Ingeniería y Competitividad, Volumen 19, No. 2, p. 11 - 24 (2017)

DOI: https://doi.org/10.25100/iyc.v19i2.5287

MECHANICAL ENGINEERING

Engine data collection and development of a pilot driving cycle for Pereira city by using low cost diagnostic tools

Registro de información en motores de automóviles y desarrollo de un ciclo de conducción piloto para la ciudad de Pereira usando herramientas de diagnóstico de bajo costo

Carlos A. Romero[1§], Luz A. Mejía[2], Ricardo Acosta[1]

[1]Escuela de Tecnología Mecánica, Universidad Tecnológica de Pereira. Pereira, Colombia.
[2]Facultad de Ingeniería Mecánica, Universidad Tecnológica de Pereira. Pereira, Colombia.
cromero@utp.edu.co, *adriamec@utp.edu.co, ricosta@utp.edu.co*

(Recibido: Marzo 05 de 2016 - Aceptado: Junio 08 de 2017)

Abstract

The objective of this paper is to present a methodology designed to develop a driving cycle to model traffic in the Pereira city in Colombia. Under the scope of this pilot work, four different gasoline passenger cars furnished with real time datalogging equipment were used to collect speed-time data under actual traffic along Pereira urban area. The speed-acceleration characteristics were analyzed, and target driving parameters were defined and evaluated. The designed method for building the driving cycle was then applied. As a result, a simple driving schedule for analyzing propulsion, fuel consumption rate, and emission control strategies of automobiles under Pereira downtown conditions has been proposed. Under the scope of the same project, was also studied the utility of the engine specific data collected during the vehicle operation for the purposes of engine performance assessment.

Keywords: *Driving cycle, engine data collection, low cost diagnostic tools.*

Resumen

El objetivo de este trabajo es presentar una metodología para la obtención de un ciclo de conducción representativo del tráfico en la ciudad de Pereira, Colombia, usando herramientas de bajo costo. Se escogieron cuatro vehículos equipados con sistemas de registro de velocidad y aceleración para circular en uno de los corredores viales más congestionados de la ciudad. Las características de velocidad y aceleración fueron analizadas y se evaluaron y definieron los parámetros de conducción. Se diseñó un método para construir el ciclo de conducción y se construyó el ciclo. Como resultado, se obtuvo un ciclo simple de conducción que puede servir de referencia para el análisis de consumo de combustible y diseño de estrategias para control de emisiones de automóviles bajo las condiciones de operación en la zona urbana de Pereira. En el ámbito del mismo proyecto, también se estudió la utilidad de la información recolectada, con herramientas de diagnóstico de bajo costo, durante la operación de los vehículos para propósitos de evaluación del desempeño de los motores.

Palabras Clave: *Ciclo de conducción, herramientas de diagnóstico de bajo costo, recolección de datos del motor.*

1. Introduction

Measures for reducing the dependency on fossil-fuels for combustion engines include improving efficiency and substitution of gasoline with alternative fuels. Among these, ethanol is one of the most extensively used all over the world because it is high-octane, clean-burning, and has high combustion speed.

To evaluate the influence of ethanol blending on second-by-second fuel consumption under par-ticular driving conditions of Colombian traffic jammed cities, a driving cycle that really represents the speed-load demand imposed by the traffic conditions on Colombian roads is required. A driving cycle is not only used to evaluate fuel consumption and pollutant emissions but is also used to validate models that predict the behavior of vehicles as they provide a more realistic view of performance under simulated loads in software or on the test bench. On the way to obtain the driving cycle, after examining the available resources to collect vehicle data, it was realized that there are benefits for service technicians and repair shops. They can take advantage of many low cost diagnostic tools available on the market to enhance their methods and equipment in order to accurately locate and diagnose vehicle issues.

There are two objectives of the present work: 1- to outline the application and performance of low cost vehicle diagnostic tools to address the need of service technicians, and 2- discuss the methodology for building a particular driving cycle. Providing information on how to extract vehicle parameters from the OBD system (vehicle speed, engine speed and load) and how correlate them with engine operating parameters (engine temperature, timing advance, coolant temperature, air flow rate, intake air temperature, intake manifold pressure, throttle position, etc.), allows for a more qualified work of service automotive technicians lacking the budget to purchase a trademarked scanner. In fact, they can test the engine and the entire vehicle under selected combinations of in town and highway driving vehicle situations, and adequately evaluate the engine performance following the actual performance of its sensors and actuators.

Given the elevated costs of testing benches and their associated instrumentation, it is very practical to explore the usefulness of real time information provided by OBD-II data obtained through cell phones, smart-phone and such alike devices to collect data valuable in the study of vehicle dynamics, especially for the development of surrogate driving cycles, as well as for synchronous evaluation of the operating conditions of the engine.

The paper is organized as follows: The first part focuses on reviewing the diagnostic and recording tools used to collect vehicle operating data. The second part of the paper is devoted to describing the procedure to obtain a particular driving cycle. In the third part, it is outlined the implementation of the methodology to obtain the pilot driving cycle for Pereira city, Colombia. Finally, the results and the main conclusions of this work are outlined at the end of the paper.

2. Overview of vehicle diagnostic tools and development of driving cycles

Today's vehicles contain several communication networks dedicated to different fields of application. The recent development of electronic systems and telematics in the automobiles, along with various wireless communication technologies has made it possible to connect and exchange information with a vehicle, e.g. by using GPS, tablets, and cell phones as has been mentioned by Alessandrini et al. (1), Casey et al. (2) and Duran et al. (3). This opportunity to easily communicate with a vehicle and its electronic systems has introduced interesting possibilities for vehicle-related diagnostics, fleet management, and maintenance and repair services. These services can, for example, collect information about the engine and vehicle dynamics and then use this information for different purposes including driver behavior, driving cycle, and driver aggressiveness assessment.

Since the first navigation services, much effort has been put forth by many automotive institutions and researchers to improve the exactness and deliverance of the turn-by turn instructions, i.e. that the instruction is correct and delivered at the right moment. This has been possible by the advancement of the GPS technology, which now gives a much more accurate positioning than it did a few years ago. This aspect highlights another important feature with such services: the ability to collect vehicle dynamics related data from electronic systems and to use this information to deal with automotive traffic studies.

Monitors and diagnostics can continuously check fuel consumption, driving distance, driving pattern. This information is used to facilitate optimal routing strategies, service needs and analyze driver performance. Based on data readings (e.g. current speed and total distance), managers can discover differences in fuel consumption, which can indicate unnecessary hard driving. Some vehicle parameters that can be collected with high frequencies (2-5 Hz) are vehicle speed, air/fuel ratio, intake airflow, engine speed, engine load , accelerator pedal position, Lambda sensor voltage, catalyst temperature, close/open loop information, absolute load (volumetric efficiency), intake air pressure and EGR and ignition advance.

There are also some other parameters collected at slower rates: the intake air temperature, the coolant temperature, the ambient temperature and pressure, the tank fuel level and the battery voltage.

Internet connection allows diagnosing and solving vehicle problems from a remote geographical location, e.g. a central service center or a local repair shop. The ability to wirelessly connect with a vehicle provides experts or service technicians with on-board data that can be examined. Vehicle problems can be analyzed and some maintenance operations can be carried out remotely and thus prevents the need of an appointment in a repair shop. If the problem cannot be managed remotely the service technician can inform the driver of a service appointment or send roadside assistance to the vehicle.

The emergence of complex electronic systems is having an effect on how the diagnosis of a vehicle is carried out by the service technician. In the past the service technician only had the mechanical parts of a vehicle to consider. Today, service technicians not only have to master the mechanical parts, but they also need to manage the electronic systems of a vehicle in order to correctly diagnose. This circumstance has made it necessary to provide service technicians with proper diagnostic methods and tools. These tools, connected to the vehicle's electronics, provide service technicians with diagnostic data, which identifies the cause of a problem or provides important information for further trouble-shooting.

2.1 Scan tools and code readers

Modern vehicles have a large network of control modules that operate power-train, braking, steering, suspension system, climate control, lighting, entertainment, communications and navigation. The network provides functions and capabilities that were not even on the radar a decade ago: Bluetooth connectivity, hands-free communication and email, automatic emergency braking, blind spot detection, adaptive cruise control, stability control, electronic steering and crash-avoidance systems, among others. Modern electronic systems within a vehicle are linked all together via a communicating system by a protocol called Controlled Area Network, CAN.

A short list of modules encountered in a vehicle includes: ABS/traction control/stability control module, airbag (SRS) module, alarm module for anti-theft system, cruise control module (if not integrated within the PCM), electronic steering module, fuel pump control module, injector driver module, instrument cluster control module, keyless entry module, lighting module, remote start/immobilizer module, suspension control module, transfer case module (4WD), vehicle communication module, plus all kinds of "mini" modules for power windows, power seats, heated/cooled seats, power sliding doors, door locks, sunroofs, air flow control doors inside the Heating Ventilation Air Conditioning (HVAC) system, and so on.

Since the introduction in 1985 of the first On-Board Diagnostic (OBD) regulation by the California Air Resources Board (CARB), issued to monitor critical emission related components, and to implement a diagnostic trouble code system (DTC), on board diagnostics has evolved to improve, with the current OBD II, diagnosis and repair efficiency featuring: sensor diagnostics, fuel system monitoring, misfire monitoring, catalyst monitoring, exhaust gas recirculation

(EGR) system monitoring, evaporative system monitoring, secondary air system monitoring, malfunction indicating light illumination. Today CAN protocol forms part of the OBDII, it allows data from many different vehicle systems to be shared via a common communication link, the data bus. Most vehicles have two or three of these data buses that operate at different speeds (baud rates). Some share data at high speed and others share less important information at lower speeds. The data is coded so each module knows what to read and what to ignore. Regulation regarding exhaust emissions became more and more stringent with the OBD II and Euro standards. The new developments mean that engine control units have to check the plausibility and consistency of sensor signals, for example, that a certain engine speed corresponds to a certain air mass flow.

A variety of OBD hand-held scan tools from aftermarket scan tool and original equipment manufacturers (OEM) are available to perform diagnostics and repair services. The two main categories of vehicle diagnostic tools are code readers and scan tools. Most proprietary scanners can be setup in two ways for most vehicles. The preferred setup is “vehicle-specific”, in which the user selects the manufacturer of the vehicle and enters selected portions of the Vehicle Identification Number (VIN) that specify the year, model, and engine size of the vehicle. With the “vehicle-specific” setup, scanners are able to sample data with a frequency of less than once per second.

Out of the many aftermarket scan tools offered on the market, commercial brands available to as are the following: Sunpro™, Snap-on™, OTC™, Actron Kal-Equip 9615™, Auto Xray EZ-Link™ OBDII Scanner, Blue Streak Electronics BDM Pro Diagnostic Monitor™, Interro Systems PST 500™, Matco Tools Determinator™, MPSI Pro Link 9000™, SPX-OTC Monitor Enhanced 4000™, Vetronix Corporation Mastertech™. Some of the OEM scan tools are Chrysler DRBIII (SPX-Miller), Ford New Generation Star Tester (Hickok), General Motors Tech II/SPX-OTC Tech 2 Flash (Hewlett-Packard), Toyota Diagnostic Tester (Vetronix), Nissan Consult, VAG 551 (VW and Audi).

Code readers can pull codes from vehicle electronic control unit, allowing the user to read and clear codes. Some code readers also provide basic access to freeze frame data from the vehicle controllers. Scan tools are code readers that allow the user not only to read and clear codes, but also to view all of the available data from vehicle system controllers. Depending on the tool, it is possible to scroll through all of the available information or set up a customized list of parameter IDs (PIDs) of interest. Depending on the specific scan tool, it may display only very basic information about what each code means, or it may provide some level of information about troubleshooting and repair procedures. The most expensive scan tools provide extensive knowledge bases that can speed up a diagnostic procedure considerably.

Osciloscopes and multimeters make up the other main vehicle diagnostic tool category. These tools are essential to read, record and analyze all the signals coming from all the automotive control systems. Along with osciloscopes and multimeters, automotive manufacturers provide proprietary diagnostic tools that combine oscilloscope, multimeter, and troubleshooting procedures together in a single unit. Most of this equipment is very expensive for service technicians.

2.2 Low cost car diagnostic tool alternatives

Over the past half decade, there has been an explosion of aftermarket tools that allow the OBD II connection to transmit vehicle performance parameters, such as instant fuel economy, engine speed, temperature, and vehicle speed. Coupling this valuable information with the accelerometers and *GPS* locating ability of common smartphones allows the user to get a good insight of vehicle performance, efficiency, and even driving behaviour. There are some *applications* and devices for performance driving noted below.

alOBD ScanGenPro™. This is a free software for Android™, designed to provide basic automotive diagnostic and vehicle data collection. It allows the user to interact with vehicle’s computer network (PCM/ECU/TCU), and works with ELM™ Bluetooth Device to connect to the OBD II Port, allowing OBD II data collection and storage, reading and clearing active DTCs. The program supports viewing pending DTCs as well. Data from engine parameters can be saved to device's internal storage as a CSV file, and saved data can be viewed in a graphical form. Data can also be exported using Android's standard export services: e-mail, Bluetooth, etc.

Torque™. This is free software for Android devices that uses both Google Earth real-time car-performance displays and a calculated horsepower and torque measurement. It automatically records 0 to 60 mph sprints. Like diagnostic-only OBD II devices, it also retrieves and resets fault codes.

ELM327™. The ELM327™ scanner allows inspecting OBD engine data on Android phones, tablets and laptops; combined with Torque software allows the user to fully customizable dashboard screens and dials. These devices help in retrieving diagnostic trouble codes (DTCs) and clearing malfunction indicator lights. Scan tools that include an *ELM327*™ microcontroller and a Bluetooth chip have the capability to communicate with smart phones, tablets, and laptops, via Bluetooth, USB, and Wi-Fi. *ELM327*™ OBD-II Software allows using a computer and a hardware interface to get the information from the car's computer. The *ELM327*™ interface sends data to the laptop from the vehicle in real time, supports all OBD-II protocols (*OBD-II Protocols:* J1850 PWM (Ford vehicles), J1850 VPW (GM vehicles), ISO9141-2 (Asian, European, Chrysler vehicles), ISO14230-4 (Keyword Protocol 2000), ISO15765-4 (CAN)), and can read and clear DTC's.

CarChips. The Davis Instruments' CarChips can log over 20 parameters and up to 300 hours of driving data, depending on the number of parameters logged and the logging intervals. Vehicle speed can be logged with a resolution of up to 1 km/h and a frequency of up to 1 sample per second. Performance parameters monitored include engine speed, throttle position, engine load, fuel pressure, battery voltage, timing advance, coolant temperature, air flow rate, intake air temperature, intake manifold pressure, and oxygen sensor output voltage.

2.3 Development of driving cycles

As described by Tamsanya et al. (4), a driving cycle is a time series of vehicle speeds recorded at equally spaced time points, that is representative of a typical driving pattern of vehicles in a location (a driving cycle can be built for agricultural machines, delivery transport, etc.). For vehicle fuel consumption studies, for instance, a test driving cycle, attempts to synthesize real driving conditions with respect to a number of measures, including speed, acceleration, specific power, trip patterns, road grade, and temperature. Driving cycles have been developed to provide a simple but intensive in information speed-time profile that is representative of urban driving. With the minimum time duration, driving cycles must assemble all the information (speed, acceleration, deceleration and their derivatives) contained in a set of characteristic city routes, different in time duration and distance travelled.

Understanding vehicle use plays a fundamental role in assessing the influence parameters such as fuel composition and properties have on engine performance. Typically consisting of speed and time information, operational driving cycles have been used to assess the value of new technology, to evaluate the benefits of a transportation improvement, to estimate on-road emissions on alternative routing, to evaluate the influence that some technology in particular has on fuel consumption, to evaluate driver's behavior, and drive-cycle aggressiveness. Driving cycles are used for certification, for comparison of vehicles, and as an engineering tool in vehicle design. Due to the increased use and importance of driving cycles, there is a strong need for methods to design and use representative driving cycles.

Driving cycles have recently been developed, for example, for Athens by Tzirakis et al. (5), for eleven cities in China by Wang et al. (6), for Hong Kong by Hung et al. (7), for Edinburgh by Esteves-Booth et al. (8), and for Pune by Kamble et al. (10).

Galgamuwa et al. (9) presented a broad commented review of the methods found in the literature to develop driving cycles in the world: auxiliary wheel, photo electronic sensor, car dataloggers, car chasing. Tzirakis et al. (5), Wang et al. (6), Tamsanya et al. (2006) and Kamble et al. (10) reported the use of chasing car, portable emission measurement system (PEMS). André et al. (11) and Kulkarni et al. (12) mentioned the use of a GPS device. Esteves-Booth et al. (8) quoted the application of on-board measurement and performance box (PB).

Route selection, data collection, cycle construction and cycle assessment are the four major common steps in driving cycle development. Routes selected have to be representative of actual road network and the -traffic flow conditions affected by spatial or temporal conditions such as land use, road type, topography, intersections and population density in that area; vertical alignment of the road as well as weather conditions and micro texture of the routes must be considered.

Galgamuwa et al. (9) presented four major driving cycle construction methods: micro-trip based cycle construction, segment based cycle construction, pattern classification cycle construction and modal cycle construction. With the micro-trip based method, the real data is divided into micro trips and assigned into different bins according to average speeds. The cycle is constructed using micro trips in such a way that the target parameters are met (population parameters). While selecting micro trips for the cycle there are two main methods, namely, random selection and best incremental method.

3. Methodology for development of the pilot driving cycle for Pereira city by low cost tools

In this work, an empirical approach to measurement of on-road engine performance and speed-acceleration profile of automobiles running under Pereira traffic conditions during a normal journey is applied. With a population of approximately 700,000 people, Pereira shares many traffic problem similarities with Bogotá. The combination of narrow streets, high traffic volumes and population size makes of Pereira a representative congested Colombian city to be selected to assess the level of pollutant emissions, fuel consumption, vehicle energy balance, and couple them to real on-road vehicle velocity profile. The approach taken to develop the driving cycle in this *pilot work*, has been based on the conclusions from the first experimental activities and built around the reported in the literature driving cycle construction methodologies. The methodology proposed to build a driving cycle is described in the next sections of the paper, and can be explained following the flow chart presented in Figure 1.

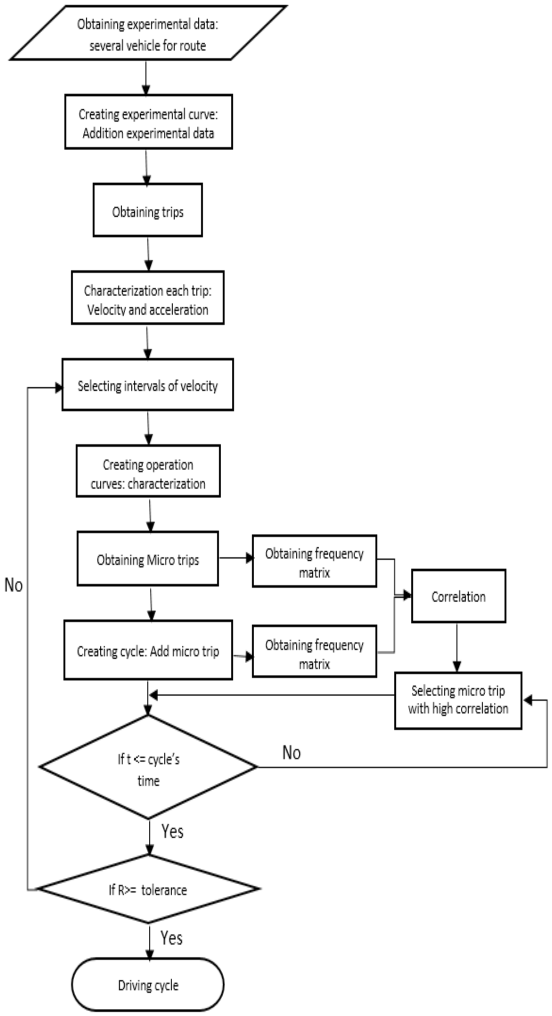

Figure 1. *Flow chart for driving cycle construction.*

3.1 Preliminaries

Route selection. Two commonplace routes covering most traffic conditions in Pereira city were selected by a manual process of studying a detailed map of Pereira for the pilot work. The criteria used for route selection was to represent the "home to work" trips, representative of the congestion found in the city of Pereira, including streets with high average daily traffic, traffic light sequences and road grades. The upper picture in Figure 2 shows the characteristics of one of the city circuits selected with an overall distance of 5,38 km, including the orographic profile. This route corresponds to a highway with traffic lights separated large distances, and test obtained on peak hours from 12:30 to 1:15 PM, according to the information consulted with the Pereira Traffic Institute. The other planned route circuit (Figure 2, below) with a length of 9,46 km corresponds to an urban road with traffic lights every 200 meters.

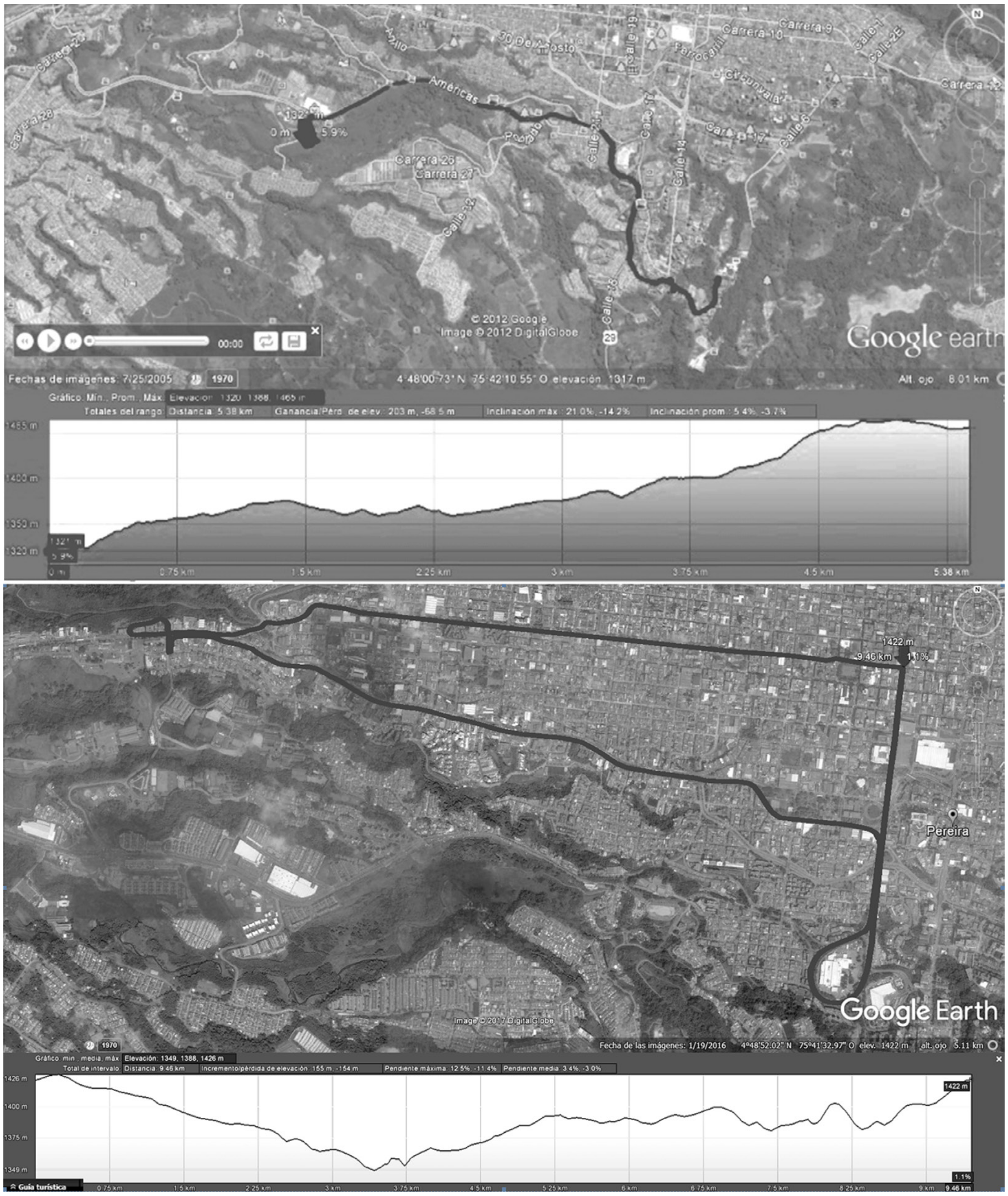

Figure 2. *General layout of the test places. Aerial photograph of the traveled area, showing waypoints. Image provided by Google Earth, 2014 © DigitalGlobe. The length of the first route is 5,38 km. The length of the second route is 9,46 km.*

Vehicle selection. Four gasoline passenger cars –Nissan Tiida, Renault Logan, Chevrolet Aveo, and Mazda 323- were selected for the data collection taking into the account the market share and their growth rate in Pereira. Vehicle data are presented in Table 1.

Table 1. *Data of tested vehicles.*

Vehicle	**Mazda 2**	**Nissan Tiida**	**Renault Logan**	**Chevrolet Aveo**
Fuel type	Gasoline	Gasoline	Gasoline	Gasoline
Model year	2012	2011	2011	2011
Engine size/Type	1,5/DOHC 16V	1,8/DOHC 16V	1,4/ SOHC 8V	1,6/DOHC 16V
Compression ratio	10	9,8	9,5	9,5
Maximum engine power [kW/rpm]	76/6000	93/5200	56/5250	77 /5800
Maximum engine torque [Nm/rpm]	135/4000	197/4800	113/3000	145 / 3400

Instrumentation Selection. For developing the driving cycle, the vehicle speed was logged from the CAN-bus of vehicles using ELM327™ and Torque app, which allows displaying the recorded data by the device. This application is versatile, inexpensive compared to specialized scanner and a great advantage is its easy upgrade. A Garmin GPS is also used to estimate the altimeter of the routes.

3.2 Collection of driving data

The speed-time data was collected using ELM327™ as well as smartphone device with *Torque* software. On the selected routes, the data collection included recording engine parameters, vehicle speed, and road profile. Test were conducted under normal cloudy conditions of Pereira city, no weather information was recorded. Accelerations were calculated by taking the derivative of the processed vehicle speed trace. It is important to perform at selected times over several days to ensure a good characterization. However, since this is a pilot work intended to develop a methodology to build driving cycles, the number of tests were limited to the available time and without repetitions. For a same route data were taken with the different vehicles to create the experimental curves.

A sample of the rough plot obtained simultaneously with the ELM327 and GPS is shown in Figure3. The time resolution used with these devices was 0,1 second for both of them.

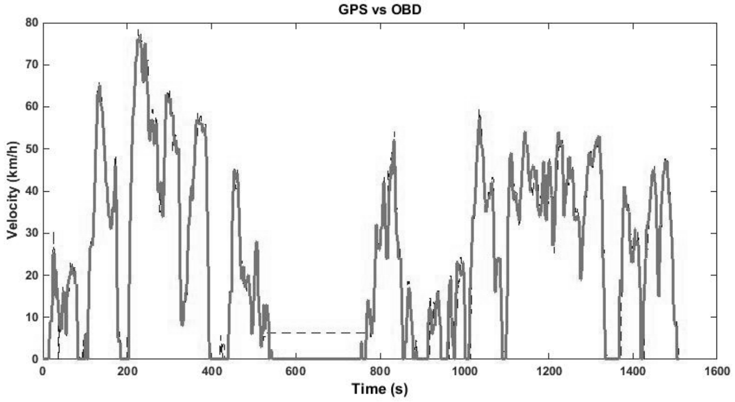

Figure 3. *Comparison of the speed traces logged both with the GPS (—) and the OBD ELM327 system (----).*

3.3 Data analysis

The analysis of base data involved the development of speed–acceleration frequency matrix, which is used to obtain the target parameters: percent time in acceleration, percent time in deceleration, percent time in cruise, percent time in idle and average velocity. Generating a driving cycle has several stages for data processing and requires an evaluation criterion to ensure the collection of the most representative information. In the methodology proposed in this work that criterion is the correlation coefficient: the performances of experimental and modeled driving cycles are compared using linear correlation coefficients between observed and predicted speed-acceleration frequency matrices.

The process of generating the driving cycle has the following sequence:

3.3.1 Obtaining the experimental trace

Experimental data correspond to curve obtained on the route. Driving data at zero velocity for more than 200 seconds are filtered as it does not represent normal driving patterns. The experimental trace is divided on trips, which starts and ends when the velocity is zero, Figure 4. Each trip is characterized according to its average velocity and acceleration.

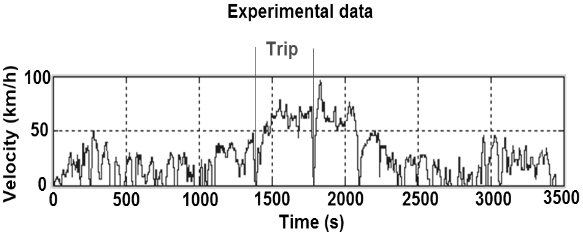

Figure 4. *Experimental data for first route.*

3.3.2 Creating operation curves

Every route traveled produces an *experimental curve*. These curves are divided in sections (trips), using two delimiters whenever the speed of the vehicle is zero. For every resulted section its average speed is calculated. This average speed in turn is classified in intervals. The used intervals are defined by speed ranges, chosen in such a way that they have a similar quantity of data, making it unnecessary to weight for any factor that balances the components of low, average or high speed. In the next step, the trips are pooled and pegged next to each other in accordance with their corresponding ranges of average speed. The set of sections that belong to the same interval of average speed is named an *operation curve*.

As a result of this process, several operation curves are obtained. For each curve there are determined the time in operation, percentage of stopped time, average velocity, and acceleration. It is worth mentioning that theoretically for each operation curve a particular driving cycle could be drawn. Therefore, several driving cycles might be obtained for the same route. Nevertheless, every curve of operation not necessarily generates a driving cycle with a high correlation, by what cycles with less favorable correlation are rejected. In each selected route, the *modeled driving cycle* is selected by the major correlation to its curve of operation.

3.3.3 Construction of micro – trips

Each operation curve is divided into micro-trips. Each micro-trip is a trace of the operation curve defined by the average velocity. This part of motion consists of acceleration, cruise and deceleration modes. By convention, a period of average velocity is the beginning and end of a micro-trip as Figure 5 shows.

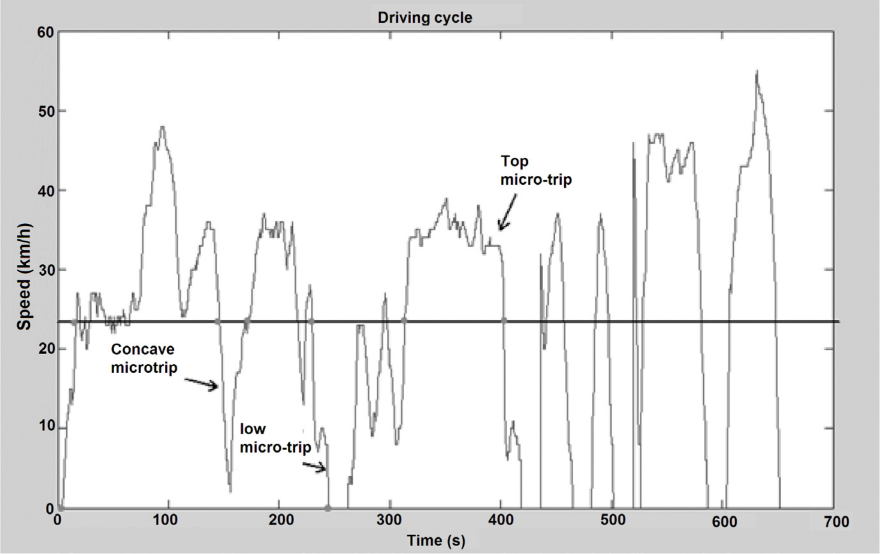

Figure 5. *Real driving curve with its micro-trips shown.*

3.3.4 Generating frequency matrix

For each operation curve the maximum values of velocity and acceleration are determined and each variable is divided into intervals. The frequency matrix is constructed indicating, for each velocity interval, the number of data encountered for each acceleration interval along the operation curve. For each micro-trip it is obtained a frequency matrix with the same velocity and acceleration intervals used on the operation curve. Subsequently, the correlation factor R between the current operation curve's frequency matrix and that of the corresponding micro-trip is obtained.

3.3.5 Generating and evaluating cycle

The driving cycle is initiated with the micro-trip with the higher correlation. The next micro-trip to add is selected according to the correlation factor between the operation curve's frequency matrix and that of the actual driving cycle. Since each added micro-trip generates a different frequency matrix, it is again necessary to evaluate the correlation between the operation curve and the new driving cycle. The micro-trip that generates the driving cycle with the higher correlation is the one selected. If the duration of the generated driving cycle was not sufficient, then the other micro-trips can be added to get a sufficient driving cycle duration. The total duration of the driving cycle is considered based on the fact that it should be long enough to describe all traffic situations and obtain the emissions sufficiently. The total driving cycle duration for the test routes chosen in this study are set around 450 seconds (for the first route) and around 650 seconds (for the second route), which are within the range obtained experimentally during 5 test runs performed preliminary with various vehicles along commonplace routes in Pereira city, conducted specifically with the aim of appraising the mean time spent by drivers during their “home to work” trips. The New European Driving Cycles, for instance is within the range of 1200 seconds, sufficient to test vehicle fuel consumption and emissions.

A code has been composed to generate the micro-trips and calculate required parameters of the cycle (acceleration frequency, cruise and idle, etc.). In the end, it is pegged the percentage of idle time corresponding to the experimental trace. If the correlation between the actual operation curve and the final driving cycle is low, other intervals for velocity and acceleration are selected and the process is restarted. A correlation factor R close to 1 is an indicator of a high positive linear relationship between the two frequency matrices, so it is pursued to obtain a driving cycle with a factor R as close as possible to unity.

4. Results

For the first route selected, it was obtained a driving cycle with an average velocity of 30,39 km/h and a correlation factor R of 0,94**.** Figure 6 shows the initial experimental curve, the modeled driving cycle and the frequency spectrum which resulted in the cycle. The obtained driving cycle corresponds to the order of micro-trips with the highest correlation factors obtained for different arrangements of velocity and acceleration intervals, as indicated in the methodology. In this driving cycle, the maximum velocity was 75 km/h. It is seen that the characteristic driving cycle is very variable in velocity, while the acceleration ranges between -1,3 and 1,3 m/s^2. These values of speed and velocity are characteristic of urban driving conditions dependent of traffic lights with sufficient y runout distances to achieve a high average velocity. With these characteristics and the correlation factor close 1, it can be stated that the obtained driving cycle is representative of the route.

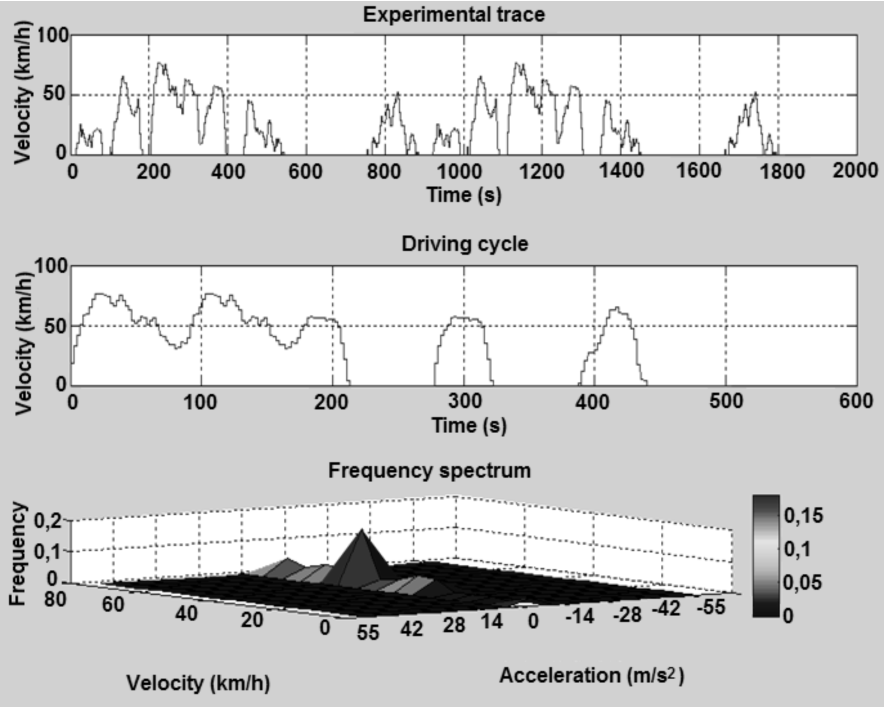

Figure 6. *Representation of the velocity–acceleration frequency spectrum and derived constructed driving cycle obtained after processing Pereira real driving cycle, Route 1.*

The second route has an average speed of 12,8 km/h implying the slow transport movement along the roads of Pereira. The high percentage of idle time, 21,85 %, is characteristic of traffic congestions, longer stoppage duration at signals and frequent stops in the city. Figure 7 shows the high percentage of acceleration and deceleration (between -4,5 and 2,5 m/s^2), attributable to the stop and go driving pattern. In the Driving Cycle obtained for Pereira during this pilot study, the vehicles spend significant part of their traveling time running in the 1st and 2nd gears. This cycle has a correlation factor of 0,98, indicating a very strong positive linear relationship with the experimental cycle.

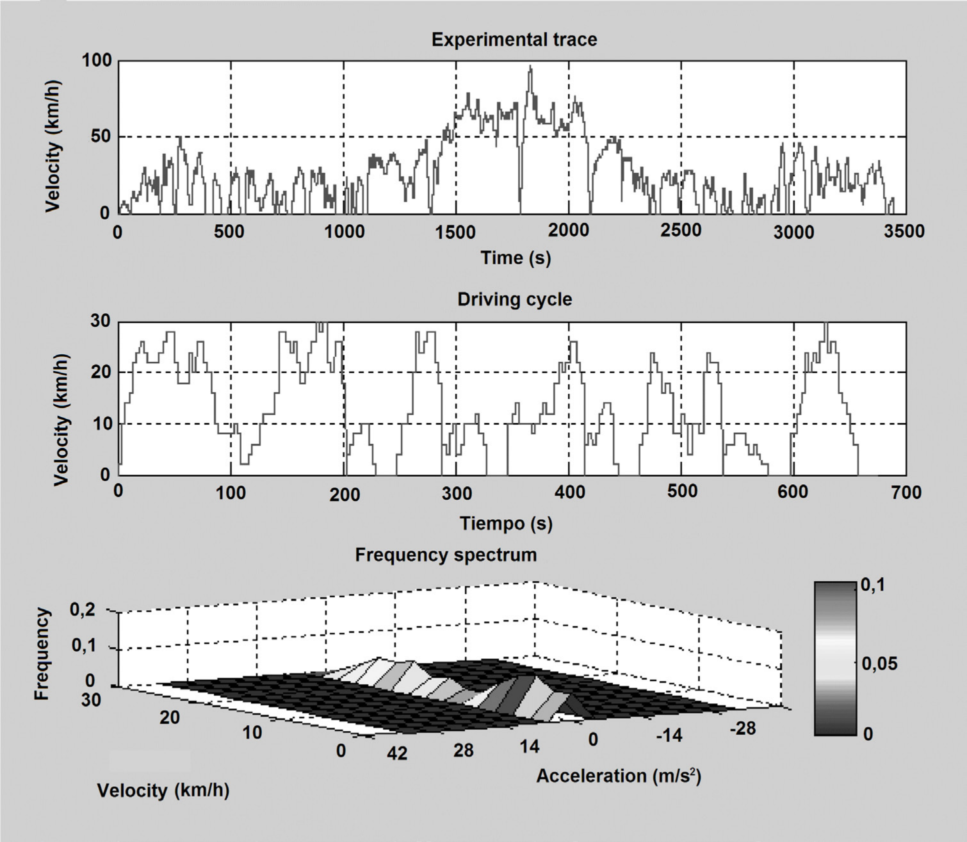

Figure 7. *Representation of the velocity–acceleration frequency spectrum and derived constructed driving cycle obtained after processing Pereira real driving cycle, Route 2.*

Table 2 contains the comparison of the experimental curve and the cycle obtained for the two selected routes. It is observed that the experimental curves and their corresponding driving cycles have close values for their average velocity, average accelerations and average decelerations; there is a strong positive linear relationship between the actual mean values and those given by the obtained driving cycles.

Table 2. *Comparative values between experimental traces and constructed driving cycles.*

Route	Average velocity (km/h)		Average acceleration (m/s^2)		Average deceleration (m/s^2)	
	Experimental trace	**Driving cycle**	**Experimental trace**	**Driving cycle**	**Experimental trace**	**Driving cycle**
1	27,37	30,39	0,58	0,36	-0,86	-0,63
2	16,2	12,8	0,75	0,73	-0,77	-1

As it has been pointing out previously, an *experimental driving pattern* tends to be extensive in time, while the *modeled driving cycle* is desired to be sufficient in time duration to cover such objective information as speed, acceleration, deceleration and their derivatives. This explains the differences in time duration of the experimental traces and driving cycles obtained.

5. Conclusions

Engine and vehicle operation parameters during vehicle real-driving operation were logged using low cost ELM327™ scan tool and Torque™ program for Android™, combined with GPS device. It became clear that modern vehicles provide access to their electronic control units for diagnosis and servicing, allowing access to high speed engine data readings. Diagnostics hardware and apps like Torque Pro step in, putting vehicle data at the technicians' fingertips.

It has been concluded that the experimental data logged during the vehicle driving, using low cost scan tools, is of good quality and not only serves for monitoring and diagnostic purposes, but also for processing engine operation modes with their corresponding engine performance mean data.

It has been presented a methodology to construct a pilot driving cycle of city vehicles, using micro-trips extracted from real-world driving data. The methodology is easy to implement, requiring only values of vehicle position, speed and time. Based on the methodology, a pilot driving cycle for Pereira city was constructed considering important parameters of the time–space profile, obtained from experimental curves: the percentage acceleration, deceleration, idle, cruise, and the average speed.

Real-world driving patterns collected in Pereira serve as examples of real-world driving data. In addition to serving as a *trial* of real-world driving, these data were processed into speed traces. Although the results presented show only two driving cycles corresponding to two routes in two different schedules, five driving cycles were obtained in the developed work, corresponding to other routes of high traffic in the city.

Despite the fact that it has been a pilot work, it paves the way of a more comprehensive campaign to face in the near future, intended to obtain an all-validated Pereira driving cycle, based on the selection of a set of different vehicles and road routes, representative enough to capture the vehicle dynamics of the Pereira city, with consideration of topography, vertical alignment of the road as well as weather conditions and micro texture of the routes.

6. References

1 Alessandrini A, Filippi F, Orecchini F, Ortenzi F. A new method for collecting vehicle behavior in daily use for energy and environmental analysis. In: Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 220(11); 2006; UK. Thousand Oaks, CA: SAGE publications, Institution of Mechanical Engineers; 2006. p. 1527-7. DOI: 10.1243/09544070JAUTO165.

2 Casey E, Smith W, Timoney D. Exa-mination of low-cost systems for the determination of kinematic driving cycles and engine operating conditions in Dublin, Ireland. Detroit (MI): SAE International; 2009. SAE Technical Paper No.: 2009-01-2791. DOI: 10.4271/2009-01-2791. Presented at SAE 2009 World Congress.

3 Duran A, Earleywine M. GPS Data Filtration Method for Drive Cycle Analysis Applications. Detroit (MI): SAE International; 2012. SAE Technical Paper No.: 2012-01-0743. EEC Directive 90/C81/01. Presented at SAE 2012 World Congress. DOI:10.4271/2012-01-0743.

4 Tamsanya S, Chungpaibulpattana S, Atthajariyakul S. Development of automobile Bangkok driving cycle for emissions and fuel consumption assessment. In: The second Joint International Conference on Sustainable Energy and Environment; 2006; Bangkok, Thailand; 2006. p. 1-6.

5 Tzirakis E, Pitsas K, Zanniko F, Stournas S.Vehicle Emissions and Driving Cycles:

Comparison of The Athens Driving Cycle (ADC) With ECE-15 and European Driving Cycle (EDC). Global NEST. 2006 may;8(3):282-90.

6 Wang Q, Huo H, He K, Yao Z, Zhang Q. Characterization of vehicle driving patterns and development of driving cycles in Chinese cities. Transportation Research Parte D: Transport and Environment. 2008 jul;13(5):289-97.

7 Hung W, Tong H, Lee C, Ha K, Pao L. Development of a practical driving cycle construction methodology: A case study in Hong Kong. Transportation Research Part D: Transport and Enviroment. 2007 mar;12(2):115-28.

8 Esteves-Booth A, Muneer T, Kirby H, Kubie J, Hunter J. The measurement of vehicular driving cycle within the city of Edinburgh. Transportation Research Part D: Transport and Environment. 2001 may;6(3):209-20.

9 Galgamuwa U, Perera L, Bandara S. Developing a general methodology for driving cycle construction: Comparison of various established driving cycles in the world to propose a general approach. Journal of Transportation Technologies. 2015 oct;5(4):191-203.

10 Kamble S, Mathew T, Sharma G. Development of real-world driving cycle: Case study of Pune, India. Transportation Research Part D: Transport and Enviroment. 2009 mar;14(2):132-40.

11 André M, Joumard R, Hickman AJ, Hassel D. Actual car use and operating conditions as emission parameters: derived urban driving cycles. Science of The Total Environment. 1994 may;146-147:225-33.

12 Kulkarni A, Sapre R, Sonchal C. GPS based methodology for drive cycle determination. Warrendale (PA): Society of Automotive Engineers; 2005 apr. SAE Technical Paper No.: 2005-01-1060. DOI: 10.4271/2005-01-1060. Presented at SAE 2005 World Congress.