# Preliminary results on emission and driving behaviour of ATENA fleet test project in Naples

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## ABSTRACT

One of the objectives of the Atena project [1] was the definition of a methodology for the predictive evaluation of the environmental impact of different types of vehicles used in an urban scenario.

The target is to obtain a methodology that allow the decision maker to verify in simulation the effects of possible measures like low enforcement to the access restrictions or vehicle fleet composition.

The main obstacle is the realisation and the managing of real driving cycles in order to that overtake the limits derived from the utilisation of typical cycles (i.e. ECE o NEDC) or the simple consideration of average speed.

The starting point is a digital representation of the urban network where all the roads are represented with one or more arcs and for all this arcs is available an estimation of the traffic variables like the vehicle flow [vehicles per hour] or the average speed [kph]. Every arc is described in terms of traffic parameters like the type of road (i.e. highway, district road).

The results presented in this work will be the starting point for the definition of one methodology to describe the emissions of vehicles fleets in terms of traffic parameters.

## INTRODUCTION

The methodology requires the identification of a set of driving cycles linked statistically to the traffic variables. This set is used for the emission characterisation of a vehicle during his mission from one generic starting point to a generic target point.

It has to be taken in account that the actual technology doesn't allow a practical on board measure of pollutants, so it was necessary to measure the emissions on the chassis dynos.

Apart the transport variables, it has taken in account other two variables: the slope effect that is relevant in terms of engine load and the temperature that is important to monitor the so called light-off temperature of the catalytic converters.

## METHODOLOGY

The aim of this analysis is to evaluate the emission of cars under urban traffic condition. The methodology applied in order to do this, in part original and in part derived from literature, is composed of the following phases:

- data acquisition
- subdivision of each trip into 'cinematic sequences' (speed vs. time curves between subsequent stops)
- characterisation of sequences in term of statistical parameters and classification of sequences into well-differentiate classes
- identification of cycles like part of a trip homogeneous in term of engine or transportation parameter
- classification of cycles and individuation of representative cycles
- analysis of the use of the different type of cycles
- emission measurements

DATA ACQUISITION – A statistical approach required a good experimental database. In this case the Atena project presented an ideal scenario due the utilisation of an experimental fleet of 55 ICE vehicles, 30 sedan FIAT Marea Bi-Power and 25 SUV Fiat Multipla derived. Every vehicle is equipped with an on-board telematic system that allow the data acquisition of engine, vehicle and geographic variables, the memorisation end the transmission to a control station using a store-and forward methodology. The data acquisition system was unattended. The data acquisition is switched on automatically at the engine start. The acquisition ends at the following key-off. Every acquisition covers a specific mission of the vehicle and it was possible, due the acquisition rate up to 2 Hz, the data store up to 8 hours of missions.

The vehicles were used from personnel of Naples municipality to supply public utility services. The amount of space travelled (near 1.500.000 Km) and the time (more than 3 years) gave to the researchers a good coverage of the Naples City.

DATA MANAGING –The data stored in the on board system were periodically forwarded to the control station when the on board memory is occupied more than 50%. The native format is compressed and crypted, sent to the ground station via the GSM cellular network.

A specific software will convert data in order to be compatible with commercial SW like SAS™ o Matlab™ applications.

Due the unattended process, it was possible the acquisition of non-relevant missions (i.e. service manoeuvres), so this missions were skipped using a specific a cleaning process.

ANALYSIS OF SEQUENCES - Each test (velocity vs. time profile) has been divided in cinematic sequences where cinematic sequence indicate the speed vs. time curve between successive stops (speed = 0). The stop time is always reported at the beginning of the sequence. In Fig. 1 it is reported an example of sequence.

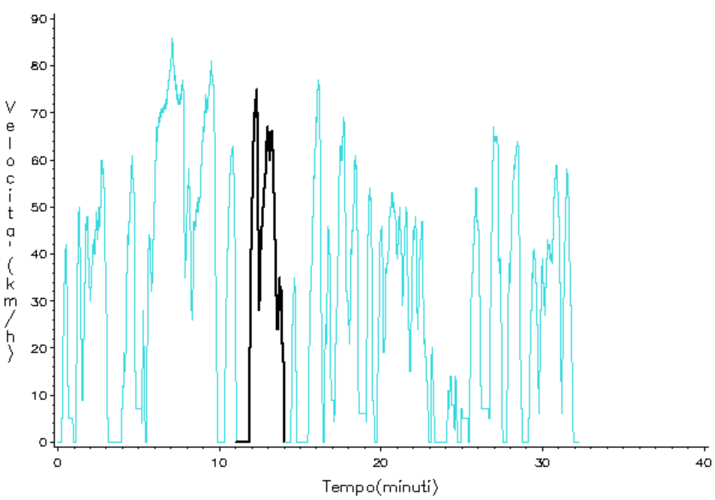



**Fig. 1 – Sequence example**

CLUSTERING OF SEQUENCES - A first step of the analysis is to find well-differentiated and homogeneous group of sequences. In order to do this it is important the definition of a set of parameters on which define 'similar' or 'different' two sequences.

For this scope three big categories of variables are available:

- engine
- transportation
- cinematic

Obviously there are some superimposition between this group of parameters and the choice of the variables to be used is very important and linked to the specific aim of the analysis.

The cinematic variables used in order to characterise the sequences are linked to the profile executed on chassis dynamometer and to the functionality of motor. Some examples of these variables are:

- average speed, running speed;
- stop duration, driving duration, percentage of time with constant speed;
- acceleration and deceleration mean;
- standard deviation, different percentiles on running speed, acceleration and deceleration;
- percentage of time in different range of velocity;
- percentage of time in different gears and in other vehicle mode.

After some preliminary studies on the considered variables, it has been applied a principal component analysis that permitted to find few variables, linear combination of the previous one and perpendicular each other, that explain a big amount of the total variance.

In this space, the application of clustering algorithms (non-hierarchical and hierarchical) permitted to find homogeneous groups of sequences. This group has been described using cinematic aspects (also with graph obtained with multivariate analysis) and founding the sequence that represents the cluster itself. A 'discriminant analysis' permits also to assign other sequences not considered in clustering analysis.

DETERMINATION OF CYCLES - The next point is the choice of the methodology to apply in order to identify 'cycles'.

The "cycle" has to be, for definition, a set of successive sequences that could be considered a "unique" because homogeneous and, at same time, enough long to evaluate the emissions.

The overall methodology was applied with two approaches:

- without polarisation of sequences.
- with sequence clustering polarised in terms of
  - characteristics of the road: type, capacity and slope
  - traffic condition

CLUSTERING OF CYCLES - The cycles has been studied in order to find well differentiated and homogeneous group of cycles.

The methodology applied at this scope is similar to the one applied for clustering sequences:

- identification of the variables

- principal component analysis
- clustering of the cycles
- discriminant analysis

Also in this case, the choice of the variables is linked to the aim of the project and some used variables are:

- total time, driving time
- number of sequences
- travelled distance
- average speed
- mean of acceleration and deceleration
- sequences belonging to the cycles

In the next tables are reported some statistic for the cycles obtained with both the approaches.

| *Cluster* | *Name* | *Seq.* | *%* | *Space* | *Time* | *Av.* |
|---|---|---|---|---|---|---|
| 1 | Medio | 13371 | 29 | 10524 | 685 | 15 |
| 2 | Medio | 9099 | 20 | 6198 | 308 | 20 |
| 4 | Lungo | 7675 | 17 | 18801 | 711 | 26 |
| 3 | Stop & go | 4100 | 9 | 444 | 64 | 7 |
| 7 | Lungo | 3723 | 8 | 10450 | 299 | 35 |
| 6 | Micro | 3550 | 8 | 182 | 39 | 5 |
| 8 | Soste | 2043 | 4 | 1194 | 195 | 6 |
| 5 | Stop & go | 1833 | 4 | 377 | 28 | 13 |
| 9 | Veloce | 1010 | 2 | 10216 | 191 | 53 |

**Table 1 – Traffic polarised clusters**

| *Cluster* | *Length [m]* | *Time wit speed > 0 [h]* | *N. sequences* | *Time with acc>0,15 m/s2* | *Vmax / time* |
|---|---|---|---|---|---|
| 20 | 522,7 | 44,9 | 73,7 | 1,7 | 0,5 |
| 11 | 33,6 | 19,1 | 1,3 | 7,0 | 0,9 |
| 14 | 21,2 | 44,4 | 1,3 | 61,6 | 0,8 |
| 13 | 542,6 | 60,8 | 16,7 | 11,7 | 0,6 |
| 8 | 113,7 | 60,6 | 3,0 | 14,8 | 0,6 |
| 16 | 40,3 | 50,0 | 1,3 | 6,6 | 0,9 |
| 5 | 427,0 | 65,5 | 6,8 | 18,6 | 0,6 |
| 9 | 92,3 | 84,8 | 1,3 | 10,4 | 0,8 |
| 15 | 245,6 | 2,9 | 1,3 | 37,6 | 0,6 |
| 7 | 481,4 | 15,5 | 1,4 | 23,8 | 0,6 |
| 10 | 237,7 | 82,9 | 1,3 | 139,1 | 0,7 |
| 19 | 866,8 | 3,9 | 1,9 | 15,3 | 0,6 |
| 6 | 446,6 | 87,9 | 1,2 | 22,5 | 0,6 |
| 17 | 12,4 | 10,7 | 1,2 | 19,0 | 15,8 |
| 3 | 1288,8 | 92,0 | 1,4 | 48,5 | 0,4 |
| 2 | 4213,0 | 94,1 | 2,1 | 39,4 | 0,3 |
| 1 | 2815,9 | 96,7 | 1,0 | 130,6 | 0,2 |
| 4 | 7962,8 | 97,0 | 1,2 | 180,3 | 0,2 |
| 12 | 18245,7 | 96,7 | 1,6 | 238,6 | 0,2 |
| 18 | 52,8 | 10,8 | 1,1 | 24,1 | 60,1 |

**Table 2 – Non polarised clusters**

REPRESENTATIVE CYCLES AND TECHNICAL CYCLES - For each group of cycles it has defined a representative cycle that represents the cluster itself.

Using the result of 'discriminant analysis' performed on the cycles and Euclidean distance in the space of the principal component three criteria have been used to choose the cycle that better represents its group:

- the 'a posteriori' probabilities obtained by discriminant analysis;
- the group-specific density estimate obtained by the discriminant analysis;
- the distance from the centre of group in the space of the principal components.

A group of relevant representative cycles are presented in appendix (Fig. 8 to 13); in fig. 14 to 16 are reported the overall data of cycles in terms of vehicle behaviour.

The technical cycles to be repeated on the chassis dynamometer have been obtained from these cycles repeating them a different number of times in order to have cycles enough long in order to evaluate the emissions with good approximation.

## BENCH TEST

The emission evaluation of the synthetic cycles was carried out on the test bench. The execution of these non-conventional cycles required a specific programming of its control SW for the generation of speed profile (Driver Aid).
After this first phase it has been carried out the practical feasibility on the test bench with the utilisation of two vehicles; at the end of the process it was verified successfully the correctness of the speed reproduction with an acceptable number of violations.
The test bench has also the capability of the emulation of the vehicle speed wind with the utilisation of a variable speed fan that reproduces the road environment.

The entire test was carried out after a pre-heating cycle in order to obtain an acceptable temperature of the catalyst. Finally, every test was repeated from 2 to 12 times in order to stabilise the results and obtaining a relevant number of samples bags.

During the bench test the vehicle on board acquisition system was operative in order to acquire the engine variable.

After the test, the following emission values have been elaborated:

- Carbon monoxide (CO)
- Carbon dioxide ($CO_2$)
- Total Hydrocarbon (HC)

- Nitrogen oxides ($NO_x$)

## EMISSION RESULTS

In appendix are reported the emissions results of the more relevant representative cycles. In fig. 17 for CO, in fig. 18 for HC, in fig. 19 for NOx and in fig. 20 for $CO_2$.

The emissions were carried out from Methane use on the Marea vehicles and expressed in g/km.

It has to be taken in account that the values showed are relative to non-normalised cycles for vehicles that respect the Euro 2 (Dir. 96/69) normative.

## BENCH-FIELD VERIFY FOR ENGINE VARIABLES

It has been developed a comparison between the engine variables obtained developing the bench test and the engine variable obtained from the vehicle field test; particularly it has been worked with engine speed and manifold pressure in the different cycles.

This analysis is interesting because allow a preliminary validation of the statistical approach that carried out the definition of representative cycles and their emissions.

It has been pointed out a substantial coherence between the engine parameters acquired with the on board system during the field tests and what obtained from the bench test. It is possible achieve that the process followed for the individuation and execution of representative cycles fits with the real engine utilisation.

It is reported the positioning of cycles from road or test bench in terms of the two first dimensions carried out by the correspondence analysis applied to the contingency table derived from the use of:

- on the 18 row the type cycle and the acquisition place (road/bench);
- on the 64 columns the manifold pressure (MAP) classes and the engine speed;
- in the intersection the number of acquisition type related, acquisition place, cycle type, acquisition place, MAP class and engine speed.

In this map, that covers 94% of the data variability, are indicated with a red star the road test and with a blue dot the bench test ones; on the side the cycle identificator.

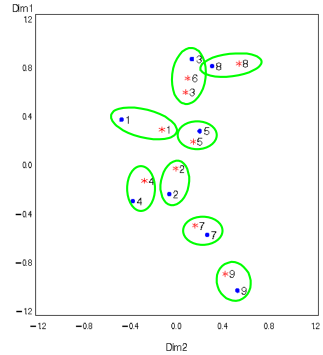



**Fig. 2 – Bench-road verify**

Fig. 2 shows the evidence that the same cycle performed with the vehicle on the road or on the test bench carries out a similar performance in terms of principal variables.

## TRANSFERABILITY OF METHODOLOGY TO OTHER URBAN AREAS

Particularly interesting from the transport point of view is the link between cycle clusters and transport variables.

The statistical activity in this framework can be substantially synthesised in the following steps:

- Determination of external condition types (traffic level, slope, type and street capacity) with the major relevance.
- Classification of similar missions types (road and traffic) and individuation of the relevant transport condition.
- Transport condition characterisation on cycle basis in term of space travelled.

In the second phase has been applied multivariate methodologies (correspondence analysis e cluster analysis) starting from the contingency table with on the rows the cycle types and on the columns the possible cross-links for street type, capacity and traffic level.
It has been defined the following groups of type/capacity.

| Group | Street | Capacity (class) |
|---|---|---|
| 1 | INTERQUARTIERE | 1 |
| | QUARTIERE | 1 |
| | QUARTIERE | 2 |
| | QUARTIERE | 3 |
| | SCORRIMENTO | 1 |
| 2 | INTERQUARTIERE | 2 |
| | INTERQUARTIERE | 3 |
| | QUARTIERE | 4 |
| | QUARTIERE | 5 |
| | SCORRIMENTO | 2 |
| 3 | INTERQUARTIERE | 4 |
| | INTERQUARTIERE | 5 |
| | QUARTIERE | 6 |
| | QUARTIERE | 7 |
| | QUARTIERE | 8 |

| Group | Street | Capacity (class) |
|---|---|---|
| | QUARTIERE | 9 |
| | QUARTIERE | 10 |
| | SCORRIMENTO | 3 |
| | SCORRIMENTO | 4 |
| 4 | INTERQUARTIERE | 6 |
| | INTERQUARTIERE | 7 |
| | INTERQUARTIERE | 8 |
| | SCORRIMENTO | 5 |
| 5 | INTERQUARTIERE | 9 |
| | INTERQUARTIERE | 10 |
| | SCORRIMENTO | 6 |
| | SCORRIMENTO | 7 |
| | SCORRIMENTO | 8 |
| | SCORRIMENTO | 9 |
| | SCORRIMENTO | 10 |
| 6 | AUTOSTRADA | 1 |
| | AUTOSTRADA | 2 |
| | AUTOSTRADA | 3 |

**Table 3 – Transport conditions**

The intersection with traffic levels determines the 12 transport conditions considered.

For each class it has been carried the percentage in terms of space travelled.

The utilisation of these percentiles and the related emissions is the base for the transferability to other urban areas.

## NON POLARISED CLUSTERS

A relevant contribution to the state of art can be given by the analysis of data made available by ATENA telematic system. In fact, besides data detected by the fleet of different technology vehicles, data relative to vehicle flow in several crossings of Naples road network are detected and sent to the central station for data storage. This fact allows one to put in relation vehicle performance characterised by driving cycles with traffic characteristics assessed by vehicle flow in the same road where driving cycles were performed. In the following figures an example of analysis aiming to develop this relationship is given. In the figure 3 are represented the starting points of driving cycles, performed by the Fiat Marea car in a micro zone of Naples centre, are localised by means of GPS latitude and longitude data detected on the road and represented in a lat/long diagram. In the figures 4, 5, 6 and 7 the data relative to the driving cycles are reported as well as vehicle flows detected in the Viale Gramsci road outlined in the figure 3. In particular for driving cycles performed in Viale Gramsci during one year of fleet operation, frequency histograms of clusters, starting point time, and mean velocity are shown. Vehicle flows refer to a short period of one week and are just reported (with a polynomial curve fit and 95% confidence prediction interval) as an example of data and analysis, which are currently acquired and carried out.

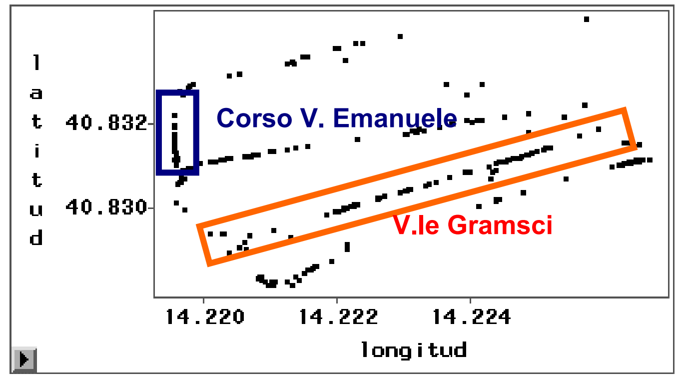
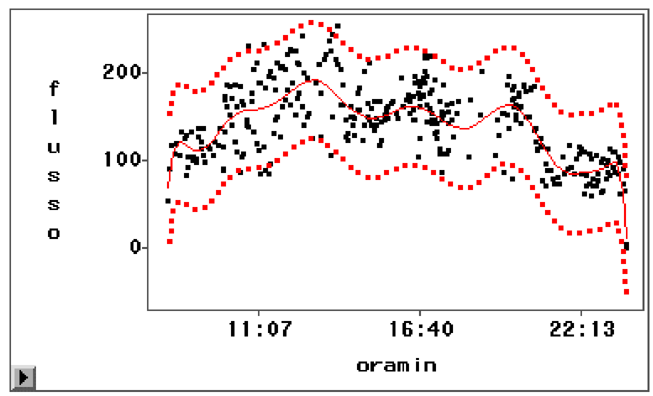



Fig. 3 – Localisation of starting point - zone 113

Fig. 4 – Time diagram of vehicle fluxes in viale Gramsci – direction P.zza Sannazzaro



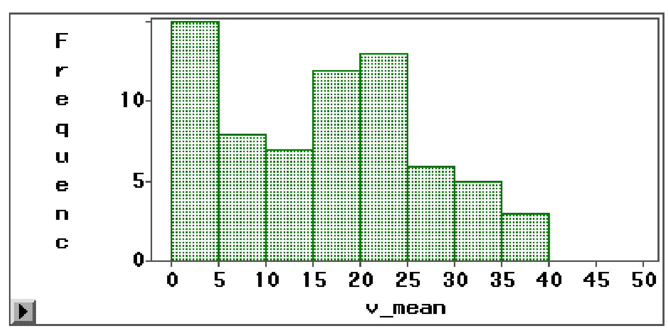




Fig. 5 Distribution of average speed in the cycle

Fig. 6 – Initial time distribution

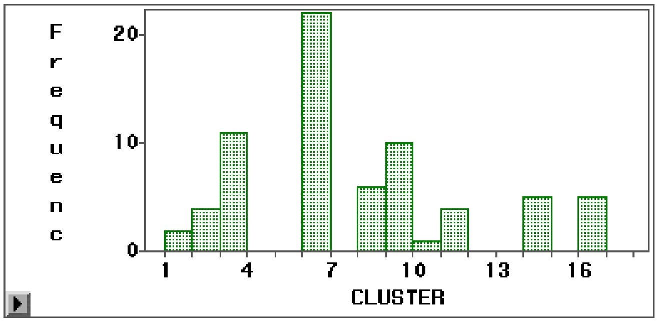
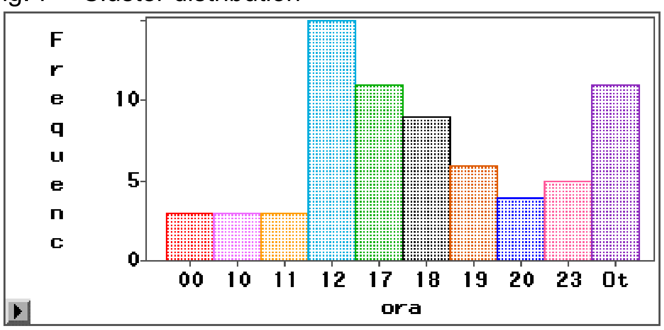



Fig. 7 – Cluster distribution




## CONCLUSIONS

It has been synthesised some representative driving cycles from the statistical analysis of real behaviour in the Naples City.

The evaluation of emissions of the emission has been carried out at the test bench with the repetition of representative cycles.

The methodology was applied with two types of approach: non-polarised clustering and transport polarised clustering.

It has been verified the good fitting between engine variables from field missions and test bench values, in accord with obtained in a previous work applied in the past [6,7] carried out by CRF on behalf of Emilia Romagna region (Italy). The difference between the Naples application and Emilia application was the fact that the vehicle fleet in Naples was free to travel, instead in Emilia there was the use of fixed missions.


## ACKNOWLEDGMENTS

The project was managed by the City of Naples and developed by Fiat Auto, Fiat Research Centre, Elasis, CSST and with the collaboration of the Engine Institute of CNR (Italian National Council Research) and University of Naples.

The Italian Ministry of Scientific Research and Development as well as the European Community granted the project.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## DEFINITIONS, ACRONYMS, ABBREVIATIONS

**SUV** Sport Utility Van

**ICE** Internal Combustion Engine

**CRF** Centro Ricerche FIAT

**MAP** Manifold air pressure

## APPENDIX

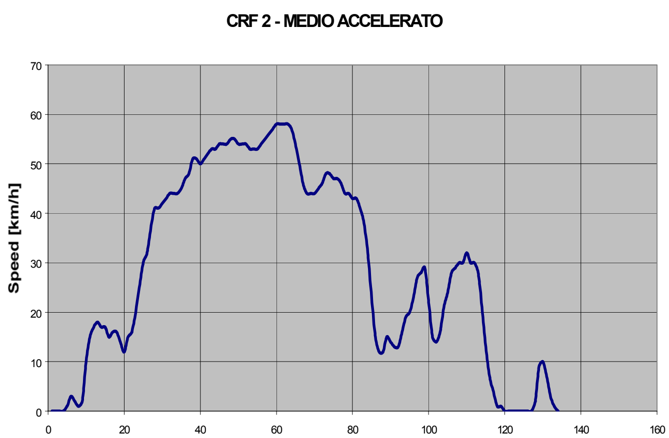



Fig. 8

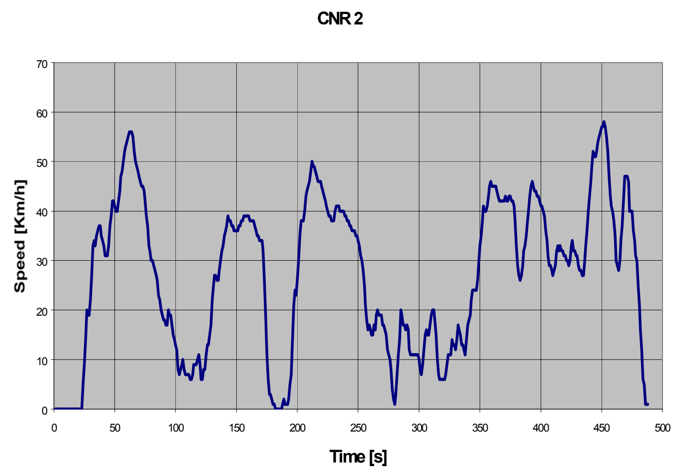



Fig. 9

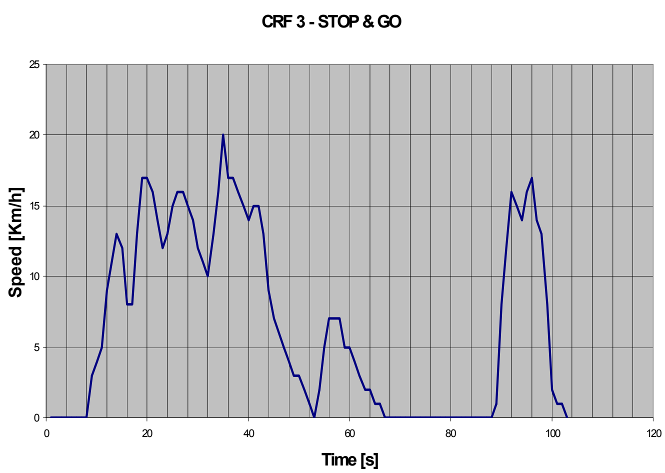



Fig. 10

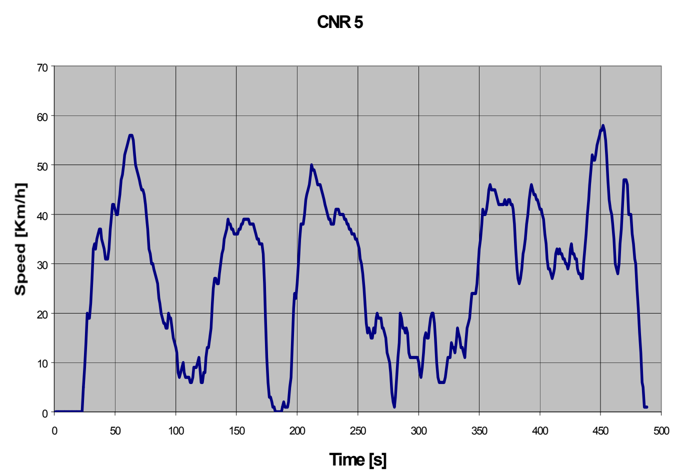



Fig. 11

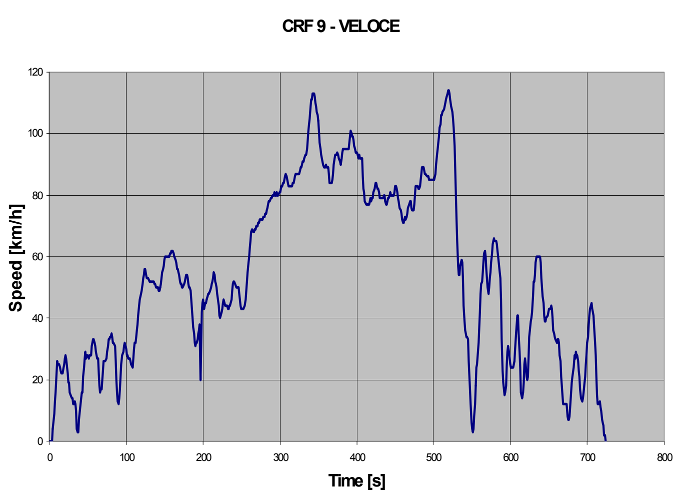



Fig. 12

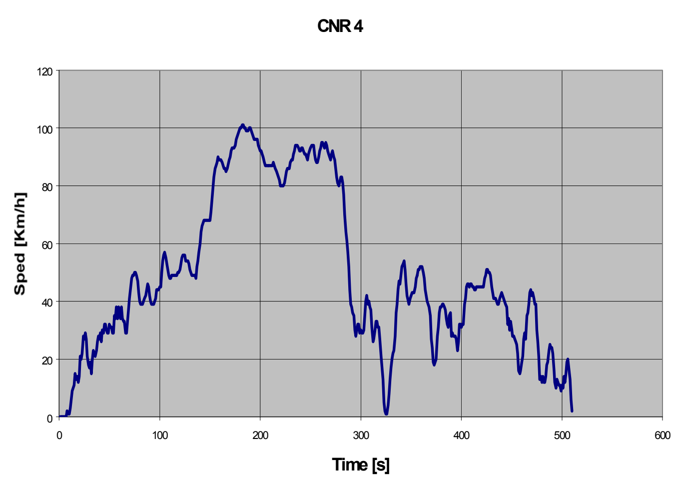
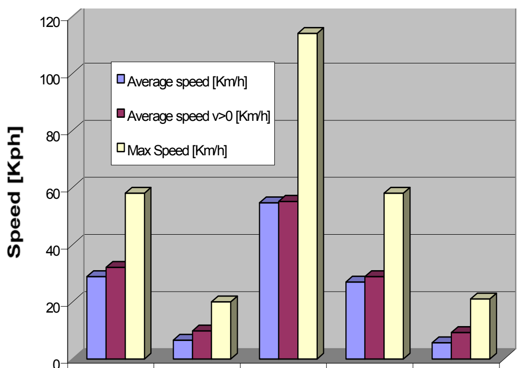
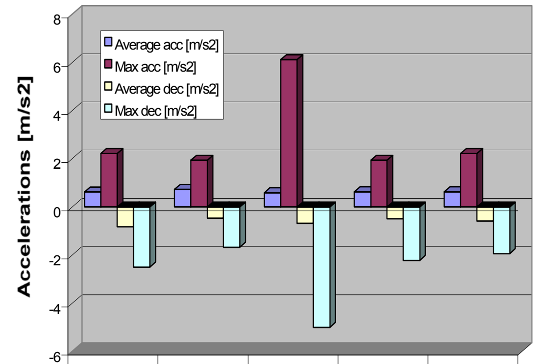



Fig. 13



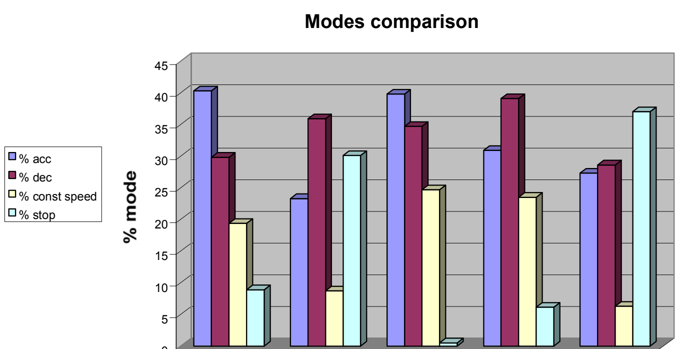

| | CRF 2 | CRF 3 | CRF 9 | CNR 2 | CNR 5 |
|---|---|---|---|---|---|
| Average speed [Km/h] | 28,8 | 6,6 | 54,7 | 26,9 | 5,7 |
| Average speed v>0 [Km/h] | 32,1 | 9,8 | 55,2 | 28,8 | 9,2 |
| Max Speed [Km/h] | 58 | 20 | 114 | 58 | 21 |

Fig. 14 – Speed comparison




| | CRF 2 | CRF 3 | CRF 9 | CNR 2 | CNR 5 |
|---|---|---|---|---|---|
| Average acc [m/s2] | 0,62 | 0,73 | 0,59 | 0,63 | 0,63 |
| Max acc [m/s2] | 2,22 | 1,94 | 6,11 | 1,94 | 2,22 |
| Average dec [m/s2] | -0,82 | -0,46 | -0,67 | -0,5 | -0,58 |
| Max dec [m/s2] | -2,5 | -1,67 | -5 | -2,22 | -1,94 |

Fig. 15 – Acceleration / deceleration




| | CRF 2 | CRF 3 | CRF 9 | CNR 2 | CNR 5 |
|---|---|---|---|---|---|
| % acc | 40,3 | 23,3 | 39,8 | 30,9 | 27,3 |
| % dec | 29,8 | 35,9 | 34,7 | 39,1 | 28,6 |
| % const speed | 19,4 | 8,7 | 24,7 | 23,5 | 6,3 |
| % stop | 8,9 | 30,1 | 0,5 | 6,13 | 37 |

Fig. 16 – Cycles modes comparison

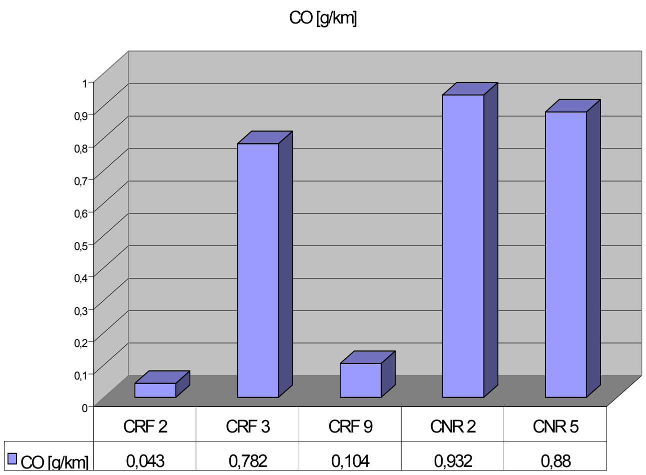



Fig. 17 – CO emissions

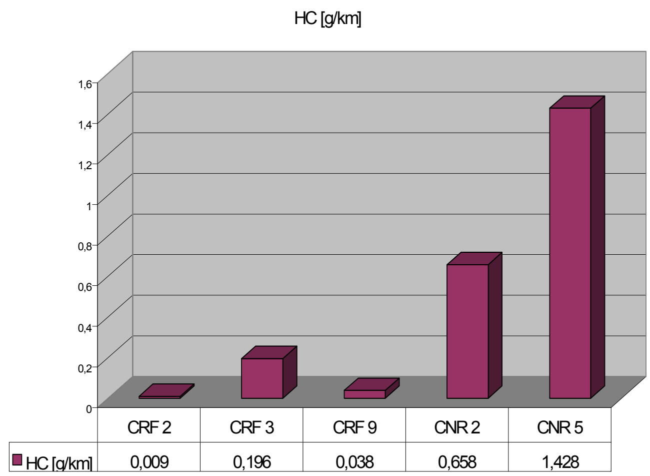



Fig. 18 – HC emissions

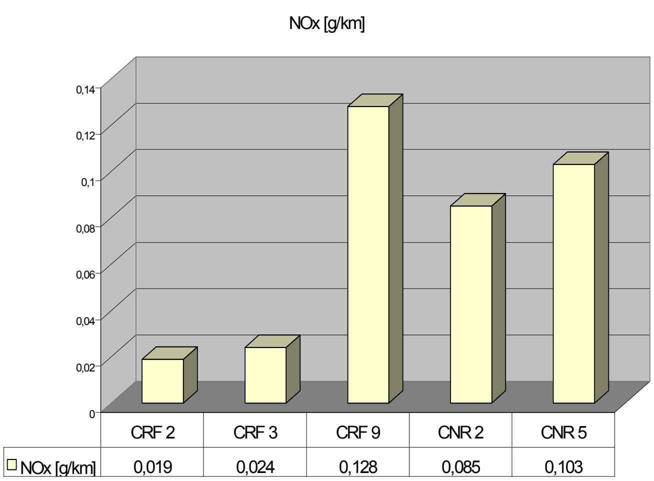



Fig. 19 – NOx emissions

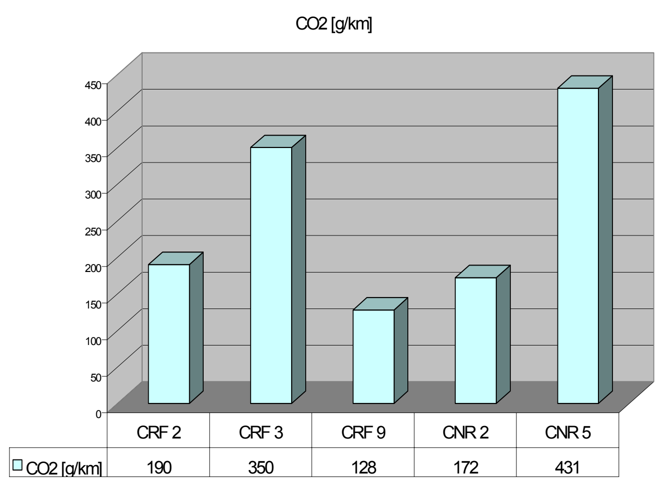



Fig. 20 – CO emissions