Effects of Congestion on Energy Consumption and Vehicle Emissions in Urban Driving Cycles in the City of São Paulo

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ABSTRACT

Automobiles are currently responsible for around 73% of the pollutants resulting from the greenhouse gases effect in the city of São Paulo. The drive cycles from the standards used in Brazil for vehicle homologation do not represent real driving behavior, and data such as the slope of the road are disregarded. This work aims to present a representative drive cycle on heaviest traffic routes of metropolitan city of São Paulo. It compares vehicle dynamic influence, energy and fuel consumption results to Brazilian standard as well as CO2 emissions. The comparison between urban drive cycles used on NBR 6601 standard versus real scenario by using a vehicle as a test selecting heaviest traffic routes according to CET (Traffic Engineering Company) was performed. As a result, considering top 9 routes, energy demand average (MJ/Km) was 30% higher compared to Brazilian drive cycle standard and Energy consumption was 4,9% higher compared to Brazilian vehicle labeling program. The average of elevation profile angle found was around – 0,2 degrees. Emissions of C02 results compared to CO2 AEA (Automotive Engineers Association) standard were similar with a slightly higher difference of 0,6%. In summary, the results of the experiment supported the fact that besides vehicle energy consumption and CO2 emissions, elevation profile of the routes must meet, by a vehicle, a certain performance at some point during the route.

RESUMO

Os automóveis são responsáveis atualmente por cerca de 60% dos poluentes resultantes do efeito estufa na cidade de São Paulo. Os ciclos de condução das normas utilizadas no Brasil para homologação de veículos não representam o comportamento real de condução e dados como a inclinação da pista são desconsiderados. Este trabalho tem como objetivo apresentar um ciclo de condução representativo em vias de tráfego mais intenso da cidade metropolitana de São Paulo. Compara a influência dinâmica do veículo, os resultados de energia e consumo de combustível com o padrão brasileiro, bem como as emissões de CO2. Foi realizada a comparação entre os ciclos de condução urbano utilizados na norma NBR 6601 e o cenário real, utilizando um veículo de teste que seleciona as vias de maior tráfego segundo a CET (Companhia de Engenharia de Tráfego). Como resultado, considerando as 9 principais vias, a demanda média de energia foi 30% maior em relação à norma brasileira de ciclos de condução e o consumo de energia (MJ/Km) foi 4,9% maior em relação ao programa brasileiro de etiquetagem veicular. A média do ângulo do perfil de elevação encontrado foi de cerca de -0,2 graus. Os resultados das emissões de C02 em comparação com a norma AEA (Automotive Engineers Association) foram semelhantes, com uma diferença ligeiramente superior de 0,6%. Em suma, os resultados da experiência apoiaram o fato de que, além do consumo de energia do veículo e das emissões de CO2, o perfil de elevação das rotas deve satisfazer, na perspectiva veicular, um determinado desempenho em algum ponto durante o percurso.

GENERAL INFORMATIONS

DRIVE CYCLES - Each country has its own standard procedures for approving, certifying or estimating pollutant emissions, which can vary significantly between different regions. Regarding driving cycles, the SAE J2711 standard (Practical recommendation for measuring fuel economy and emissions of vehicles) defines that they can also be used as a reference for evaluating energy expenditure on fuel. To determine the variation in speed over a predetermined time, for standardized cycles, chassis dynamometers are used, simulating the behavior of a car in different operating conditions [1]. In Brazil, the regulatory body responsible is the Environmental Sanitation Technology Company (CETESB), through the Motor Vehicle Air Pollution Control Program (PROCONVE). This program, along with the Brazilian Vehicle Labeling Program (PBEV), uses the North American FTP-75 driving cycles, for consumption and emissions tests in urban use, and HWFET, for on-road consumption, which are present in the ABNT NBR 6601 and NBR 7024 standards, respectively [11].

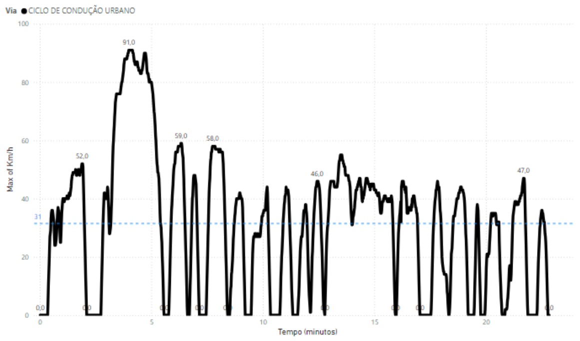

Figure 1: Urban Drive Cycle from Brazilian Standard ABNT NBR 6601 [13].

Although the aforementioned cycles are used for vehicle homologation and certification, they do not represent the peculiarities of real conditions in places where they were not designed [3].

This work aims to present a representative drive cycles from heaviest traffic routes of metropolitan city of São Paulo, compare vehicle energy, fuel consumption and CO2 emissions to current local standards and some results worldwide.

ABOUT THE ACTOR

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INTRODUCTION

ENERGY CONSUMPTION – Created in 2009, Brazilian Vehicle Labeling Program (PBEV) voluntarily displays on participating models the vehicle's energy efficiency rating in its category, and the reference values for mileage per liter, in the city and on the highway, with different fuels. This vehicle rating, within the same category, ranges from 'A' (most efficient) to 'E' (least efficient) [9].

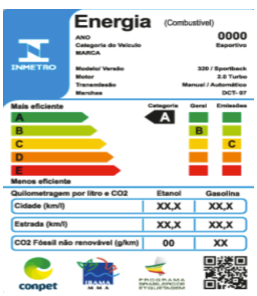


Figure 2: Brazilian Vehicle Labeling Program example.

Consumption figures are published in km/l and MJ/km in the table available on the PBE website, so that electric vehicles can be compared with combustion vehicles.

CO2 EMISSIONS – A study carried out in some countries by the International Energy Agency (2019) compares the average ratio between the values obtained in the real cycle and the values proposed by the standard cycles. In China, a 14% greater difference in fuel consumption was obtained in the real cycle in 2007, increasing to 34% in 2017. As for the European Union, there was a difference in fuel consumption in new cars between the real cycle and the 9% in 2001, rising to 39% in 2017 [3].

For Japan, the difference was 24% in 2008 and in 2008 and rose to 46% in 2014. For the United States, the EPA's label values more accurately reflect the difference in fuel consumption in relation to the real the actual driving cycle, but the difference between U.S. Environmental Protection Agency (EPA) and actual fuel consumption has also increased over time. Before 2008, the values displayed on EPA labels were consistently lower, from around 1% in 2001 to 4% in 2007 [11].

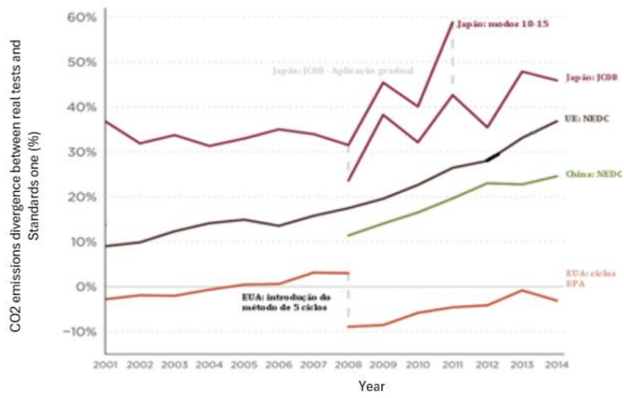


Figure 3: CO2 Emissions divergence between real tests and standards worldwide.

FUEL CONSUMPTION - Simulation of results using the same gasoline and the same types of cars shows a variation in results, even when using the same type of vehicle with cycles from other countries. For different types of cars, such as the pickup truck, a difference in fuel economy of up to 28% less is shown for the Japanese cycle compared to the American one [11].

Vehicle	US - CAFE (Miles per Gallon)	NEDC (Miles per Gallon)	JC08 (Miles per Gallon)	Difference (%) CAFE - NEDC	Difference (%) CAFE - JC08
Small Car	34,8	32,4	27,6	-7%	-21%
Large Car	26,6	24,7	21,5	-7%	-19%
Minivan	23,9	20,5	17,2	-14%	-28%
SUV	20,2	17,6	14,6	-13%	-28%
Pickup	18,8	15,9	13,5	-15%	-28%

Figure 4: Fuel consumption comparison between US standard and Japanese one for same vehicles type.

Several local drive cycles have been developed around the world to compare these differences, but a few cycles have been proposed to Brazil. So far, the only proposed cycles were in Fortaleza, Santa Maria and Recife cities.

METROPOLITAN CITY OF SÃO PAULO - The Traffic Research Department – DPT, responsible for planning, mapping, tabulating, systematizing, analyzing and making available the data from the Mobility Report on the Main Road System of São Paulo, researched volumes and speeds in all regions of the city in 2019 [16].

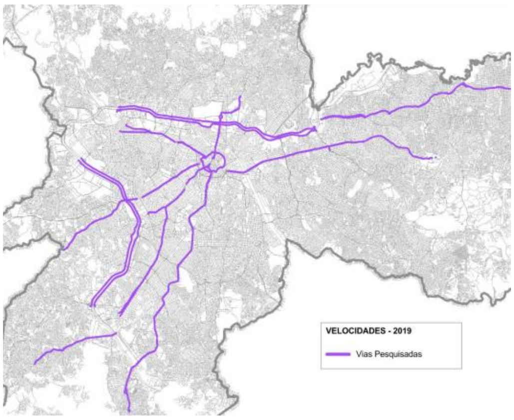
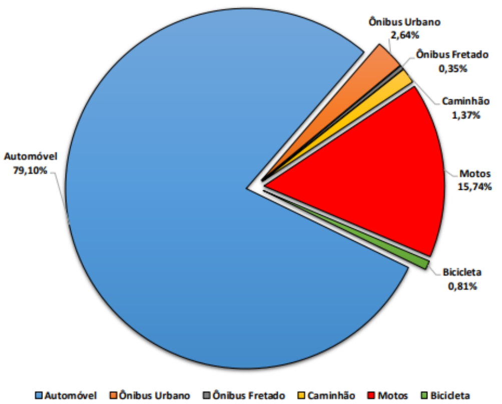


Figure 5: São Paulo city roads area researched by CET.

This report covers the main roads in all areas of the city, predominantly arterial and rapid transit, and presents a snapshot of volumes and speeds on a working day. Since these are samples, and not the total number of roads, they do not represent the volume of all traffic in the city. The data can, however, be used to identify trends over the years and allow comparisons between locations [16].

The results of the composition of vehicles on the roads surveyed in 2019 are shown in Graph 1. Cars account for 79.10% of the sample, followed by motorcycles with 15.74% trucks account for 1.37%, city buses 2.64%, charter buses 0.35% and bicycles 0.81%. It is important to note that, areas with restricted circulation (Zones of Maximum Restriction), trucks and charter buses are prohibited at the time of the survey on several monitored roads monitored.



Graph 1: Vehicle composition of the routes.

The speed and travel time survey aims to measure the average speed based on the distance and travel time of the roads, in order to understand how vehicles travel along each road. The surveys were conducted on two typical days of the year. Some roads were divided into sections according to their physical or connection characteristics, and the data are presented by direction and time slot, as in the volume survey tables. The data were collected using handheld GPS signal receivers, which record the position (latitude and longitude) every second of the trip, allowing travel times to be obtained in the sections already defined on each road surveyed. In the test vehicle, the researcher travels along the road in the middle of the traffic flow with the GPS device. The speed measurement refers to the average speed in space, that is, the distance of the section (in km) divided by the time spent (in hours) [16].

VEHICLE DYNAMICS - Vehicular dynamics is the study of interactions between vehicles, driver and load reactions into longitudinal, vertical and lateral areas. Longitudinal dynamics studies longitudinal movement (x) and rotations around (y) in response to torques applied to the wheels. It is responsible for calculating the power consumption required by the vehicle, using equations for the forces acting on the system such as aerodynamic resistance and friction between the tires and the road, as well as factors relating to the angle of inclination of the road and driver behavior [12].

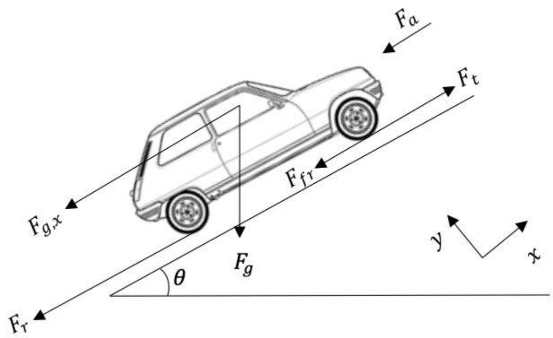


Figure 6: Longitudinal forces acting when vehicle moves on uphill.

Where:

Ft = traction force that depends on the power provided by the engine.

Fa = aerodynamics.

Fr = roll.

Fg,x = gravitational

Ffr = braking

A survey of standard circuits in the real conditions found in any city may represent real driving behavior, including data on the uphill and downhill sections of the route. From the dynamic vehicle literature, Traction forces under acceleration, Maximum power transferred to the road, Maximum traction force and Resistance to runway inclination are data which consider elevation profile angle of the route [7].

METHODOLOGY

This work is divided into tree major steps: the first step consists of comparing current Brazilian standard urban drive cycle and a local drive cycle study in metropolitan city of São Paulo. The second step, regarding energy consumption and CO2 emissions, compares local data to Brazilian Vehicle Labeling Program. The third and last one verifies the influence of the elevation profile, considering the angle of uphill and downhill of the route, on vehicle dynamics.

ROUTES OF SÃO PAULO – An overall ranking data set in 2019 by CET (Traffic Engineering Company) came out with roads/points with the highest volumes by type of vehicle and period, also detailing the sections, direction and peak hour.

Ranking	Route	Section of highway	Direction	Peak hour a.m & p.m	Total vehicles	Distance (Km)
1	Vinte e Três de Maio, Av.	Viad. Tutóia	Bairro	07:30-08:30	10.199	4.367
2	Marginal Pinheiros - Expressa (Av. Eng. Billings)	Pte. da Cidade Universitária	Interlagos	07:00-08:00	9.478	10.702
3	Radial Leste (Av. Alcântara Machado)	Viad. Alcântara Machado	Centro	07:15-08:15	8.817	4.697
4	Marginal Tietê - Central (Av. Otaviano Alves de Lima)	Pte. do Limão	Castelo Branco	18:30-19:30	6.996	7.820
5	Marginal Tietê - Expressa (Av. Morvan Dias de Figueiredo)	Pte. da Vl. Guilherme	Castelo Branco	18:30-19:30	6.927	3.586
6	Rubem Berta, Av.	Viad. Pedro de Toledo	Centro	07:00-08:00	6.617	2.196
7	Radial Leste (R. Melo Freire)	Viad. Carlos Ferraci	Centro	07:00-08:00	6.378	2.404
8	Washington Luís, Av.	R. Renascença / Passarela de Congonhas	Centro	07:00-08:00	5.699	7.716
9	Eusébio Matoso & Morumbi, Av.	R. Cardeal Arcoverde	Centro	08:00-09:00	5.659	1.356

Table1: Overall raking with highest vehicle volume in São Paulo.

Based on this most recent data, a similar route and distance was considered for this test by selecting these heaviest routes and traveling in the peak hour on different days.

Figure 7: 9 Heaviest routes of São Paulo researched.

VEHICLE USED - A personal vehicle of the brand Nissan Versa SV, Exclusive model, manufactured year of 2021 and CVT transmission was used. Dimensions, aerodynamics and fuel consumption (Gasoline and Ethanol) are shown int the figure 7 below:

Figure 8: Nissan Versa Exclusive 1.6 datasheet.

The test conditions were the following:

- No air conditioning on;
- No rain, dry roads;
- No traffic accidents neither reforming;
- 4-wheel tires calibrated according to manual 33 lbs;
- Driver's weight (85kg) considered in the study and same weight condition for all cycles.
- Author's driving profile for all routes;
- Fuel used: Ethanol, always ¼ of the tank used for all cycles and refueled at the same gas station.

VEHICLE DATA ACQUISITION – the vehicle was equipped with a microcontroller ELM 327 responsible for translating a car's on-board diagnostics (OBD) interface. When connecting the ELM 327 to the vehicle's OBD interface, the scanner has paired with mobile's Bluetooth. To read the vehicle's information and fault codes, the scanner must be accessed via Car Scanner App on the smartphone.

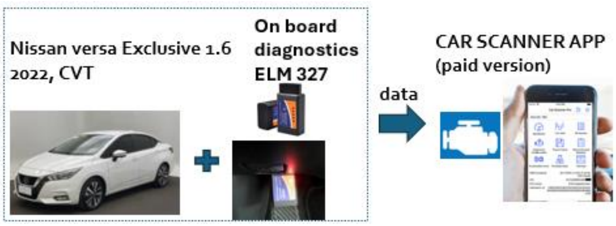


Figure 9: Vehicle equipped with OBD and Car Scanner

All the information collected by automotive sensors is sent to the Electronic Control Unit (ECU) via the Controller Area Network (CAN), which can be accessed via the OBD port in cars. As soon as the data is collected by the App, CSV data of speed, acceleration, torque, altitude, rotation per minute, time and some others are exported to CSV format and analyzed into Tableau® software.

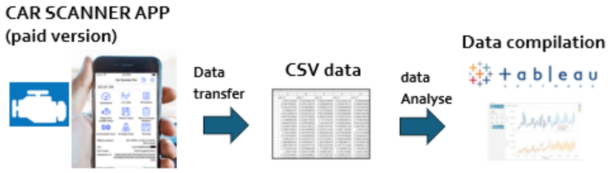


Figure 10: Process to extract data and compile it into software.

WELL-TO-WHEELS - It is a broad concept that assesses the impact of the light vehicle transport sector on greenhouse gas (CO2) emissions. This concept takes into account CO2 emissions from the production of energy and vehicle use, which we will refer to in this work as CO2eq.

The AEA (Automobile Engineers Association) carried out two important studies to support the calculation of this impact: the calculation methodology and the carbon intensity of energy sources in Brazil over several years. Carbon Intensity (IC) is calculated for Energy Production and Energy Consumption (CE) is calculated considering the use of vehicles [17].

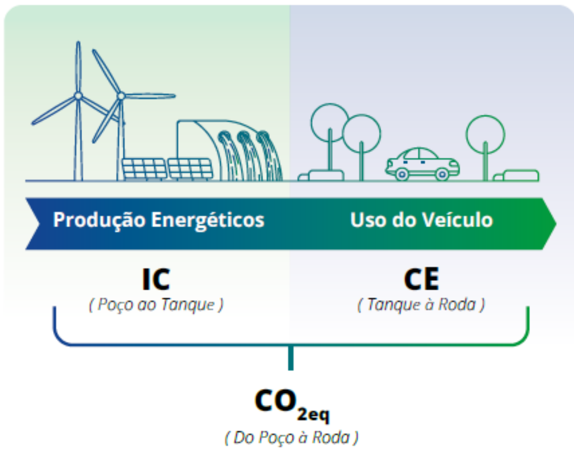


Figure 11: Well-to-Wheels CO2eq calculation [17].

The following information will be needed to calculate CO2eq emissions “From well to wheel”:

1. Energy consumption (in the case of mono-fuel or electric vehicles) or range (in the case of flex-fuel vehicles). This data can be consulted on the INMETRO website in the PBEV² Program;
2. The carbon intensity of energy sources, according to a study carried out by the AEA;

3. The energy density of fuels according to NBR 7094;

4. Ethanol use factor according to a study carried out by AEA;

5. Define the vehicle for which you want to calculate the CO2 emissions "from well to wheel" (CO2eq);

6. Search the INMETRO website for the PBEV Program: energy consumption (in the case of mono-fuel or electric vehicles) or range (in the case of flex-fuel vehicles).

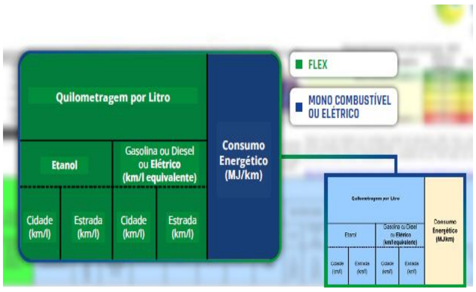


Figure 12: Example of PBEV Program which shows energy consumption and vehicle range (Ethanol or Gasoline).

ENERGY CONSUMPTION CALCULATION – Depending on the energy density, Energy consumption (MJ/km) calculation differs for each kind of fuel. For Ethanol (CE E100) density is 20,09 (MJ/L) and Gasoline (CE E22) density is 28,99 (MJ/L). Based on range data for each fuel autonomy in km/L from INMETRO, urban and roadways fuel autonomy are also considered in the calculation [17].

$$CE_{E100} = 20{,}09 \Big/ \left(\frac{\text{(Autonomia estrada [km/l]} * 1{,}3466)}{\text{(1-(Autonomia estrada [km/l]} * 0{,}0032389))} \right) \times 0{,}45 + 20{,}09 \Big/ \left(\frac{\text{(Autonomia cidade [km/l]} * 1{,}18053)}{\text{(1-(Autonomia cidade [km/l]} * 0{,}0076712))} \right) \times 0{,}55$$

Densidade energética dos combustíveis (MJ/L) conforme NBR 7024 (Anexo2)

(a) (a)

$$CE_{E22} = 28{,}99 \Big/ \left(\frac{\text{(Autonomia estrada [km/l]} * 1{,}3466)}{\text{(1-(Autonomia estrada [km/l]} * 0{,}0032389))} \right) \times 0{,}45 + 28{,}99 \Big/ \left(\frac{\text{(Autonomia cidade [km/l]} * 1{,}18053)}{\text{(1-(Autonomia cidade [km/l]} * 0{,}0076712))} \right) \times 0{,}55$$

Figure 13: Energy Consumption Calculation for each type of fuel.

CO2eq CONSUMPTION CALCULATION – In order to calculate Well-to-Wheel CO2eq emissions, it multiplies energy consumption (CE) for each fuel by its carbon intensity (IC) and use effect (FU). Carbon intensity and use effect (FU) for each year are calculated from energy demand throughout of the years [17].

$$CO_{2eq} = CE_{E100} \times IC_{E100} \times FU + CE_{E22} \times IC_{E22} \times (1 - FU)$$

Figure 14: CO2eq calculation formula

The yellow portion in the table below are the values considered in this study, once the test was performed only with Ethanol fuel [17].

ANEXO 1 — Intensidades de Carbono dos Energéticos (CO_2/MJ)

	2019	2020	2027	2032
Etanol hidratado (E100)	28,45	28,52	24,63	21,61
Eletricidade	34,22	31,77	22,58	26,62
Gasolina (E22)	77,54	77,52	76,9	76,44
Diesel B7	82,41	82,40	82,37	82,21

ANEXO 2

Densidade Energética dos Combustíveis Conforme NBR 7094	MJ/L
Gasolina E22	28,99
Etanol Hidratado (E100)	20,09
Diesel	35,65

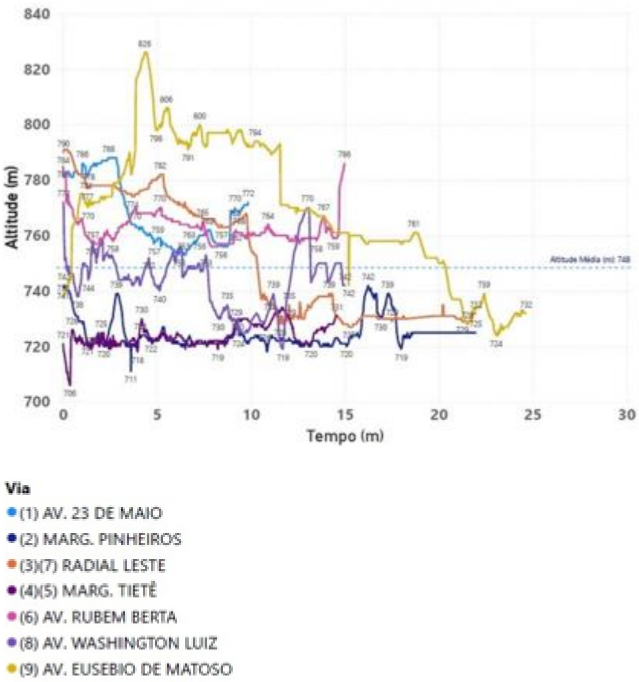
ANEXO 3 — Fatores de uso de etanol por energia (FU)[4]

2019	2020	2027	2032
30%	28%	38%	38%

Figure 15: Carbon intensity, Fuel energy density and Ethanol use factor table [17].

RESULTS AND DISCUSSION

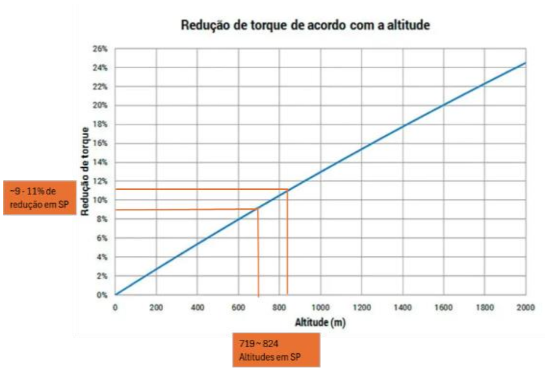
From the 9 routes selected, with heaviest traffic data in São Paulo city, it was evaluated the elevation altitude and get an average of 748 meters as shown in the grap1 below.



Graph 2: Altitude (meters) per time (minutes).

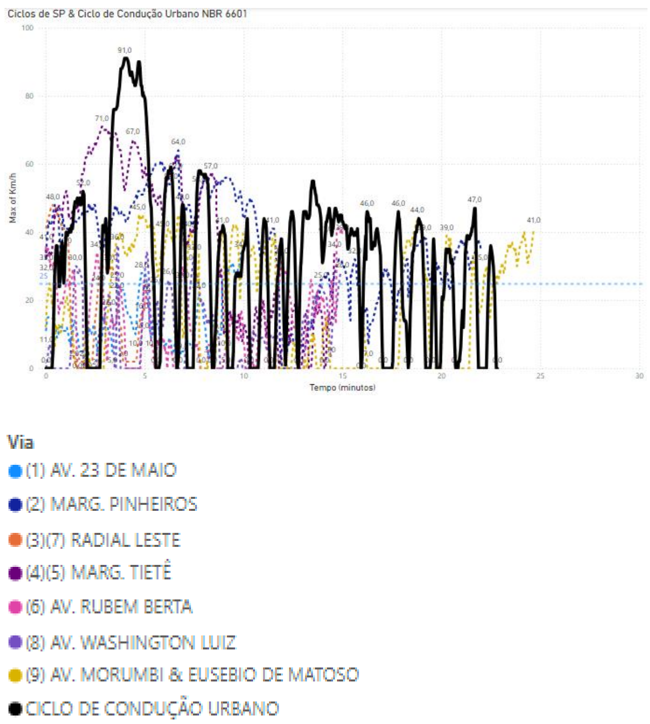
The higher the altitude, the lower the atmospheric pressure is, which means, lower amount of oxygen per volume in the atmosphere. With thin air, the car's performance decreases. This is because the engine receives less air and less fuel to burn inside the cylinders, resulting in a greater loss of power.

From São Paulo point of view, there is a torque reduction of around 9 to 11%, once its altitude range varies from 836 meters to 706 meters according to the graph below. Av. Eusebio Matoso & Av. Morumbi (9) are the ones with higher altitude.



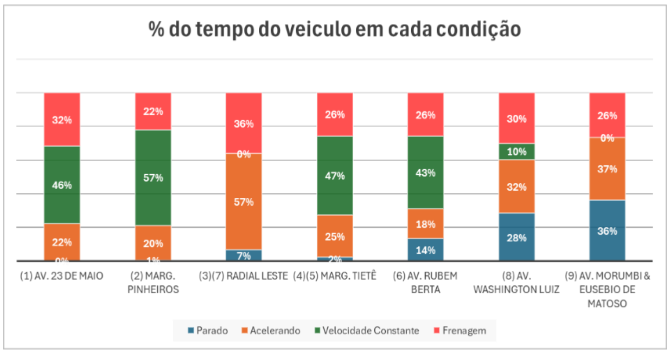
Graph 3: Torque reduction due to altitude.

Drive cycles of São Paulo compared to NBR 6601 standard consists in less average speed within almost the same period. São Paulo City shows an average speed of 26 Km/h while NBR standard shows 31,5 Km/h and higher speed peak.



Graph 4: São Paulo drive cycles and NBR 6601 urban cycle.

From the vehicle perspective, the percentage of the time in each condition (stopped, accelerating, constant speed and braking) are shown in the graph below.



Graph 5: Vehicle condition time in each drive cycles routes.

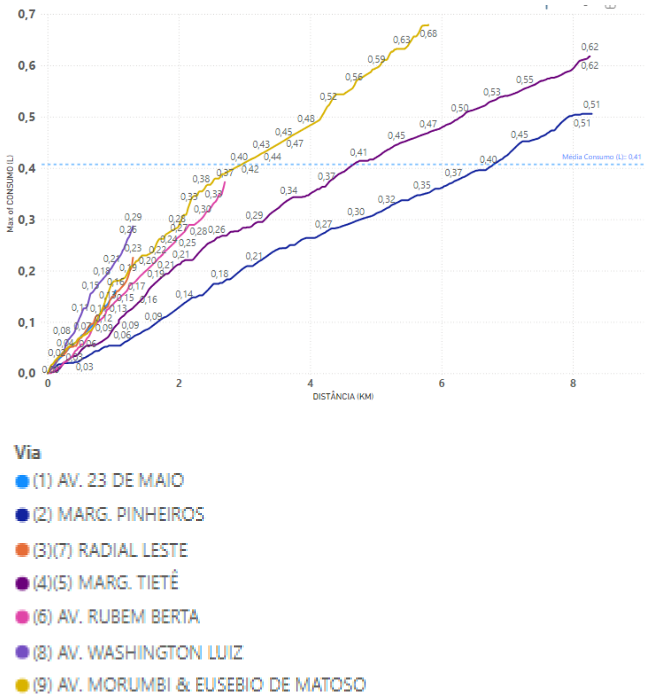
Av. Morumbi & Eusebio Matoso (9) consists in more stopped time due to the numbers of traffic lights. Also, it is almost zero constant speed due to the high numbers of uphill and downhill together with heavy traffic.

Comparing to main worldwide drive cycles, São Paulo city has its particularity. Lower average speed, higher stopped time, lower average acceleration and higher energy consumption lead São Paulo Cycle to different and not so close results.

PARÂMETRO	FTP-75 (média)	NEDC	JC08	WLTC	Ciclo SP
Duração (s)	1369	1180	1204	1800	1052
Distância (km)	11,99	11,03	8,17	23,27	8,3
Velocidade média (km/h)	31,5	33,6	24,4	46,5	20,85
Velocidade máxima (km/h)	91	120	81,6	131	71
Paradas	18	14	12	9	41
Tempo parado (s, %)	241 (18%)	280 (24%)	346 (29%)	226 (12%)	195 (13%)
Tempo em cruzeiro (s, %)	109 (08%)	475 (40%)	21 (2%)	66 (4%)	435 (29%)
Tempo acelerando (s, %)	544 (39%)	247 (21%)	432 (36%)	789 (44%)	450 (30%)
Tempo desacelerando (s, %)	475 (35%)	178 (15%)	405 (33%)	719 (40%)	435 (29%)
Aceleração média positiva (m/s²)	0,5	0,59	0,42	0,41	0,03
Desaceleração média (m/s²)	-0,58	-0,82	-0,45	-0,45	-0,46
Desaceleração mínima (m/s²)	-1,48	-1,39	-1,19	-1,5	-2,26
Demanda Energética (MJ/km)	0,35	0,37	0,29	0,45	0,472

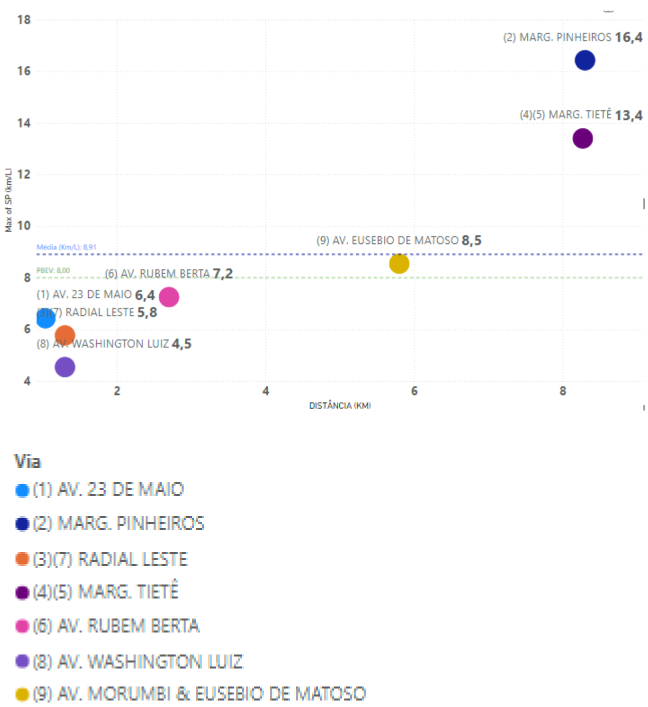
Table 2: Drive Cycles parameters compared to São Paulo.

In terms of fuel consumption, graph 5 indicates the cumulative fuel consumption in liters by each route in São Paulo Cycle. Av. Morumbi & Eusebio Matoso (9) and Av. Washington Luiz (8) are the ones with higher consumption and, consequently, higher stoppage timing.



Graph 6: Vehicle Ethanol liters consumption by distance travelled.

PBEV shows that for the vehicle used for this work, the average consumption for urban driving cycles is 8 Km/l. The average consumption of São Paulo Cycles reached 8,91 Km/l, where Marg. Pinheiros (2) and Marg. Tietê (4)(5) consisted of lower consumption of around 15 Km/l and Av. Washington Luiz (8) higher consumption around 4,5 Km/l.



Graph 7: Fuel average consumption for each route.

Energy consumption (MJ/km) average of São Paulo Cycles results show that results are around 5% compared to PBEV.

VIA	DISTÂNCIA (Km)	(a) CE E100 (MJ/Km) - SP	(b) CE E100 (MJ/Km) - PBEV	Percentual da diferença (a)/(b)
(8) AV. WASHINGTON L.	1,3	2,640	1,748	51%
(3)(7) RADIAL LESTE	2,3	2,201	1,748	26%
(1) AV. 23 DE MAIO	1,04	2,033	1,748	16%
(6) AV. RUBEM BERTA	2,7	1,869	1,748	7%
(9) AV. EUSEBIO M.	5,8	1,673	1,748	-4%
(4)(5) MARG. TIETÊ	8,27	1,277	1,748	-27%
(2) MARG. PINHEIROS	8,3	1,148	1,748	-34%
Média		**1,834**	**1,748**	**4,94%**

Table 3: São Paulo Drive Cycles Energy consumption compared to PBEV.

CO2eq results were very similar to PBEV, where the difference was almost 0%.

VIA	DISTÂNCIA (Km)	(a) CO2eq "Do Poço a Roda" - SP	(b) CO2eq "Do Poço a Roda" - PBEV	Percentual da diferença (a)/(b)
(8) AV. WASHINGTON L.	1,3	116,88	109,75	6%
(3)(7) RADIAL LESTE	1,3	113,38	109,75	3%
(1) AV. 23 DE MAIO	1,04	112,03	109,75	2%
(6) AV. RUBEM BERTA	2,7	110,72	109,75	1%
(9) AV. EUSEBIO M.	5,8	109,16	109,75	-1%
(4)(5) MARG. TIETÊ	8,27	105,99	109,75	-3%
(2) MARG. PINHEIROS	8,3	104,96	109,75	-4%
Média		**110,44**	**109,75**	**0,63%**

Table 4: São Paulo Drive Cycles CO2eq emissions compared to PBEV.

Route 2030, Established by the Federal Government, it sets standards and guidelines to modernize the Brazilian automotive industry.

They have established energy efficiency targets, reducing from PBEV 1,74 (MJ/km) to 1,62 (MJ/km) its energy consumption for vehicles. Comparing São Paulo Cycles to this new target, there is a difference of 13,24% higher.

VIA	DISTÂNCIA (Km)	(a) CE E100 (MJ/Km) - SP	(b) CE E100 (MJ/Km) - ROTA 2030	Percentual da diferença (a)/(b)
(8) AV. WASHINGTON LUIZ	1,3	2,640	1,620	63%
(3)(7) RADIAL LESTE	2,3	2,201	1,620	36%
(1) AV. 23 DE MAIO	1,04	2,033	1,620	25%
(6) AV. RUBEM BERTA	2,7	1,869	1,620	15%
(9) AV. EUSEBIO DE MATOSO	5,8	1,673	1,620	3%
(4)(5) MARG. TIETÊ	8,27	1,277	1,620	-21%
(2) MARG. PINHEIROS	8,3	1,148	1,620	-29%
Média		**1,834**	**1,620**	**13,24%**

Table 5: São Paulo Drive Cycles CO2eq emissions compared to Route 2030.

Others local drive cycles works have compared energy demand (VDE), by calculating average of Energy consumption by the distance travelled in other cities. Several studies for local drive cycles were performed as well, but only a few ones were in Brazil.

Therefore, not 100% of the local drive cycles around the world were performed at the same way, but as we can see in the table below, Energy demand of São Paulo Cycle (SP) is close to the scenario of WLTC cycle.

Local	Referência	DEV
Atenas	Karavalis et al (2007)	0.371
Chennai	Arun et al (2017)	0.255
Edimburgo	Esteves-Booth et al (2001)	0.292
Fortaleza	Azevedo et al. (2017)	0.319
Jilin, China	Wang et al., (2018)	0.326
Santa Maria 12h	Roso e Martins (2015)	0.199
Sydney	Kent, Allen e Rule (1978)	0.371
Toronto	Amirjamshidi e Roorda (2015)	0.290
WLTC		0.435
FTP-75		0.339
SP	**Tráfego Congestionado**	**0.472**

Table 6: São Paulo Energy demand (DEV) compared to others local drive cycles.

Elevation angle on roads with heavy traffic average was around -0,20 graus, which means, from vehicle dynamic perspective there is no big impacts. However, the perspective for the residents in these areas, there is somehow impact in case of uphill (more engine noise and pollution) and downhill (excessive braking and speed exceed).

VIA	Média (% de inclinação)	Média Ângulo de elevação (graus)	Máximo Ângulo de elevação (graus)	Mínimo Ângulo de elevação (graus)
(1) AV. 23 DE MAIO	**-1,23%**	-0,72	5,99	-17,61
(2) MARG. PINHEIROS	**0,17%**	0,10	7	-7,78
(3)(7) RADIAL LESTE	**-0,28%**	-0,17	2,44	-4,58
(4)(5) MARG. TIETÊ	**0,27%**	0,17	10,38	-6,34
(6) AV. RUBEM BERTA	**-0,83%**	-0,50	6,04	-10,05
(8) AV. WASHINGTON LUIZ	**-1,72%**	-1,01	5,17	-18,99
(9) AV. MORUMBI & EUSEBIO DE MATOSO	**0,64%**	0,39	7,01	-5,53
Média	**0,00**	**-0,20**	**6,29**	**-10,13**

Table 7: São Paulo Elevation angle of the routes

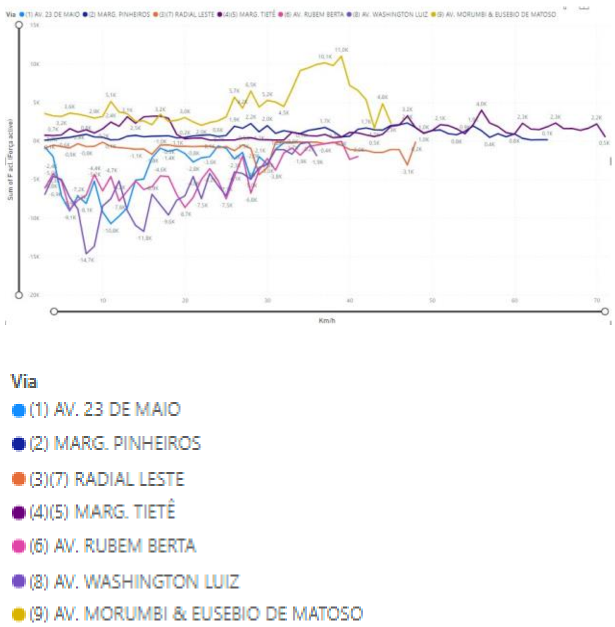
From the slope resistance (Qs) point of view, the following calculation was performed in order to see which route demands more resistance from vehicle.

$$Q_s = Gsen(\alpha)$$ (equation 1)

Where:

- G = Peso do veículo $[N]$;
- α = Ângulo de inclinação da pista $[rad]$.

As the result, the route Av. Eusebio de Matoso & Av. Morumbi (9) are the one with more stoppage time and less constant speed compared to the others, reached a peak of 11.000 (N), highest slope resistance results compared to the others.



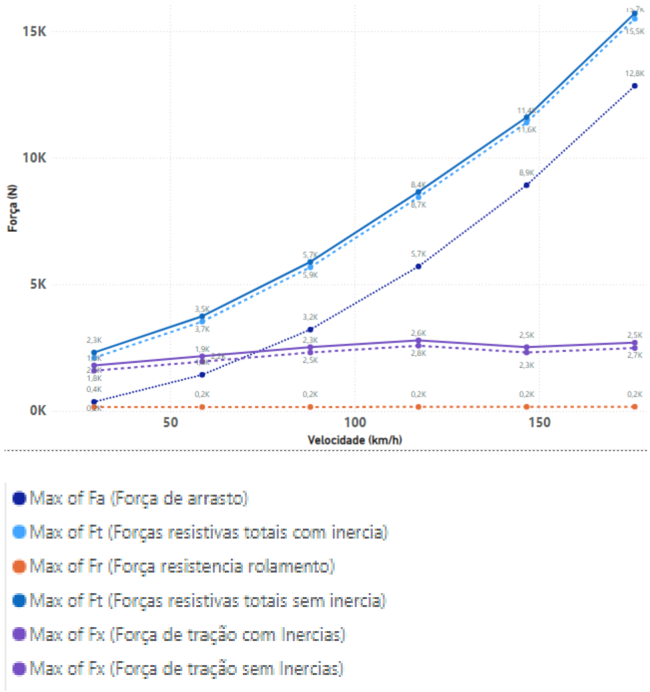
Graph 8: Slope resistance.

The average elevation in percentage from all 9 routes reached 0%. In the table below we can see the car travelled distance was more downhill conditions than uphill.

VIA	DISTÂNCIA (Km)	Tempo (m)	Velocidade de Média (km/h)	Média (% de inclinação)	Média F acl. (N) (Força de Aclive)
(1) AV. 23 DE MAIO	1,3	15	10	-1,23%	- 138
(2) MARG. PINHEIROS	2,27	21,8	27	0,17%	19
(3)(7) RADIAL LESTE	1,04	9,86	13	-0,28%	- 31
(4)(5) MARG. TIETÊ	2,7	15	13	0,27%	30
(6) AV. RUBEM BERTA	5,8	24,6	19	-0,83%	- 93
(8) AV. WASHINGTON LUIZ	8,27	14,6	38	-1,72%	- 193
(9) AV. MORUMBI & EUSEBIO DE MATOSO	5,79	21,9	26	0,64%	72
Média	**3,88**	**17,54**	**20,86**	**0,00**	**- 48**

Table 8: São Paulo Cycle elevation profile percentage average.

From the vehicle perspective point of view, considering elevation profile average of 0%, Resistive forces as a function of speed with and without rotational inertias are shown in the graph below.



Graph 9: Resistive forces with and without rotational inertia.

It can be seen a difference on rotational traction forces of -10% and the total forces of -4% with inertia.

CONCLUSION

Considering these nine routes from the heaviest traffic in São Paulo City, in a practical test by using a vehicle, it can be seen that energy demand required for the vehicle is 30% higher. Speed average is -31% and acceleration average are -83% lower compared to current Brazilian urban drive cycle standard. Despite being few data, NBR 6601 standard does not reflect urban scenario of São Paulo City.

Regarding energy consumption and CO2 emissions, fuel consumption with -11%, energy consumption (MJ/km) 4,94% and CO2eq with 0,63% represent low divergence. However, when compared to Route 2030 target, there is a difference of energy consumption (MJ/km) of 13,24% compared to Brazilian vehicle labeling program.

The average angle of the elevation profile, considering the angle of uphill and downhill of the 9 routes is -0,20 degrees. Although being almost 0 degrees, from the vehicle dynamics perspective, in some routes, it must meet uphill and downhill route systems requirements.

Also, in face of average impact on fuel consumption and CO2eq emissions, the results do not show big differences compared to NBR standard. It is important to note that on the routes that occur uphill, residents of that place may suffer with engine noise and air pollution.

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