Abstract: The urban drive cycles for five different light duty vehicles (LDV) are developed in this study. The study presents the methodology in the development of the drive cycles in which the speed profile of the specific type of vehicle is surveyed with an on-board instrument. The speed data is processed using a program to execute the methodology in generating candidate drive cycles. The selected drive cycles are then used in the chassis dynamometer laboratory to estimate the fuel economies of each type of light duty vehicle considered. The developed drive cycles for the different types of light duty vehicles, namely (1) private cars, (2) taxis, (3) public utility jeeps, (4) UV express, and (5) light duty trucks have average speeds of 17.97 kph, 13.57 kph, 10.87 kph, 14.69 kph and 8.43 kph respectively. The measured fuel economies for all the light duty vehicles tested ranges from 3 to 12 km/liter.

Keywords: fuel economy, drive cycle, chassis dynamometer, alternative fuels

1. INTRODUCTION

1.1 Background

Economic progress increases the need to transfer people and commodities from one location to another. As population grows, demand for mobility increases, which, in turn, raises the number of vehicles on the road. This condition aggravates ambient air quality—an increase in the concentration of air pollutants from tail pipe vehicle emissions that can potentially cause respiratory diseases to vulnerable sectors. At the same time, the increase in fossil fuels consumption elevates emission of carbon dioxide (CO₂) in the air which is the main gas associated to climate change.

Figure 1 shows the average total final energy consumption in 2008 and 2009 of the Philippines. The transport sector comprises the highest percentage (37.1 %).
Out of the 37.1% share of the transport sector from the total energy consumption, road transport has the highest percentage of 79.3% of 8.37 MTOE (2006) (Source: Key Energy Statistics by DOE, 2014). From 2001 to 2009, the transport sector consumed 68% of the total petroleum usage (oil and oil products) in the country with approximately 70 thousand megabarrels out of the 103 thousand consumed every year (DOE, 2014).

The number of motor vehicles in the Philippines has increased with an average annual rate of 6.18% (2008 to 2012) as shown in Table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Motor Number of Vehicles</th>
<th>Annual Growth (%)</th>
<th>Light Duty Vehicles (Cars, UV and SUV)</th>
<th>Annual Growth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>7,463,393</td>
<td>4.54</td>
<td>2,934,086</td>
<td>2.55%</td>
</tr>
<tr>
<td>2011</td>
<td>7,138,942</td>
<td>7.60</td>
<td>2,861,088</td>
<td>3.27%</td>
</tr>
<tr>
<td>2010</td>
<td>6,634,855</td>
<td>6.66</td>
<td>2,770,591</td>
<td>4.70%</td>
</tr>
<tr>
<td>2009</td>
<td>6,220,433</td>
<td>5.59</td>
<td>2,646,110</td>
<td>3.54%</td>
</tr>
<tr>
<td>2008</td>
<td>5,891,272</td>
<td>6.51</td>
<td>2,555,578</td>
<td>0.35%</td>
</tr>
<tr>
<td>2007</td>
<td>5,530,052</td>
<td>-</td>
<td>2,546,702</td>
<td>2.55%</td>
</tr>
</tbody>
</table>

Source: Land Transportation Office (LTO)

Vehicle emissions is one of the major problems in the cities, especially in Metropolitan Manila. Air pollutants such as carbon monoxide, nitrous oxides, sulfur oxides and particulate matters can cause immediate or long-term effects in humans such as headache, allergic rhinitis, nose irritation, emphysema, and asthma. Particulate matter in the air, such as PM10 containing toxic substances, penetrates deep into the lung tissues. Long-term exposure to fine particulates from air pollution is a serious environmental risk factor attributed to cardiopulmonary and lung cancer mortality. An amount of 10 μg/m³ increase in 24-hour average ambient PM10 concentrations can cause approximately 1 percent of all-cause mortality including respiratory and cardiac, and increase in respiratory and cardiac admissions (Streeton, 2000).

Tailpipe emissions is also implicated in the issue of global warming and climate change as various gases, notably CO₂, have significantly increased in volume in the air. Climate change is defined as the long-term change in average weather conditions which includes
According to the United Nations’ Intergovernmental Panel on Climate Change (IPCC), the global climate is undergoing remarkable changes as the direct result of greenhouse gas emissions from human activity.

Aware of the current situation, the government initiates campaigns to curb the use of fossil fuels such as the use of alternative fuels, e.g. electric vehicles, ethanol mix with petrol, coco methyl ester mixed diesel, LPG, natural gas, etc. A comprehensive law was enacted called the Biofuels Act of 2006 which generally aims to reduce dependence on imported fuels with due regard to the protection of public health, the environment, and natural ecosystems (Biofuels Act, 2006).

In 2006, as a result of the government’s initiatives, the total energy consumption posted a decrease of 6.4 % from 8.94 MTOE (2005) to 8.37 MTOE. The increase of fuel prices may also have caused the decline in fuel consumption. Additionally, the promotion of the use of alternative fuels is being undertaken by the government to reduce the consumption of diesel or gasoline. There were noted increases in consumption of (1) CME to 0.54 thousand tonnes of oil equivalent (kTOE); (2) ethanol to 0.54 kTOE, and (3) LPG reaching 4.03 kTOE (DOE, 2007). Decreasing the demand for fossil fuels can have beneficial effect in the leverage of the country’s trading of fossil fuels (DOE, 2007).

The Philippine Clean Air Act of 1999, aims to mitigate hazardous gas emissions coming from different sources. The Department of Transportation and Communications (DOTC) implements the set emission standards for motor vehicles as provided in the Act. The Department of Environment and Natural Resources (DENR) is mandated by the law to revise the standards every two years or as the need arises.

Through the initiative of the Philippine Commission on Climate Change, local governments are directed to make inventory of carbon footprints of any activity pertaining to the use of energy. Carbon dioxide emissions of road vehicles are obtained by the total fuel consumption of either gasoline or diesel.

1.2 Statement of the Problem

In the Philippines, motorcycles and tricycles comprise the bulk of total vehicular population (55.81%), followed by light duty vehicles (39%). In Metro Manila, 64 % comprises light duty vehicles which include for-hire vehicles such as the taxis, public utility jeepneys and UV express. As primary sources of major air pollutants from fossil fuel emissions that are hazardous to health, and of CO₂ emissions that contribute to climate change, it is strategic to set priority in reducing vehicle emissions as well as fuel consumption of this type of vehicle in order to decrease air pollution and lower the demand for fossil fuels.

One of the basic activities to mitigate the impacts of vehicle emissions on health and environment is to measure baseline conditions. The baseline conditions would typically be the basis for comparison as to whether a scheme for mitigation would be effective or not. Whether obtained from actual site measurement or simulated, the values shall be used for assessments of effectiveness due to improved ambient air quality or more efficient fuel consumption.

In the estimation of emissions and fuel consumption, emission factors and fuel consumption factors are measured in the chassis dynamometer laboratory using the local drive cycles.

The first urban driving cycle for Metro-Manila was developed in 1996. With the significant changes in the traffic conditions, vehicle attributes, driving styles of drivers in Metro Manila, the drive cycle for the different types of light duty vehicles need to be updated.
In addition, different types of vehicles have different route and operational characteristics; therefore, there is a need to develop separate drive cycles for each type of light duty vehicle. Moreover, the fuel consumption factors of different types of vehicles are needed in most planning or assessment of present and future land transportation facilities when computing the fuel savings of motorists and reduced CO$_2$ emissions in the atmosphere with and without the proposed infrastructure development.

1.3 Objectives of the Study

In light of the issue of mitigating vehicle emissions, this study aims to:
1) develop drive cycles of five different types of light duty vehicles, namely:
   a) Private cars;
   b) Taxis;
   c) Public Utility Jeepneys;
   d) UV Express;
   e) Light Duty Trucks;
2) measure fuel economy of each type of light duty vehicle using the developed drive cycles;

1.4 Significance of the Study

The developed local drive cycles of specific light duty vehicles which incorporate local traffic, vehicle road and driver characteristics, together with the availability of chassis dynamometer laboratories, will facilitate further studies on alternative fuels, emerging vehicle technologies and other vehicle or fuel related studies.

The estimated fuel economies of measured vehicles can be used in the inventory of carbon dioxide emissions of the said type of vehicles and in the macro analysis of the impact of alternative fuel vehicles in response to climate change mitigation.

1.5 Conceptual Framework

Figure 4 shows that driver behavior, vehicle attributes, traffic, and road conditions are integral elements of the drive cycles which affect the speed of a vehicle. The drive cycles represent the summarized driving operations of the different types of light duty vehicles in Metro Manila. By testing the subject vehicle (using the developed drive cycles in the chassis dynamometer) in which different peripheral devices are included in the system, the vehicle performance in terms of fuel consumption can be measured.

In this study, using the developed drive cycles, the fuel economies of the different light duty vehicles are measured.

Due to the unavailability of the gas emissions analyzer, emissions were not measured.
1.6 Limitations of the Study

1) The drive cycles developed were for urban setting only, particularly in Metro-Manila;
2) Only a limited number of vehicles were tested in the laboratory;
3) The air conditioning system of some of the vehicles tested (private cars, taxis and UV Express) in the chassis dynamometer was turned off while testing to eliminate variability of the power consumed by the vehicle;
4) The vehicles tested were set to full load when tested in the chassis dynamometer. For light cargo vehicles, the gross weight capacity rating indicated in the certificate of registration was set.
These limitations affect the actual consumption of the vehicles. The air-conditioning system of vehicles responds variably depending on ambient temperature. Therefore, its effect on fuel consumption differs within the day or across seasons of the year.
During operations of the light duty vehicles, the load factor is not at all times 100%. The load factor varies directly with fuel consumption. Therefore, full load capacity setting during testing would result to increased fuel consumption compared to less loading. Measurement of fuel consumption, therefore, is more conservative due to this limitation.
5) The speed data were generally gathered from paved flat terrain. In future considerations, drive cycles derived from roads with considerable gradient may also be implemented in the chassis dynamometer at the UP-VRTL. The software of the chassis dynamometer can simulate specified gradient by increasing the set load of the vehicle. This is due to the increased resistance contributed by the vehicle’s weight while it is inclined when it ascends a terrain.
2. REVIEW OF RELATED LITERATURE

In this study, a variety of literature has been reviewed in order to establish a reliable methodology in fulfilling the set forth objectives. It is important to review the methodologies used in the development of the different drive cycles not only abroad but also locally. This section discusses the different studies related to the development of drive cycles.

The development of drive cycles in the Philippines started in 1995 with the project “Performance Testing of Selected Road Vehicles Using the Chassis Dynamometer Under Simulated Urban and Highway Traffic Conditions”. The main consultant of the project was Ricardo G. Sigua of the University of the Philippines, College of Engineering (UPCOE). In this project, Sigua developed the first urban drive cycle for private cars which has parameters: maximum velocity, 56 kph; minimum velocity, 0 kph; % idle period, 33.72%; average running speed, 22.14 kph; duration, 1299 seconds.

Sigua used car following technique in gathering speed data. The chase car was equipped with on-board data acquisition system which was composed of a data acquisition computer, flow meter/transmitter, speed/distance sensor, data processing computer. The car was a Toyota Corolla with a four-speed manual transmission and an engine displacement of 1300 cc.

Abuzo, et. al. (2004) developed a drive cycle for the tricycle to quantify emissions from this type of vehicles as well as to determine some of the factors that affected the emissions. The drive cycle for tricycle was developed with a maximum speed of 43.0 kph, maximum acceleration of 6.97 m/s² (minimum acceleration of 6.44m/s²), and average speed of 19.94 kph. Findings of the study revealed that four-stroke tricycles have lesser HC and CO emission concentrations compared to the two-stroke type. It was also revealed that CO concentration was significantly affected by fuel-oil ratio and loading.

Biona, et.al. (2006) also developed the drive cycle of tricycles which took into account the road gradient effects on engine load. The speed data of the subject tricycle was obtained by installing a data logging device system. The system consisted of magnets attached to the spokes of the rear wheel of the motorcycle producing pulses as it passed through a magnetic sensor. The pulses were converted to voltage as it passed through a frequency to voltage converter circuit. A microcontroller converted these voltages to speed data. The developed device logged speed values on a per second interval. Biona compared the Metro Manila tricycle drive cycle with the Indian drive cycle. It showed that the Metro Manila drive cycle was a lot slower but was characterized by higher acceleration rates.

Thaweesak, et.al (2009) developed the drive cycle for the public utility jeepney (DC251) in Metro Manila. The drive cycle that was developed was used in testing the effects of coco methyl ester to the neat diesel in different concentrations, i.e. 1% (B1), 3% (B3), 5% (B5) and 10% (B10), in terms of engine performance such as engine power and emissions. DC251 had absolute difference of 17.78%, average running speed of 15.85kph, average speed of 10.59kph, average acceleration of 0.46 m/s², average deceleration of -0.48 m/s², maximum speed of 45.8kph, minimum speed of 0kph and duration of 1,367 seconds. In this study, the increases in the maximum power for B1 and B5 were not significant, while B3 and B10’s increases were significant. For fuel economy, all observed increases were not significant. The decrease in the opacity for B10 compared to neat diesel was not significant, while the increases for B1, B3, and B5’s were significant.
Diaz, et.al. (2010) developed the drive cycle for taxicabs running on gasoline. In this study, a program in C++ language was developed for more convenient computations of absolute value difference of candidate drive cycles. The program automatically computed for the maximum, average and minimum acceleration; and maximum, average and minimum speed. It has an absolute difference of 13.93% from the target drive cycle. Moreover, its idle time is 28.95%, maximum velocity of 74.03 kph, minimum velocity of 0 kph, maximum acceleration of 1.99 m/s², minimum acceleration -2.01 m/s², average velocity of 20.84 kph, average acceleration of 0.00 and an average running speed of 29.42 kph. The developed program for this study made significant improvement compared to the FORTRAN based previously used in the development of drive cycle for the public utility jeepney in Thaweesak’s (2009) study.

Pokharel, et. al., in 2013, developed the drive cycle for the public utility jeepney (PUJ) running on liquefied petroleum gas (LPG). The speed data needed in the development of the drive cycle, were gathered from auto-LPG PUJ’s operating in Makati City specifically the Mantrade (Magallanes, EDSA) to Philippine Race Club (PRC) route. An on-road survey of fuel consumption was also conducted using the full tank method for purpose of comparison between the actual and the laboratory run. The developed drive cycle for auto-LPG was simulated in the chassis dynamometer; however, the full tank method was still used in the measurement of LPG consumed. The estimated fuel efficiency from the data gathered on the on-road test was 3.54 kilometer per liter. The maximum power of Auto LPG Hyundai Theta 2.4 OEM engine was measured to be 51.79 kW

3. DRIVE CYCLE DEVELOPMENT

The major parts in the development of the drive cycles are: (1) speed data gathering, and (2) processing of gathered data. It is important that the source of speed data comes from a variety of vehicle models, route, and time of operation. This is to assure representation of the categories mentioned. There are certain types of LDV which do not have definite routes, i.e. private cars, taxicabs and light cargo vehicles. Public utility jeeps (PUJ) and UV express vehicles have predefined routes. The survey of speed data was conducted during the usual time of operations of the subject vehicles.

3.1 Speed Data Survey

The speed data profile of the subject vehicle is gathered in developing drive cycles. The two methods which can be employed are: (1) chase car technique and (2) on-board instrument (Global Positioning System or GPS) device.

The chase car technique is a method wherein a vehicle (chase car) is instrumented with an automatic logging of one-second interval of its instantaneous speed. This “chase car” chases a vehicle in order to emulate its speed. In doing so, the recorded speed of the chase car shall be considered the speed of the target car.

The chase car method was not employed in this study. During a pilot test of the chase car technique, it was deemed dangerous to implement this due to the current attitude of drivers in the metropolis in which drivers of private vehicles are not used to vehicles following them due to suspicion of car waving or robbery. Instead the use of a GPS device was employed due to its reliability and ease of implementation. The GPS device automatically logs speed of subject vehicles at one-second intervals. The GPS device is placed on the dashboard of the subject vehicle usually with an adhesive tape to fix its position
during the course of the speed survey and to provide better satellite connection. Two models were used in this study, i.e. Model 78S and Model 76CSx. The Garmin GPS 76CSx stores speed data (kph) and can be set to store data every one second. It also logs current time (time of survey) and date, and geographical coordinates of points within the routes. With a four-gigabyte micro SD card inserted in the device, it is capable to storing up to three hours of data. The 78S model has greater capacity of recording due to its automatic archiving of logs.

3.2 Sampling of Surveyed Vehicles

Five types were considered in this study, i.e. private cars, taxis, utility vehicles express, public utility jeepsneys and light duty trucks. Therefore, sampling was clustered according to the five types of light duty vehicles. The criterion in the sampling was the dominant model in the in-use vehicle fleet. Eventually, the selected vehicles had been limited according to the availability of willing participants. Issues like confidentiality, security, privacy and availability of potential participants were frequently encountered.

The main urban roads in connecting the north, south, east and west of Metro Manila are Epifanio De Los Santos Avenue (EDSA), Commonwealth Avenue, Carlos P. Garcia Avenue (C-5), España Avenue, Taft Avenue, Rizal Avenue, Osmeña Avenue and other major arterial roads. In these roads, high volume of different light duty vehicles can be observed.

3.3 Survey Proper

3.3.1 Private Cars

A characterization of the in-use fleet of private light duty vehicles provided STRADCOM-LTO (excluding Honda), showed Toyota utility van to have the highest percentage (15.1%) composition followed by cars (11.9 %) of the same brand. The next dominant brand was the Mitsubishi which comprised 9.5% for its utility vans and 5.4 % for its cars. Other dominant brands were Isuzu, Nissan, and Hyundai which comprised 13.8 %, 7.3 % and 2.6 %, respectively.

The time of survey was from 6:00 A.M. to 8:00 P.M. These trips were mostly home to work trips. Some trips were within working hours in which office-to-office trips were made. A total of sixteen different vehicles were surveyed with different drivers. The duration of each trip was around 20 to 45 minutes. The surveys took place in January, October and November, 2011. Among the models of surveyed private cars were, Honda City (2003, 1996), Toyota Hi-Ace (1993), Toyota Vios (2010, 2007), Toyota Altis (2011, 2007), Toyota Innova (2008), Toyota Corolla (1999), Mitsubishi Pajero (1994, 1993), Mitsubishi Lancer (1998), Nissan Exalta (2000), Ford Ranger (2011) and Mazda 3 (2010).

Among the main roads traversed by the vehicles were: (1) Commonwealth Avenue, (2) Quezon Avenue, (3) Epifanio Delos Santos Avenue (EDSA), (4) España Avenue, (5) Taft Avenue, and (6) Gil Puyat Avenue. Origin-destination trips with corresponding distances of the surveyed vehicles were: (a) Makati to UP (16.2 km), (b) UP to Makati (15.1 km), (c) Taft Avenue to UP (15.9 km), (d) Cainta to Taytay (9.6 km).

3.3.2 Taxis

One unique characteristic of the taxi is that it has no specific route. It traverses the paths to where the passenger would wish to be taken. The taxi is usually driven alternately by two drivers who take turns every 24 hours. Some taxis operate only from eight to twelve hours in
 Registry of the in-use taxis in the National Capital Region comprises a majority (78%) of Toyota brand, followed by Hyundai (9.0%) and Nissan (8.1%).

The speed survey conducted for taxis had two batches. The first batch consisted of four days of survey (two weekdays and two weekends) with a total of ten runs using three different vehicles with different drivers. The second batch composed of 13 different taxicab drivers with 13 different units running on either gasoline or liquefied petroleum gas (LPG). The time of operations of taxicabs surveyed was between from 7:00A.M. to 8:00P.M. The surveys took place in February and July, 2010 and July, 2013. Among the models of the surveyed taxis were Toyota Avanza (2012, 2010,20007), Toyota Corolla (2000, 1998, 1997), Toyota Vios (2012, 2010), Nissan Sentra GX(2005, 2003), Kia Rio(2012, 2011).

The traversed roads of the surveyed taxis were: (1) Commonwealth Avenue, (2) Quezon Avenue, (3) EDSA, (4) C5 Circumferential Road, (4) University Avenue, (5) Taft Avenue, and (6) Quirino Avenue. Origin-destination trips with corresponding distances of the surveyed vehicles were: (a) Ayala Avenue to Vito Cruz, Vito Cruz to UP Campus (21.2 km) (b) Bonifacio Global City to Cubao (11.6 km) (c) C.P. Garcia Avenue to Bonifacio Global City (13.5 km), (d) UP Campus to Philcoa, Philcoa to E. Rodriguez/Gilmore Avenue (18.5 km).

### 3.3.3 Public Utility Jeepneys

Public utility jeepneys (PUJ) are officially classified under the utility vehicle (UV) category. It is the most common public transport in the Philippines. These public vehicles were originally built from surplus US military jeeps used during World War II. They are most popular for their vibrant decoration and numerous seating capacity. They are manufactured locally and its parts, e.g., engine, chassis, are also available locally. (Bayan 1995:29 and Ebata, et al., 1996 cited in Bacero, et. al. 2009).

In the registry of public utility vehicles in the Land Transportation Office, the rebuilt vehicle is mainly identified through its engine type (e.g. 4BA1, 4BC2). Majority of the vehicles’ engine year models were not indicated in the registry. The top three engine models are 4BA1, 4BC2 and C240 which comprise 10%, 10% and 8% of the total fleet, respectively.

The speed surveys for the public utility jeepneys were done on-board using GPS device. The time period of the surveys was generally from 8:00 A.M. to 7:00P.M. The surveyed jeepneys were identified by their engine type and designated routes. The surveyor asked the drivers about the models of their jeepney engines. The surveyors also asked the drivers what were the ages of their vehicle engines. The ages of the vehicles varied from ten to twenty years. The engines’ ages were difficult to determine since most were already used when installed to the PUJ.

The surveyors paid for their fares as they boarded the PUJs. The device was placed on the dashboard of the jeepney. For the first batch of the survey of speed profile of test jeepneys, a video camera was placed adjacent to the GPS device to capture 1-second interval reading of speed. Both devices were housed in a plastic container. The video recording was later encoded on a spreadsheet file. The routes surveyed were Parang – Stop & Shop, Guadalupe – L. Guinto and Project 8 - T.M. Kalaw. In the succeeding batches of speed data surveys, the track recording using GPS was discovered as an easier option in logging the instantaneous speed of subject vehicles.

Traversed roads were: (1) Tandang Sora Avenue, (2) Commonwealth Avenue, (3) España Boulevard, (4) Quiapo Boulevard, (5) Taft Avenue, (6) Rizal Avenue/Extension and (7) Gil Puyat Avenue. Origin-destination trips with corresponding distances of the surveyed
vehicles were: (a) Taft Avenue to Monumento (11 km), (b) Fairview to Vito Cruz (29.8 km) (c) UP Katipunan Extension to Quirino Highway (9.8 km) (d) EDSA to Taft Avenue (12.6 km)

3.3.4 Utility Vehicles (UV Express)

UV Express vehicles are air-conditioned public utility vehicles operating on a point-to-point destination. They can deviate slightly from their designated routes but are not allowed to pick-up passengers along the way. Point-to-point means the driver can only load or unload at designated terminals. However, in the current operations of this mode of transport, the loading and unloading policy is not strictly implemented. At each terminal, the driver has to queue and fill the vehicle up to its capacity. The loading capacities of these utility vehicles are 10, 18 and 18 persons, respectively. Fare is higher compared to PUJs.

The prevalent models in the UV Express fleet are Mitsubishi Adventure, Toyota Hi-Ace and Nissan Urvan. The statistics of the brands, models and years registered are summarized in Table 3.7. The table shows Toyota, Nissan and Mitsubishi brands dominate the UV Express type of vehicles with 46.4%, 18.4% and 18%, respectively.

During speed data gathering, the surveyor boarded the UV Express vehicle at the terminal. Figure 25 shows UV Express vehicles parked in the queue. The surveyor was instructed to board a different type of vehicle on the way back to the same route to gather more samples of vehicles with different drivers. The models of the surveyed UV Express vehicles were: Nissan Urvan (2012, 2011, 2007), Toyota Hi-Ace (2012), Toyota Tamaraw FX (1997), Mitsubishi Adventure (2010, 2007, 2000), Isuzu Highlander (2001, 1998). The surveyed routes were: a) North Avenue to SM Mega Mall, b) North Avenue to Novaliches Bayan, c) SM Mega Mall to Binangonan, d) Buendia to Fairview, e) Parang Fortune Cubao, f) Eaton Centris to SM Fairview, g) EDSA Central to Binangonan, h) Binangonan to EDSA Central, i) Rodriguez, Montalban to Cubao, j) Cubao to Antipolo

The major roads traversed by the UV Express were, (1) Quezon Blvd., (2) Commonwealth Avenue, (3) Espana Avenue, (4) Epifanio Delos Santos Avenue and (5) Taft Avenue, (6) Quirino Hi-way and (7) Ortigas Avenue/Extension. All surveyed vehicles travelled on relatively flat roads except for the Cubao to Antipolo route which roads had flat and rolling portions. The latter comprised 9.7% of the total time of data surveyed for the UV Express vehicle. Origin-destination trips with corresponding distances of the surveyed vehicles were: (a) Philcoa to Gil Puyat Avenue (28.0 km) (b) Eaton Centris to Fairview, Fairview to Eaton Centris (35 km), (c) Trinoma Mall to Megamall, Mega Mall to Trinoma Mall (18.2 km) (d) Trinoma Mall to Bayan, Novaliches; Bayan, Novaliches to Trinoma Mall (22.0 km).

3.3.5 Light Duty Trucks

The common category for light duty trucks has a gross vehicle weight rating (GVWR) of 6,000 (2,720 kg) to 14,000 lbs (6,350 kg) (US DOT Vehicle Inventory and Use Survey 2009). The registry for “Trucks for Hire” provided by the LTFRB indicates that Isuzu and Mitsubishi/Fuso are the dominant brands of trucks, although their respective registered years and vehicle models are mostly not indicated. Isuzu and Mitsubishi/Fuso constitute 44.5% and 28.2%, respectively, of the total fleet of trucks registered in the National Capital Region.

In the survey for the speed data, two companies were selected, namely: (1) Toppan Paper Products Co., Inc., (2) MDL Trucking. The first company is a supplier of papers to different clients and uses its vehicle fleet to deliver its own goods. The second is a
truck-for-hire company which delivers mainly in Luzon areas. The surveys on both companies took place from March 25 to 30, 2013.

The vehicles surveyed were all running on diesel fuel. Models of surveyed vehicles were: Mitsubishi Canter, Mitsubishi L300, Isuzu Closed Van, Fuso Canter and Isuzu Elf. The vehicles had gross capacities from 3200 kg to 4800 kg.

The surveyed light duty trucks did not have regular schedule of trips. The schedule of a trip depended on when it was selected and dispatched for a certain trip. Its major route was mainly dependent on its destination. However, the detailed route may be influenced by personal or collective knowledge of the drivers on which route would provide shorter travel time. All surveyed roads were in urban areas. The portions of speed data taken while on the highways (e.g. SLEX, NLEX) or rural roads were excluded.

The major roads traversed by surveyed light duty trucks were: (1) Visayas Avenue, (2) Congressional Avenue, (3) Tandang Sora Avenue, (4) Commonwealth Avenue, (5) Kalayaan Avenue, (6) Kamuning Road, and (7) Commonwealth Avenue. Origin-destination trips with corresponding distances of the surveyed vehicles were: (a) Tandang Sora Avenue and Anonas St. (17.7 km) b) Doña Felicidad, Fairview (22.7 km) (c)Visayas Avenue and Marikina (30.6 km)

3.4 Processing of Data

3.4.1 Downloading Speed Data from the GPS Device
A program called “Mapsource” developed by Garmin company, was used to download data from the GPS device. To download speed data from the GPS device, a USB connector was used to link the device to the computer. The device was turned on and Mapsource was activated, in which the “Transfer, Receive From Device” menu was selected. A window automatically showed the model of the GPS device connected to the computer. The “Receive” button was then clicked to start downloading speed data. Every download was saved in a file with extension “*.gdb”.

3.4.2 Cleaning of Data

The speed data of each type of vehicle was cleaned to remove GPS errors and other data errors attributable to survey conditions.

An extra copy of the original spreadsheet file was kept for future reference before the spreadsheet file was cleaned. There were different cases of errors in the spreadsheet file due to different causes. A prevalent case of error was the sudden increase of recorded speed. These errors were eventually deleted.

The number of hours of cleaned speed data is shown in Table 2. The total number of seconds of cleaned speed data ranged from 82,921 to 147,715.

Table 2. Number of Hours of Speed Data Gathered and Cleaned

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Duration of Total Samples</th>
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<td></td>
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<tr>
<td>Light Duty Trucks</td>
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</tbody>
</table>
3.4.3 Microtrip Concept

In developing the drive cycles, the microtrip concept was used. A program was developed to execute steps in assembling each drive cycle and comparing combined probability distribution of each candidate drive cycle with its target drive cycle.

A micro-trip is a 0 kph to 0 kph two-minute trip or more. The “cleaned file” ready for processing was accessed by a program named “Drive Cycle Analysis”. The step-by-step process is described as follows:

1) The probability distribution function of the “target drive cycle” is computed. The target drive cycle is the overall cleaned speed data profile of the type of vehicle being considered. Other attributes of the target drive cycle are computed, i.e. maximum, average and minimum acceleration; maximum, average and minimum speed; class width (velocity); and class width (acceleration);

2) A function in the program creates microtrips derived from the target drive cycle. An example microtrip assignments is shown in Figure 3;

3) The microtrips are selected randomly to form a drive cycle which has an approximate duration of twenty minutes. The microtrips are arranged chronologically as they are selected. Each microtrip starts with a 0 kph and ends with 0 kph speed which is equal or greater than two minutes in duration. The selected minimum duration of drive cycles is 20 minutes.

4) The combined speed-acceleration probability distribution of the assembled drive cycle is computed along with other parameters such as maximum, average and minimum acceleration; maximum, average and minimum speed; class width (velocity); and class width (acceleration). The number of class intervals of either the speed or acceleration is given by Equation 1 or popularly known as the Sturges’ Formula;

\[
\text{Number of Class Intervals} = 1 + 3.3 \log N \quad (1)
\]

where:

N is the number of points (seconds).
5) The sum of all the absolute value differences of each cell is given by Equation 2, where $n$ is the number of intervals, $\rho_{tc}$ and $\rho_{dc}$ are the matrices of the combined speed-acceleration probability distribution of the target drive cycle and generated drive cycle, respectively;

$$\sum_{i,j=1}^{n} |(\rho_{tc} - \rho_{dc})_{ij}|$$  \hspace{1cm} (2)

6) The sum of the absolute value differences is then considered as the criterion whether the candidate drive cycle will be discarded or not. Figure 4 shows the graph of the combined speed-acceleration probability distribution of the target drive cycle and generated drive cycle. The shape of the 3D graphs approximates the similarity of the target drive cycle with the generated drive cycle;

![Target Drive Cycle and Drive Cycle Graphs](image)

Figure 4. Combined speed-acceleration probability distribution

7) A drive cycle is set to qualify as a candidate if its absolute value difference from its target drive cycle is less than 20% (Sigua, 1997);

8) Before the program runs, the name of the text file to be processed and the maximum value difference are individually specified;

9) A candidate drive cycle is formed for every run. Ten candidate drive cycles are developed for each type of vehicle;

10) One is selected as the final drive cycle from the ten candidate drive cycles that were generated. The criterion in selecting the final drive cycle is its applicability in the chassis dynamometer laboratory. The developed candidate drive cycle which has the least maximum acceleration has the greater chance of being selected as the final drive cycle;

11) Steps 1 to 8 are executed for each type of vehicle. Figure 35 shows a flowchart summarizing these steps.

12) Smoothing is considered when the final drive cycle is difficult to implement in the actual testing in the chassis dynamometer laboratory. One method of smoothing a curve is the Moving Average Method which is given by Equation 3 (Robertson, 2010),

$$\text{Mav}(t_i) = \frac{1}{n} \sum_{i=1}^{n} W(t_i)$$  \hspace{1cm} (3)
where:

\[ W(t_i) = \text{any time-varying or spatial-varying series of related data} \]
\[ n = \text{window width} \]

Three programs were developed for the processing of data. The objectives of these programs were: (1) to generate candidate drive cycle and (2) to smooth the selected drive cycle.

### 3.5 Developed Drive Cycles

This section presents the important statistics of the final drive cycles developed in the study. The speed time graph and combined probability distribution of the final drive cycle and target drive cycle are likewise shown. For each type of LDV, ten candidate drive cycles were generated. From the ten candidates, the one with the lowest maximum acceleration was chosen as the final drive cycle. The drive cycle with the lowest maximum acceleration was selected to minimize stress on vehicles when implemented on the chassis dynamometer test in measuring fuel consumption. The resulting parameters (e.g. fuel consumption) measured in the chassis laboratory were deemed to be valid because of its drive cycle’s qualification according to its absolute value difference of the combined probability distribution function with the target drive cycle. The summary of the statistical parameters of the developed drive cycles are shown in Table 3.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Private</th>
<th>Taxis</th>
<th>PUJ</th>
<th>UV Express</th>
<th>Light Duty Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum speed, kph</td>
<td>60.0</td>
<td>59.8</td>
<td>54.4</td>
<td>55.0</td>
<td>63.0</td>
</tr>
<tr>
<td>Maximum acceleration, m/s²</td>
<td>2.64</td>
<td>0.94</td>
<td>1.22</td>
<td>1.53</td>
<td>1.25</td>
</tr>
<tr>
<td>Average Speed, kph</td>
<td>17.98</td>
<td>13.6</td>
<td>10.9</td>
<td>14.69</td>
<td>8.43</td>
</tr>
<tr>
<td>Average running speed, kph</td>
<td>23.53</td>
<td>17.8</td>
<td>19</td>
<td>24.37</td>
<td>12.71</td>
</tr>
<tr>
<td>Average acceleration, m/s²</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Minimum speed, kph</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Minimum acceleration, m/s²</td>
<td>-2.64</td>
<td>-1.37</td>
<td>-2.22</td>
<td>-2.22</td>
<td>-2.08</td>
</tr>
<tr>
<td>Duration, seconds</td>
<td>1,244</td>
<td>1,262</td>
<td>1,239</td>
<td>1,441</td>
<td>1,300</td>
</tr>
<tr>
<td>Distance, km</td>
<td>6.21</td>
<td>4.81</td>
<td>2.9</td>
<td>5.9</td>
<td>2.93</td>
</tr>
<tr>
<td>Percent difference, %</td>
<td>19.26</td>
<td>17</td>
<td>15.1</td>
<td>19.16</td>
<td>17.71</td>
</tr>
<tr>
<td>Idle Period, %</td>
<td>23.71</td>
<td>23.69</td>
<td>42.78</td>
<td>39.76</td>
<td>35.00</td>
</tr>
</tbody>
</table>

#### 3.5.1 Private Cars

The final drive cycle constitutes a series of microtrips with parts of idle periods as shown in Figure 5. Maximum speed of 60 kph occurred at approximately 660 seconds elapsed time from the starting time.
3.5.2 Taxis

The drive cycle model for taxicabs shows an idle period comparable to the private cars. This may be due to the similarity of the traffic and road conditions of the two types of vehicles. The speed-time graph of the drive cycle model for taxicabs is shown in Figure 6. The maximum speed occurred at approximately 600 seconds elapsed time from the start.

3.5.4 Public Utility Jeepneys

The drive cycle model for PUJ indicates a higher idle period of 42.78 % compared to the private car’s drive cycle and taxicab’s drive cycle. This may be due to the nature of operations of its represented type of LDV in which passengers alight in many locations along its designated route. The speed-time graph of the drive cycle model for the public utility vehicle is shown in Figure 7. The maximum speed occurred at approximately 800 seconds elapsed time from the start.
3.5.3 Utility Vehicles (UV Express)

The drive cycle for UV Express indicates a higher idle period of 39.76 % compared to the private cars drive cycle and taxi drive cycle. This may be due to the nature of operations since passengers of this utility vehicle alight not in one location only but also at midway between terminals. The speed-time graph of the drive cycle model for UV Express is shown in Figure 8. The maximum speed occurred at approximately 700 seconds elapsed time from the start.

3.5.5 Light Duty Trucks

The drive cycle model for light duty trucks indicated a lower idle period of 35.00 % compared to the UV Express drive cycle and PUJ drive cycle. The speed-time graph of the drive cycle model for the light cargo vehicles is shown in Figure 9. The maximum speed occurred at approximately 500 seconds elapsed time from the start.
3.5.6 Comparison of the Final Drive Cycle Statistics with Other Drive Cycles

Statistics of the different drive cycles developed abroad and in this study are shown in Table 4. Drive cycles considered in the comparison included those developed from Japan, US and Thailand.

Table 4. Statistics of the Developed Drive Cycles and the Drive Cycles of Other Countries

<table>
<thead>
<tr>
<th>Parameters</th>
<th>This Study</th>
<th>Other Drive Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Private Cars</td>
<td>Taxi UV Express</td>
</tr>
<tr>
<td>Maximum Speed, kph</td>
<td>60</td>
<td>59.8</td>
</tr>
<tr>
<td>Maximum Acceleration, m/s²</td>
<td>2.64</td>
<td>0.94</td>
</tr>
<tr>
<td>Average Speed, kph</td>
<td>17.98</td>
<td>13.57</td>
</tr>
<tr>
<td>Average Acceleration, m/s²</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average Running Speed, kph</td>
<td>23.53</td>
<td>17.77</td>
</tr>
<tr>
<td>Minimum Speed, kph</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Minimum Acceleration, m/s²</td>
<td>-2.64</td>
<td>-1.37</td>
</tr>
<tr>
<td>Duration, seconds</td>
<td>1244</td>
<td>1262</td>
</tr>
<tr>
<td>Distance, km</td>
<td>6.21</td>
<td>4.81</td>
</tr>
<tr>
<td>Percent difference, %</td>
<td>19.26</td>
<td>17.01</td>
</tr>
<tr>
<td>Idle Period, %</td>
<td>23.71</td>
<td>23.69</td>
</tr>
</tbody>
</table>

In the Japanese 2005 emission regulation, JC-08 chassis dynamometer test cycle was introduced for emission measurement and fuel economy determination for both gasoline and diesel light vehicles. The test represented driving in congested city traffic, including idling periods and frequently alternating acceleration and deceleration. FTP-75 (Federal Test Procedure) defined by the US Environmental Protection Agency (USEPA) was likewise used for emission certification and fuel economy testing of light-duty vehicles in the United States. LA-92 was a dynamometer driving schedule for light-duty vehicles developed by the California Air Resources Board. The Bangkok drive cycle (BDC) was developed mainly to measure emissions and fuel consumption of vehicles in Bangkok, Thailand. It was
developed due to the severe traffic conditions in Bangkok. This traffic condition should be inherent in the drive cycle that will be used in the measurement of emissions and fuel consumption in the chassis dynamometer laboratory to best represent the driving conditions in the city.

JC-08, FTP-75 and LA-92 show a higher range of maximum speed from 81.6 to 107.4 kph compared to the drive cycles developed in this study which ranged from 54.4 kph to 63.0 kph.

The corresponding average speed of the drive cycles developed in this study ranged from 8.43 kph to 17.98 kph while those of the other drive cycles (i.e. for Japan and United States) ranged from 24.5 kph to 39.6 kph.

Higher maximum and average speeds of the drive cycles developed in the United States and Japan are indicative of better road and traffic conditions in these countries. It can be observed, however, that the BDC has a relatively the same average speed with the developed drive cycles in this study. It can be surmised that Bangkok City and Metro-Manila may have similar driving conditions in terms of the different factors that influence average speed which in turn affect fuel economy of vehicles. Moreover, JC 08, FTP-75 and LA-92 indicated longer distance covered with relatively the same time duration which also showed higher average speed.

The developed drive cycles in this study have lower minimum acceleration (higher deceleration) that ranges from -1.37 m/s² to -2.64 m/s² compared to FTP 75 and BDC which have values -0.475 m/s² and -0.687 m/s², respectively. Higher decelerations in driving patterns imply wasted energy which usually translates to higher fuel consumption. Lower deceleration indicates better driving behavior which translates to savings in fuel consumption.

4. CHASSIS DYNAMOMETER FUEL CONSUMPTION TESTS

In most countries, the actual driving patterns of vehicles are simulated in a laboratory using a chassis dynamometer. To mimic actual driving patterns of a specific type of vehicle, a drive cycle is developed from a speed profile data of the type of vehicle being considered. A chassis dynamometer is an assembly in which the test vehicle's driving wheels, which is either the front or the back, stands on a roller where it will run. The speed of vehicle is controlled by following the designated drive cycle. Air current is simulated as the vehicle increases its speed by a fan placed in front of the vehicle. The friction between the wheels and the roller can also be set according to the assumed weight of the vehicle. As the vehicle is run, peripheral devices such as a fuel flow meter and an emissions analyzer can be mounted to the test vehicle to measure fuel flow and emissions.

The basic objective when a vehicle is tested in a chassis dynamometer is to measure fuel consumption and engine performance in terms of fuel efficiency and emission. Other purposes of testing a vehicle in a chassis dynamometer are: to tune the engine under load in real time; to determine the best speed to create a specific torque on the engine for shifting, to calibrate engine management controls in conjunction with on-board diagnostics systems; to investigate combustion behaviour; to check friction, lubrication, and wear of moving surfaces under load; to determine maximum torque and horsepower ratings at different engine speeds; and to determine the effects of engine load on the air/fuel ratios using an oxygen sensor (Schwaller, 2014).

Table 5 summarizes the measured fuel economies of the five types of light duty vehicles in kilometres per liter of fuel using the developed drive cycles. It also shows the idling fuel consumption in kilogram per hour.
Table 5. Summary of Drive Cycle and Idling Fuel Economies

<table>
<thead>
<tr>
<th>Type of LDV</th>
<th>Private Cars</th>
<th>Taxis</th>
<th>UV Express</th>
<th>Public Utility Jeepneys</th>
<th>Light Duty Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Economy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drive Cycle (km/l)</td>
<td>5.59</td>
<td>10.02 to 11.03</td>
<td>9.05 to 9.27</td>
<td>6.71</td>
<td>7.99 to 9.60</td>
</tr>
<tr>
<td>Idling (kg/hr)</td>
<td>1.27</td>
<td>0.53</td>
<td>0.38 to 0.41</td>
<td>-</td>
<td>0.49 to 0.58</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

In this study, the drive cycles for the five types of light duty vehicles traversing major roads in Metro Manila, i.e. private cars, taxis, UV express vehicles, public utility jeepneys and light duty trucks, were developed. The availability of these drive cycles paved the way for further studies on the performance of light duty vehicles operating in Metro Manila, using a chassis dynamometer laboratory.

The methodology used in the development of drive cycles, i.e. combination of on-board speed data collection and random selection of microtrips, was shown to be effective in developing the drive cycle representative of the actual operations of the specific type of vehicle considered. Consequently, the drive cycles were suitably implemented in a chassis dynamometer to obtain fuel consumption of corresponding type of light duty vehicles, e.g. private car drive cycle to a private car.

The developed drive cycles in this study had lower minimum acceleration and average speed compared with the drive cycles developed in Japan and the United States. The attributes of the drive cycles, such as average speeds and minimum acceleration, provided information on the country’s current driving profile of motorists which reflected the driving habits and current driving conditions such as traffic and road conditions, and fleet characteristics. Lower acceleration translated to faster decrease of speed which characterized larger dissipation of energy or momentum compared to gradual decrease of speed. It was shown in the case study that lower average speed corresponded to lower fuel economy or higher fuel consumption. Therefore, the Metro Manila drive cycles manifested higher fuel consumption of vehicles compared to vehicles in Japan or United States.

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