

Evaluation of the combined driving cycle and its effect on fuel efficiency in a vehicle with an Otto cycle engine

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Abstract

The study proposed to analyze the combined driving cycles and their effect on fuel consumption within the Distrito Metropolitano de Quito. For this, a test protocol was established where the orography of the land, traffic density and road infrastructure of the District were studied. These factors allowed the evaluation of consumption through a global positioning system and a canister in order to systematically travel a set of roads in distance, time, and average speed in a vehicle with an Otto cycle engine. The data was processed through a statistical analysis of minimization of weighted averages. The findings revealed that the combined driving cycle obtained a high reliability (99.7%) in each procedure. The outcome of the study concluded that the combined cycle was differential to that proposed by the manufacturer, since there is a variation of 40% as proposed by the vehicle manufacturer.

Keywords: driving cycle; fuel consumption; otto cycle; traffic condition.

Introduction

Driving cycles are used by various vehicle manufacturers. However, these do not fit the reality of all countries based on road design, type of

intersections, type of local neighborhood and traffic conditions. The driving cycle is a profile of speeds drawn on a speed-time plane, which represents a typical way of driving in a city or highway, taking into account the technology of the vehicle, the characteristics of traffic, roads, climatic and geographical characteristics (altitude, among the most important) and also characteristics of the drivers themselves. These driving cycles are of great importance, among which are: the planning of an adequate development of a city, the development of technology for new cars, the validation of models that predict the behavior of vehicles on public roads and in the inventories of polluting emissions in large cities. These, in turn, allow establishing strategies to control the ecological balance of the place, city or region; This is understood as the relationship of interdependence between the elements that make up the environment that makes possible the existence, transformation and development of man and other living beings.(Alcántar et al., 2015; López et al., 2022; Quinchimbla y Solis, 2017)(González-Ortega et al., 2019; Ismadiyorov y Sotvoldiyev, 2021; Palomeque y Navas, 2018)(Ahn et al., 2002; González-Oropeza, 2005; Llanes et al., 2018)(Guzmán et al., 2018; Huang et al., 2020; Liu, 2018)

In Ecuador, a study was identified on driving cycles where Leguisamo et al. (2019); Moawad et al. (2009); Sciarretta y Vahidi (2019) developed a method to determine emission factors in light gasoline vehicles in the city of Quito. The researchers proposed a methodology to estimate the emission factors of pollutants such as NO_x, CO₂, CO and HC generated by the fleet of light gasoline vehicles, since this sector is the most representative. The findings revealed that the average speed in the district was 26.1 km/h. This value was 5.6 km/h lower than the standardized FTP-75 standard (31.7 km/h). The(Quinchimbla y Solis, 2017) selected route was the result of the analysis of several possible routes, based on data on vehicular influx, importance of the main roads and the distribution of slopes according to statistical data provided by the Metropolitan Air Monitoring Network (REMMAQ). In turn, the selection of the method of measuring emissions en route with on-board equipment for the estimation of emission factors considered the geographical characteristics of the city of Quito.

For this study, due to the number of roads, it was considered appropriate to select two tentative routes for each driving scenario, that is, two for city, two for road and two for combined cycle, which will be presented in an orderly manner in the research method.

Materials and Methods

The study had a guideline of application of the direct methodology for the development of driving cycles(Quinchimbla y Solis, 2017; Sitnik et al., 2014). In this way, the performance of the tests and the way in

which the data were collected gave way to the analysis of fuel consumption for the fixing of the repeatability and reproducibility of the measurement process by applying control figures that allow validating the representative driving cycles of the Metropolitan District of Quito.

Obtaining the combined driving cycle

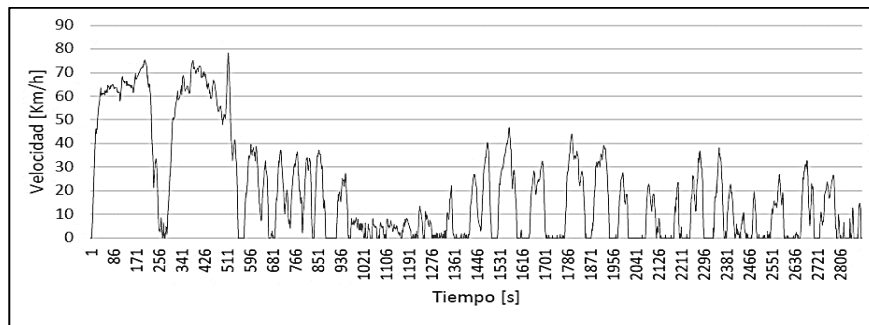
The results of the information processing are derived from the experimental curve with the lowest value of Y (0.1098) belonging to route 4 of route C2, which corresponds to the route that begins at Bridge 5 located on Av. Rumiñahui and then continues through Av. Rumiñahui, Pichincha, Gran Colombia, October 12, Patria, Pérez Guerrero, América, Colón and ends at the roundabout of Plaza Artigas; in the East-West direction at 7H00. The combined driving cycle representative of the DMQ was found in the speed data at every second (see table 1 and fig. 1).

Table 1: DMQ combined cycle driving parameters

Average speed (km/h)	Maximum speed (km/h)	Idle time (s)	Number of stops	Total elapsed time(s)	Distance traveled (m)	Positive average acceleration (m/s ²)	Maximum positive acceleration (m/s ²)	Time with positive acceleration(s)
19,186	78,326	960	63	2889	15. 673,042	0,403	1,456	1. 036

Note. The data were obtained from the vehicular behavior on the route over four days of the week, data were taken for 22 effective hours and a total distance of 405,156 km was traveled.

Fig. 1: Combined driving cycle representative of the D.M.Q.



Construction of the combined driving cycle.

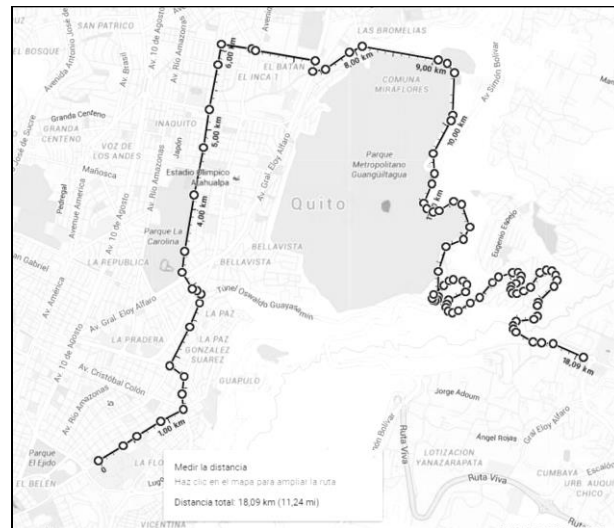
The combined driving cycle translates the typical way of driving of the majority of people who enter daily from regions outside the city (valleys, other cities) in a combined cycle, that is, 50% city, and the other 50% remaining on the road, since it took into account the characteristics of road traffic, climatic and geographical characteristics (altitude, among the most important) and also characteristics of the drivers themselves.

Combined Path Definition 1

The combined cycle route in the DMQ began at the Supermaxi Shopping Center in Cumbayá and then continued through Av. Interoceánica, Libertador Simón Bolívar, De los Granados, Eloy Alfaro, Río Coca, Shyris, December 6, Francisco de Orellana, Coruña, October 12 and ended at the Catholic University (intersection Av. 12 de octubre and Jorge Washington); the distance covered was 9,990 meters of suburban part and 8100 m of urban part, with a total length of 18,090 m.

The elevation profile of Route C1 established that the highest point of elevation is located on Av. Libertador Simón Bolívar (height of the Monteolivo Cemetery, 2870 m), while the point with the lowest height is on Av. Interoceanica (height of the Supermaxi of Cumbayá, 2399 m; the latter is located at the beginning of the route and the lowest was found at the entrance of the Tumbaco Valley (see figure 2).

Fig. 2: Combined route 1



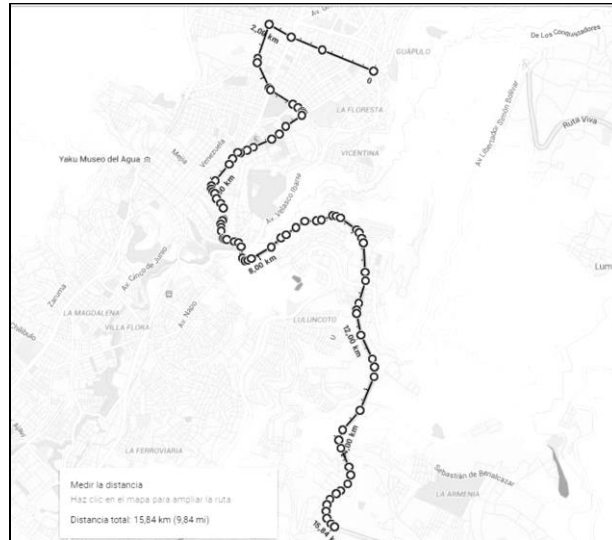
C2 Combined Path Definition

This route began at Bridge 5 located on Av. Rumiñahui and then continued through Av. Rumiñahui, Pichincha, Gran Colombia, October 12, Patria, Pérez Guerrero, América, Colón and ended at the roundabout of Plaza Artigas (intersection of Av. Colón with October 12); the route had a distance of 7993 m of suburban part and 7680 m of urban part, with a total length of 15673 m. Figure 3 shows the selected route based on vehicular flow.

The elevation profile of route C2 established as the highest point Av. Rumiñahui (height of the bridge that crosses Av. Simón Bolívar over Av. Rumiñahui, 2877 m), while the points with less height is in the El Trébol sector, 2755 m and Av. Rumiñahui (height of Bridge 5, 2619 m); the

lowest height value was found located in the Quebrada Machángara and at the entrance of the Valle de los Chillos (Figure 3).

Fig. 3: Combined route 2



Empirical Development Protocol

The methodology applied in this study is based on the execution of dynamic tests, since gasoline was used as the only fuel to obtain real data on its consumption (Nests y Salisa, 2019; Leguísamo et al., 2020). Therefore, it was established in seven stages: a) selection of the test vehicle, b) measuring equipment, c) test protocol, d) repeatability and reproducibility, e) data collection, f) data analysis, and, e) analysis of results obtained.

Test Vehicle Selection

The selected vehicle was an active Chevrolet Aveo std 1.4 of the year 2008, as it presented the characteristics of a four-cylinder engine, with a manual gearbox, and has a fuel supply system to electronic injection. This vehicle was chosen, since, according to the registry registry of the DMQ car park, it has been the most used.

Measuring equipment

This equipment allowed to measure the amount of fuel consumed by the vehicle and consisted of the following elements: a) pressure gauge (100 psi), b) pressure hoses, c) shut-off valves, and, d) electric compressor. Similarly, a (Gaikwad et al., 2019; Guang y Jin, 2019) global positioning system (GPS) was used for the development of driving cycles for the measurement of the average travel speed, in such a way that the tests have been carried out under similar traffic conditions.

Test protocols

The tests were carried out during 3 working days for each driving cycle, twice a day (city cycle 08h00 and 13h00, road cycle 07h00 and 13h00 and combined cycle 07h00 and 13h00). To this end, the protocol conditions of the vehicle were inspected: i) inspection of the mechanical conditions of the vehicle, ii) locate it at the beginning of the route, iii) disabling the fuel pump of the vehicle, iv) identification of the connection points for the installation of the Canister, v) connect the Canister in the intakes and return of gasoline of the engine, (vi) filling the Canister with a base of 5 litres of petrol; (vii) pre-empting the Canister at a pressure similar to that of the operation of the vehicle's power supply system by means of a compressor; (viii) putting the vehicle into operation and driving towards the established route, (ix) obtaining the average speed of travel by means of GPS, (x) completion of the test cycle and control of the volume of fuel consumed by means of a measuring specimen.

Repeatability and reproducibility

The reliability of the method was verified by processing and analyzing the values obtained, these had to be kept within an optimal confidence range. The application of control charts established repeatability and reproducibility. Variation in measurements was inevitable. Given this, the control charts allowed to determine when this variation exceeds the acceptable limits and analyze if the measurement process is carried out correctly. To this end, the evaluation was carried out using 2 types of tests: a) repeatability consisted of taking measurements of the test variables on the same day, with the same vehicle and under the same conditions; b) reproducibility lay in developing measurements of the test variables on different days, with the same vehicle and under the same conditions.(Benajes et al., 2018; Ortiz-Soto et al., 2018)(Prakash et al., 2019)

Data collection and processing

The measurements were made in each of the conduction cycles representative of the DMQ, through the procedure 6 measurements were made for each cycle. The total distance covered was 330.3 km (see table 2).

Table 2: Measurements obtained by the driving cycle

			Distance (km)	Average speed (Km/h)	Volume Consumed (mi)	Fuel Consumption (Km/Liter)	Fuel consumption (Liter/km)
Combined Cycle	Day 1	Measurement 1	15,673	16,246	1552	10,0985825	0,09902318
		Measurement 2	15,673	17,592	1469	10,6691627	0,09372807

	Day 2	Measurement 1	15,673	16,734	1537	10,1971373	0,09806674
		Measurement 2	15,673	15,857	1496	10,4766043	0,09545078
	Day 3	Measurement 1	15,673	21,255	1610	9,73478261	0,10272443
		Measurement 2	15,673	16,372	1531	10,2370999	0,09768392

Descriptive statistical application

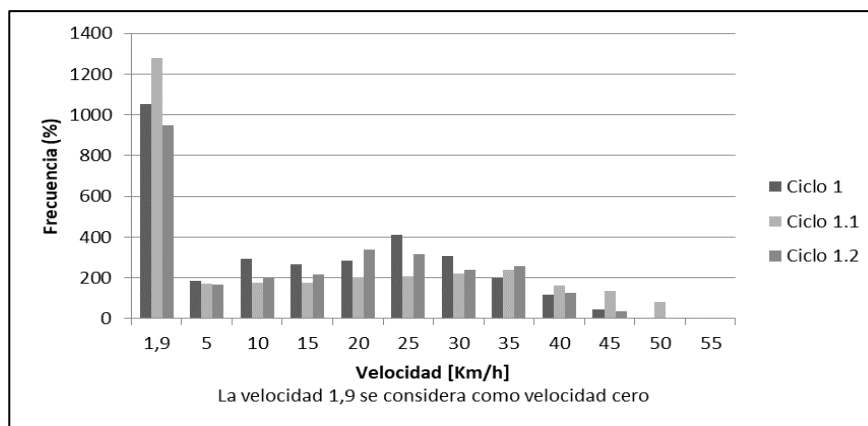
The mean has been used to measure the variation of the sample means under an acceptable level of confidence. An upper (LSC X) and lower (SCIX) control limit are set around an acceptable mean. The $\bar{X}$ value serves as an estimate of μ (average or mean). If the data is within an acceptable range, random variation occurs. However, if these exceed the mean or are below it, the control process has detected an assignable cause variation.

Results

Comparative analysis of the cycle obtained

The two cycles that follow the cycle obtained are route 2 of route C2 and route 9 of route C2, whose Y values are 0.1166 and 0.1168 respectively. The representative cycle was identified as the C1 cycle, while those that approach it by their score were represented as Cycle C1 and Cycle C2 respectively. Through an analysis of speed frequencies, a comparison was made to know the behavior of each of them during their journeys. From the result obtained in Figure 1, it emerged that the combined driving cycle is representative in the DMQ since there was a pattern behavior among the routes that are closest to the average of all of them (see figure 4).

Fig. 4: Frequency of speeds of the representative cycle and the two closest cycles



Data analysis

The repeatability and reproducibility of the measurement process was verified by means of the control charts the evolution of the procedure. Figures 5 and 6 did not present errors of assignable cause, since none of the ranges and sample means calculated outside the control limits (see Table 3).

Table 3: Repeatability and reproducibility of the measurement process

CC. (km/l)	Measurement 1	Measurement 2	Average ($\bar{X}$)	Range (R)
Day 1	10,0985825	10,6691627	10,3838726	0,57
Day 2	10,1971373	10,4766043	10,3368708	0,279467
Day 3	9,73478261	10,2370999	9,98594127	0,50231733
			$\bar{X} = 10,236$	$R = 0,45$
			$LSC_x = 11,083$	$LSC_R = 1,472$
			$LIC_x = 9,388$	$SLR = 0$

Note. The calculation of the average was established through vehicle analysis in the period of 3 working days.

Fig. 5: Control for fuel consumption sample means

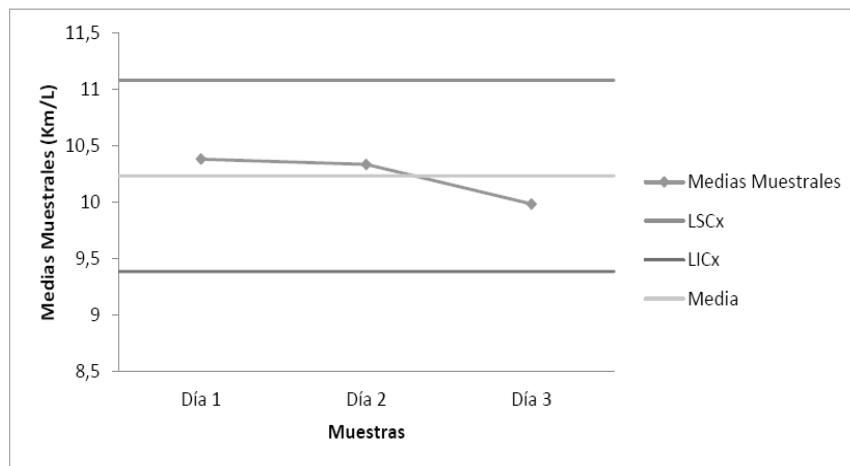
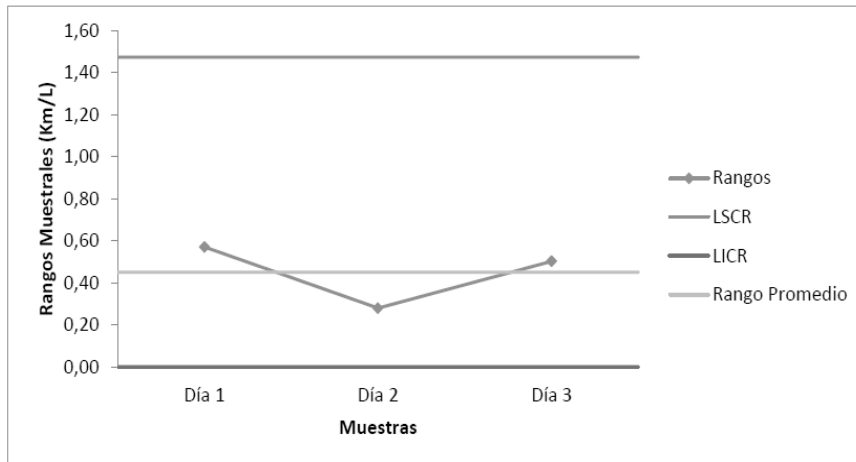


Fig. 6: Control for fuel consumption sample ranges



Control for mean and sample ranges of average velocity

The results of the information processing presented in Table 4 identified the differences of the average speed measurements between each of the tests. Random errors are not due to errors of assignable cause, since none of the means and sample ranges exceeded the control limits (see Figure 7 and Figure 8).

Table 4: Differences in average speed measurements

Average speed (Km/h)	Measurement 1	Measurement 2	Average ($\bar{X}$)	Range (R)
Day 1	14,291	13,044	13,6675	1,25
Day 2	13,229	13,639	13,434	0,41
Day 3	17,267	13,198	15,2325	4,069
			$R = 14,111$	$R = 1,91$
			$LSC_x = 17,699$	$LSC_R = 6,235$
			$SCI_x = 10.523$	$LIC_R = 0$

Note. The differentials were obtained from the average and dispersion statistical processes.

Fig. 7: Control for velocity sample averages

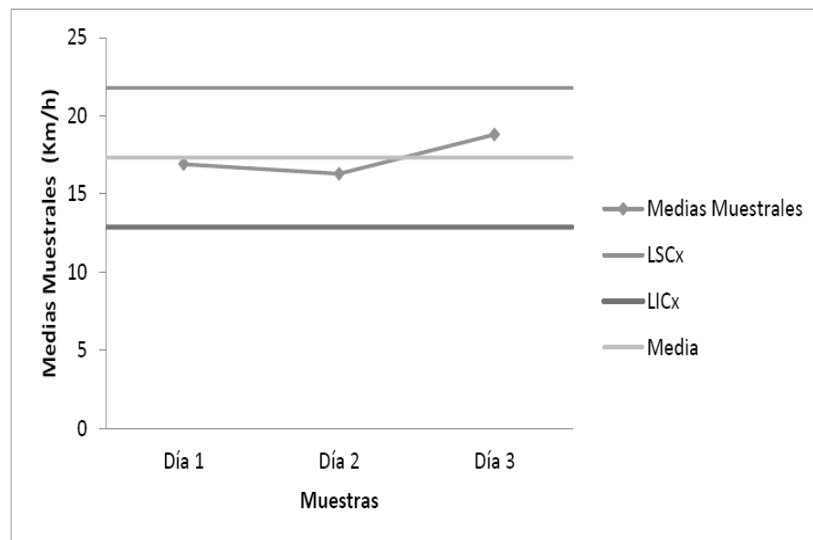
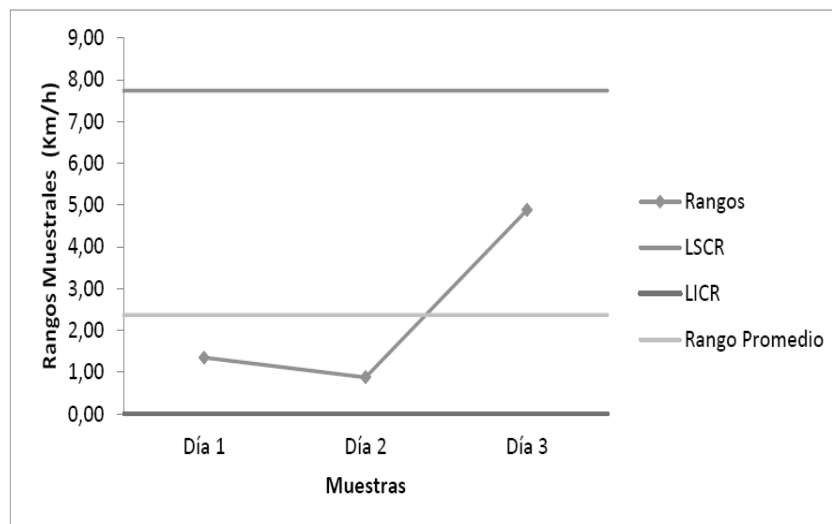


Fig. 8: Control for velocity sample ranges



Analysis of results obtained

The analysis related the average speed with which the vehicle circulated during the tests and the average values of fuel consumption obtained in the combined cycle in the DMQ. In the control figures of the fuel consumption measurements, the range and average values were within the confidence limits, in this way it has been guaranteed that the measurement procedure in all the tests is carried out correctly and with this the repeatability and reproducibility of the same was established. The determination of fuel consumption values was reliable, as it used the representative driving cycles of the DMQ.

The average speed of travel depended on traffic conditions, therefore, it was impossible for the values in each test to be equal, however, the amounts were similar. In this way, the control figures showed that the average speeds were within the confidence limits for the relevant tests under similar traffic conditions. It should be noted that the consumption obtained in the combined driving cycle was differential to that proposed by the vehicle manufacturer. The finding showed that the combined consumption obtained in the DMQ cycles was higher than that indicated by the manufacturer, reflecting a percentage variation of 40%.

Table 4: Diagnostic effect of otto cycle motor vehicle

Type of vehicle	Fuel consumption (km/L)	Fuel consumption (L/100 km)	DMQ cycles (L/100 km)	Manufacturer's data sheet (L/100 km)	Percentage change (%)
	Ciclo combinado	Ciclo combinado			
2008 Chevrolet Aveo 1.4	10,236	9,769	9,76	5,9	40

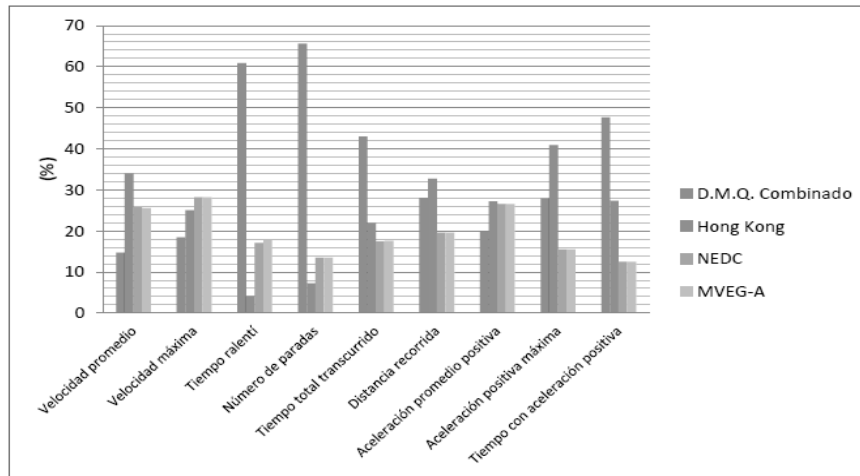
Note. The results were obtained from the application of the vehicle with otto cycle engine.

Discussion

Comparison with combined driving cycles developed in other countries

It is considered important to make a comparison of the combined cycle developed for the DMQ and other cycles with the same characteristics developed in other countries, in order to know the contrast of the driving parameters of each of them. As observed in Figure 9, the driving parameters of each cycle considered do not have similarities, this result is because there is a set of factors such as traffic density, terrain orography and road infrastructure that are independent of driver behavior and that significantly influence driving parameters (see figure 2).

Fig. 9: Comparison of combined driving cycle at country level



Conclusions

The purpose of this study was to analyze combined driving cycles and their effect on fuel consumption within the Metropolitan District of Quito. For this, a test protocol was established where the orography of the terrain, traffic density and road infrastructure of the District were studied. These factors allowed the evaluation of fuel consumption in vehicles with Otto cycle engines. The combined driving cycle was validated by testing in three real-world scenarios with different traffic conditions. The statistical tests reflected a high certainty (99.7%) in each procedure, therefore, the cycles obtained were acceptable.

The results showed that the consumption with combined cycle (9,769 L / 100 km) was differential to that proposed by the manufacturer, since a comparison of fuel consumption in the DMQ cycles and those indicated by the vehicle manufacturer was developed. This finding was differential on average to the percentage variation of the cycles.(Kasseris et al., 2018; Olmos et al., 2018; Prakash et al., 2019)(Nakada et al., 2019; Rao et al., 2018)

The delimiters of the research showed that the diagnostic vehicle must be driven with the same driver in order to achieve repeatability and reproducibility in the tests carried out in the representative cycles of the DMQ. Therefore, researchers should consider a specific testing protocol for measuring fuel consumption in order to avoid assignable cause errors in the results. Similarly, the tests must be executed with rain-free environmental conditions and without any irregular event on the roads due to the variation of traffic conditions.

A posteriori research showed that it is necessary to simulate on a dynamometer the driving cycles obtained to establish the level of fuel

consumption for each type of vehicle according to the standardization of test conditions. On the other hand, current estimates of emissions inventories should be improved by cataloguing DMQ driving cycles with actual District conditions.

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