP in relation to the MP model, you can get the correct EP elevation profile (Fig. 8). It is aligned with the kinematics and the real distance traveled by the vehicle (Fig. 9). The proper alignment of the data processing on the Path is especially noticeable, comparing Figs. 8 and 9, when the vehicle is stationary around the second 600 and 1200.

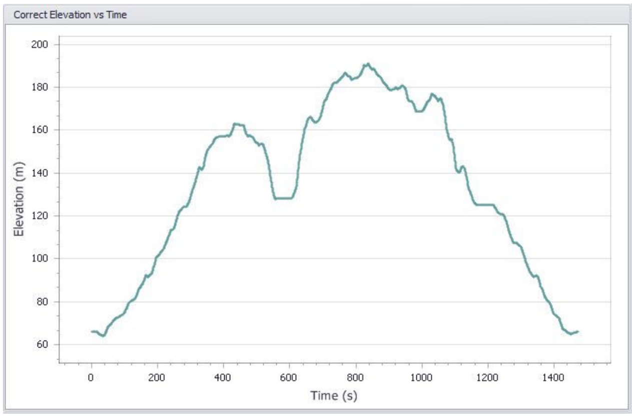


Fig. 8 Correct elevation vs time of the Path

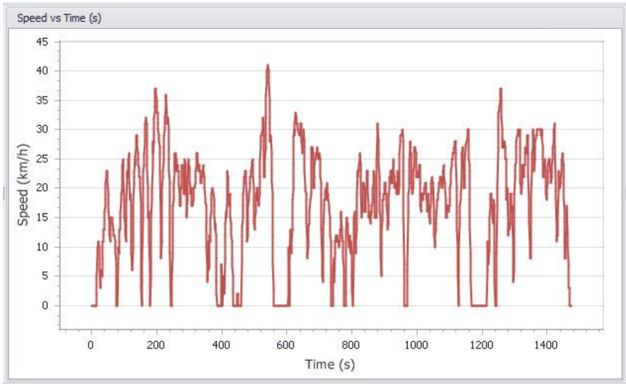


Fig. 9 Speed profile of the Path

V. Statistical Approach

Multivariate statistical analysis is used to perform correlations between vehicle kinematic operating conditions (kinematic sequences) and related measured emissions (mean/total value on a sequence). By these methodologies, the effectiveness of technological measures and/or different vehicle power fuels to improve emissions in real world use is also quantitatively evaluated.

Measured emissions are analyzed either by the instantaneous emissions profile, and/or by making the overall mean for a sequence. As vehicle operating conditions obviously vary continuously as a function of route and traffic, the overall average approach does not allow a precise quantitative evaluation because it does not take into account the vehicle operating conditions. These features could be considered analyzing and characterizing vehicle operating conditions, including also the instantaneous vehicle location. Moreover, on each path there will be streets with different gradients.

The integrated statistical approach is based on the analysis of parts of movements between two successive stops called a kinematic sequence. The sequence consists of an idling part and a running part. So, each of speed profiles is subdivided into kinematic sequences. The kinematic pattern of each sequence is characterized by a number of parameters; the entire set of parameters is a multivariate observation of X variables, statistically defining the sequence. X variables being mutually correlated and very numerous, to better characterize sequences and classify them into homogeneous groups, Principal Component Analysis and Cluster Analysis were utilized.

Vehicle operating conditions are in a first phase described by means of kinematic sequences; these are chosen in such a way that represents analogous conditions of speed and acceleration, taking further account of localization by means of GPS data. A particularly information that it could be investigated in this work is the slope variability along the streets during each journey performed by the instrumented vehicle. Slope is statistically analyzed in order to obtain some variables whose value contributes to the sequences characterization. To each speed sequence, the emissions time series detected at the same time is related.

Before analyzing the data, an accurate synchronization of emissions profile and GPS signal data with the velocity profile was performed. Moreover an accurate procedure was followed (block 2 in Fig. 2) to recover the exact altitude because the elevations coming from the GPS had a margin of error too high to be considered (about 10m).

To characterize the sequence pattern, many variables (k) are utilized to describe different aspects related to idle, acceleration of sequence and slope.

Elevation values are processed getting six variables, DS1-DS3 describing downhill road and DS4-DS6 uphill road, representing the percentage variation relative to the sequence duration. Values that define the ranges of the variables DS1-DS6 in the Table I are derived from the study of the distribution of frequencies of the incremental delta slope.

In the following table variables characterizing sequences are reported.

TABLE I
VARIABLES CHARACTERIZING KINEMATIC SEQUENCE

Variable	Description
mv (km/h)	Mean of running speed (v>0)]
mv2(km2/h2)	Mean of square speed (v>0)
mv3(km3/h3)	Mean of cube speed (v>0)
Tral (s)	idling time v=0 in second
Trunning (s)	total running time (v>0) in second
Dist (m)	distance covered
DS1 (%)	%time with delta slope <-0.70 meters (m)
DS2 (%)	%time -0.70<= delta slope <-0.20 meters (m)
DS3 (%)	%time -0.20<= delta slope <0 meters (m)
DS4 (%)	%time 0<= delta slope <0.20 meters (m)
DS5 (%)	%time 0.20<= delta slope <0.70 meters (m)
DS6 (%)	%time with delta slope >=0.70 meters (m)
Time(s)	Total duration of the sequence (s)
m_vapos (m2/s3)	Mean of instantaneous values of product (a(t)•v(t)) when v(t)>0 and a(t)>0
Paccel1 (%)	%time with acceleration in range [-∞;-1.4] m/s2
Paccel2 (%)	%time with acceleration in range [-1.4;-0.6] m/s2
Paccel3 (%)	%time with acceleration in range [-0.6;-0.2] m/s2
Paccel4 (%)	%time with acceleration in range [-0.2;+0.2] m/s2
Paccel5 (%)	%time with acceleration in range [+0.2;+0.6] m/s2
Paccel6 (%)	%time with acceleration in range [+0.6;+1.4] m/s2
Paccel7 (%)	%time with acceleration in range [+1.4;+ ∞] m/s2

These variables are related to all possible aspects analyzed, both these related to the kinematics and acceleration distributions of the vehicle, than those relating to the variability of the gradient of altitude. In terms of kinematic, they refer to speed and acceleration attributes, time duration and length of driving cycle, idling and driving time.

As a consequence, observations (sequences) must be analyzed utilizing multivariate statistical methods. Since a sequence is represented by a considerable number of variables, mutually correlated, a Principal Component Analysis (PCA) is performed. Each Principal Component tends to characterize different typical features of sequences. Observed sequences are classified into homogeneous groups (clusters) by applying a clustering method, utilizing principal components calculated for each sequence. Kinematic sequences belonging to a cluster have similar patterns, but display within-cluster variability, which is evaluated by statistical criteria.

Discriminant analysis is applied to outline features and reciprocal differences of clusters. Canonical Discriminant Analysis is used to determine which variables discriminate between clusters (groups) of multivariate observations. Functions of these variables are called in the paper Can1, Can2, etc. Plots of the first two canonical variables, give a good two-dimensional representation of observations. The 21 kinematic variables shown in Table I are utilized in the Factor Analysis of sequences. After that the Cluster Analysis is applied and results are illustrated in the Can 1, Can 2 scatter plot (Fig. 10). In this case the sequence clusters are well differentiated in the space of first three canonical variables. Can 1 is correlated with variables that differentiate the cluster's sequences from slow to fast and long time duration, while Can 2 and Can 3 is correlated to variables that explain different gradient of the street. Groups are quite internally homogeneous and well differentiated in terms of mean velocity, distance covered and different percentage of DS1-DS3 (representing sequence realized for most of the time in downhill road) and DS4-DS6 (representing sequence realized for most of the time in uphill road). Cluster 2 and 4 are well differentiated on the third axis Can 3 (not represented in the paper) where the effect of DS1 class is greater.

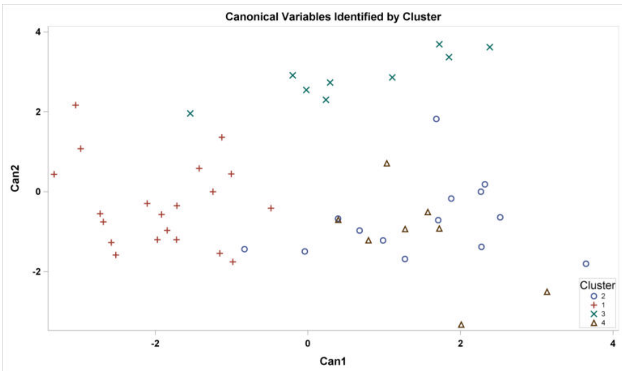


Fig. 10 Cluster representation of sequences

Table II presents the results of some variables of Cluster

Analysis. The 4 road tests are subdivided in 51 sequences, which are grouped in four clusters. For each cluster the table presents mean values of variables most representative, so it is possible to point out fundamental differences in the kinematic features.

Cluster mean values of some original variables (mean velocity, sequence duration, idling time and distance covered) are reported. Cluster 1 represents sequences along the road path mostly downhill with a short distance realized and only for 30% of the time in uphill road part. Clusters 2 and 3 cover about the same distance. They are essentially different because the cluster 2 is mostly downhill (only 10% uphill) while cluster 3 has about 70% uphill. Clusters 3 and 4 have about the same mean speed but cluster 4 is formed essentially by downhill sequences (35% uphill).

TABLE II
CLUSTER MEAN VALUES OF SEQUENCES KINEMATIC VARIABLES

CLUSTER	1	2	3	4
N	20	14	9	8
Tral (s)	11.70	23.86	2.89	3.50
Dist (m)	56.17	494.21	451.45	847.22
mv (km/h)	6.81	16.31	19.98	18.91
mv2(km^2/h^2)	110.81	449.69	478.60	419.20
mv3(km^3/h^3)	1722.19	11800.52	12310.22	9736.90
m_vapos (m^2/s^3)	0.873	0.535	0.716	0.468
Time(s)	29.70	109.07	81.33	161.25
DS1 (%)	27.02	58.46	12.92	12.77
DS2(%)	6.59	19.47	1.00	29.81
DS3(%)	35.77	10.91	8.45	21.35
DS4(%)	26.21	5.76	30.08	25.39
DS5(%)	4.41	4.19	40.96	10.38
DS6(%)	0.00	1.64	6.11	0.38

In Fig. 11 an overlay of representative sequences profile of each cluster is shown. The kinematic characteristics are consistent with the values of Table II.

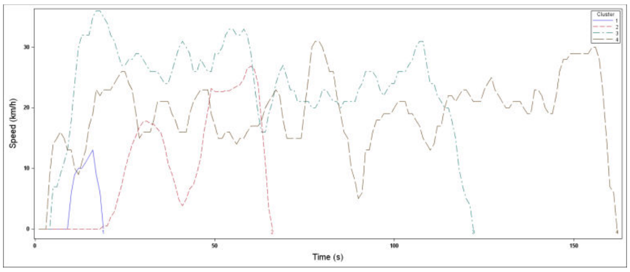


Fig. 11 Speed profile overlay of representative sequence for each cluster

VI. EMISSION RESULTS AND DISCUSSION

The time series of each regulated emission acquired during each trip is split into sequences. CO_2 and fuel consumption (FC) are expressed in g/s, CO and NO in mg/s. Correlation analysis between a kinematic sequences and the corresponding emission sequence is performed in the same traffic situation (determined by cluster) and same GPS location. A trend analysis is performed via the visualization of emission instantaneous profile and kinematic sequences for each cluster.

Fig. 12 reports a GPS (a) and the elevation profile (b) of a trip with colour related to the identify cluster, that is uphill road, flat road, downhill road. In particular the road path characteristics are well related to cluster characteristics reported in previous table.

Moreover in Fig. 13 pollutant emissions (a, b, c) and FC (d) profiles relative to the same trip are shown. Time series of CO_2, NO, CO, and FC are coloured according to cluster sequences road characteristics. We have to consider that this result is not a qualitative one but it is obtained by statistical cluster analysis of succession of sequences. Here it's possible to note that at similar kinematic conditions (i.e. mean speed) in all sections of road we have different emission profile. This confirms the importance of the variable slope in emission evaluation in real use analysis. In particular the identified experimental path is well-balanced in terms of slope with an average uphill of 6.9%, while downhill has an average gradient of 6.5%.

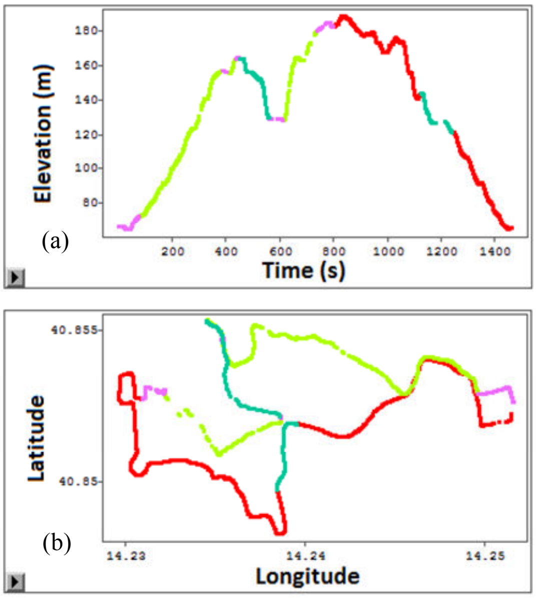
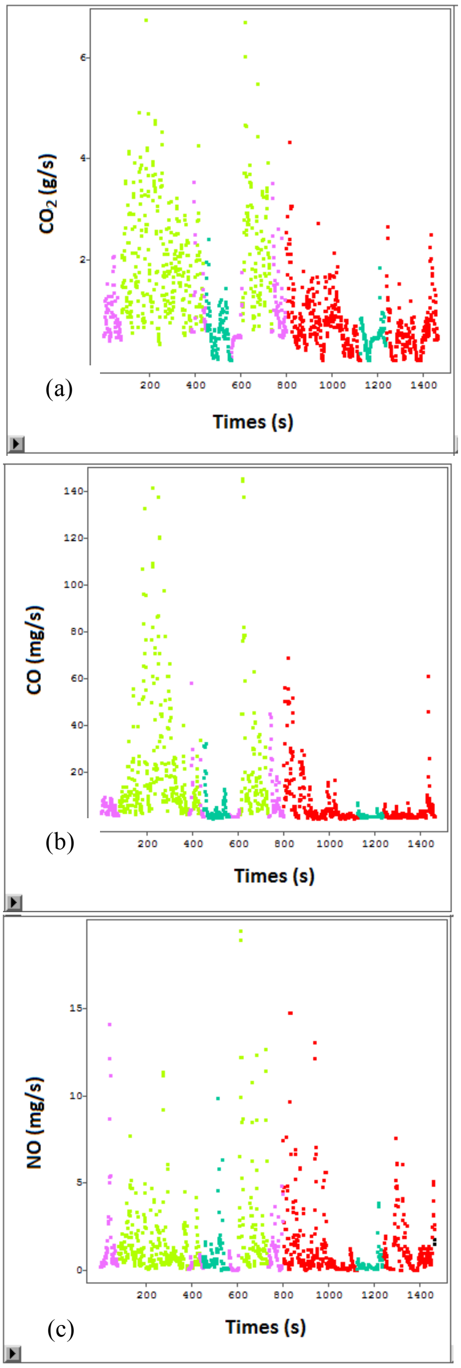


Fig. 12 (a) GPS profile of a trip coloured according to cluster; (b) Elevation profile of the same trip



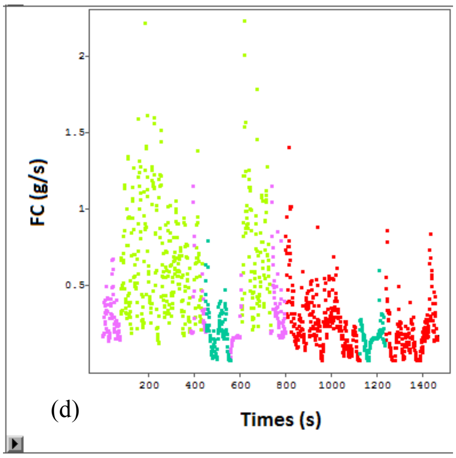


Fig. 13 (a), (b), (c) Emissions and (d) fuel consumption profile of a trip coloured according to cluster.

In Table III, to better underline and quantify difference due to cluster of sequences and their characteristics, mean velocity (*mv*), mean of each emission and FC are summarized for each cluster. Also the maximum emission values are recognized in cluster 3, probably due to kinematics sequences high percentage of uphill phase. Although it shows the same mean velocity, a strong reduction effect for each emission could be evidenced in cluster 4, formed essentially by downhill sequences. Emission reduction are stronger for CO emission, but also clearly stated for NO and CO_2. Regarding cluster 2 emission mean values, they are slightly more than cluster 4; it presents also a lower average speed and a very high value of idling time. The same consideration could be made for fuel consumption. Cluster 1 represents sequences along the road path mostly downhill with a short distance and it shows minimum values for each emission and also for fuel consumption.

TABLE III
CLUSTER MEAN VALUES OF SPEED, EMISSIONS AND FUELS CONSUMPTION

Cluster	mv (km/h)	CO_2 (g/s)	CO (mg/s)	NO (mg/s)	FC (g/s)
1	6.81	0.8344	3.8576	0.8856	0.2708
2	16.31	1.4306	6.2474	0.9761	0.4640
3	19.98	1.9556	19.1960	2.1640	0.6397
4	18.91	0.9547	5.3890	0.9511	0.3103

VII. CONCLUSION

The aim of this activity is to compare fuel consumption and emissions on road during real world experimental tests, in order to identify some characteristics of road that strongly influence emission production. Moreover this paper seeks to give a contribution to on-board measurements, in different geographical areas, with PEMS using a statistical methodology. The methodology allows to characterize cars operating conditions in different trip zones and to define groups of sequence in clusters with typical kinematic pattern. Experimental data are subdivided in sequences, which are grouped in cluster, so it is possible to point out fundamental differences in the kinematic features. Particularly attention is given to the construction of appropriate variables to characterize the slope variation along the road path after the reconstruction of the GPS signal. Through the statistical approach we identified four clusters which group the kinematic sequences in a very characteristic way, showing the goodness of the procedures and the variable definition.

The approach followed in this paper allowed us to evaluate the emissions trend with two cars gasoline fuelled on a particular path road characterized by uphill and downhill gradient variability. Results show an influence of this street feature on emissions and fuel consumption.

ACKNOWLEDGMENT

This activity research is realized within a national scientific project PON01_00744 DRIVE IN2, partially supported by the Italian Ministry for University and Research (project PON01_00744 DRIVE IN2). It was carried out by the Istituto Motori of the National Research Council.

REFERENCES

[1] Andrè, M. Joumard, R. Vidona, R. Tassela, P. Perret, P., "Real-world European driving cycles, for measuring pollutant emissions from high- and low-powered cars". Atmospheric Environment, 40 (31), pp. 5944-5953, 2006.
[2] Joumard, R. André, J.M. Rapone, M. Zallinger, M. Kljun, N. André, M. Samaras, et al "Emission factor modelling and database for light vehicle". Artemis deliverable 3. Inrets report, Bron, France, n°LTE 0523, p. 237, 2007.
[3] Rapone M., Prati M.V., Meccariello G., Della Ragione L., Costagliola M.A., A Novel Statistical Model For The Evaluation Of Vehicle Emission Factors. Application To A Euro III Gasoline Car Fleet, Proceedings 7th International Conference On Engines For Automobile. Ice2005. Capri, Naples. September 2005. Sae Paper 2005-24-024.
[4] André M. "Real-world driving cycles for measuring cars pollutant emissions - Part A : The Artemis European driving cycles". INRETS report, Bron, France, n°LTE 0411, 97 p., 2004.
[5] Merkisz, J., "Real Road Tests – Exhaust Emission Results From Passenger Cars", Journal of KONES Powertrain and Transport, Vol. 18, No. 3, 2011.
[6] Weiss, M., Bonnel, P., Hummel, R., Urbano, M., Colombo, R., Lanappe, G., Le Lijour, P., Sculati, M.,"Analyzing on-road emissions of light-duty vehicles with Portable Emission Measurement Systems (PEMS)", JRS scientific and Tecnical Reports, EUR 24697 EN - 2011, ISBN 978-92-79-19072-8.
[7] Della Ragione L., Meccariello G., Costagliola M.A., Prati M.V., Statistical evaluation of slope's effect on real emissions and fuel consumption performed with different cars in Naples urban area, TRA Transport Research Arena 2014 Conference, Paris, April 2014
[8] Boriboonsomsin K., M. Barth1 (2009). Impacts of Road Grade on Fuel Consumption and Carbon Dioxide Emissions Evidenced by Use of Advanced Navigation Systems. Journal of the Transportation Research Board, Volume 2139 / 2009, Pages 21-30
[9] Frey H.C., K. Zhang, N.M. Rouphail (2008). Fuel Use and Emissions Comparisons for Alternative Routes, Time of Day, Road Grade, and vehicle Based on In-Use Measurements. Environ. Sci. Technol. 2008, 42, 2483-2489
[10] Hong S. Bae1, Jihan Ryu and J. Christian Gerdes (2005). Road Grade and Vehicle Parameter Estimation for Longitudinal Control Using GPS. Proceedings, Annual Meeting of the Air & Waste Management Association, June 20-23, 2005, Minneapolis, MN
[11] Meccariello, G., Della Ragione, L., Prati, M., Costagliola, M. et al. (2013). "Real Time Emissive Behaviour of a Bi-Fuel Euro 4 SI Car in Naples Urban Area," SAE Int. J. Fuels Lubr. 6(3):2013, doi:10.4271/2013-24-0173.
[12] Meccariello G., Della Ragione L., Costagliola M.A., Prati M.V (2012). Evaluation of Emission Factors for New Technology S.I. Euro 4 Cars. Journal of Computing and Information Technology 20(3), 217-224.
[13] SAS/STAT, SAS/GRAPH, SAS/INSIGHT Software Version 9.3 (http://www.sas.com).

G. Meccariello graduated in 1999 in economics from the University of Naples "Federico II" (Italy). He received his PhD in 2005 from the Department of Transportation Engineering "Luigi Tocchetti" of the University of Naples "Federico II" (Italy). He is a researcher of vehicle performance and emissions for sustainable transportation at Istituto Motori of National Research Council of Italy. His research field of interest includes statistical and soft computing methods for modeling driving cycles and emissions of vehicles in real-use, with special concern for vehicle mission profile in urban areas and exhaust emissions evaluation. He is involved in the development of models for vehicular emission factors determination based on measurements of pollutant emissions. He is a developer in c# .net Framework. He is, also, working with SAS System, particularly in the field of multivariate statistical analysis with SAS/STAT and SAS/GRAPH.

L. Della Ragione graduated in 1988 in mathematics from the University of Naples "Federico II" (Italy). Presently, she is a researcher of CNR-IM Her main research activities concern the environmental impact of vehicles. Her principal areas of interest include multivariate statistical analysis and time series analysis. The main research subjects are vehicle mission profile in urban areas and the development of methods for the evaluation of exhaust emissions as a function of vehicle operating conditions in the traffic. In this context she has developed some statistical codes applied to determine driving cycles by vehicle speed records in the traffic obtained by instrumented cars performing planned. Also she is involved in the development of models for vehicular emission factors determination based on measurements of pollutant emissions. Dr. Della Ragione is responsible for research group working on "Statistical methods for driving cycle modelling and emission factors development".