Development of Drive Cycles and Measurement of Fuel Consumption for Light Duty Trucks

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Abstract: The urban drive cycle for the light duty truck in Metro Manila is developed in this study. Furthermore, the estimated fuel economy of the said light duty vehicle is measured and estimated. 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, downloaded and processed. In the survey of speed data, a Global Positioning System (GPS) device is used as an on-board instrument. The GPS device is placed on the dashboard of every surveyed vehicle and it recorded instantaneous speed in its memory. The speed data is downloaded from the device using software provided by the maker of the device (Garmin) called Mapsource. The speed data is processed using a program to execute the methodology in generating candidate drive cycles. The program creates drive cycles by randomly appending microtrips to form a minimum of twenty minute speed time profile. Furthermore, along with the generated drive cycle, the program also indicated how it compared with the target drive cycle by computing their individual absolute value difference of their joint speed-acceleration probability distribution. Ten drive cycles are developed which have absolute value differences less than 20% for selection of the final drive cycle model. The selected drive cycles are then implemented in the Vehicle Research and Testing Laboratory at UP College of Engineering, Mechanical Engineering Department to measure fuel consumption of sample light duty trucks and estimate fuel economy. The developed drive cycle model for light duty trucks have an average speed of 8.43 kph and the estimated fuel economy the tested light duty trucks ranges from 3.81 to 4.20 km/liter.

Keywords: drive cycle, chassis dynamometer, combined speed-acceleration probability distribution

1.0 INTRODUCTION

1.1 Background of the Study

An inevitable consequence of economic progress is the potential increase in the need to transfer people or goods from one location to another. In parallel, the continuous growth in population further increases the demand for mobility. This increase in demand for mobility spurs increase in the population of vehicles in the road which worsens ambient air quality due to the increased concentration of air pollutants from tail pipe vehicle emissions that potentially causes lung related diseases to vulnerable sectors. The increase in fossil fuels consumption also translates to increased emission of CO_2 in the air which is the main gas associated to climate change.

There has not been a drive cycle model for light duty trucks in Metro Manila. The light duty truck drive cycle model will be useful in fuel economy studies of the same vehicle type operating in Metro Manila since the model depicts driving behavior of light duty trucks drivers. Also, the drive cycle model incorporates the road and traffic conditions in the metropolis. The drive cycle model facilitates the measurement of fuel economy in the chassis dynamometer laboratory.

1.2 Objectives of the Project

The objectives of the study are: 1) develop the drive cycle model for light duty trucks and 2) measure fuel consumption of three light duty trucks by chassis dynamometer testing.

1.3 Conceptual Framework

In the development of the needed drive cycles, the psychological and personal attributes of the different drivers of the subject vehicle should be inherent in the finally selected drive cycle. Other inherent attributes of the drive cycles are: current traffic and road conditions, vehicle models, engine and age.

The drive cycles should 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. This conceptual framework is illustrated in Figure 1.

In this study, with the developed drive cycles, the fuel economies of the different light duty vehicles were measured. Due to the unavailability of the gas emissions analyzer, emissions were not measured.

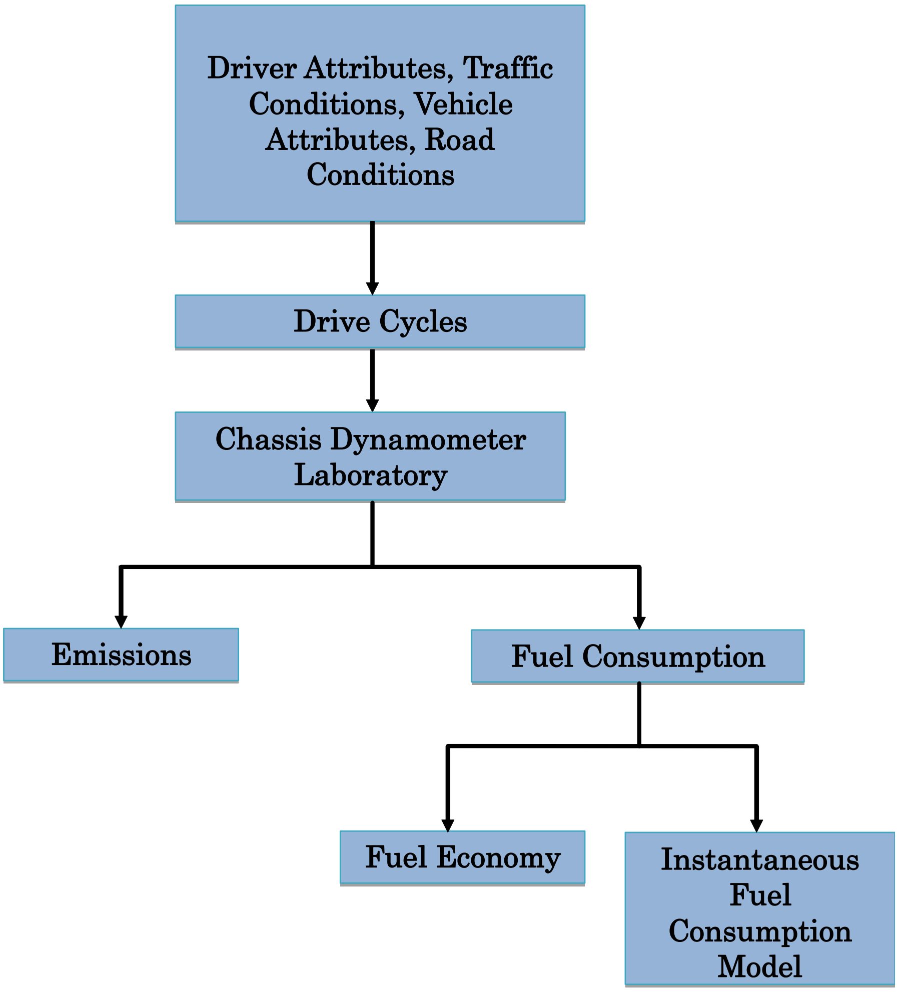

Figure 1. Conceptual Framework

1.4 Scope and Limitations

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 was turned off while testing to eliminate variability of the power consumed by the vehicle;

4) Furthermore, 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 LDV's, 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.

2. Review of Related Studies

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". This project was undertaken by the Department of Energy and the the Philippine National Oil Company – Energy Research and Development Center (PNOC-ERDC). The project was completed in March, 1997. It was funded by the Philippine Council for Industry and Energy Research and Development (PCIERD). The main consultant of the project was Ricardo G. Sigua of the University of the Philippines, College of Engineering (UPCOE).

The parameters of the developed urban drive cycle for private cars is as follows:

Maximum Velocity, kph:56
Minimum Velocity: 0
% Idle: 33.72
Average Running Speed, kph: 22.14
Duration, seconds: 1299

The speed-time graph of the drive cycle is shown in Figure 2.

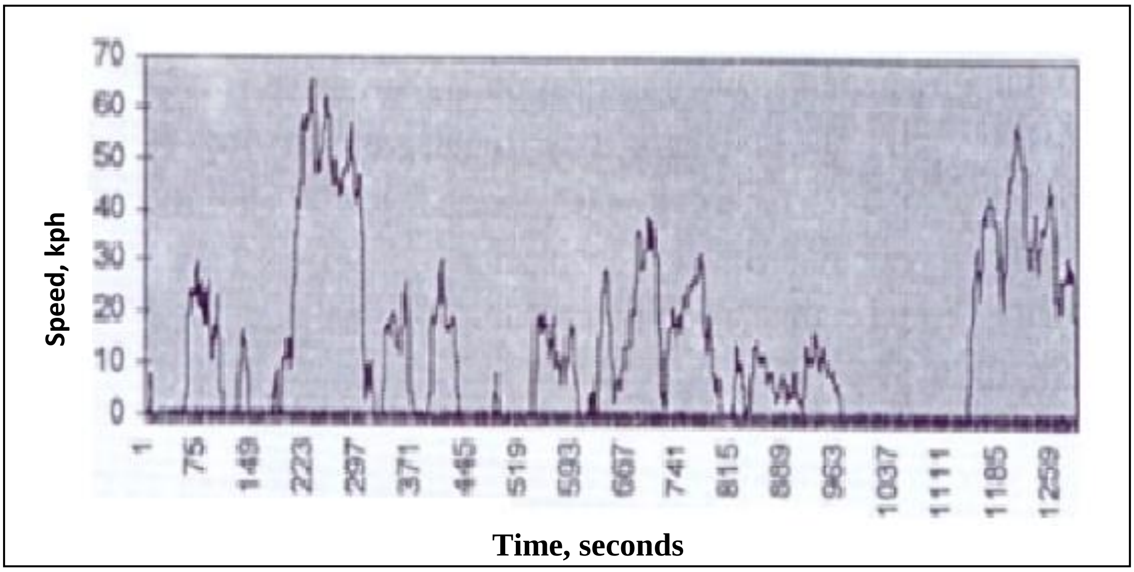

Figure 2. Speed-Time Graph of Urban Drive Cycle in Metro Manila (Sigua, 1997)

The study by Sigua used car following technique in gathering speed data. The chase car was equipped with on-board data acquisition system which is composed of a data acquisition computer, flowmeter/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. During the survey, problems on the magnetic sensor and fuel flow meter attached to the chase car were encountered due to vibrations, corrosion and excessive heat. Therefore, no fuel consumption readings were recorded.

These drive cycle was succeeded by the development of drive cycles for tricycles in Metro Manila by Abuzo, et. al. (2004) and Biona, et. al. (2006).

Abuzo, et. al. (2004) developed a drive cycle for the tricycle for purpose of quantifying emissions from this type of vehicles as well as to determine some of the factors that affect the emissions. The drive cycle for tricycle was developed witha 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 4-stroke tricycles have lesser HC andCO emission concentrations compared to the 2-stroke type. It was also revealed that CO concentration is significantly affected by fuel-oil ratio and loading. The speed-time graph of the drive cycle developed is shown in Figures 3.

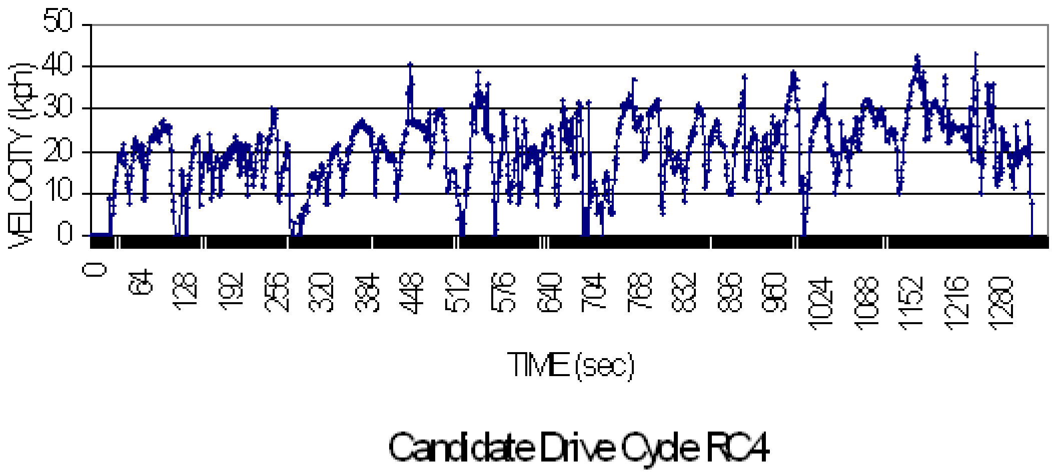

Figure 3. Time-Velocity Trace of Candidate Cycle (Source: Development of Drive Cycle and Emission Concentration Models for In-Use Tricycles in Metro Manila by Abuzo, et. al.)

The developed drive cycle has statistics as follows:

Maximum velocity = 43.0 kph
Average velocity = 19.94 kph
Minimum acceleration = - 6.44 m/s2
Maximum acceleration = 6.97 m/s2
Idle time (percentage) = 4.0%

Abuzo's findings include: (1) that in-use tricycles with 4-stroke engines emit lower volumes of CO and HC than tricycles with 2-stroke engines, (2) noticeable emissions of 4-stroke tricycles showed that in general the CO concentrations were relatively high with relatively low HC concentrations, (3)that, when vehicles are subjected to varying loads, the emissions for both engine types across all vehicle models (W, X, Y and Z) also vary, (4) there was great variability of CO and HC emissions for different fuel-oil ratios for 2-stroke tricycle models.

Biona, et.al. (2006) also developed the drive cycle of tricycles which takes 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 consists of magnets attached to the spokes of the rear wheel of the motorcycle producing pulses as it passes through a magnetic sensor. The pulses are converted to voltage as it passes through a frequency to voltage converter circuit. A microcontroller converts these voltages to speed data. The developed device logs speed values on a per second interval. Figure 4 and 5 shows the drive cycle model and load test cycle developed for tricycles in Metro Manila.

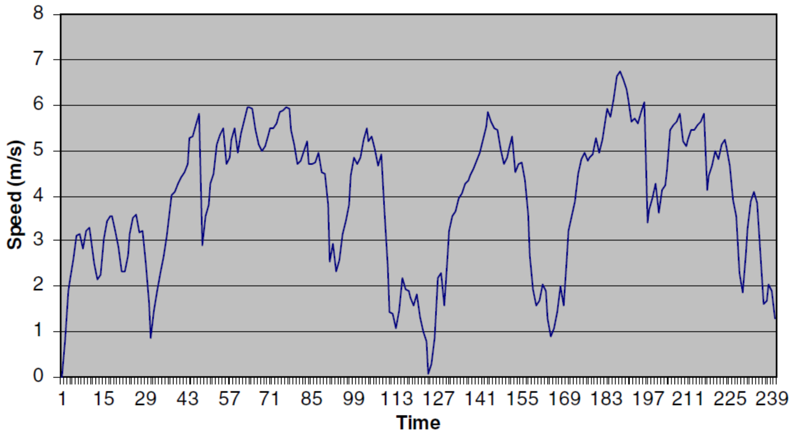

Figure 4. Drive Test Cycle Model for Tricycles in Metro Manila
(Source: Drive cycle development for tricycles by Biona, et. al.)

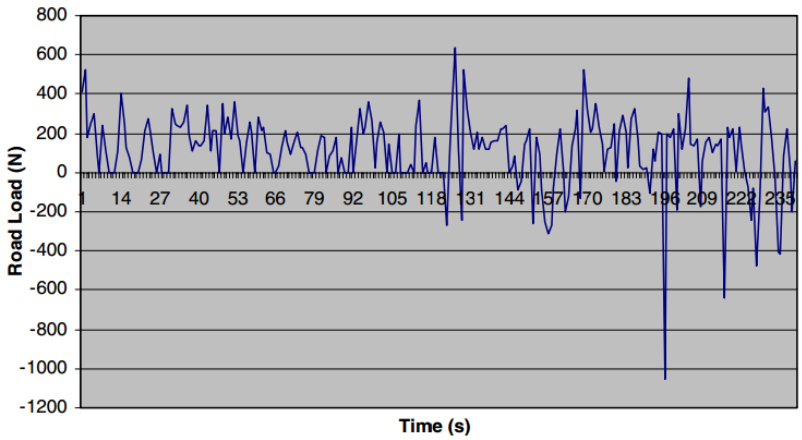

Figure 5. Load Test Cycle for Tricycles in Metro Manila
(Source: Drive cycle development for tricycles by Biona, et. al.)

Biona compared the Metro Manila tricycle drive cycle with the Indian drive cycle. It showed that the Metro Manila drive cycle is a lot slower but is characterized by higher acceleration rates. He said that it could be expected that emission factor that would result from the test would be higher considering that most emissions occur during acceleration mode. The significant difference on the average velocity would entail difference in emissions. The results emphasized the importance of customizing test cycles specifically to the characteristics of actual operational modes. Table 1 shows comparison of the Indian and Metro Manila Drive Cycle.

Table 1 Indian and Metro Manila Drive Cycle Comparison

Parameter	Indian	Metro Manila
Average velocity (m/s)	6.09	3.93
Maximum velocity (m/s)	11.67	6.75
SD velocity (m/s)	3.81	1.54
Average acceleration (m/s^2)	0.000	0.02
Maximum acceleration (m/s^2)	0.670	1.07
SD acceleration (m/s^2)	0.425	0.52
Average positive acceleration (m/s^2)	0.18	0.30
Maximum positive acceleration (m/s^2)	0.67	1.07
SD positive acceleration (m/s^2)	0.24	0.22

(Source: Drive cycle development for tricycles by Biona, et. al.)

Thaweesak, et.al (2009) developed the drive cycle for the public utility jeepney 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. The drive cycle (DC251) developed is shown in Figure 6. DC251 have absolute difference of 17.78%, average running speed of 15.85kph, average speed of 10.59kph, average acceleration of 0.46 m/s^2, average deceleration of -0.48 m/s^2, 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 are not significant, while B3 and B10's increases are significant. For fuel economy, all observed increaseswere 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.

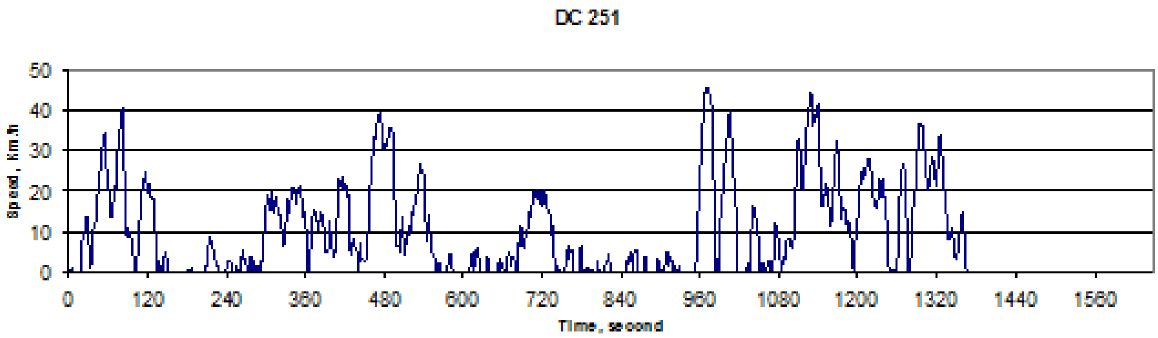

Figure 6. Drive Cycle Model for Public Utility Jeepneys (Diesel) in Metro Manila

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 computes for the maximum, average and minimum acceleration; maximum, average and minimum speed. The developed drive cycle for the taxicab is shown in Figure 7. 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.

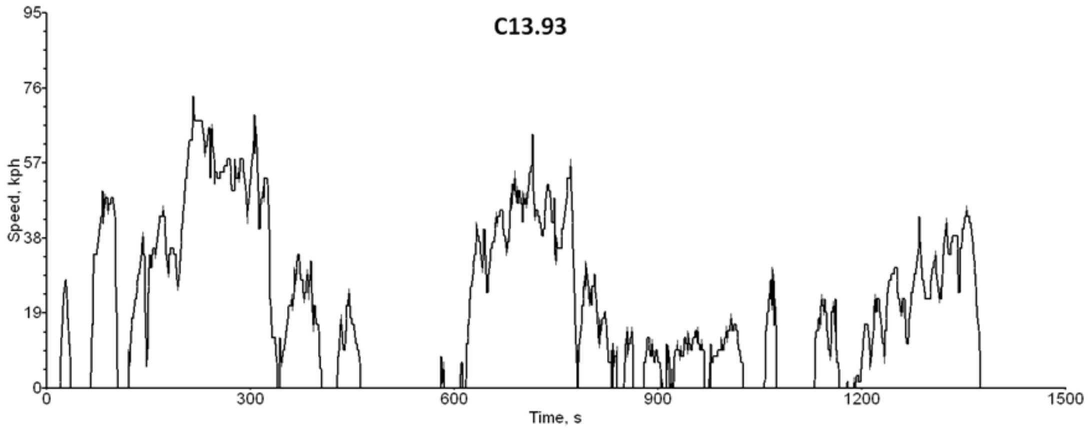

Figure 7. Drive Cycle Model for Taxicabs (Gasoline) in Metro Manila (Diaz, 2010)

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. The developed drive cycle is shown in Figure 8. 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

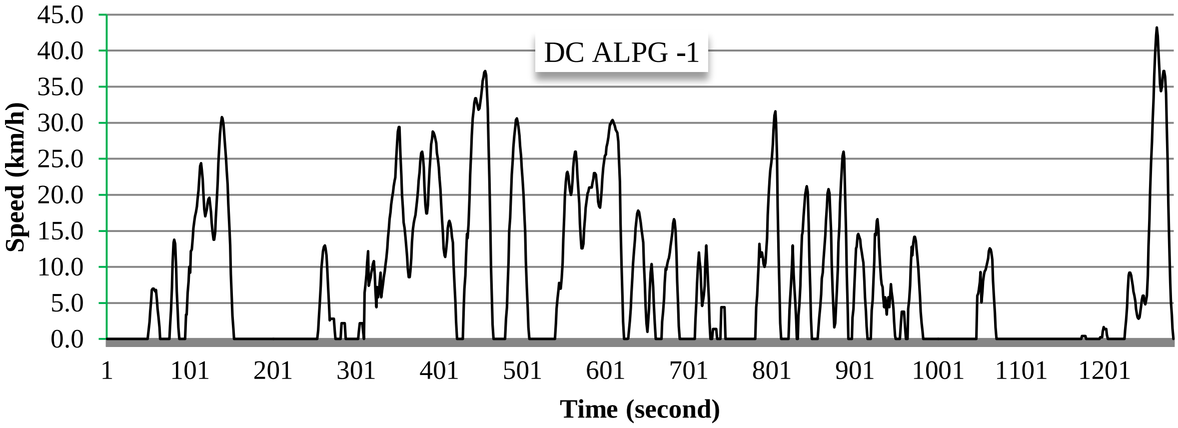

Figure 8. Auto-LPG Public Utility Jeepney Drive Cycle (Pokharel, et. al., 2013)

Sukanya et.al, in 2006, developed a drive cycle fit for the traffic conditions in Bangkok City. The development of Bangkok Drive Cycle (BDC) was mainly aimed for the estimation of emissions and fuel consumption of vehicles in the city. The developed drive cycle is shown in Figure 9. BDC has maximum speed of 62 kph, maximum acceleration of 2.7 m/s^2, maximum deceleration of -3.3 m/s^2, duration of 1160 s and covered distance of 5.71 kilometers.

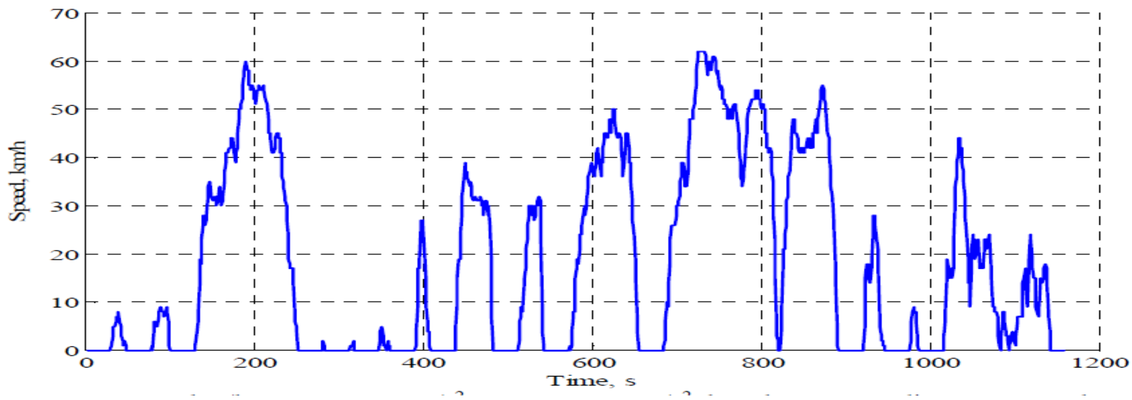

Figure 9. Bangkok City Driving Cycle (Sukanya et.al.)

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 come from a variety of vehicle models, route, and time of operation. This is to assure representation of the categories mentioned. However, light duty trucks do not have a definite route. The routes a light duty truck will take during its operation will depend mainly on its destination, i.e. location of its delivery of cargo. Moreover, it will also depend on the predisposition of the driver as he responds to the traffic conditions he will encounter.

3.1 Speed Data Survey

To develop drive cycles, speed data profile of the subject vehicle is gathered. The two methods which can be employed are: (1) chase car technique and (2) on-board instrument (Global Positioning System) 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 vehicles in order to emulate its speed. In so doing, the recorded speed of the chase car shall be considered the speed of the target car. In other systems, a laser detector is attached to the chase car to measure relative speed of the target car. This further refines the accuracy of measurement. The configuration of the described system is shown in Figure 10.

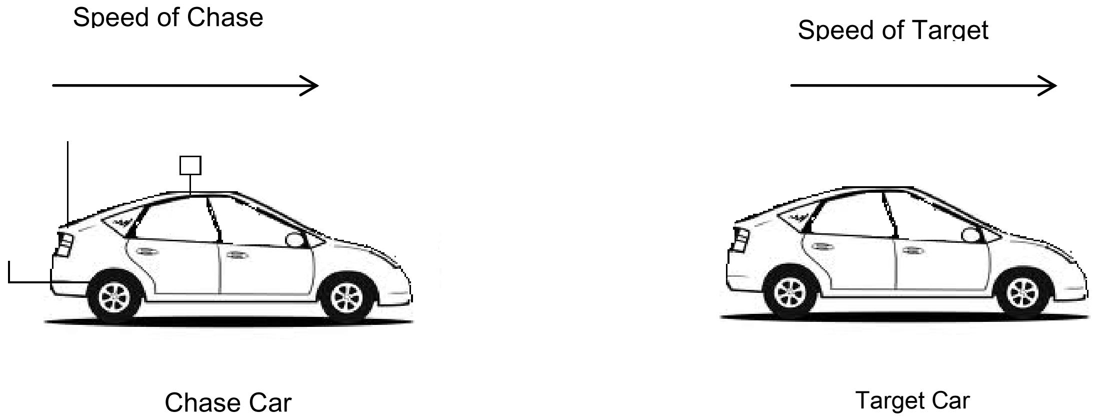

Figure 10. Chase Car Technique

In this study, this method was not employed because it could endanger the surveyors and driver of the chase car when the latter tries to emulate the speed of the target car. Also, as assessed during the pilot test, this technique is not appropriate in 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 carnap or holdup.

The use of a GPS device was employed in this study 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. Placing the device on the dashboard provides better satellite connection. Figure 11 shows the two models of GPS devices used in the study.

Figure 11. Different Models of Garmin GPS Used in the Study
(Left: Model 78S, Right: Model 76CSx)

The Garmin GPS 76CSx stores speed data (kph) and can be set to store data every 1 second. It also logs current time (time of survey) and date, and geographical coordinates of points within the routes. With a 4-gigabyte micro SD card inserted in the device, it is capable to storing up to 3 hours of data. The 78s model has greater capacity of recording due to its automatic archiving of logs. The archived files are compressed to occupy lesser memory space. To avoid discontinuity of survey due to lack of memory of the GPS, a surveyor would carry two units. In some days of the survey period, a laptop computer was carried along to facilitate immediate download of data. Spare batteries of the devices were also brought along to change low charged batteries. Figure 3 shows the GPS (Garmin Model 76SCX) placed on the dashboard of a surveyed private vehicle. Niemeier (1999) mentioned the reliability using GPS device in measuring instantaneous speeds of vehicles used for development of drive cycles.

The speed data gathered from sampled light duty trucks are appended and cleaned, i.e. removing readings which are outliers (sudden increase in reading that may be due to signal disturbance). After cleaning the speed data, the speed (with one-second interval recording) is copied to a text file which will then be processed by a program called "Drive Cycle Analysis". The program executes the following routine as enumerated below:

1) Generation of the Candidate Drive Cycle
   The code of this program can be found in Appendix C. Its algorithm is as follows:
   1. Input name of input file
   2. Read input file
   3. Input maximum allowable absolute value difference
   4. Create output filename "Target Cycle"
   5. Write to Target Cycle maximum and minimum acceleration, maximum and minimum speed, average speed, average acceleration;
   6. Create file "Microtrips". Write generated microtrips.
   7. Randomly pick microtrips to generate candidate drive cycles (total duration not lower than 1,200 seconds but stops appending microtrips as the 1,200 seconds duration is exceeded)
   8. Compute probability distribution function of target drive cycle
   9. Compute probability distribution function of candidate drive cycle
   10. Compute absolute value difference of probability distribution function of target drive cycle and candidate drive cycle
   11. If absolute value difference is greater than the set maximum allowable absolute value difference, stop.
   12. Create output filename "Candidate Cycle"
   13. Write to "Candidate Cycle" maximum and minimum acceleration, maximum and minimum speed, average speed, average acceleration; generated candidate drive cycle
   14. Display value "absolute value difference".

To run the program, the input file is placed in a directory containing the executable file name "Drive Cycle Analysis". As the program is executed, the program prompts input of the filename. Consequently, it prompts input of the allowable maximum absolute value difference. The program then randomly picks micro-trips to generate candidate drive cycles and compares it with the target drive cycle by computing the absolute value difference with their probability distribution function. The program stops and displays the computed absolute value difference when the same is less than the set maximum absolute value difference. Otherwise the program generates another candidate drive cycle until the set maximum allowable absolute value difference is met. The program automatically computes maximum and minimum acceleration, maximum and minimum speed, average speed and average acceleration. The program then writes these statistics to the output files every time a candidate drive cycle is generated.

Twenty candidate drive cycles with absolute difference not exceeding 20% are generated using the said program. The final drive cycle is finally selected with the lowest maximum acceleration. The criterion for selection, i.e. having the lowest maximum acceleration among the candidates is mainly due its potential ease of implementation in the chassis dynamometer laboratory.

3.5.5 Light Duty Trucks

Table 2 shows the statistics of the drive cycle and target drive cycle.

Table 2 Drive Cycle and Target Drive Cycle Statistics - Light Duty Trucks

Parameters	Values	
	Target Drive Cycle	Final Drive Cycle
Maximum Speed, kph	95	63
Maximum Acceleration, m/s^2	2.78	1.25
AverageSpeed, kph	11.11	8.43
AverageAcceleration, m/s^2	0	0
Average Running Speed, kph	16.06	12.71
Minimum Speed, kph	0	0
Minimum Acceleration, m/s^2	-7.08	-2.08
Duration, seconds	127,129	1,300
Distance, km	-	2.93
Percent difference, %	-	17.71
Idle Period, %	31.51	35.00

In Figure 12 and 13, the combined speed acceleration probability distribution graph of the surveyed light cargo vehicles shows only one peak which is at zero speed and acceleration. The graph shows relative similarity of combined speed acceleration probability distribution of the target drive cycle and final drive cycle.

The speed-time graph of the drive cycle model for the light duty truck is shown in Figure 14. The maximum speed occurred at approximately 500 seconds elapsed time from the start.

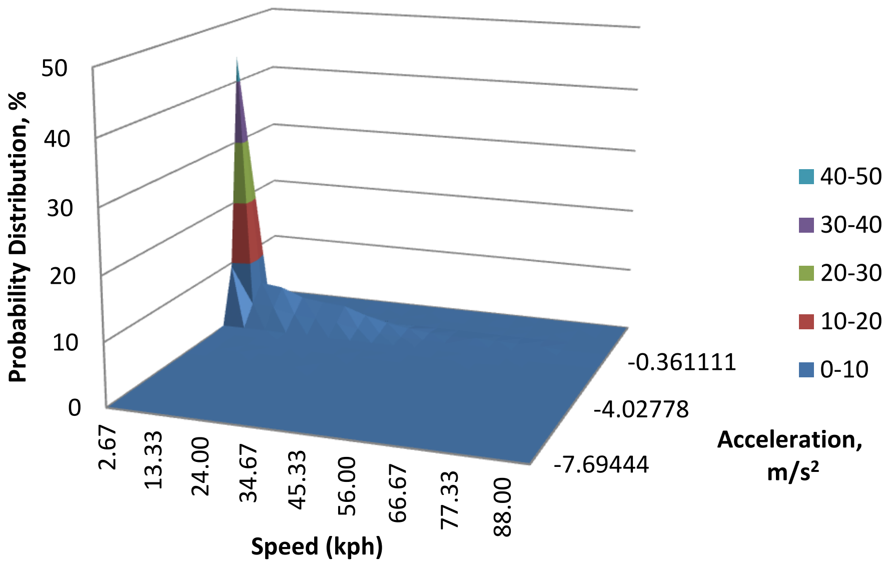

Figure 12. Combined Probability Distribution Function of Target Drive Cycle of Light Duty Trucks

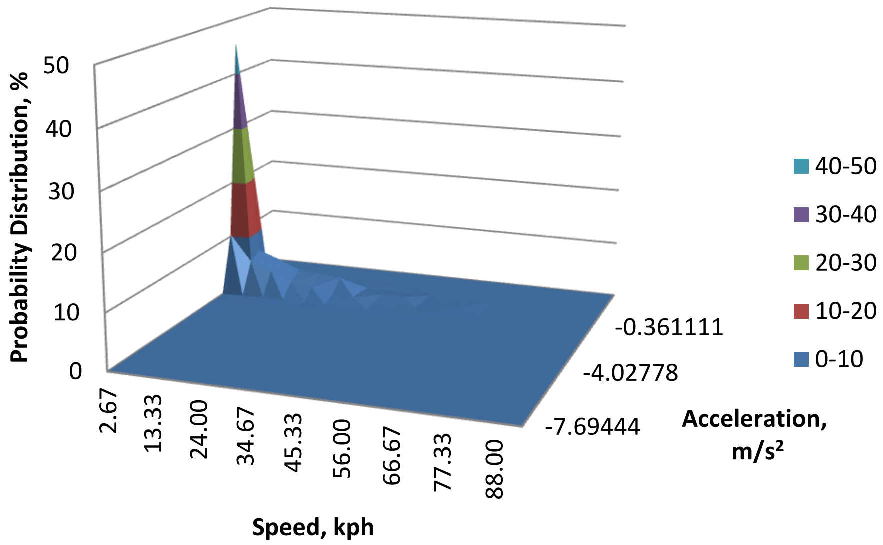

Figure 13. Combined Probability Distribution Function of Final Drive Cycle of Light Duty Trucks

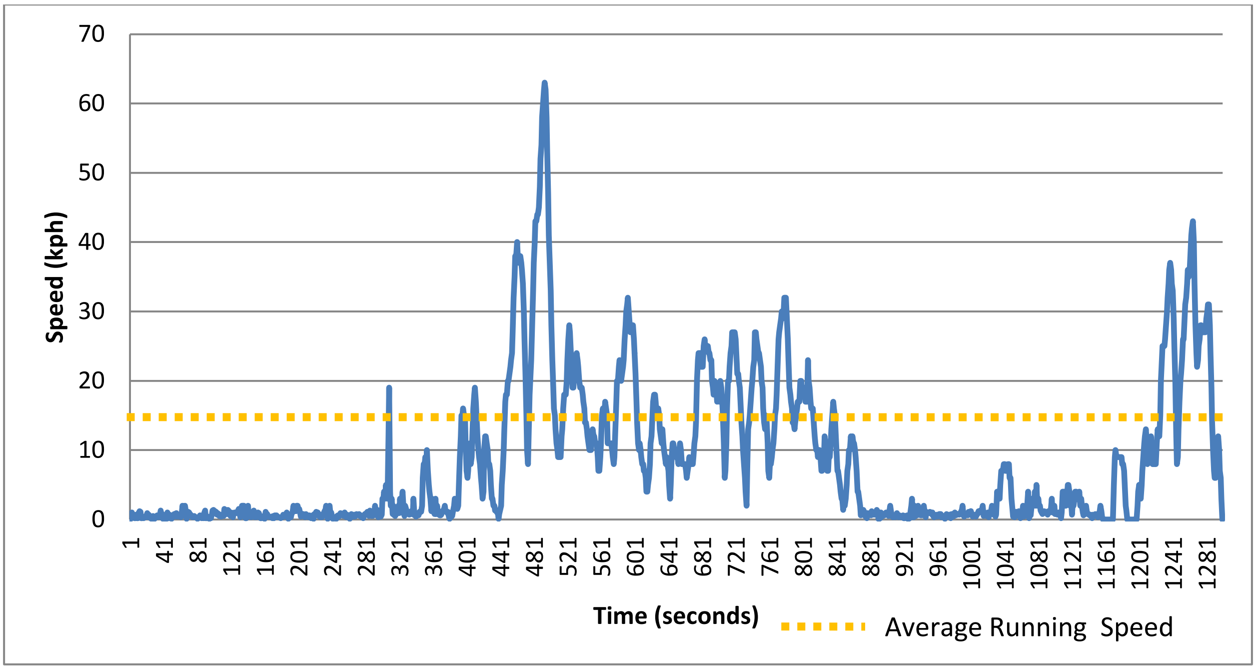

Figure 14. Drive Cycle of Light Duty Trucks

4. Chassis Dynamometer Testing for the Light Duty Truck for the Measurement of Fuel Consumption

In Figure 15, the light duty trucks tested are shown mounted on the chassis dynamometer. The models of the three vehicles are Mitsubishi Canter, Isuzu Elf and Isuzu 4JB1 Rebuilt. All of these vehicles are rear-wheeled and run on diesel. The computed average fuel consumption rates using the light cargo vehicles drive cycle are 3.81 km/li, 4.03 km/li and 4.20 km/li for Canter, Elf and 4JB1 Rebuilt, respectively as shown in Table 3.

Figure 15. Light Duty Trucks Mounted on the Chassis Dynamometer

Table 3 Fuel Economy of Three Light Duty Trucks

Test Vehicle	Drive Cycle (km/li)			
	Trial 1	Trial 2	Trial 3	Average
Canter	3.84	3.83	3.76	3.81
Isuzu Elf	3.80	4.44	3.83	4.03
Isuzu 4JB1	4.08	4.24	4.30	4.20

5. CONCLUSIONS AND RECOMMENDATIONS

In this study, the drive cycle for light duty trucks have been developed. The methodology used in this study was shown to be effective in developing the drive cycles representative of the actual operations of the specific type of vehicle being considered.

The developed drive cycle model for light duty trucks have an average speed of 8.43 kph and the estimated fuel economy the tested light duty trucks ranges from 3.81 to 4.20 km/liter.

The fuel economy indicates conservative values due to the implemented full load capacity in the chassis dynamometer. Since the drive cycle used in the chassis dynamometer tests are for urban operations, the fuel consumption, therefore, can be used for inventory of fuel consumption in the urban setting.

The limitations of the study mentioned in Section 1 demands further studies on the extent of the effect of the air conditioning system during vehicle operations to fuel consumption. To improve generated fuel consumption factors' accuracy, more vehicles should be tested in order to incorporate other factors affecting fuel consumption such as age of vehicle or engine and vehicle loading.

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