Urban Driving Cycles for Greece

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Abstract

The development of real world Driving Cycles using traffic data from Athens was carried out in the Laboratory of Fuel Technology and Lubricants, NTUA. The target of this project is the examination of the impact of the specific driving profiles of vehicles moving in the Greek cities on fuel consumption and exhaust emissions. These driving cycles have already been used to evaluate the behaviour of alternative and renewable fuels, in previous works carried out by the authors. Other applications are the tests on new technological advances (hybrid, start-stop) and vehicle efficiency. The methodology of constructing the driving cycles for this work is part of a greater project which included the development of methodologies for driving cycle construction and is described in a previous work carried out by the authors. Data were collected using sophisticated electronic equipment and Matlab was used for the processing and the construction of the final driving cycles. In this work's frame several driving cycles were produced in order to compare certain parameters. The Greek Urban Driving Cycle (GUDC) for passenger cars was directly compared with a same duration motorcycle driving cycle which was developed for that purpose. The comparison reveals great differences in driving speeds and other main characteristics of the cycles. GUDC was also compared with other passenger car driving cycles. The Greek Urban Driving Cycle for Motorcycles (GUDCM) was developed according to a duration that is needed for a motorcycle to cover the same distance as the passenger car, according to their measured average speeds. A significant parameter when developing a real world driving cycle for a specific city or area is whether the road gradient is included in the bench test. Road gradient can be included in the results by incrementing to mean values of positive and negative acceleration. In the present work road gradient is included in the GUDCM. Another cycle that uses the true average values of accelerations and therefore does not include road gradient was developed suggesting that its lower travelling speeds were the result of the uneven topography of Athens.

Introduction

In order to evaluate the environmental impact from vehicle emissions, researchers have developed Driving Cycles (DCs) used for laboratory chassis dynamometer emission testing. DCs are speed-time profiles simulating the driving conditions in a city road network. Emissions from vehicles constitute the main source of air pollution in urban areas. Major and continuous infrastructure interventions, expanding transportation network, atmospheric pollution problems, energy conservation and sustainability issues together with the car fleet changes such as vehicle number, technological evolution, fuel specifications as well as driving behaviour, affect the travelling speed profile of the vehicles and impose the need for the continuous examination and update of the driving patterns of an area as far as passenger cars DC are concerned. This composite movement of the vehicles results on driving profiles that consists of a complicated series of accelerations, decelerations and frequent stops. Those driving characteristics are responsible for increased fuel consumption and exhaust emissions and limited efficiency of emission control systems in vehicles.

Other factors directly associated with driving conditions are road network topography and driving style. Uphill driving is aggravating for the engine and contributes to increased fuel consumption and exhaust emissions as more power is needed for the vehicle. Aggressive driving also results in reduced efficiency of the emission control systems of cars (Gense, 2000; OECD, 2004; Tzirakis et al., 2007). In addition, motorcycles constitute a significant share of vehicle fleet in southern European countries and especially Greece. Due to their differences in speed profiles compared to cars, driving cycle development for motorcycle emission testing is considered essential (Leonga et al., 2002; Chen et al., 2003).

There are two major categories of DCs, legislative and non-legislative. According to legislative driving cycles, exhaust emission Specifications are imposed by governments for the car Emission Certification. The New European Driving Cycle (NEDC) is used for laboratory test

approvals in the EU. It is based on traffic data from European capitals (Paris and Rome) consisting of constant accelerations, decelerations and travelling speeds. FTP-75 used in the USA and the 10-15 used in Japan. Non-legislative cycles such as the Hong Kong driving cycle (Tong et al., 1999), and the Athens Driving Cycle (ADC 2002) (Tzirakis et al., 2006) are a useful tool in research for energy conservation and pollution evaluation through the vehicle testing on exhaust emissions and fuel consumption (Lyons et al., 1986; Simanaitis, 1977) as well as in the field of vehicle design tooling and marketing (Watson et al., 1982). The real world DC of the Artemis project includes real driving data from many European cities (Andre, 2004). There are also numerous real world DCs developed throughout the world cities, mostly for passenger vehicles and rarely for motorcycles (Chen et al., 2003) so that researchers in universities and organizations can apply them for dynamometer emission testing. Since 'Real world' driving cycles reflect more accurately the urban driving conditions, they support research on fuel behavior comparison, alternative and renewable fuels (i.e. Biodiesel), fuel reformulation, fuel additive development engine modification and for testing on new technological advances (hybrid, start-stop) and vehicle efficiency (Karavalakis et al., 2010). Comparison of results from chassis dynamometer tests with NEDC and 'Real World' driving cycles based on traffic data from European and non-European cities showed significant differences in emission and fuel consumption levels (Karavalakis et al., 2007; Ergeneman et al., 1997). Each city has a unique driving profile and the collected traffic data result in a different driving cycle depending on characteristics such as the road network, the driving behavior and the vehicle fleet potentiality and number (Andre et al., 2006).

There are two ways of developing a driving cycle. One is composed from various driving modes of constant acceleration, deceleration and speed (like the NEDC and ECE), and is referred as modal or polygonal (Kuhler and Karstens, 1978). The other type is derived from actual driving data and is referred as "real world" cycle. Such cycles are the FTP-75 and the ADC. The real world cycles are more dynamic, reflecting the more rapid acceleration and deceleration patterns experienced during on road conditions. Researchers describe in their work the methodology of constructing a driving cycle using on-road data. The methodologies include techniques such as the chase car method with instrumented vehicles, route selection or complete road network coverage of specific areas and cycle construction where a large number of road data specification, meets the corresponding specification of the cycle. Since the beginning of driving cycle development scientists were using the available technology to log and process on-road data from moving vehicles in order to conclude to a representative result (DC). A number of its characteristics should meet in the largest percentage possible, the corresponding characteristics of the on road data. Several methods were developed by scientists, in order to conclude to a driving cycle from a set of road data. Sometimes the process was in extend of the whole trip a vehicle was performing and some others in extend of its micro trips. W.T. Hung and others describe the Hong Kong cycle construction methodology (Hung et al., 2007).

Methodology

The methodology of constructing the driving cycles for this work is part of a greater project which included the development of methodologies for driving cycle construction and is described in a previous work carried out by the authors. Modern electronic equipment and information technology (IT) was used to collect driving data and road gradient.

For a general work frame, the peculiar area of Athens was selected for the collection of on-road data with the aid of instrumented vehicles. The procedure followed for the development of DCs comprises of three major components, the logging technique, the route or area selection and the cycle construction methodology. The first two components are described in authors' previous work (Tzirakis and Zannikos 2011).

Matlab programming was adopted to develop the method for the statistical processing of the road data and the development of the final real world DCs, (Tzirakis et al., 2008). Figure 1 on the next page, shows the flow diagram of the method that was implemented for the development of Driving Cycles presented in this paper. A capable number of phases were selected from each group according to their duration starting from the mean value of the duration of each group. The number of phases selected depends upon the accuracy and the number of the input criteria and the capability of the computer used to do the combinations. The selected phases are then used for a very large number of combinations, which depends on the number of the groups and phases selected from each group, which are performed in order to have the desired result of which the basic characteristics (input criteria) will be as close to the

characteristics of the road data as possible. The basic criteria where based upon a number of average values of the on-road data which must agree with those of the final cycle. Those criteria are: % stop time, % positive acceleration, % negative acceleration, average speed without the stops, average positive acceleration and average negative acceleration.

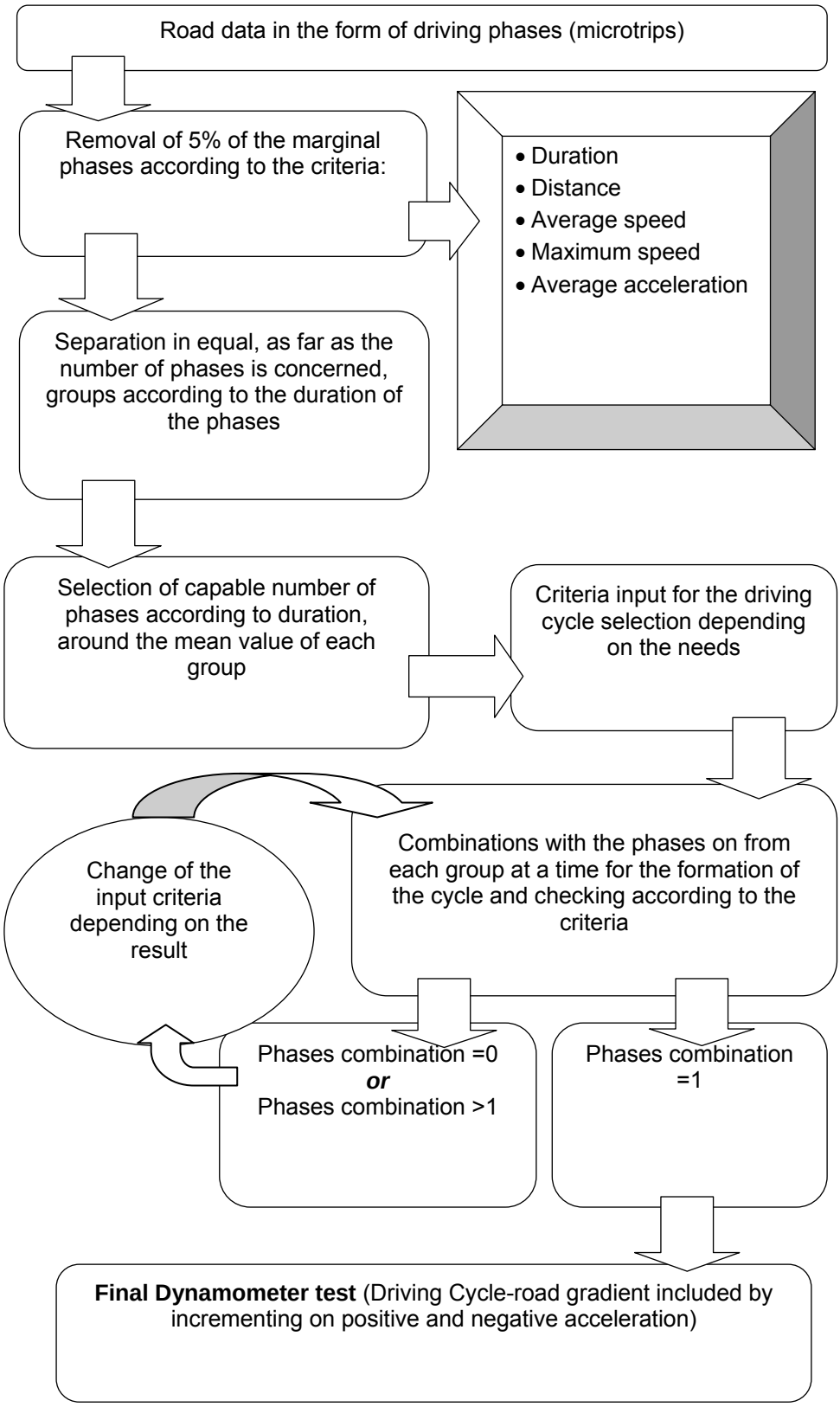

Figure 1: Flow diagram of the method used for the construction of the driving cycles.

A significant parameter when developing a real world DC for a specific city or area is whether the road gradient is included in the bench test. DCs are usually developed assuming that test vehicles are driven on zero gradient and therefore, when a vehicle is tested on a chassis dynamometer it is assumed that it is driven on a flat road. In cases where the topography plays a significant role on the speed profile of the vehicles, it is essential that the road gradient is included in the final dynamometer test, through the DC.

Road gradient is included in the results by incrementing to mean values of positive and negative acceleration and gives accurate results even though the accelerations are changed in order to include road gradient. The additional acceleration (α_{add}) that a vehicle wastes when driven on an inclined road could be easily calculated. It is the component of acceleration of gravity parallel to the road surface:

$\alpha_{add} = g\ (H_2-H_1)/d$

Where g is the acceleration of gravity, d is the distance covered for 1 second (data logging interval=1Hz) and H_2-H_1 is the altitude difference between the logs.

Results

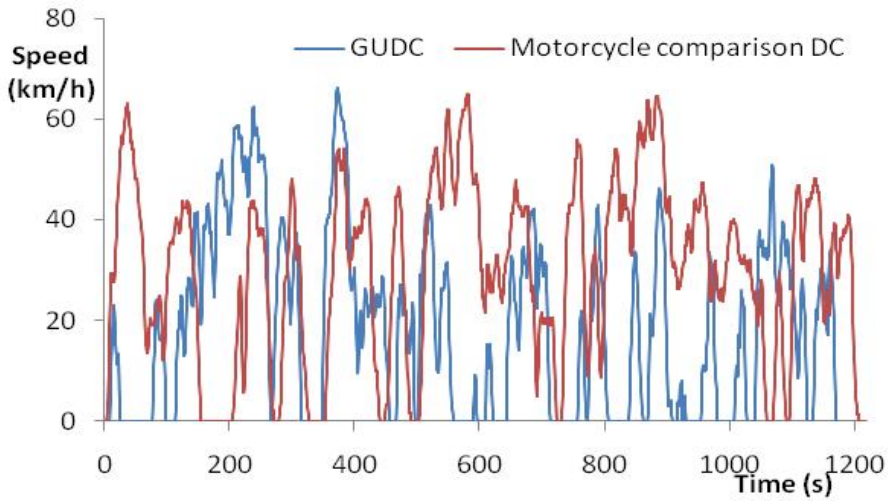

Figure 2. GUDC for passenger cars vs. a motorcycle DC.

Table 1. Comparison between GUDC and other DC.

	GUDC	Motorcycle comp.DC	Athens 2002	NEDC	Artemis Urban	ECE-15	Hong Kong
Duration (s)	1175	1217	1160	1180	993	195	1548
Average speed (kmh^{-1})	18.67	29.1	20.21	33.6	17.65	18.4	25
Average speed-no stops (kmh^{-1})	27.31	34.06	27.17	44.8	24.66	26.5	30.4
Stop (%)	31.66	12.16	25.6	25.42	28.4	30.8	17,8
Time %-positive acc.	34.04	38.21	36.21	20.93	34.64	21.5	34.5
Average positive acc. (ms^{-2})	0.692	0.555	0.668	0.726	0.732	0.642	0.593
Distance (m)	6094	9837	6512	11007	4870	990	10330
Driving phases (microtrips)	20	9	16	13	22	3	11

Several driving cycles were produced in order to compare certain parameters. Figure 2 shows the Greek Urban Driving Cycle (GUDC) for passenger cars. For comparison purposes a

motorcycle DC was developed using nearly the same duration. For 1175 seconds the average value of stops for the motorcycle was 8.62. Assuming that the stops are 9, the duration of the motorcycle DC for comparison purposes should be 1217s. While top speed is not very different between the two cycles, significant differences can be seen in the travelling speeds. In addition to that, the main characteristics of the two cycles shown on table 1 greatly support the differences between the two types of transportation within a city. For almost the same duration the distance covered by the motorcycle is 1.6 times higher. Microtrips are only 9 against 20 of the passenger car and positive acceleration is lower due to increased travelling time.

It should be mentioned that the characteristics of GUDC are close to those of ADC 2002 and Artemis driving cycles. The percentages in the brackets on table 2 denote the accuracy of the resulted driving cycle characteristics compared to the average values of the collected on road data. The characteristics of the developed GUDC meet the corresponding values of the on road data in percentages that exceed 98.5%.

Table 2. Comparison of GUDC characteristics with the corresponding of the collected on road data.

Characteristic	Data Average Values	GUDC
Duration(s)	1180	1175(99,58%)
Moving time (s)	805	803(99,75%)
Average speed (km/h)	18,94	18,67(98,57%)
Stop time (%)	27,76	27,31(98,84%)
Positive acc. time (s)	31,76	31,66(99,69%)
Negative acc. time (s)	400	400(100%)
Average positive acc. (ms-2)	421	421(100%)
Average negative acc. (ms-2)	0,686	0,692(99,13%)

The Greek Urban Driving Cycle for Motorcycles (GUDCM) was developed according to a duration that is needed for a motorcycle to cover the same distance as the passenger car, according to their measured average speeds. Figure 3 shows GUDCM compared to a DC developed without taking into account the road gradient. When road gradient is included through acceleration the cycle is more aggressive resulting in higher travelling speeds. The program chooses lower travelling speed phases when constructing the non gradient driving cycle as the average positive and negative accelerations are smaller.

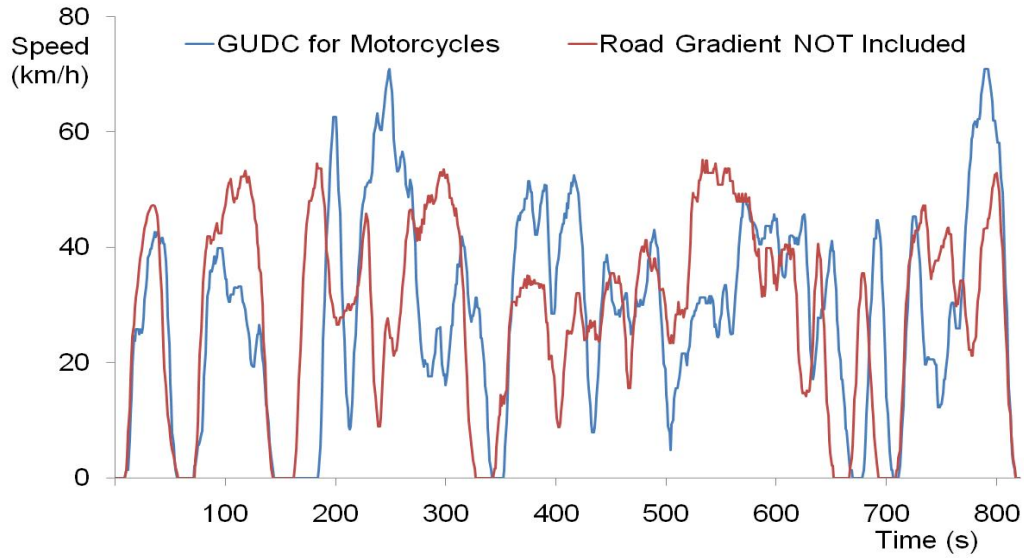

Figure 3. GUDCM compared to DC with no road gradient taken into account.

Table 3. Comparison table of GUDCM and a DC without taking into account the road gradient.

Characteristic	Data Average Values	GUDCM	DC-No Road Gradient included
Duration(s)	822	822(100%)	822 (100%)
Moving time (s)	723	723(100%)	723 (100%)
Average speed (km/h)	29,04	28.86 (99.38%)	29.05 (99.96%)
Stop time (%)	12,07	12.04 (99.75%)	12.04 (99.75%)
Positive acc. time (s)	312	313 (99.68%)	311 (99.68%)
Negative acc. time (s)	300	299 (99.67%)	299 (99.67%)
Average positive acc. (ms-2)	0.6045 (0.5398)	0.6065 (99.67%)	0.5411 (99.76%)
Average negative acc. (ms-2)	0.6497 (0.5598)	0.6349 (97.72%)	0.5629 (99.45%)

In the data average column on table 3, the values of acceleration in the brackets are those estimated from the true recordings of speed. The increased values of acceleration are those that include the road gradient calculated as described in the methodology section. Accuracy for GUDC is even higher than GUDC exceeding in all occasions the percentage of 99%. The methodology used suggests that the accuracy of the result increases as the amount of data increase.

Conclusion

Comparing the passenger car and motorcycle driving cycles, significant differences can be observed in almost all of their characteristics which are in favour of the motorcycle. Average speed is nearly 1.6 times higher than the corresponding of the passenger car. Travelling speeds are in some cases similar. However, the distance covered by the motorcycle for the same period of time is unbeatable due to the limited stops.

One of the most important parameter that affects driving pattern and therefore exhaust emissions and fuel consumption is the road gradient. This is a typical characteristic of a Greek city topography and road network. In this work, road gradient was taken into account when developing the DCs, in terms of positive and negative acceleration. This acceleration comprehension results in a more aggressive DC.

More criteria could be added in the program in order for the resulting driving cycles to be more representative in relation to the characteristics of the road data. Real world driving cycles are extremely useful for environmental and technico-economic applications and need to be constantly and frequently updated through new road data recordings, set by the changes in traffic conditions which are the result of the development of road networks, the growing and change of the car fleet, the traffic adjustments or the changes in driving behavior, in order to be reliable and to meet up to date traffic conditions.

References

Andre M, R. Joumard, R. Vidon, P. Tassel, P. Perret (2006), Real-world European driving cycles, for measuring pollutant emissions from high- and low-powered cars, *Atmospheric Environment,* 40, 5944–5953.

Andre M. (2004), The ARTEMIS European driving cycles for measuring car pollutant emissions. *Science of the Total Environment*, 334 & 335, 73–84.

Chen K.S., W.C. Wang, H.M. Chen, C.F. Lin, H.C. Hsu, J.H. Kao, M.T. Hu (2003), Motorcycle emissions and fuel consumption in urban and rural driving conditions, *The Science of the Total Environment,* 312, 113–122.

Ergeneman M., C. Sorusbay, A. Goktan (1997), Development of a driving cycle for the prediction of pollutant emissions and fuel consumption, *International Journal of Vehicle Design*, 18, 391-399.

Gense N.L.J. (2000), Driving Style, Fuel Consumption and Tail Pipe Emissions, *TNO Automotive,* March, Delft.

Hung W.T., H.Y. Tong, C.P. Lee, K. Ha, L.Y. Pao (2007), Development of a practical driving cycle construction methodology: A case study in Hong Kong, *Transportation Research Part D*, 12, 115–128.

Karavalakis G., E. Tzirakis, F. Zannikos, S. Stournas, E. Bakeas, N. Arapaki, A. Spanos (2007), Diesel/Soy Methyl Ester Blends Emissions Profile from a Passenger Vehicle Operated on the European and the Athens Driving Cycles, *SAE 2007 Transactions, Journal of Fuels and Lubricants,* ISBN: 978-0-7680-1983-4, ISSN: 0096-736-X, SAE Paper, Ref No 2007-01-4043.

Karavalakis G., E. Tzirakis, S. Stournas, F. Zannikos, D. Karonis (2010), Biodiesel Emissions from a Diesel Vehicle Operated on a Non-legislative Driving Cycle, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1556-7230, 32, 4, 376–383.

Kuhler M, D. Karstens (1978), Improved driving cycle for testing automotive exhaust emissions, *SAE Technical Paper*, Series 780650.

Leonga S.T., S. Muttamaraa, P. Laortanakul (2002), Influence of benzene emission from motorcycles on Bangkok air quality, *Atmospheric Environment,* 36, 651–661.

Lyons TJ, J.R. Kenworthy, P.I. Austin, P.W.G. Newman (1986), The development of a driving cycle for fuel consumption and emission evaluation. *Transportation Research 20A,* 6, 447-462.

OECD (2004), Can Cars Come Clean? – Strategies for Low-Emission Vehicles, *OECD Publications,* 2 rue Andre Pascal 75775 Paris, Cedex 16, ISBN-92-64-10495-X.

Simanaitis D.J. (1977), Emission test cycles around the world, *Automotive Engineering,* 85, 34-43.

Tong H. Y., W.T. Hung, C.S. Cheung (1999), Development of a driving cycle for Hong Kong. *Atmospheric Environment*, 33, 2323-2335.

Tzirakis E, A. Kyriakidis, F. Zannikos (2008), Methodologies for driving cycle development, using on-Road data from Athens, *Proceedings of: Transport Research Arena Europe,* Slovenia.

Tzirakis E, K. Pitsas, F. Zannikos, S. Stournas (2006), Vehicle Emissions and Driving Cycles: Comparison of the Athens Driving Cycle (ADC) with ECE-15 and European Driving Cycle (EDC), *Global NEST Journal,* 8, 3, 282-290.

Tzirakis E., F. Zannikos (2011), Development of passenger car and motorcycle driving cycles for Athens, *Proceedings of the 12th International Conference on Environmental Science & Technology,* 242.

Tzirakis E., F. Zannikos, S. Stournas (2007), Impact of driving style on fuel consumption and exhaust emissions: defensive and aggressive driving style, *Proceedings of the 10th International Conference on Environmental Science and Technology*, 1497-1504.

Watson H.C., E.E. Milkins, J. Braunsteins (1982), The development of Melbourne peak cycle, *SAE-A and ARRB Traffic Energy and Emissions Conference,* 82148.