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REAL DRIVING CYCLES IN BELO HORIZONTE AND ITS IMPACTS ON EMISSIONS AND FUEL CONSUMPTION

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Abstract. *In order to reduce the level of pollutants from vehicles, CONAMA launched in 1986 the PROCONVE Program. Since them, this program has been implemented in stages. In November 2018, a new stage was launched: the P8 phase. This phase proposes to change the drive cycle from ETC to WHTC until a new specific cycle for Brazil is formulated. Thus, the proposal of this work is to present a new urban driving cycle for heavy duty vehicles for Belo Horizonte, Brazil. This cycle was obtained by experimental measurements velocity in Belo Horizonte's buses. The ETC and WHTC was compared to this real drive cycle, considering the typical values of the parameters that characterize the three cycles. The second stage of the analysis compared the vehicle's emissions and fuel consumption in each of those cycles. It was observed that the urban part of the WHTC was more closely of the real driving cycle. However, the ETC cycle has an engine operating regime more similar to the real cycle. The emissions of NOx, CO and HC presented lower values in case of the European cycles. The opposite was observed on fuel consumption rate. It is concluded that none of the theoretical cycles is faithful to the reality of Belo Horizonte, and it is suggested that Brazilian real cycles should be investigated in order to build a most representative cycle.*

Keywords: *Real Drive cycles, Proconve P7 and P8, Emissions Brazil's Legislation, WHTC Cycle, ETC Cycle.*

1. INTRODUCTION

The National Council of the Environment's (CONAMA) resolution No. 18 of May 6, 1986 promoted the creation of the Program for the Control of Air Pollution by Automotive Vehicles (PROCONVE). The program had a lot of objectives, including: reduce the pollutants by motor vehicles; create inspection and maintenance programs for vehicles in use; and to promote the improvement of the technical characteristics of liquid fuels. These objectives would be achieved mainly through the establishment of emission limits for air pollutants (CONAMA, 1986). Thus, since the 1990s, the Brazilian government new limits are laid out which are arranged in stages: L phases refer to light vehicles and P-phase to heavy vehicles. The Table 1 shows the evolution of emissions limits according the PROCONVE phase to heavy duty vehicles.

The resolution published on November 16, 2018 by the CONAMA established the new phase of the Pollution Control Program of Air by Motor Vehicles - PROCONVE P8 (CONAMA, 2018). The document tells about legislation on emissions and noise from heavy duty vehicles manufactured from 2022-2023, and is equivalent to the EURO VI. As mentioned in the IEMA's study (Institute of Energy and Environment, 2015), the P8 phase not only increased the number of controlled compounds, but also proposed important developments. Among them, the choice of a driving cycle most representative of the reality: the World Harmonized Test Cycle (WHTC). This cycle will be used in place of that cycle used in phase P7: the European Transient Cycle.

Table 1. Evolution of Emissions Vehicle for P-phases of PROCONVE(1)

Phase	Manufacture Year	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	MP (g/kWh)	NP (#/kWh)
P1	1990-1993	14.00	3.5	18.00	-	-
P2	1990-1993	11.20	2.45	14.40	0.60	-
P3	1994-1997	4.90	1.23	9.00	0.40	-
P4	1998-2002	4.00	1.10	7.00	0.15	-
P5	2003-2008	2.1	0.66	5.00	0.10	-
P6	2009-20012	1.5	0.46	3.50	0.02	-
P7	2013-2022	1.5	0.46	2.00	0.02	-
P8	2023	1.5	0.13	0.40	0.01	$8x10^{11}$

(1) The data refer to compression-ignition engines submitted to stationary cycles.

IEMA (2015) has compared the main parameters of both theoretical cycles and other two standard cycles from "Orange Country" and "Manhattan", as shown in Table 2. According the Technological Research Institute (Instituto de Pesquisa Tecnológica, 2007) those standard cycles are appropriate to represent de São Paulo's buses, and because of that it can be considerer that the WHTC cycle is more representative of the reality on the roads. This differences in representativeness is still noticeable when one observes the urban part of the four cycles (Fig. 1).

Table 2. Comparison of the average parameters of the urban stretches of the base cycles of the ETC and WHTC and representative cycles of the conditions of use of the buses of São Paulo

Parameter	Manhattan (congested)	Orange Country (Corridor)	WHTC Urban	ETC Urban
Average Speed (km/h)	11.0	19.8	21.2	23.2
Speed Standard deviation (km/h)	11.8	16.6	18.1	13.4
Speed Strd. deviation/ Avr. Speed (%)	107	84	85	58
Maximum Speed (km/h)	40.7	65.4	66.2	49.9
Downtime/Total time (%)	36	21	22	9
Number of bus stops/km	6.2	2.9	1.5	1.0

The level of pollutants released into the atmosphere depends strongly of the technical characteristics of the vehicle and its operations conditions. Factors like weight and age vehicle, fuel type, after treatment system and drive cycle have an expressive influence in the quantity of pollutants (Clark, 2002). Jacondino (2003) studied the effect of the introduction of the traffic variables in the emissions level measurement, showing differences of 10% in CO and NOx emissions and 120% in case of the HC.

Because of that great influence, driving cycles used to measure the emissions level should be faithful to the real conditions found on-road. (Samuel, 2002; Moawad, 2009). In the literature, many studies are arising comparing the performance of the theoretical cycles and real cycles. Duarte (2016) tested vehicles with portable emission measurement system in order to know the differences between the emissions level and fuel consumption came from the NEDC cycle and the real conditions on-road. This study shows that the fuel consumption is 23,9% higher in real conditions. Differences in level emissions of HC and NOx also were observed. Similarly, Roso (2016) speaks of about 50% of underestimation in pollutant emission level using theoretical cycles instead real cycles.

In that scenario, international authorities have shown considerable concern about the effectiveness pf driving cycle. Thus, the WHTC cycle emerges as a proposal to this question, representing a great advance in the fight against the emissions. Developed by United Nations Economic Commission for Europe (UNECE), the cycle was formulated considering typical driving conditions in United States, the European Union, Australia and Japan. One of the novelties brought by the cycles is that it includes both cold and hot start, a critical condition for many compounds. (DieselNet, 2019).

Although the WHTC cycle is notoriously more reliable than the ETC cycle, the CONAMAS's resolution states that a new Brazilian cycle can be proposed for the P8 phase. (CONAMA, 2018). In Addition, the WHTC cycle does not considered the typical conditions of emergent countries as Brazil in its formulation. Therefore, this work aims to study traffic conditions of the Brazilian city Belo Horizonte and discuss the feasibility of the use of this cycle in this place.

For that, the speed profile of three bus lines was measured, and the data were used to generate a real urban driving cycle specific to the metropolitan region of Belo Horizonte. This cycle was compared to the urban part of the cycles used in phase P7 and P8. In the first instance, the comparison was made using the main parameters of the three cycles, similar to those shown in Table 2. In the second stage, a computational model of a vehicle was generated on GT- Suite in order to compare the emissions and fuel consumption from the three cycles. Using more accurate receivers, the methodology employed here can be used to study traffic conditions throughout the national territory, and thus formulate a driving cycle that best represents the reality of Brazil.

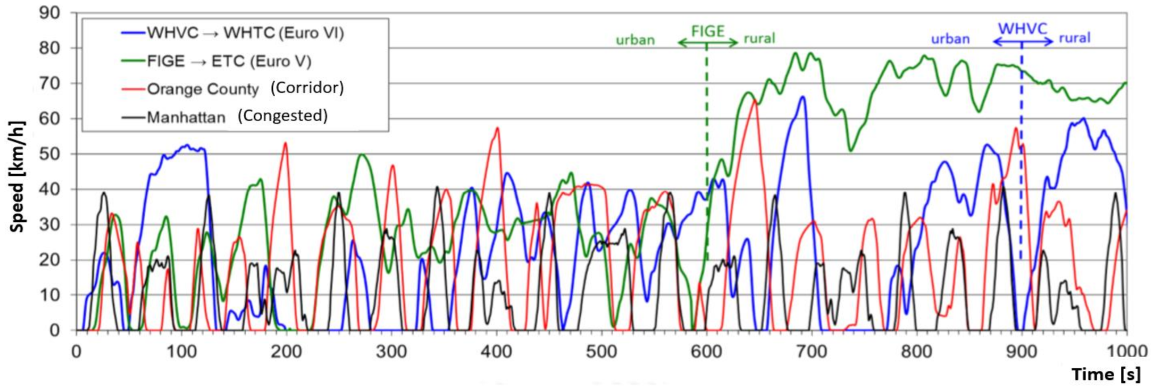

Figure 1. Urban sections of ETC and WHTC cycles compared to representative cycles of São Paulo, Brazil
IEMA, 2015 – Adapted.

2. METHODOLOGY

2.1 The Route and Data Acquisition

To make the real drive cycle for Belo Horizonte, the itinerary of 3 buses are adopted (Fig. 2). They will be called as line A, B and C. According to the Departamento de Edificações e Estradas de Minas Gerais (DEER-MG, 2019), the lines leaves of the North Region of the principal city, it crosses a great extension of the Belo Horizonte and arrives until the neighborhood Industrial City, in Contagem. These lines were adopted because they represent several types of traffic conditions. The bus crosses highway and urban stretches, inside or outside the exclusive bus corridor. This subjects the bus to very different traffic conditions, which allows a more coherent assessment of the public transport behavior of the city and its metropolitan region.

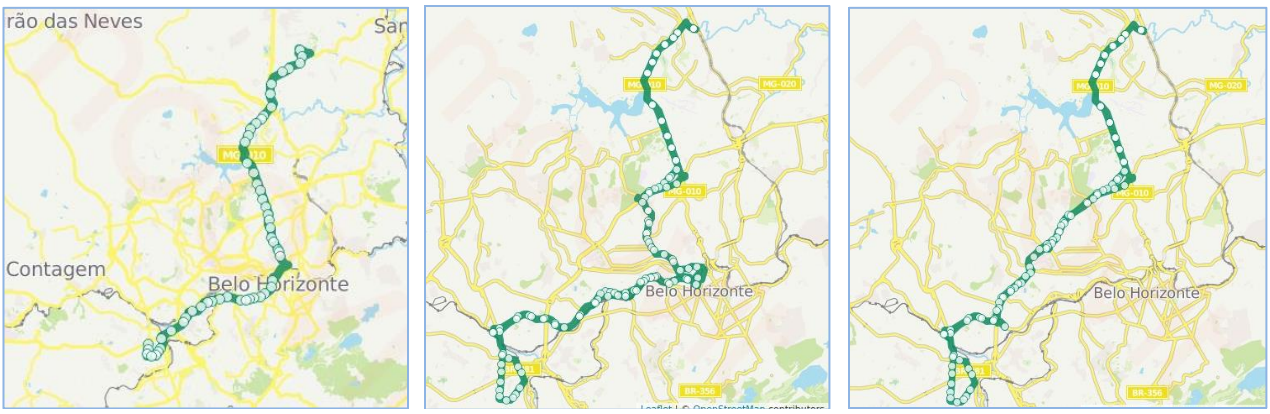

Figure 2. Itinerary of the lines A, B and C, respectively.
Developed by the authors using *Moovit App*

The speed profile of the buses was given by the *Global Position System GPS*, application that allows to know the position of a body using satellites' signals. Each satellite emits a specific radio signal, which is received by a receiver in the earth. In turn, the receiver calculates the position of the user by measuring the difference of the time of emission and reception of the signal (Alves, Sérgio, 2006). That methodology was already used by Hung, Wing et al., 2007 in construction of a Hong Kong's driving cycle.

A smartphone was used as a receiver of the GPS signal. Currently, that kind of receptor provides measures with accuracy from 5 to 15 meter. The *GPS Speedometer App* was adopted to do the interface between the GPS signal with the user. The software developed by *California Cyber Developers®* records the instantaneous position of the receptor every 2 seconds. Its variation on the time furnishes the speed profile of the trajectory.

The measurements of the speed transients occurred between January 21th and February 8th, 2019. During five days of week, the drive cycle performed by the bus was sampled. From January 21th to January 25th Line A speed profile was taken. From January 28th to February 1st Line B was sampled, while Line C was tested from February 4th to February 8th. Table 3 shows the start time of measures in both directions: Belo Horizonte-Contagem (BH-CON) and Contagem-Belo Horizonte (CON-BH). That methodology was adopted to capture the speed variations during the day.

Table 4. Start time to the speed profile measures

	Line A		Line B		Line C	
	BH-CON	CON-BH	BH-CON	CON-BH	BH-CON	CON-BH
Day 1	5:30 AM	3:50 PM	5:30 AM	4:02 PM	5:45 AM	3:28 PM
Day 2	6:50 AM	5:22 PM	6:30 AM	5:37 PM	6:45 AM	5:28 PM
Day 3	7:50 AM	6:22 PM	7:50 AM	6:12 PM	7:45 AM	6:28 PM
Day 4	8:30 AM	7:32 PM	8:30 AM	7:22 PM	8:45 AM	7:28 PM
Day 5	10:45 AM	8:12 PM	9:30 AM	7:57 PM	9:45 AM	8:28 PM

2.2 Real Driving Cycle Constructuion

The construction of the real driving cycle was based on the velocity averages method. As the speed points were available every 2 seconds, an average was made by point considering the 30 measured trips. The stretches taken by the lines take approximately 1 hour, therefore 1800 speed points were taken. However, to be consistent with the urban sections of European driving cycles, only the first 600 seconds of the real cycle was considered for the analysis. In order to increase the curve accuracy, interpolations were made between the velocity points.

2.3 The Vehicle Simulation

Gamma Technologies' GT-Suite software allows customization of the model to be used in the simulations. For this, it is necessary to inform the program about the characteristics of the engine, chassis, tire, transmission etc. A driving cycle can be imposed to this model alternating both accelerator and brake pedal, which forces the vehicle to follow the speed profile of the cycle. (Roso Vinícius, 2016). This is represented by the differential equation of motion Eq.1 integrated in the time.

$$\tau_{vehicle} = \left[I_{trans1} + \frac{I_{trans2}}{R_t^2} + \frac{I_{dsh}}{R_t^2} + \frac{I_{axl}}{R_d^2 R_t^2} + \frac{M_{veh} r_{whl}^2}{R_d^2 R_t^2}\right] \frac{d\omega_{drv}}{dt} \left[\frac{I_{trans2}}{R_t^3} + \frac{I_{dsh}}{R_t^3} + \frac{I_{axl}}{R_d^2 R_t^3} + \frac{M_{veh} r_{whl}^2}{R_d^2 R_t^3}\right] \omega_{drv} \frac{dR_t}{dt} + \left[\frac{F_{aer} + F_{rol} + F_{grd}}{R_d R_t}\right] r_{whl} \quad (1)$$

Were I_{trans1} and I_{trans2} are the input and output inertia of transmission system respectively. R_d is the final drive transmission, while R_t is the transmission ratio for each gear. I_{dsh} is the moment of inertia of the drive shaft and I_{axl} refers to the wheels' inertia; Wheel radius is given by r_{whl} and the vehicle mass is M_{veh}; The term $\frac{dw_{drv}}{dt}$ represents the vehicle speeds as time function. The forces F_{aer}, F_{rol}, F_{grd} are, respectively, aerodynamics force, rolling resistance force and weight.

To know the transient behavior emissions and the fuel consumption of the vehicle when it is following a drive cycle, *GT-Suite* software was used. Its main interface is shown in Fig. 3. The modeled vehicle was a small bus with 38 chairs, whose main features can be seen in Table 5.

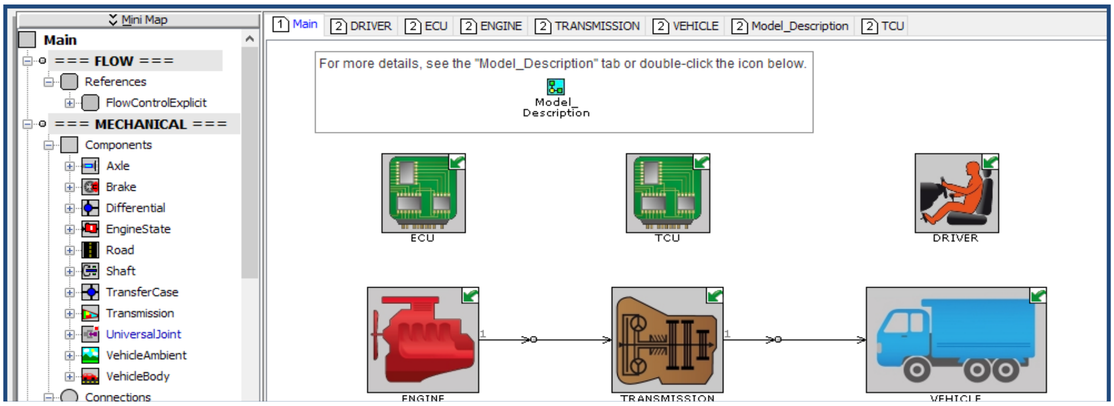

Figure 3 – Main Interface of GT- Suite
Developed by the authors using GT-Suite

To build the computational model, it is necessary input the engine, transmission and vehicle data. To model the engine, its geometric characteristics and the torque map in the various acceleration pedal positions are required. This map can be seen in Fig. 4. Also, the geometric characteristics of the vehicle were transmission are inserted. Those input data can be seen in Table 5.

Table 4. Main vehicle and engine characteristics

Vehicle	
Weight (kg)	7200
Total length (m)	7.950
Wheelbase (m)	4.350
Vehicle Frontal Area (m^2)	6.480
Vehicle drag Coefficient	0.5
Engine	
Maximum Power @ Engine Speed (kW/rpm)	125 /3500
Maximum Torque @Engine Speed (kW/rpm)	450 /1400
Cylinder Capacity (cm^3)	2998
Bore (mm)	95.8
Stroke (mm)	104
Compression Ratio	17.5 ± 0.5
Idle Speed (rpm)	800 ± 25
Transmission	
Gear Ratio	(5.15/ 3.02/ 1.96/ 1.36/ 1/ 0.8) Reverse (4.64)

In order to check the transient behavior of NOx, HC and CO emissions and fuel consumption, the stationary map of these quantities is imputed on the model. Through the engine torque map (Fig.4) and Eq. 1, the program can simulate the dynamic behavior of these parameters as the vehicle follows a driving cycle. The *GT-Post* module was then used to view simulation results.

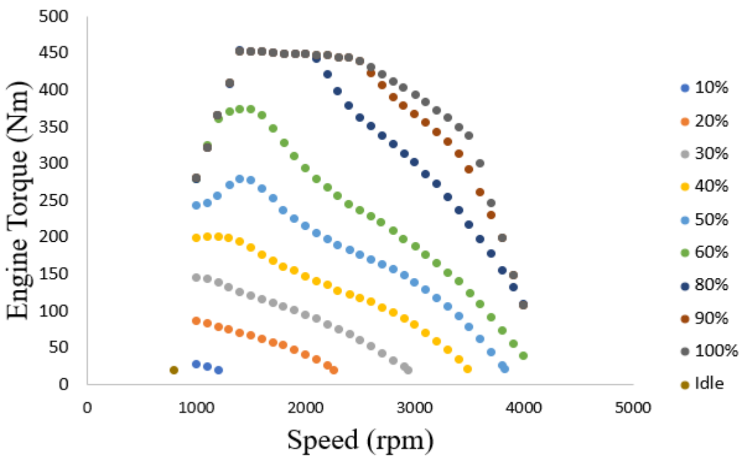

Figure 4. Engine Torque map
Developed by the Authors

3. RESULTS

3.1 Driving Cycle Comparation

The methodology described on item 2.2 was used to generate the real driving cycle for Belo Horizonte. Figure 5 shows the cycle formulated for whole trajectory. Figure 6 shows the Urban parts of the Real Drive Cycle for Belo Horizonte (DCBH).

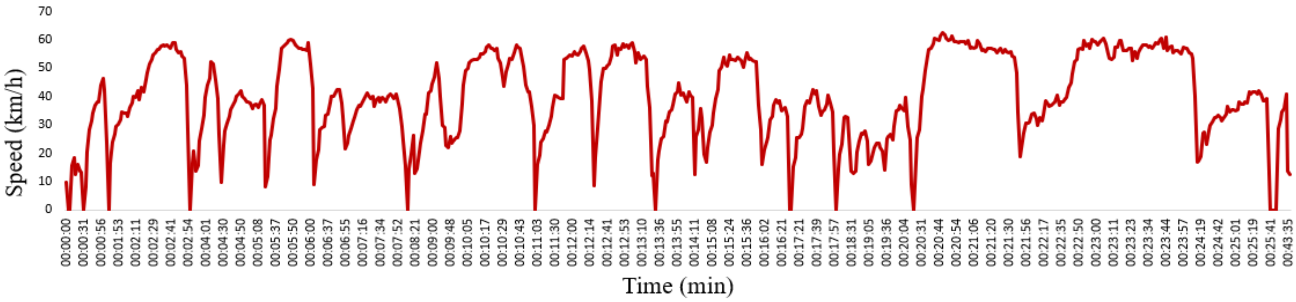

Figure 5. Real Driving Cycle of Belo Horizonte for whole trajectory
Developed by the authors

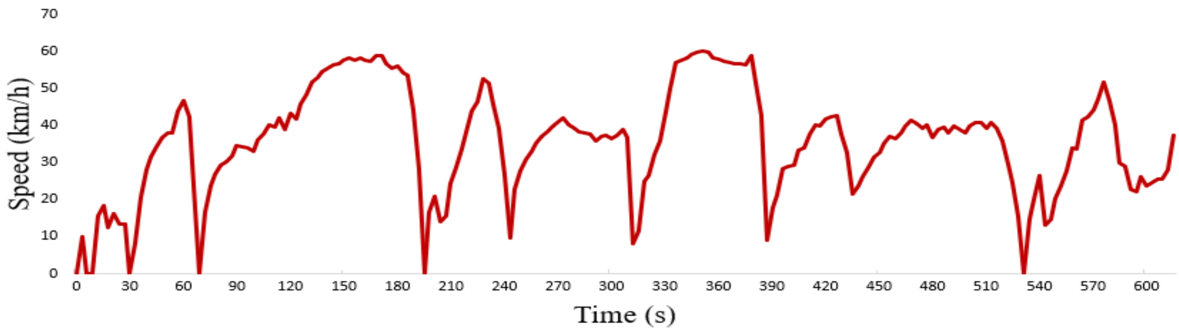

Figure 6. Urban part of the Real Drive Cycle of Belo Horizonte
Developed by the authors

Table 5 shows a comparison between the main parameters of the Urban part of the DCBH, ETC and WHTC. The urban part of the WHTC cycle presented all parameters closest to the DCBH cycle except the maximum speed and the percentual downtime.

Figures 7, 8 and 9 show the engine distribution map as a function of the time. The real driving cycle has 90% of its time in the range from 1625 to 2070 rpm. WHTC shows this percentage in the narrow range from 1800 to 1900 rpm. However, the ETC has 90% of its time from 1600 to 1900 rpm. This shows that in this respect the ETC cycle is better suited to the reality of Belo Horizonte. At idle speed, the actual cycle is also closer to the ETC cycle, which is easily explained by the fact that the percentage of downtime be similar.

Table 5. Comparison between the main parameters of the Urban part of the DCBH, ETC and WHTC

Parameter	DCBH Urban	ETC Urban	WHTC Urban
Average Speed (km/h)	35.8	21.2	23.2
Speed Standard deviation (km/h)	11.5	18.1	13.4
Speed Strd. deviation/ Avr. Speed (%)	31%	85%	58%
Maximum Speed (km/h)	62.9	66.2	49.9
Downtime/Total time (%)	28%	22%	9%
Number of bus stops/km	1.2	1.5	1.0

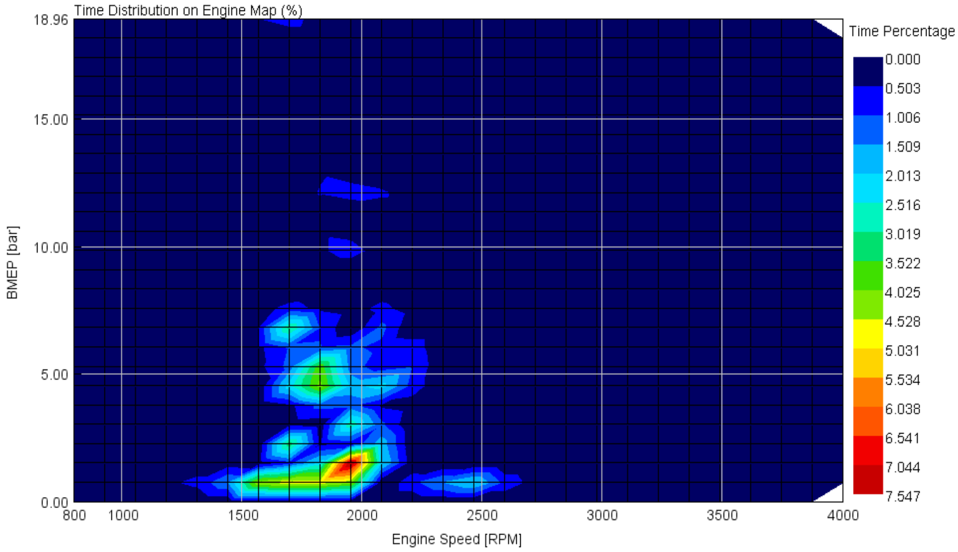

Figure 7. Time distribution on Engine Map when the vehicle follows the DCBH
Developed by the Authors using *GT-Suite*

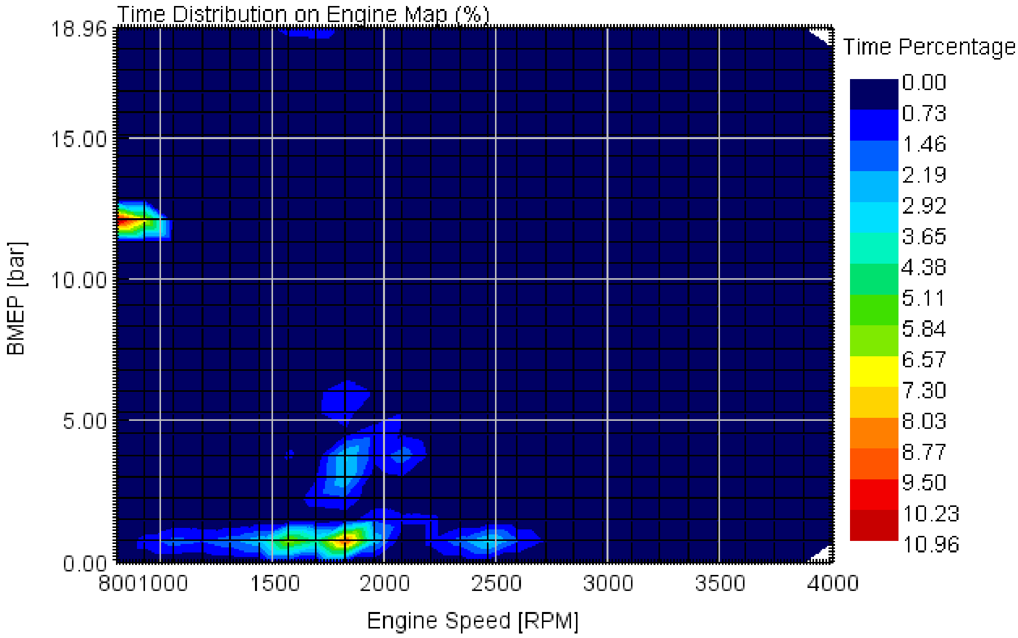

Figure 7. Time distribution on Engine Map when the vehicle follows the WHTC
Developed by the Authors using *GT-Suite*

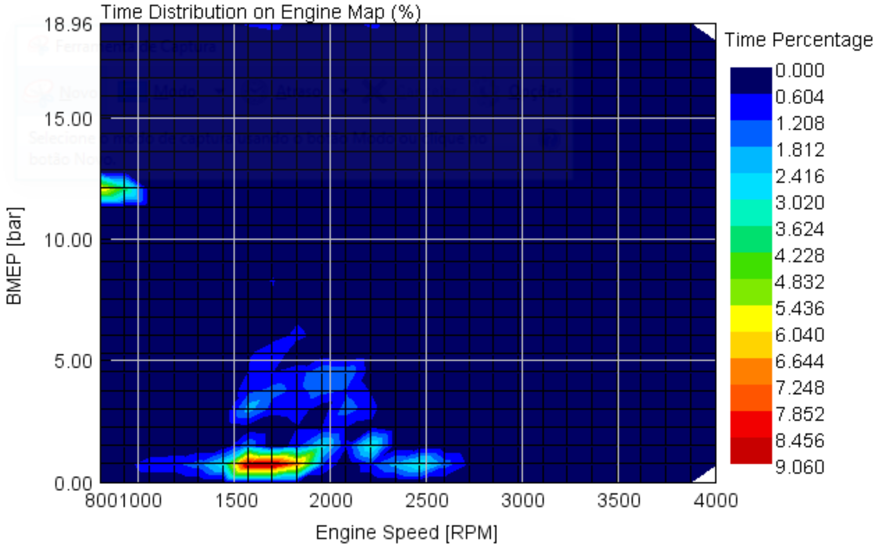

Figure 7. Time distribution on Engine Map when the vehicle follows the ETC
Developed by the Authors using *GT-Suite*

3.2 Emissions and Fuel Consumption

The transient behavior of the fuel consumption, NOx emission, HC emission and CO emission are shown in Fig. 9, 10, 11 and 12, respectively. All of them refers to the urban real driving cycle. Similar to the analysis done in item 3.1, the main parameters of transient behavior of those quantities are shown on Table 6.

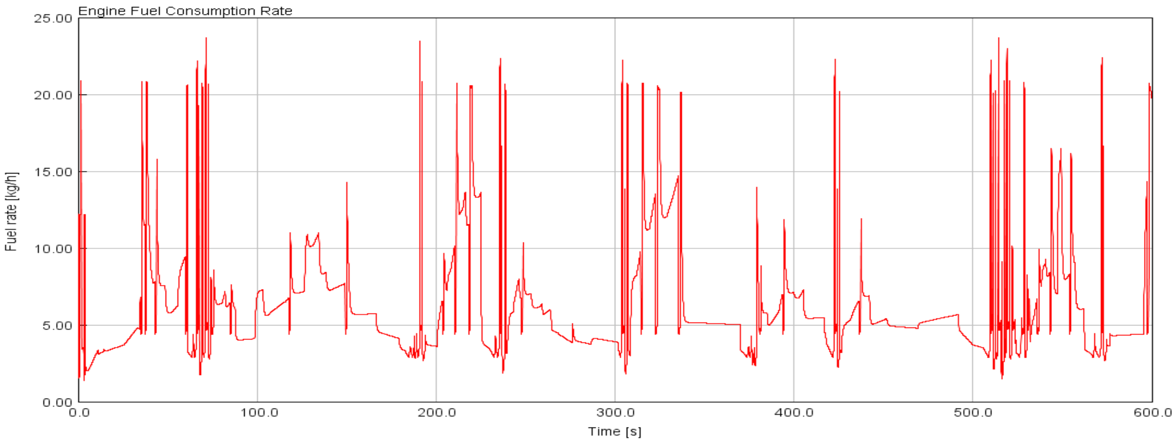

Figure 9 – Engine Fuel Consumption Rate during Urban DCBH
Developed by the Authors using *GT-Suite*

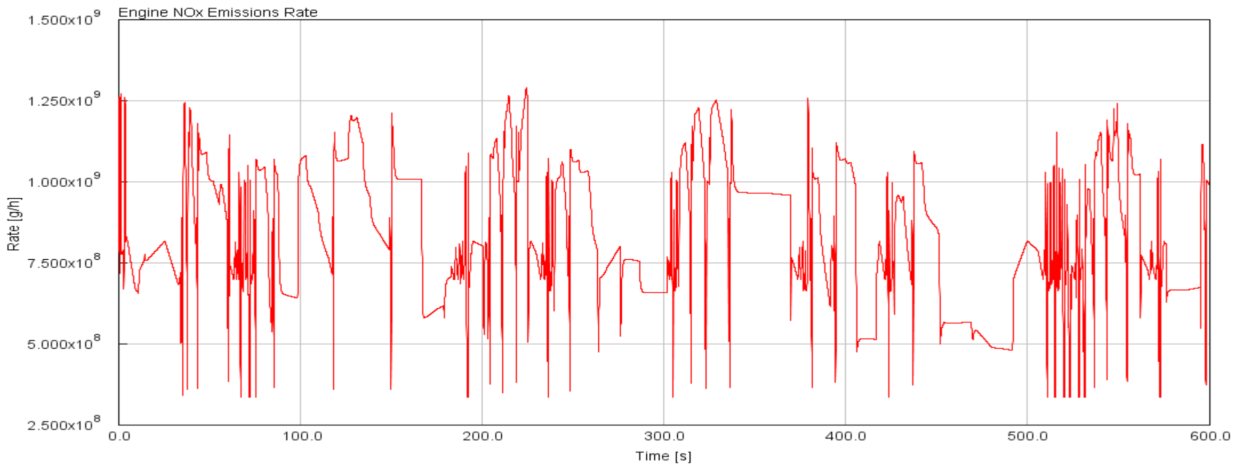

Figure 10 – Engine NOx emission Rate during Urban DCBH
Developed by the Authors using *GT-Suite*

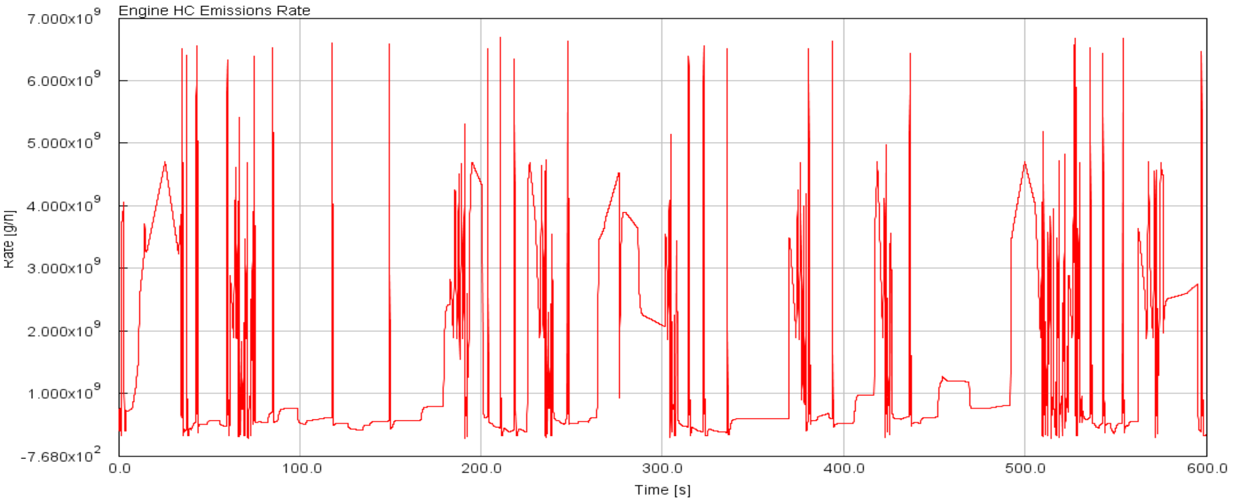

Figure 11 – Engine HC emission Rate during Urban DCBH
Developed by the Authors using *GT-Suite*

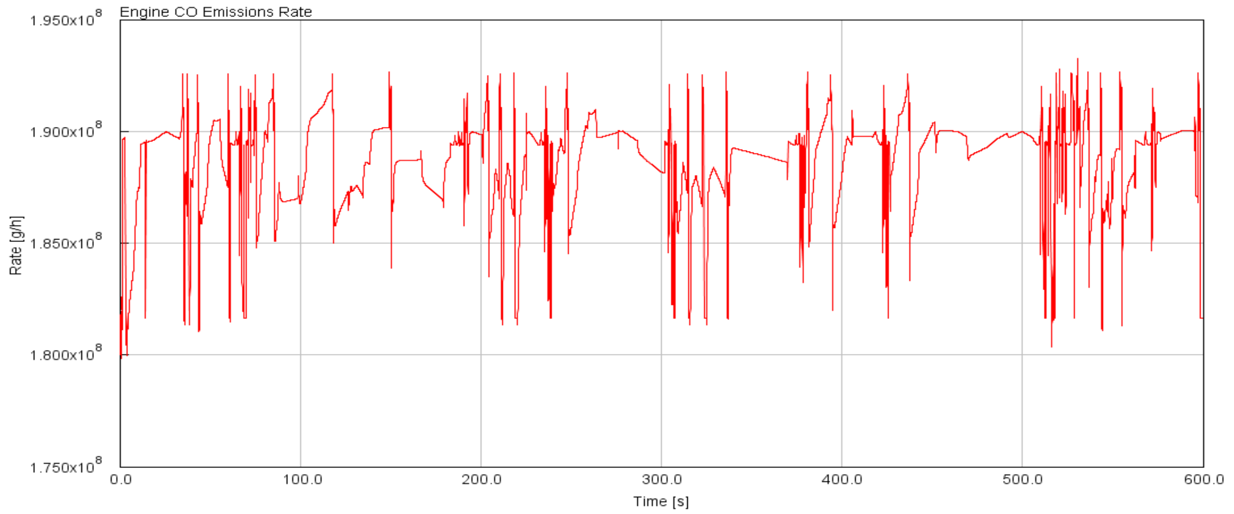

Figure 12 – Engine CO emission Rate during Urban DCBH
Developed by the Authors using *GT-Suite*

Comparing the fuel consumption sampling error between the three cycles, it was found that the average fuel consumption of the ETC is 12% higher than the actual cycle. However, the WHTC cycle had an average consumption 17% lower than the Belo Horizonte cycle. This is justified by the fact that the P8 phase cycle has a longer time operating at idle. Regarding NOx emission, the ETC cycle presented 40% underestimation and the WHTC presented 30%. The same occurred with HC emissions, which was 36% lower for ETC and 43% for WHTC. In turn, CO emissions were 18% lower for both theoretical cycles. All the above-mentioned percentages compare the European cycles with the real cycle of Belo Horizonte.

4. CONCLUSION

The speed profile followed by the vehicle has a great influence on fuel consumption and emissions. Comparing the constructive parameters of the driving cycles used in both P8 and P7 phase, the WHTC is more representative of the Belo Horizonte's reality. However, the ETC cycle has an engine operating regime more similar to the real cycle. NOx, HC and CO emissions were lower in all cases compared to the Belo Horizonte cycle. The opposite was observed in fuel consumption, with the consumption of European cycles higher than the real cycle.

It is concluded that some caution should be taken when using European cycles for approval of Brazilian engines. It is suggested that the Brazilian authorities gather data throughout the national territory and propose a cycle consistent with the reality of the country, because only then the purpose of reducing emissions will be achieved.

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6. RESPONSIBILITY NOTICE

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