ANALYSIS OF A DRIVING CYCLE PROPOSED FOR BRASOV CITY

Dinu Covaciu, Ion Preda, Daniela Florea, Janos Timar, Ovidiu-Vasile Câmpian

Transilvania University of Braşov, Romania

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ABSTRACT - A driving cycle is a standardised driving pattern, described by means of a velocity-time table. The typical driving profile comprises accelerations, decelerations and stops and it is simulated by software or on a laboratory chassis dynamometer. The European Driving Cycle is the common reference in Europe, but this cycle could not describe satisfactorily the driving characteristics in every urban area. In this paper is proposed a new driving cycle for Brasov city, based on real data collected using instrumented vehicles. The proposed cycle is a transitory one and it is compared with other known urban driving cycles, as global parameters. The pollutants emissions of a reference car, driving the proposed cycle and the European Urban Driving Cycle, were also compared.

The onboard data acquisition equipments were GPS devices. The collected data covers typical roads of the city. It was developed a dedicated CAD software tool for data analysis and for identification of the driving patterns. The support of the application is AutoCAD and the programming language used is AutoLisp.

INTRODUCTION

A driving cycle consists in a series of data representing a speed versus time variation. Usually, the driving cycles are used as standard conditions for testing vehicles performances, like fuel consumption and emission level. Some cycles are established theoretically, others are determined experimentally, based on measurements of driving characteristics and identification of driving patterns [3]. There are two types of driving cycles: transitory and modal. A modal driving cycle includes longer periods of constant speed driving. A transitory cycle has many changes in speed and is representing more realistic the vehicle behaviour. As examples, in *figure 1* are shown the New European Driving Cycle (NEDC) and the cycle FTP-75 used in USA. The first is a modal cycle and the second is a transitory one.

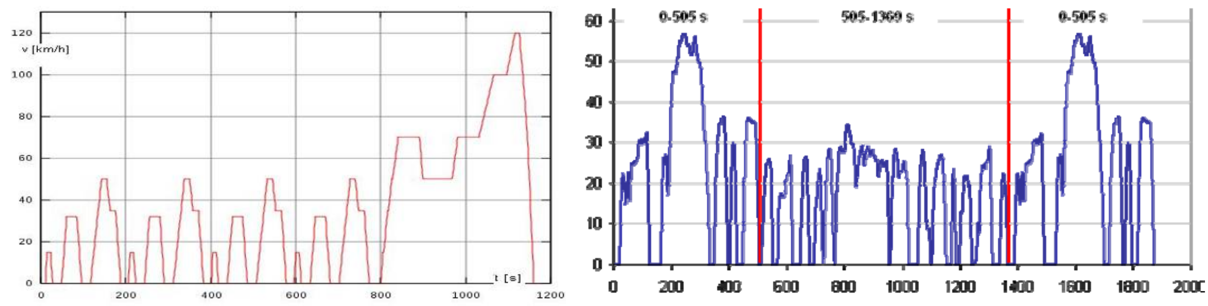

Fig.1 – New European Driving Cycle (left) and FTP-75 cycle (right)

A transitory cycle simulates much closer the vehicle behaviour than a modal cycle. A particular driving cycle can be considered as a characteristic of the road traffic in a certain area, like a city. Based on this idea, many particular driving cycles were developed for particular urban areas, based on statistics [9].

The main parameters of a driving cycle are: duration, distance, average speed and maximum speed and can give good indications about the nature of the cycle. But adding the mean values of positive and negative accelerations, the cycle can be characterised even better.

METHOD FOR A DRIVING CYCLE DEVELOPMENT

Basically, the process of a driving cycle development implies [2]:

- collecting the representative driving data (speed, time) using one or more vehicles equipped with data acquisition devices;
- analysis of data that describes the driving conditions;
- development of one or more driving cycles, representative for existent driving conditions, based on recorded speed and, in some cases, accelerations, starting conditions, gear changes, temperatures or loads.

Collecting the required data means recording the variation of speed versus time, then a statistical processing in order to identify a representative pattern. The most used methods for collecting data are [5]:

- the *chase car* protocol – a car equipped with a range-finder laser system collects second-by-second speed/time profiles from target vehicles assumed to represent typical driving behaviour;
- the *instrumented vehicle* protocol – speed sensors are installed on vehicles and the travel speed of each instrumented vehicle is recorded; the vehicle should follow the traffic flow.

A modern version of the instrumented vehicle protocol is represented by the use of GPS devices [10]. Using GPS devices for road traffic study presents some important advantages:

- the existence of a very precise and universal time information;
- the existence of three-dimensional position data;

The position and time information can be used to obtain other useful information as height, slope, velocity and acceleration.

Having the real driving data collected, an important and difficult issue is to identify a representative pattern that can be associated with the driving cycle for the studied area (city, region or highway). There is not a general scheme for analysis of heterogeneous data collected on different tracks. An effective method is by using the fuzzy logic [8]. Basically, the records of each track are split in short sequences that will be compared to each other. These sequences, represented as speed/time diagrams, are similar to signal pulses and are called *driving pulses*. An example is shown in *figure 2*.

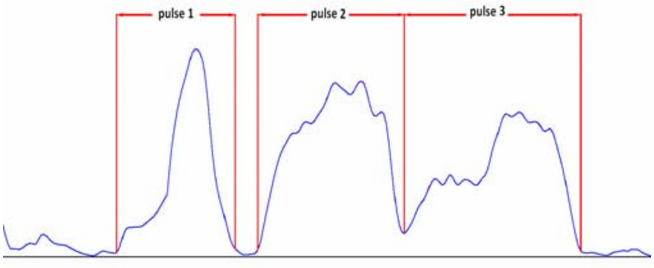

Fig. 2 - Driving pulses

The speed/time diagram, which represents a track, is a sequential series of isolated pulses. Each pulse represents the vehicle travel between two stops. Each pulse is characterized by the length of the road segment and the average speed on that segment. It is possible to establish a pattern, a set of fuzzy rules, and each driving pulse is checked if is matching the pattern. If, using the chosen pattern, it is not possible to find a cycle matching most of analyzed tracks, the pattern will be changed. The comparison may be done in a graphical or an analytic way. The graphic method uses the representation of the pattern as a diagram and then the common area of both diagram (driving pulse and pattern) is measured [6]. The analytic method uses some reference values for pulses parameters, like average speed, length, acceleration and a tolerance. Then the parameters of each pulse are checked if fits in the reference values with their respective tolerances.

BRASOV DRIVING CYCLE

The GPS data acquisition method [4] was used for collecting traffic data in Brasov city. The acquisition rate of the used GPS device was 1 Hz (one record per second). Different vehicles were driven over selected routes, for many times, during an entire year. An example of data (speed and acceleration) collected on the same track is shown in *figure 3*. The upper graph shows the variation of speed (blue) and acceleration (red) with time; the lower graph shows the variation of speed and acceleration with distance.

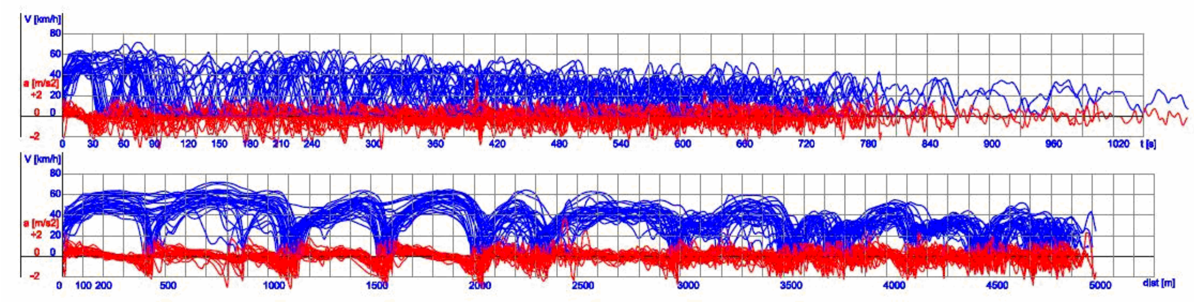

Fig. 3 Speed and acceleration variation versus time (up) and distance (down)

The probability density functions of vehicle speed and acceleration, for all tracks, are shown in *figure 4*.

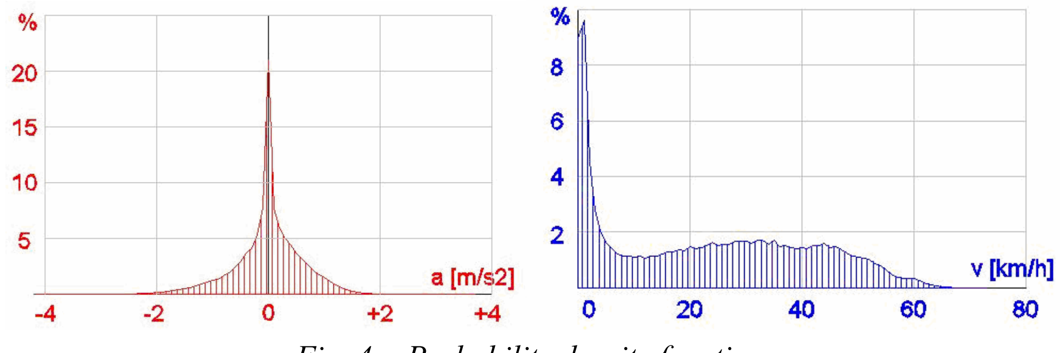

Fig. 4 - Probability density functions
of vehicle speed and acceleration – all urban tracks analyzed

Using all the recorded data (82 tracks), the average values obtained for the main parameters of driving in Brasov city are:

- duration: 710 seconds;
- length: 4.44 km;
- average speed: 22.5 km/h;
- maximum speed: 73 km/h.

Using the method described above, all the registered tracks are split in driving pulses. After a statistic analysis [6], the number of pulses composing the cycle and their parameters are those in *table 1*. The resulted parameters of the cycle (average speed and acceleration, statistic distribution of speed and acceleration) are very close to the ones determined for all registered tracks.

Table 1 – Length and average speeds for driving pulses

Pulse length (sec.)	18	41	18	41	18	41	70	18	41	80	110	Average
Average speed (km/h)	10	25	10	25	10	25	34	10	25	34	40	**22.5454**
Maximum speed (km/h)	15	40	15	40	15	40	52	15	40	52	70	

Considering the values in *table 1* and the average accelerations and decelerations, it can be determined a modal driving cycle, shown in *figure 5*.

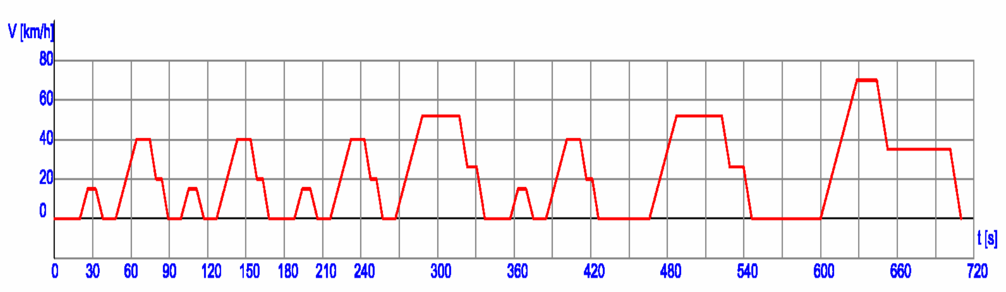

Fig. 5 - The proposed modal driving cycle

In order to keep the transitory character of the cycle is not just enough to compare the global parameters. The final proposed cycle should be composed by real driving pulses, extracted from the registered tracks. So, keeping the same principle of fuzzy logic, the pulses are compared as parameters and the pulse that is closest to the average values is used in the final cycle.

Since it was not possible to identify individual driving pulses close enough to the target parameters, the comparison was done between blocks of driving pulses. A characteristic of driving in Brasov city is that the driving sequences are not separated by complete stops. An example is in *figure 2*: the second and third pulses in the figure are considered as a block. The blocks of driving pulses were assembled in diagrams representing virtual tracks, and the global parameters of these tracks were compared with the parameters of all the registered tracks, in order to find the track of which parameters are closest to the medium values ascertained for the entire city.

Beside average speed, duration and length, the average acceleration and average deceleration were ascertained and used for tracks comparison. This analyze was done using the diagrams drawn in AutoCAD and custom software functions developed in AutoLisp; the entire process was computer assisted. Part of the global parameters of the analyzed tracks (registered and virtual) is shown in *table 2*. The track ID is the AutoCAD property named *handle*, which uniquely identify the diagram as “polyline” drawing object.

Table 2 – Global driving parameters of the registered tracks

Track ID (*handle*)	Time	Length	Average speed	Max. speed	Average accel.	Max. accel.	Average decel.	Max. decel.
	(sec.)	(km)	(km/h)	(km/h)	(m/s^2)	(m/s^2)	(m/s^2)	(m/s^2)
2A651	1098	4.04	13.24	53.97	0.24	1.56	-0.23	-1.99
2A64F	447	3.60	29.02	62.21	0.43	1.67	-0.48	-2.16
2A64D	537	3.85	25.78	72.15	0.43	2.42	-0.46	-2.96
2A64B	536	4.11	27.60	66.36	0.43	1.40	-0.53	-2.42
2A649	442	3.89	31.67	59.62	0.43	2.12	-0.44	-2.76
2A647	642	3.80	21.28	73.27	0.40	5.06	-0.43	-5.79
2A645	453	3.56	28.31	52.40	0.43	1.78	-0.47	-1.67
2A643	483	3.68	27.46	59.07	0.38	1.75	-0.41	-1.87
2A641	735	3.86	18.89	60.80	0.28	1.62	-0.27	-1.98
2A63F	873	3.90	16.07	53.59	0.34	2.42	-0.35	-1.86
2A63D	697	4.24	21.90	65.18	0.44	1.71	-0.49	-2.17
298B7	587	4.57	28.05	59.05	0.45	1.56	-0.47	-1.71
298B3	606	4.60	27.34	56.40	0.55	1.97	-0.48	-1.90

Finally, the comparison of the parameters of recorded tracks and the parameters determined for pulse blocks has leaded to a virtual track that match closest the main driving parameters of the entire city, a transitory driving cycle shown in *figure 6*.

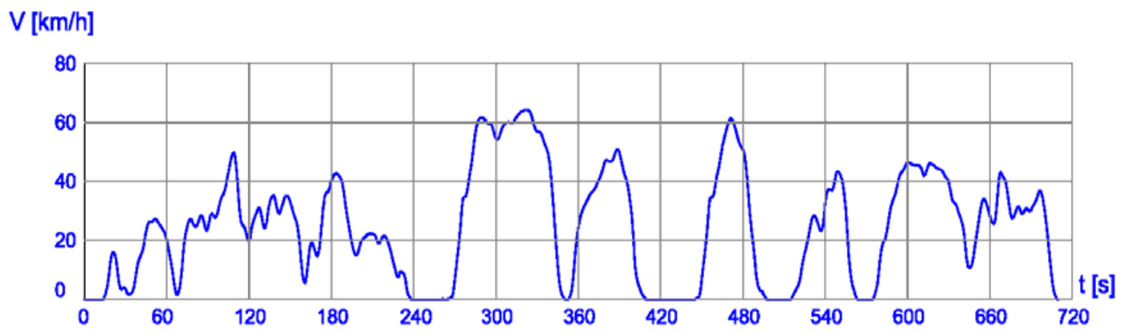

Fig. 6 - A transitory driving cycle proposed for Brasov city

The global parameters of the driving cycle (*fig. 6*) are close to the parameters determined statistically for all records:

- duration: 710 seconds;
- length: 4.87 km;
- average speed: 24.7 km/h;
- maximum speed: 64 km/h.

The maximum speed is less than the maximum speed determined from all records, but this is normal, because speeds higher than 65 km/h appeared only occasionally. The time of effective moving in the proposed cycle is 553 seconds. This means that about 22% (157 seconds) of the entire cycle duration represents stop time.

The probability density function of the speed and acceleration, for the proposed transitory driving cycle, is shown in *figure 7*. The profiles of these diagrams are not as smooth as in *figure 4*, because the number of measured points is much lower. Otherwise, the profiles of the related diagrams are quite similar.

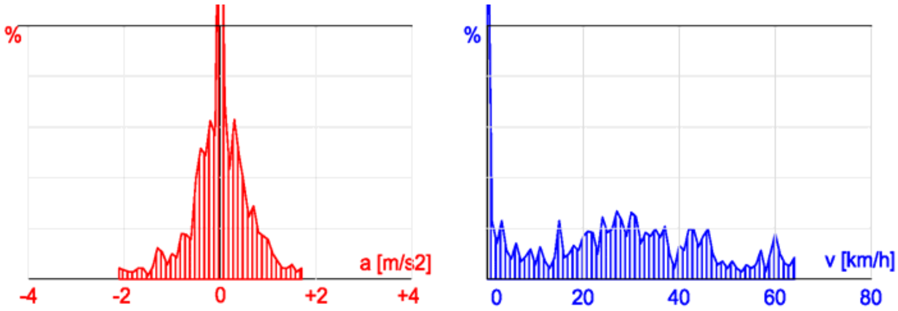

Fig. 7 - Probability density function of vehicle speed and acceleration

Table 3 – Comparison between driving cycles

Parameters	unit	ECE 15	FTP-72	NYCC	Athens	Braşov
Length	km	4x1.013	12.07	1.89	6.51	4.87
Duration	s	4x195	1369	598	1160	710
Average speed	km/h	18.7	44.6	11.4	20.2	24.7
Maximum speed	km/h	50	91.2	44.6	70.9	64

A comparison between the main parameters of the proposed driving cycle and other known urban driving cycles is presented in *table 3*. There are presented the parameters of the European Urban Driving Cycle ECE-15, the North-American cycle FTP-72, the New York City Cycle, the Athens driving cycle [11] and the Brasov driving cycle. Only the ECE-15 cycle is a modal type cycle, the others are all of transitory type. There are significant differences between the main parameters of the presented cycles, and this is highlighting the importance of knowing the real driving cycles for the area where the vehicle is operated.

ANALYSIS OF THE HC EMISSION LEVEL

The importance of knowing a probable driving cycle for a certain city results also from the difference in fuel consumption, time for (engine) warm-up or emission levels [7], compared with the values stated by the vehicle manufacturers in the technical documentation of each vehicle model. A lot of mathematical models were elaborated by various organisations, for estimating the fuel consumption and emission levels of vehicles, depending by instantaneous speed and acceleration. For analyzing the proposed driving cycle of Braşov city, it was chosen the model proposed in [1] for a reference car. This model is based on polynomial regression for estimating the CO, HC and NOx levels and permits, based on these emission levels, to also estimate the fuel consumption.

In the mentioned paper [1], the regression coefficients for HC level estimation are given, for a "composite" vehicle (a model vehicle, based on statistics). The calculation relation is:

$$\ln(HC) = \sum_{i=0}^{3}\sum_{j=0}^{3} C_{ij} \times v_i \times a_j$$

where the meaning of the symbols is:

- HC – HC emission level, in mg/s;
- C_{ij} – regression coefficients (different for acceleration and deceleration);
- v_i –instantaneous speed, in km/h;
- a_j – instantaneous acceleration, in m/s^2.

The equation above was implemented in an AutoLisp function, used to represent the HC emission level depending by speed and acceleration, as in *figure 8*.

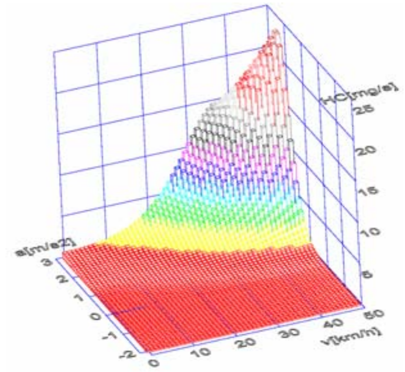

Fig. 8 - HC emission level as function of speed and acceleration (for a "composite" vehicle)

Using the same function, and considering the driving cycle as input data, it was obtained the diagram shown in *figure 9*. In this figure the variation of the HC emission level is represented over the speed and acceleration diagrams.

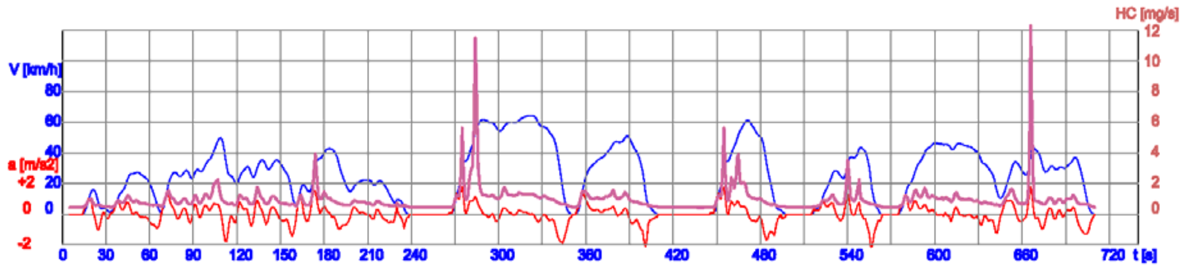

Fig. 9 - HC emission level for the proposed driving cycle
(Braşov city and a "composite" vehicle)

The average value of HC emission level determined for the European cycle is 0.768 mg/s, which means 148 mg/km. For the proposed Braşov city cycle, it was ascertained an average HC emission value of 0.964 mg/s, equivalent to 138.1 mg/km.

Even the average emission level per second is higher for the proposed cycle than for ECE-15 cycle, the emission level for one kilometre is lower. The main cause is the higher stop time for the European cycle, which is 30% of the cycle duration, since the stop time for Braşov city cycle is about 22% of the entire cycle duration.

CONCLUSIONS

A typical driving profile in an urban area consists in a complicated series of accelerations, decelerations and stops. The main goal of the driving cycles is to estimate the emissions level and the fuel consumption for various vehicle models. Since the road traffic is different for different cities, a single driving cycle can not be representative for all cities. The differences between the parameters listed in *table 3* demonstrate the importance of having a real driving cycle for each area where a certain vehicle model is used.

The driving cycle determined for Brasov city is just a proposal, based on a statistical analysis of data collected during the years 2009-2010. More data may lead to a more accurate driving cycle. It was demonstrated again that the GPS devices are suitable for collecting traffic data, especially in urban areas, even if the signal may be affected by the buildings. The rate of one record per second is just enough for this purpose and affordable handheld GPS devices are available on the market.

The data collected for this study can be used also in future traffic studies, in speed analysis or to establish the speed profile of the main roads in the city area.

ACKNOWLEDGMENT

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