Eco-driving techniques applied in a transport fleet in Ecuador: A case study with quantifiable and measurable techniques

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Abstract

Transport demand in Ecuador, located in the Andes highlands in South America, is challenging because of the highly topography variability. In fact, half of the total consumption of the local energy stands from transportation. For this reason, this study analyzes techniques for fuel consumption reduction in a transport fleet. This fleet has 26 vehicles from the same model which drive the same route of 201 km between two cities in the highlands of Ecuador where altitude range from 1889 to 3460 meters above sea level. The test was conducted before and after a transport fleet driver was trained in a vehicle that was fitted with a GPS and a fuel flow meter. Data was collected to determine driving parameters like time, speed, acceleration, road slope and instant fuel consumption. Five measurable and quantifiable techniques (idling, constant speed, hard braking and acceleration events, inertia, rpm) were evaluated. Results show that when applying eco-driving techniques compatible with vehicle and route analyzed, it is possible to generate a total fuel reduction of 8%, and reductions between 11% and 51% for each evaluated technique. The eco-driving techniques evaluated could help a transport logistics in order to reduce the fuel consumption with a low investment.

Keywords
eco-driving, driving behavior, fuel consumption, training

1. Introduction

Transportation sector producedaround 24% of the world CO_2 emissions from fuel combustion in 2015, due to fossil fuel combustion. Global CO_2-emissions from road transport grew by 68% from 1990 to 2015(I T F Transport Outlook, 2017). In order to prevent this situation car manufacturers around the world are working in more efficient engines and technologies. Transport companies are always seeking opportunities to conserve fuel which provides simultaneous emissions reductions(Xu, Li, Liu, Rodgers, & Guensler, 2017). One of the strategies that has immediate effect on reducing fuel consumption is eco-driving, which is a set of the techniques, used to reduce fuel consumption when vehicle is travelling on the road. The fuel consumption savings can reach up to 15% (Ahlstrom & Kircher, 2017). Vehicle fleets used for freight or passengers transportation, permanently are seeking to reduce operative costs(IDAE, 2013). Eco-driving techniques may also prevent early mechanical failures, improve road safety and provide extra comfort to passengers. These eco-driving techniques include modifications to gear shifting, acceleration, idle time, inertia, among others (Ferreira, Almeida, & Rodrigues, 2015; (Strömberg & Karlsson, 2013).

Based on some parameters related to driving behavior, driving style could be normal, aggressive and technical("Estilos de aprendizaje," n.d.). This classification is based on some parameters related to the driving behavior.

The fuel consumption depends on driver experience, driving mistakes, average speed, and weight-capacity ratio. In particular, driving mistakes such as acceleration, braking and speeding,are the parameters that affect the most to eco-driving effectiveness. Eco-driving training, has shown fuel consumption reduction up to 96% (Díaz-Ramirez et al., 2017).It is known that eco-driving training over time decreases its efficiency, because drivers tend to get back to its initial driving habits. In order to achieve lasting results, economic incentives and drivers public recognition could be implemented to motivate drivers to keep applying eco-driving techniques(Liimatainen, 2008). Nevertheless, it is not easy to define which is the most effective eco-driving technique(Newnam & Watson, 2011).

Hiraoka et al.(2009) applied some efficient driving techniques that present advantages in certain places due to the characteristics of the environment and the driving culture. So, many countries development transport polices in order to improve the energy efficiency such as reduce CO_2 emissions based on eco-driving (Onoda, 2009).
Many researches used equipment to obtain some variables related to: weather, positioning, engine parameters and driving behavior. For example, it is common to use GPS or GPRS devices and OBD II readers. Hence, information may be sent by bluetooth or satellite technology for subsequent data analysis(Degraeuwe & Beusen, 2013).
Thus, it is common that eco-driving techniques are taught through public programs(Strömberg& Karlsson, 2013) or merely through driving assistance devices (Corcoba, 2014).

Finally, the goal of this paper is analyzed measurable and quantifiable techniques for fuel reduction in a transport fleet with a low investing; obtaining environmental, positioning and engine variables to analyze driver behavior during pre-training and post-training phases.

2. Materials and Methods

2.1The fleet

The fleet include 26 vans used to provide passenger transport services in a 212 km. route. Vehicle specifications are the following: diesel engine, 2.5 L, 98 HP @ 3800 rpm, 226 Nm @ 2000 rpm, 2 axes, manual transmission (five speeds), 3185 kg and capacity for eight passengers. Average number of daily trips for each vehicle is four, although departure times vary according to passenger's demand.

2.2 Experimental design

This study considered two phases: a) Pre-training trips and b) Post-training trips, based on the methodology described in Jeffreys, Graves, & Roth (2016)where it measured fuel consumption in a bus fleet before and after the eco-driving training. Five measurable and quantifiable eco-driving techniques were defined for the two phases. A professional driver of a passenger fleet was selected at random of total drivers for two phases, all this to check the efficiency of proposed techniques in one driver and vehicle, for next apply these techniques with other drivers of fleet. Pre-training consisted in measure the everyday driving habits, checking if the five techniques defined are applied without training, and an important point: driver was not told the aim of the study was to investigate fuel consumption. Post-training consisted in informing the driver about his driving failures and eco-driving techniques (five included), all this considering the parameters of the vehicle and the route to reduce fuel consumption (See Figure1).

The study route was conducted from Cuenca to Loja. These cities are located at 2560 meters above sea level (m a.s.l.) and 2060 m a.s.l. respectively (See

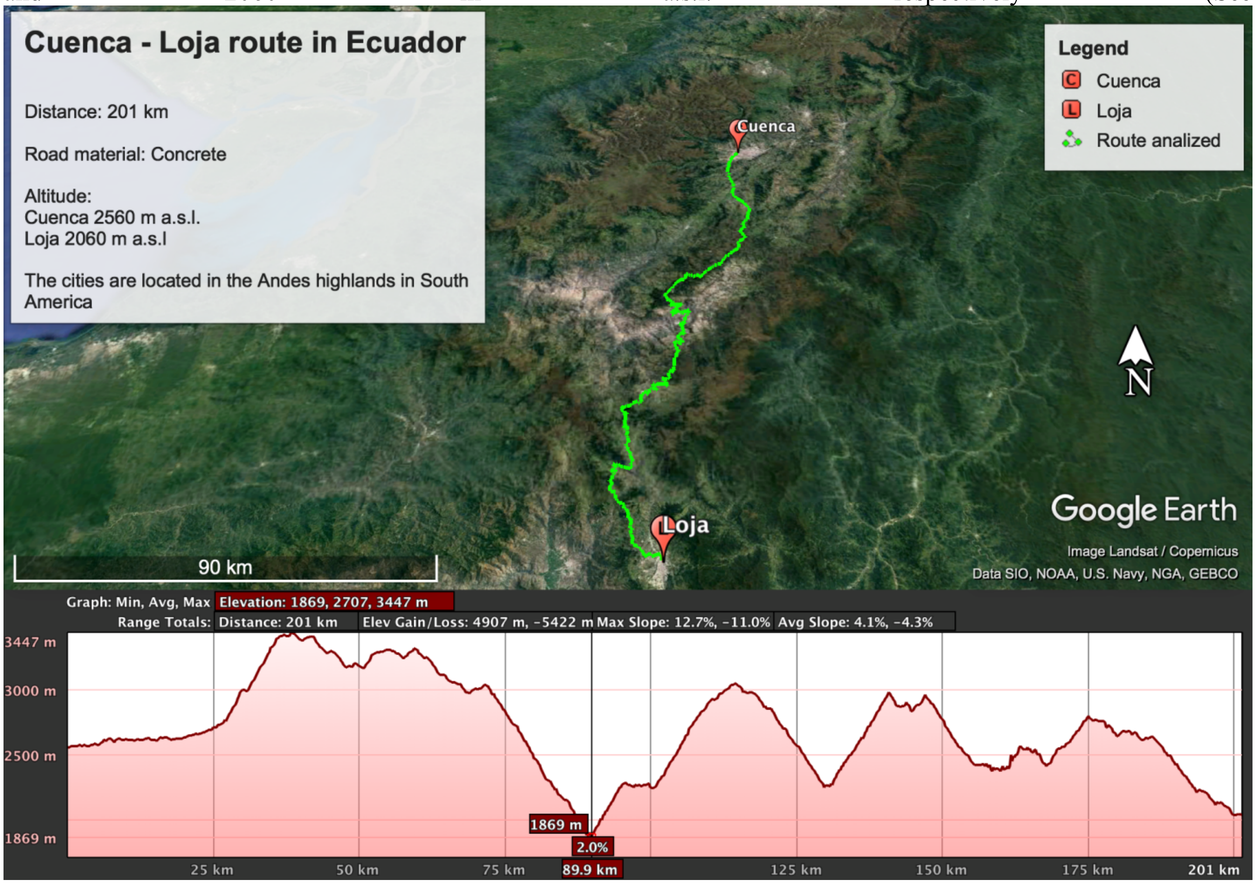

Figure 2). In the route the highest point is 3460 m a.s.l and the lowest point is 1889 m a.s.l. Approximately half of the route analyzed shows a negative slope. For this reason, on this route, drivers could take advantage of inertia. In addition, on the positive slope, drivers should perform the correct gear change combined with progressive acceleration(IDAE, 2013).Furthermore, air density and temperature change along the route (Velez & Vera, 2016).

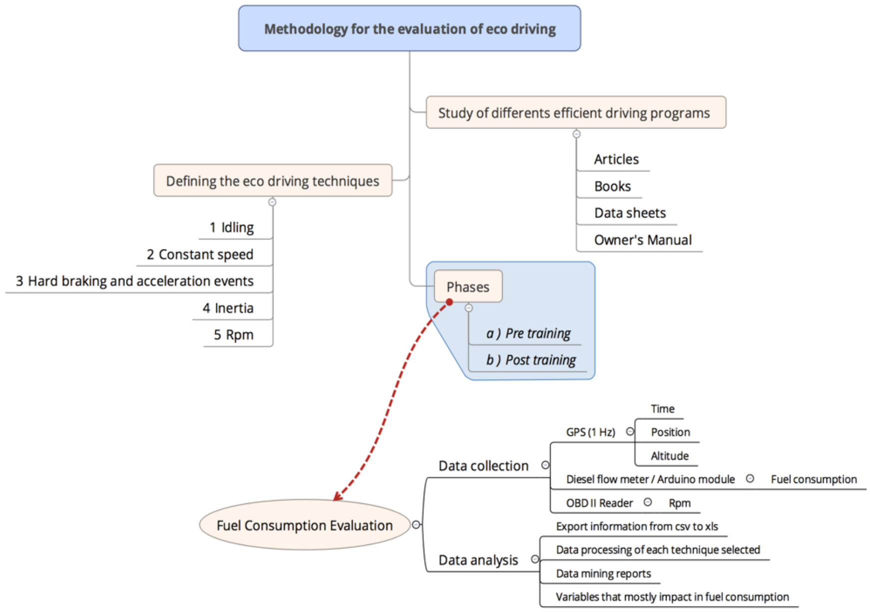

Figure1. Methodology for the evaluation of ecodriving

Additionally, the route regarding traffic intensity is classified as a low and medium level (MTOP, 2012). It allows drivers to make driving maneuvers with freedom and independence. But in some parts of the route are a lot of curves and sections with different slopes that require advanced driver expertise(MTOP, 2012).

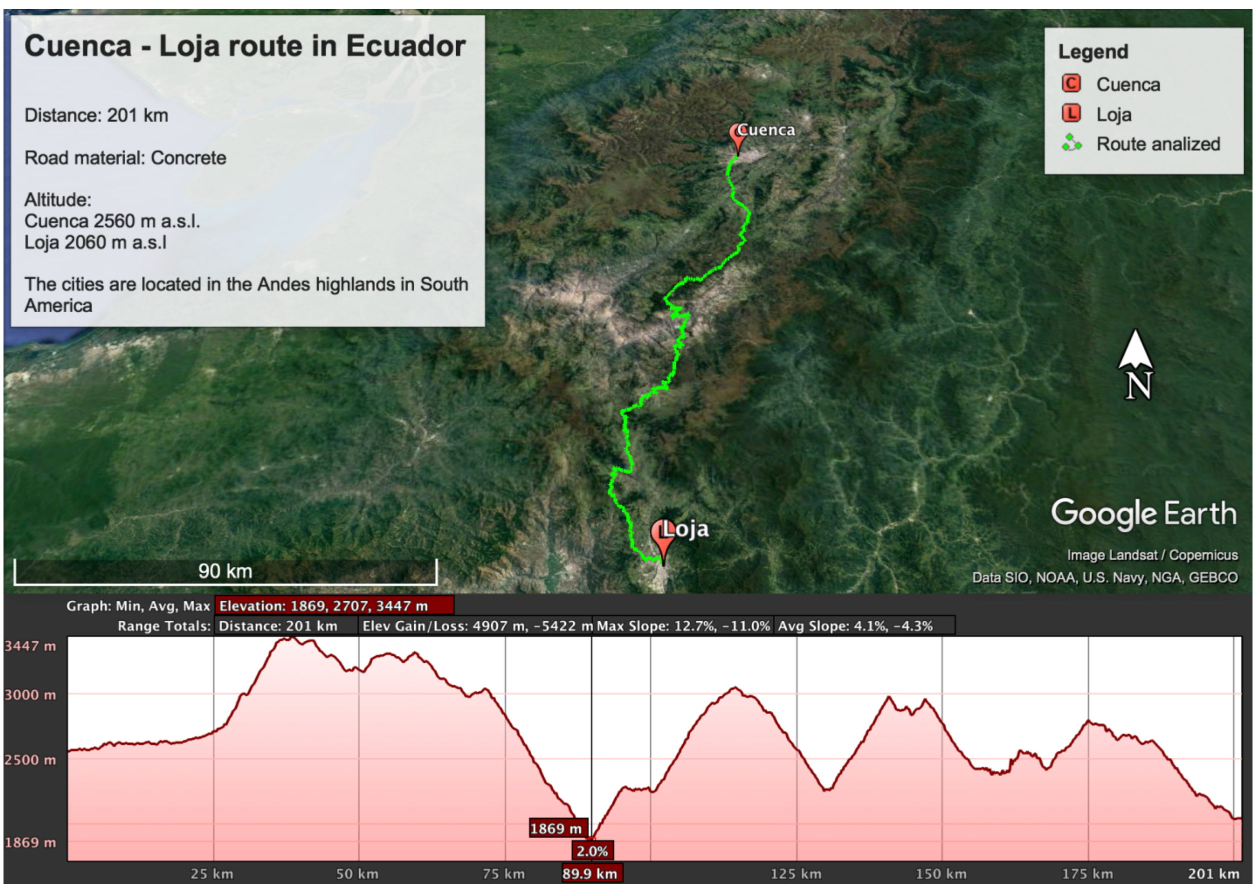

Figure 2. Cuenca-Loja route in Ecuador. Google Earth (2017)

Hernández, Fernández, & Baptista (2014) recommends a sample from three to five cases in studies limited by time and logistics. However, this study considered twelve samples from the route between cities, specifically six trips in pre-training phase and six trips in post-training phase. In both phases, the passenger's occupancy average was eight people. The driver was always the same during the trips and the departure time was around 8 a.m.

2.3 Data collection

This study was conducted from May to August 2017. The instrumentation used in the van was a diesel flow meter; connected between diesel pump and injectors circuit; with the following characteristics: starting flow rate 0.5 l/h, min flow rate 10l/h and max flow rate 100 l/h, relative accuracy error ± 3%, max pressure 2.5 MPa, compatible with engines that provides max power 134 hp. Also, an OBD II engine reader that works with an android app, to obtained the principles data of sensors around the vehicle as position, velocity, altitude and rpm regime (Baquero & Alvarez, 2018).

In each trip, it was registered the passenger number, weather conditions (dry or wet), tire pressure and and the unforeseen events. In Table 1 are specified variables obtained by each equipment.

Table 1. Obtained variables with the different equipments

Equipment	Variable without treatment	Variable calculated
Diesel flow meter &Arduino module	Time [hh:mm:ss] Position (latitude, longitude) [rad] Altitude [m] Velocity [km/h] Instantly fuel consumption [L/h]	Acceleration, deceleration [m/s^2] Time [sec, min] Slope [º, rad] Distance [m,km] Fuel consumption [L, L/100 km]
OBD II Reader	Time [hh:mm:ss] Position (latitude, longitude) [º] Altitude [m] Rpm regime [rpm]	[-]
Pressure gauge	Tires pressure [kPa, psi]	[-]

2.4 Eco-driving techniques

This study selected the most common eco-driving techniques, specifically five based on: idling, constant speed, hard braking and acceleration events, advantage of inertia and rpm regime. Thus, data related to fuel consumption was recorded for each trip.

Idling were defined as time when engine was on. This time could be present before, during and after the trip. It was important to follow manufacturer's recommendations about idling periods before turn off vehicle engine. Morshed (2010) determinates negative impacts about idling; for example, on average, a 3 liters engine uses 300 milliliters of fuel for 10 minutes of idling period. Additionally, air excess during combustion cools cylinder liners, resulting in incomplete combustion and condensation of unburned diesel in cylinder walls. Consequently, for idling periods, Pañeda et al. (2016)considered time percentage when engine is idling [%] respect of trip total time. In this case, was considered time in seconds and minutes when engine is idling and its influence in fuel consumption on liters.

The optimum fuel consumption rate occurs at **constant speed** of approximately 72 km/h (45 mi/h) (El-Shawarby, Ahn, & Rakha, 2004). Also, they concluded that fuel consumption rate increases as the cruise speed increases. In addition, Pañeda et al. (2016) considered constant speed as percentage of time. This study registered time when vehicle was moving in constant speed during the trip applying an acceleration rate indicated in Table **3**. So, this time was used to calculate equivalent time without constant speed during trip [min]. Then, were defined equivalent distance without uniform speed during trip and fuel consumption generated by does not maintain uniform speed.

Generally, acceleration values vary depending on each scenario. But Bokare & Maurya (2017) proposed parameters respect to maximum speed ranges during acceleration maneuver for diesel cars. In consequence, for maximum speed range 84-92 km/h (speed range applied in this study), maximum acceleration rate was 1.97 m/s^2, (*Mean acceleration rate=0.52* m/s^2). For decelerations, maximum speed range considered for diesel car was 98-100 km/h, generating maximum deceleration rate of 4.52 m/s^2 *(Mean deceleration rate=3.72* m/s^2*)*. Further, Corcoba (2014) explained that hard accelerations generate a exponentially increase of fuel consumption, because acceleration resistance force has to be overcome, which is proportional to vehicle mass and acceleration intensity. In addition, if driver intensively steps on throttle, he could limit full combustion time. Equally, for decelerations, energy produced by engine is wasted when driver uses brake pedal. It generates kinetic energy dissipates in heat form. Based on Ferreira, Almeida, & Rodrigues (2015),**hard braking and acceleration events** were counted in trips and their shown influence on fuel consumption. **Advantage of inertia** was measured in five sections previously defined by their slope and length characteristics (Figure 3). This technique requires an optimal gear selection and a minimum use of throttle. Pañeda et al. (2016) said that advantage of inertia did not produce fuel consumption or this consumption is near to zero. In negative slopes plots, IDAE (2013)recommends use of brake engine for security, avoiding overheating of brake system and maintaining acceptable rpm regimes. In the same way, were considered variables as: position [latitude, longitude], slope [º], [rpm], time [min] and fuel consumption during defined plots (See Figure 3); based on Pañeda et al. (2016),who determined inertia as total time percentage [%] that driving is taking advantage of engine inertia.

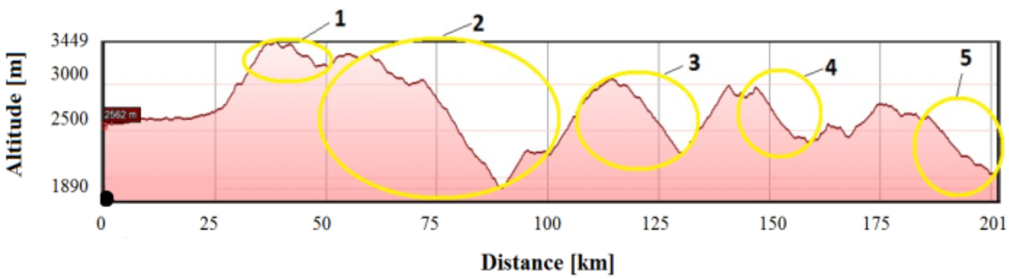

Figure 3. Sections defined by advantage of inertia. Google Earth (2017)

Finally, the last technique analyzed was **rpm regime.** It was based on: vehicle´s torque-power diagram, optimal gear selection and rpm regime between 1500 and 2000 [rpm] (IDAE, 2013).In addition, Van Mierlo et al. (2004)described three driving style tips: use of higher gear as possible, do not shifting down to a lower gear too early and keeping the car rolling without disengaging the clutch and pressing the throttle quickly. Using these recommendations, studies found rpm reduction percentage for diesel vehicles. On the route that was analyzed in this study, it was recommended to shift the gearbox around 2000 [rpm]. Although, sometimes it was necessary to reach 2600 [rpm] because the slope of the road. Thus, Pañeda et al. (2016)established a percentage of total time that engine is working outside of the best performance range. This study analyzed rpm regime during the route and focused in five sections defined for advantage of inertia. So, specify rpm regime fluctuate from 1500 to 2600.

2.5 Data analysis

Equipment employed created files in .CSV and .XLS format; allowing a quick and effective analysis through Microsoft Excel 2017 data processing software. Also, Google Maps and Google Earth Pro were used as geo-referencing software, allowing locating inefficient driving actions at a specific point. Data analysis considered: logical criteria filters, atypical data and statistical analysis for each route. Parameters and coefficient of the vehicle are described below in Table 2.

Table 2. Vehicle parameters

Parameter	**Value [Unit]**
Mass	3185 [kg]
Cd	0.5 [-]
Fr	0.008 [-]
Rd	0.191 [m]
Frontal area	3.419 [m^2]
Air density	0.89 [kg/m^3] (average)
Temperature	287.29 [ºK] (average)

Transmission relations	First: 4.39 [-] Second:2.3 [-] Third:1.35 [-] Fourth:1 [-] Fifth: 0.76 [-] Reverse:4.63 [-] Diferential:4.22 [-]

For each eco-driving technique, were used filters in order to determinate different variables showed in Table **3**.

Table 3. Techniques characteristics

Technique	**Criteria**	**Equipment used**	**Variable Obtained**	**Variable evaluated**
Idling	Velocity = 0 km/h Engine on Flow fuel ≤ 0.9 L/h	Diesel flow meter &Arduino module	Position (latitude, longitude) [rad] Time [hh:mm:ss] Velocity [km/h] Instantly fuel consumption [L/h]	Time [sec,min] Fuel consumption [liters]
Constant speed	Acceleration < - 0.7 m/s^2 Acceleration > 0.7 m/s^2	Diesel flow meter &Arduino module	Time [hh:mm:ss] Velocity [km/h] Acceleration [m/s^2]* Distance [m]* Instantly fuel consumption [L/h]	Equivalent distance [km] Equivalent Time [min] Fuel consumption [liters]
Hard braking and acceleration events	-1< a > 1 [m/s^2]	Diesel flow meter &Arduino module	Time [hh:mm:ss] Velocity [km/h] Acceleration [m/s^2]* Instantly fuel consumption [L/h]	# events Fuel consumption [liters]
Advantage of the inertia (on descents)	5 sections	Diesel flow meter &Arduino module	Position (latitude, longitude) [rad] Slope [°, rad]* Time [hh:mm:ss] Velocity [km/h] Altitude [m] Distance [m]* Instantly fuel consumption [L/h]	Time [min] Rpm [rpm] Fuel consumption [liters]
		OBD II reader	Time [hh:mm:ss] Rpm [rpm] Altitude [m] Position (latitude, longitude) [rad] Slope [°, rad]*	
Rpm regime	1500<Range<2600 [rpm]	OBD II reader	Time [hh:mm:ss] Rpm [rpm] Altitude [m] Position (latitude, longitude) [rad] Slope [°, rad]*	Time [min] Rpm [rpm]
Total fuel consumption	For each trip	Diesel flow meter &Arduino module	Time [hh:mm:ss] Instantly fuel consumption [L/h]	Fuel consumption [L/100 km]

Note: *Calculated variable

3. Results

After twelve trips in the route between the cities, were calculated average parameters showed in Table 4. In Ecuador, the difference between two phases analyzed did not show significant difference because diesel cost is cheaper than other countries in South America (GPP, 2018).

Table 4. Average parameters of twelve trips.

Parameter	Unit	Pre-training	Post-training
Average velocity	km/h	58.66 ± 0.06	57.38 ± 0.08
Max. velocity	km/h	101.48±0.05	101.93±0.02
Trip time	Hours	3.5±0.02	3.45±0.05
Tires pressure	Psi	41 ± 0.01*	43.5±0.01**
Fuel consumption	l/ 100 km	11.11 ± 0.05	10.18± 0.01
Cost	USD	6.30 ± 0.06***	5.78 ± 0.11***

Notes:
*Different pressure by each tire
**Similar pressure by each tire
***Diesel gallon price in Ecuador: 1.037 US dollars

Next, the analysis of each eco-driving technique is presented. First idling, second constant speed, then hard braking and acceleration events, after advantage of inertia and finally rpm regime.

3.1 Idling

As shown in Table 5, idling time was reduced before and after trip, while during trip, values increased. On Pre-training phase driver assumed that engine must remain between 10 and 20 minutes at idle by turbocharger heating and lubrication. After trip, Pre-training driver criteria was similar. During travel, idling time periods were generated basically by traffic, traffic signals and refueling (driver did not turn off engine).

Table 5. Idling results

Event	Variable	Value	
		Pre-training	Post-training
Before travel	Time	11.97± 0.20 min.	5 ± 0.00 min.
During travel	Total time	17.85 ±0.41 min.	20.87 ± 0.56 min.
	Intervals	21.67± 0.32	18.17± 0.21
	Max. interval	361.17 ±0.19 sec.	457.33 ± 0.78 sec.
After travel	Time	13 ± 0.27 min.	2.12 ± 0.07 min.
Fuel consumption	Liters	0.46±0.45	0.29 ± 0.18

3.2 Constant speed

This technique generated the greatest reduction during influence during all displacement. It considered criteria as anticipation, adequate warning distance and correct circulation skills in curves (See Table 6).

Table 6. Constant speed results

Variable	Unit	Value	
		Pre-training	Post-training
Equivalent time	Min	15.97± 0.21	11.63 ± 0.10
Equivalent distance	Km	13.63 ±0.22	10.11 ± 0.9
Fuel consumption	Liters	1.37±0.4	0.66 ± 0.17

3.3 Hard braking and acceleration events

Hard events were reduced in situations such as starts, curves, straight stretches and sometimes on slopes. Driver combines adequate throttle opening with low rpm regime. Required speed had to up gradually and not instantaneously. As shown Table 7, total events were reduced, although they remained. Hard braking generated greater number of events. It could be originated by lack of foresight and anticipation. Nevertheless, there exists road areas where statistically persists unforeseen events that require instantaneous speed variation. These were generated by external factors as traffic, animals crossing, pedestrians and landslides.

Table 7. Hard events results

Event	Variable	Value	
		Pre-training	Post-training
Hard accelerations	#	70.67±0.3	58.20±0.24
Hard braking	#	122.67±0.19	110.50±0.10
Total events	#	199.33±0.20	169±0.14
Fuel consumption	Liters	0.57±0.4	0.37±0.36

3.4 Advantage of the inertia

Fuel reduction was originated by correct use of gear to up speed during negative slope section start, applying opportune gear changes and minimum use of throttle, maintaining safe rpm regime and slight corrections with pedal brake (See Table 8). All of these generated greater distances with uniform speed and consequently anticipation in specify cases. Rpm increase indicates better use of engine break. This technique was the most applied before training although not correctly.

Table 8. Advantage of inertia results

Parameter	Variable	Value	
		Pre-training	Post-training
Fuel consumption	Liters	4.99±0.22	4.42±0.38
Rpm regime	rpm	2071.21±0.02	2142.50±0.03

3.5 Rpm regime

Average rpm regime remains within recommended for two cases. Maximum rpm decreased although time outside increases slightly. Obviously, average rpm increase during trip was due to actions such as brake engine use during greater periods. Referring to time under proposed regime, it increased due to idling period originated by refueling, which, as mentioned above, driver did not turn off engine and this moment included passenger disembarkation (*See Table 9*).

Table 9. Rpm regime results

Parameter	Variable	Value	
		Pre-training	Post-training
Average rpm regime	rpm	1919.21 ±0.04	1981.12 ± 0.03
Max. rpm	rpm	3377±0.07	3187.13±0.05
Time outside max. rpm	min	5±0.34	5.99±0.18
Min. rpm	rpm	694.17±0.04	600±1.11
Time outside min. rpm	min	13.67±0.34	15.02±0.33

4. Limitations

Due to working conditions of the fleet (non-fixed schedules) and limited data logging equipment, only one vehicle and one driver were analyzed in this work. Variables such as throttle position or gear-shifting were not considered, because of the limitations of the equipment. The main challenge for applying eco-driving techniques in this fleet was to make the driver aware of saving fuel, while he was focused in saving time.
In addition, the influence of variable atmospheric factors and vehicle mechanical conditions were not considered in this work.

5. Conclusions and discussion

The present study evaluated five common eco-driving techniques in a real-world scenario. The analysis had two phases, the first one was a driving evaluation without training. Whereas, the second one took place after low-investment eco-driving training. Variables were calculated and measured to evaluate each technique. This study defined the most appropriate eco-driving techniques based on the route by maintaining similar conditions such as the driver, vehicle, and schedules. Each proposed technique showed a reduction in fuel consumption after the post-training phase (Idling 36%, hard braking and accelerations 35.1%, constant speed 51.82%, inertia 11.45%). The rpm regime increased by 3.22%, this kept the revolutions within the recommended range for an optimal consumption based on the engine torque-power diagram. When all the techniques were used in conjunction, a decrease in fuel consumption and cost of 8.3% was achieved (See Table 10). This research showed that it is possible to reduce the fuel consumption by following specific vehicle driving recommendations as follows:

- Reducing idling time when the vehicle is parked (Huang & Peng, 2016).
- Selecting the correct gear based on the road's slope (Pañeda et al., 2016).
- Checking the tires' pressure periodically.
- Avoiding hard acceleration events, especially when there is traffic or when the road is not suitable for such changes in speed. This recommendation also applies to braking events.
- Keeping a constant speed is the most crucial recommendation when the car drives up to 70 km/h approximately (El-Shawarby, Ahn, & Rakha, 2004).
- Taking advance of the vehicle's inertia depending on the road's conditions.

Table 10. Results comparison

Evaluated factor	Pre-training	Post-training	Percentage
Total fuel consumption by trip	23 ± 0,6 [liters]	21,19 ± 0,11 [liters]	-8,3 %
Fuel consumption by idling periods	0,46 ± 0,45 [liters]	0,29 ± 0,18 [liters]	-36%
Fuel consumption by hard events	0,57 ± 0,4 [liters]	0,37 ± 0,36 [liters]	-35,1 %
Fuel consumption by constant speed	1,37 ± 0,4 [liters]	0,66 ± 0,17 [liters]	-51,8%
Fuel consumption by advantage of inertia	4,99 ± 0,22 [liters]	4,42 ± 0,38 [liters]	-11,4%
Average rpm regime during trip	1919,21 ± 0,04 [rpm]	1981,12 ± 0,03 [rpm]	+3,2 %
Performance	11,11± 0,05 [liters/100 km]	10,18 ± 0,11 [liters/100 km]	+ 8,3 %
Cost (Ecuador)	6,30 ± 0,06 USD	5,78 ± 0,11 USD	-8,3 %

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