DEVELOPMENT OF DRIVE CYCLE AND ASSESSMENT OF THE PERFORMANCE OF AUTO-LPG POWERED PUBLIC UTILITY JEEPNEYS IN MAKATI CITY, PHILIPPINES

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Abstract: This study developed of drive cycle for the Auto-LPG Jeepney. Five statistical candidate drive cycles were selected which had the least absolute value differences. Among the five, one was selected and was found to be non-drivable due to aggressive acceleration in some parts, thus, it had to undergo smoothening using Moving Averages Method. The final drive cycle had the following properties: maximum speed 43.2 km/h, average speed 7.7 km/h, maximum acceleration 0.9 m/s^2, duration 1,279 second and idle time 44.6%. An on-road test was also conducted for all the three Auto-LPG powered jeepneys in which boarding and alighting data, passenger load factors and fuel consumption factor (full tank method) were generated. The estimated fuel efficiency factor was 3.54 km/litre. The developed drive cycle was tested at the U. P. Vehicle Research and Testing Laboratory to determine its drivability and measure maximum power of the Auto-LPG jeepney used. The maximum power observed was 51.8 KW.

Keywords: drive cycle, speed, acceleration, chassis dynamometer, Auto-LPG jeepneys, alternative fuel

1. Introduction

Quality air is essential to maintain life on earth. Unfortunately, the quality of air we breathe today has been deteriorating and it now poses grave threat to humans and the environment. In Metro Manila alone, studies on air quality revealed that the major source of pollution comes from motor vehicles. Compared with the stationary sources and area sources-, the two other identified sources of pollution in the metropolis, pollution from vehicle emissions has been increasing more rapidly, and causes more prevalent and adverse effects to public health, particularly on the young and the elderly. The problem of air pollution is exacerbated by global warming. For its part, the Philippine government has enacted several laws, notably, Republic Act 9367 (Biofuels Acts of 2006) and Republic Act 8749 (Clean Air Act of 1999) to respond to the need to explore cleaner and alternative fuels. In addition, it is continually looking for ways to upgrade fuel quality to approximate international standards. According to the Department of Energy (DOE), alternative fuels are fuels that are not composed substantially of petroleum and therefore, are alternatives to petroleum. As a substitute to this “traditional” fuel, it is expected to yield significant energy security and environmental benefits to its users. The government has put priority on four alternative fuels with potential use in the transport sector namely, (1) Compressed Natural Gas (CNG), (2) Liquefied Petroleum Gas (LPG), (3) Bio-Ethanol and (4) Biodiesel.

1.1 Significance of the Study

With the increasing demands for a cleaner and healthier environment and for the need to address air pollution caused by emissions from the transport sector, there is a growing need to conduct studies on the various options that can contribute in mitigating these emissions. In addition, the jeepney drivers and operators as well as the commuting public have also suffered from the uncontrolled escalation of fuel prices. With the twin effects of gas emissions and fuel prices on the people and environment, studies on alternative fuels have become more urgent.

So far, drive cycles for Auto-LPG taxis and for diesel jeepneys and gasoline tricycles have been developed. This study on Auto-LPG powered in jeepney is a contribution to further understand the Auto-LPG jeepney operation. With a more methodical study on the Auto-LPG in jeepneys through the use of various data gathering methods as applied to on-road tests and laboratory research settings, and involving jeepney drivers and operators/owners, as well as the community public at large, data and insights on the Auto-LPG industry as applied to jeepneys will be established. The study can provide a pool of data to be used in further studies such as power and emissions as measured in a chassis testing laboratory. Furthermore, the data can also be used in economic studies relating to sustainable transport systems and impacts on climate change.

1.2 Conceptual Design

There are four main areas of inquiry of the study, namely, development of drive cycle, chassis dynamometer test, fuel efficiency and economy. From these areas of inquiry, data were generated -- such as on speed profile using GPS. Fuel consumption was recorded daily using “full tank method”. Developed candidate drive cycles were tested at the chassis dynamometer laboratory to determine their driveability. From these, the final drive cycle was selected.

2. Review of Related Literature

A study on initiated performance testing of vehicles using chassis dynamometer in the Philippines was conducted by Ricardo G. Sigua for the DOE and Department of Science and Technology (DOST). The 1995 study simulated the urban and highway traffic conditions. The developed drive cycles was involved the procedures: (1) collected speed traces by chase car technique, (2) developed micro trips (small trips of at least 2 minutes in duration which had to start and end at zero velocity) from on-board data logging, (3) generated target cycles (actual) and candidates (synthetic) or derived cycles by combining micro trips at random, (4) screened candidate cycles using joint probability density function and (5) selected the best drive cycle.

Abuzo, et.al (2003) study on in-use tricycles in Metro-Manila focused on solutions to reduce emissions from tricycles to enable them to comply with the standards. The study was able to develop drive cycle for tricycles, quantify on-road emissions from tricycles and evaluate the effects of various engine types like fuel-oil ratios and loads on on-road emissions. The most representative driving cycle for the corresponding group was determined by the smallest sum square difference (SSD) between the speed acceleration probability distribution (SAPD) of the candidate cycle and the overall SAPD. Equations 1 shows the formula for the SSD.

$$\text{SSD} = \sum_{i=1}^{Ns} \sum_{j=1}^{Na} (pij - qij)^2 \qquad \text{Eq. (1)}$$

where,	N_s	:	number of speed classes
	N_a	:	number of acceleration classes
	P_{ij}	:	*ij*th entry of the SAPD of the candidate cycles and,
	Q_{ij}	:	*ij*th entry of the SAPD of the overall driving speed profiles.

In the study on the effect of coco-methyl ester (CME) blends on fuel economy, engine performance and idle opacity of PUJs, Thaweesak (2009) developed drive cycles by conducting a survey on speed profiles of jeepneys running on diesel. The developed drive cycle for diesel jeepney was then used to compare fuel consumption with different blends of CME and neat diesel. The tests on the jeepney were conducted at the U. P. Vehicle Research and Testing Laboratory (UP VRTL).

Diaz, et. al. (2010) developed a drive cycle model for taxicabs operating in Metro-Manila. A Dev C^{++} program was developed to analyze the statistical computation of the target and candidate cycles and probability distribution.

2.2 Review of International Studies

In the city of Pune, India, Kamble et al. (2009) developed a drive cycle by adopting the use of micro-trips extracted from real-world data. The methodology was claimed to be unique because the driving cycle was constructed considering five important parameters of the time-space profile namely, the percentage acceleration, deceleration, idle, cruise, and the average speed. The method used was designed to better capture the heterogeneous traffic behaviors.

The Hong Kong drive cycle was developed in order to quantify vehicular emission (Hung et al., 2007). On-road real world driving data were collected from February to December, 2004. The combination of microtrips was taken at 135, 140 and 200 seconds for highway, urban and sub-urban drive cycles respectively. A candidate cycle was selected only if it was less than 5% absolute percentage difference to target statistics.

A study “Development of Automobile Bangkok Driving Cycle for Emissions and Fuel Consumption Assessment” by Tamsanya et al. (2006) which aimed to develop a realistic driving cycle for Bangkok traffic.The methodologies adopted in development of BDC were:

- Random selection of microtrips with simulated computer program
- Series of microtrips connected targeting 1200 seconds
- Equal idle periods were inserted in-between these series of microtrips a driving cycle is formed
- Numerous candidate cycles were generated
- One cycle was chosen as Bangkok Driving Cycle (BDC) closer to target statistics.

3. Methodology

Basically, there were five main methodologies used, namely: on-road tests drive cycle development using GPS, boarding and alighting survey, fuel consumption survey and socio-economic survey of operators through key informant interview. Fig.1 shows the procedures that were followed in gathering and processing the data generated using the various methodologies cited.

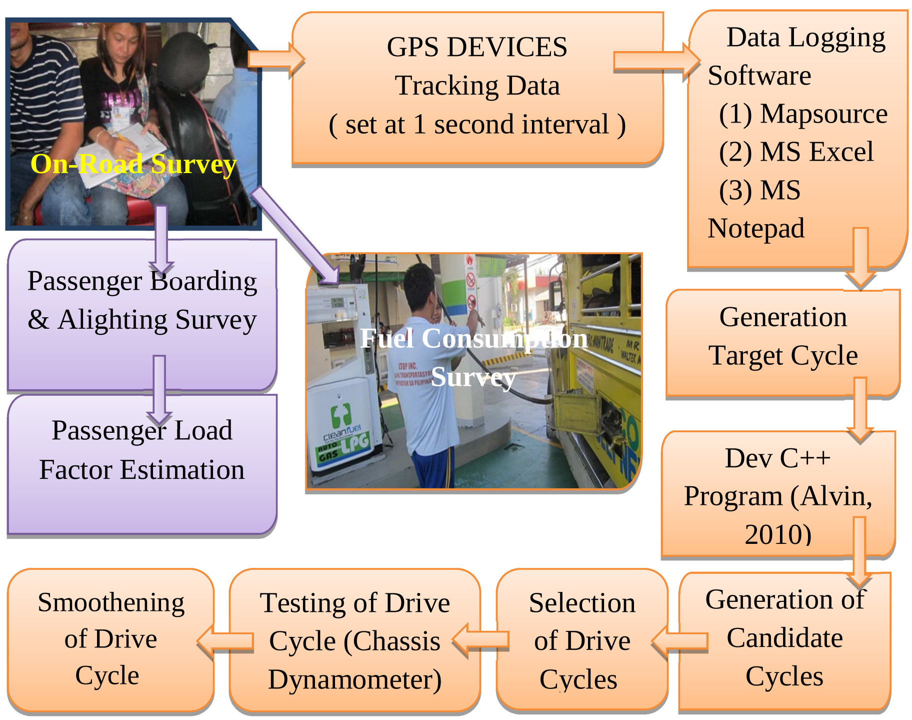


Fig. 1 Flowchart of the Procedures Adopted for the Development of Drive Cycles and Fuel Economy

3.1 On-Road Tests

The on-road test observed the passenger occupancy in between stops of the public transport route served by the Auto-LPG jeepney. Counts of passenger boarding and alighting were recorded to determine passenger load factor in peak hours and off-peak hours. The generated data were also used to compute for operating cost and actual revenue per day of the Auto-LPG jeepney drivers. The tests were equipped with handheld GPS devices that recorded tracks at 1-second interval for the development of drive cycle.

The five-days on-road test was conducted for one month on weekdays (Monday to Thursday) and weekend (Saturday) from January 22, 2012 to January 30, 2012. Sixteen stops were identified based on importance of the intersections, business area and market places. These stops were indicated on the map on Figure 2. A separate 6 days on-road test was conducted to determine the fuel consumption for Auto-LPG jeepneys in the study route

The study route, Pasong Tamo (now called Don Chino Roces Avenue) is a north-south connecting a major highway, the EDSA and other arterial roads like Pasay Road, Gil Puyat Avenue and J. P. Rizal Avenue in Makati City, Metro Manila. EDSA was also the target of southbound passengers from PRC going to Mantrade where the MRT Line 3 Magallanes Station is located. The land use pattern in the study site comprised the Central Business District (CBD) on the eastern side and partially residential urban areas on the western and northern sides. Along the study routes, there are several supermarkets and few schools. There are no public utility buses and other large vehicles plying the study route. Private cars are also predominant type of vehicles but the PUJs are the major public transport mode.

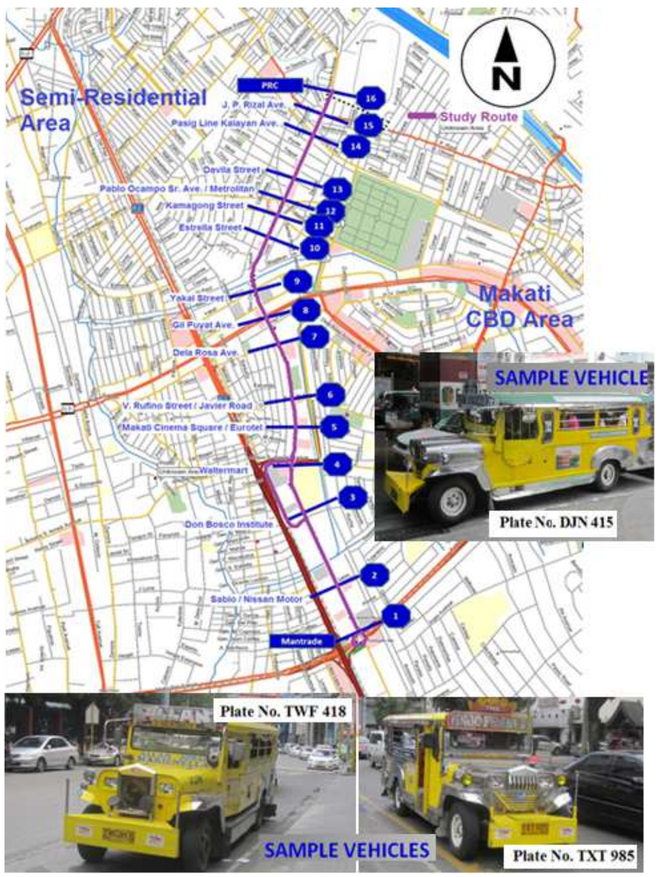


Fig.2 The Study Route (Mantrade – PRC) and Vicinity and 3 Sample Auto-LPG PUJs

The National Center for Transportation Studies (NCTS) of the University of the Philippines requested for permission from the Liga ng Transportasyon at Operators sa Pilipinas (LTOP), the group of Auto-LPG-powered jeepney operators of these PUJs. In agreeing to cooperate in the study, the LTOP allowed the on-board survey in three of its

Auto-LPG jeepneys which have been plying the route from Mantrade to the Philippine Racing Club (PRC) also Pasong Tamo since 2009.

The specification of sample vehicles is given in Table 1 below.

Table 1 Specifications of Sample Vehicles, Date and Duration of and Summary of Speed-Time Traces Collected from GPS Devices

Test Run	Date	Auto-LPG PUJ	Engine Model	Weight (Kg)	Seating Capacity	Type of Engine	Start Time	End Time	Total Time		Remarks
									Hour	Second	
1	1/22/2012 Sunday	TWF 418	Hundai Theta 2.4	GW 3400 NW 1700	21 Passengers	OEM	7:09	9:50	2:41	9660	Weekend
							10:17	12:04	1:47	6420	
							15:12	17:58	2:46	9960	
2	1/29/2012 Sunday	TXT 985	Hundai Theta 2.4	GW 3200 NW 1600	21 Passengers	OEM	9:14	11:54	2:39	9540	
							12:30	14:41	2:11	7860	
							16:11	16:57	0:46	2760	
TOTAL ON-ROAD DURATION									**12:50**	**46200**	
1	1/24/2012 Tuesday	DJN 415	Toyota 3RC	GW 3200 NW 1600	21 Passengers	Converted	11:10	12:11	1:00	3600	Weekdays
							12:12	13:57	1:45	6300	
							15:25	15:33	0:08	480	
							15:34	16:14	0:40	2400	
							16:25	17:37	1:12	4320	
							17:57	18:37	0:39	2340	
2	1/26/2012 Thursday	TXT 985	Hundai Theta 2.4	GW 3200 NW 1600	21 Passengers	OEM	9:07	11:53	2:46	9960	
							15:14	18:00	2:46	9960	
							18:03	20:05	2:01	7260	
3	1/30/2012 Monday	TWF 418	Hundai Theta 2.4	GW 3400 NW 1700	21 Passengers	OEM	7:59	10:17	2:18	8280	
							12:17	14:00	1:42	6120	
							15:29	16:32	1:03	3780	
							16:36	18:30	1:54	6840	
TOTAL ON-ROAD DURATION									**19:54**	**71640**	

3.2 Drive Cycle Development

There are two ways of developing a driving cycle. One is composed from various driving modes of constant acceleration, deceleration and speed (like the NEDC and Economic Commission for Europe (ECE), and is referred as modal or polygonal. However, these widely used driving cycles like NEDC bring considerable uncertainties when the emission estimation is carried out for a specific city or region. The other type is derived from actual driving data and is referred as "real world" cycle. Examples of such cycles are the FTP-75, BDC and the HDC. These "real world" cycles more dynamic driving in real world conditions result in higher emissions compared to those under the standard emission modal test cycles (Tzirakis et al., 2006).

This study adopted the definition of "real world" in developing the driving cycle for Auto-LPG powered jeepneys. The driving cycle of the Auto-LPG jeepney was constructed considering three important parameters i.e. speed-time trace, idle time and the maximum speed observed during on-road survey through GPS. The steps involved are:

1. Collection of speed time trace
2. Cleaning and processing of speed data
3. Selection of microtrips
4. Generation of target cycle
5. Generation of candidate cycles

3.2.1 Collection of Speed-Time Trace

The data were collected from three samples Auto-LPG powered PUJs plying along the study route, from Mantrade (Magallanes, Edsa) to Philippine Race Club (PRC) along Pasong Tamo in Makati City. Table 1 shows a sample summary of data collected. The speed time traces were collected from two models of Garmin GPS devices set at 1-second intervals to generate the target cycles. The GPS devices are Oregon®450 and GPSMAP76CSx.

3.2.2 Cleaning and Processing of Speed Data

The software “Mapsource” product of Garmin Limited especially made for the Garmin GPS was used to download and export the speed data in spread sheet (Microsoft Excel). The data generated are the tracking of vehicle speed at one-second intervals that coincided with the on-road test runs. Since the maximum speed during on-road test was not noticed more than 60 km/h, the speed data above 60 km/h were removed from the list to make the analysis of the results more realistic.

3.2.3 Generation of Target Cycle

The target cycle is a series of microtrips embodied as a single speed data in every second interval. Before the target cycle was run in the program, it was converted in text format of MS Notepad from MS Excel so that the program could run and suggest the output as a “Candidate Drive Cycles” among several lowest frequency distribution percentage differences.

3.2.4 Generation of Candidate Drive Cycles

The target drive cycle data was run in the Dev C^{++} program by selecting the minimum absolute percentage difference in several trials. Five candidate drive cycles were selected among 20 trials in lowest absolute percentage difference Basically, the criteria used for the selection of candidate cycle were the following, according to priority:

1. Lowest absolute percentage difference
2. Maximum speed compared to real speed data
3. Percentage of idle time (total zero speed)
4. Driving patterns

3.2.5 Smoothening of Statistical Data of the Drive Cycle

Smoothening of drive cycle is the process of tapering the speed profile within the criteria limit so that the cycle will not lose its characteristics. The Moving Average Method (Roberson, 2012) was chosen to be smooth the statistical speed data.

The theory behind this method is expressed in the following formula Eq. 2.

$$Mav(t_i) = \frac{1}{n}\sum_{1=1}^{n} W(t_i) \qquad \text{Eq. (2)}$$

Where,

$W(t_i)$ = waveform is any time-varying or spatial-varying series of related data

n = window width

4. Results and Discussion

4.1 Drive Cycle Development for Auto-LPG Jeepney

Test runs on weekends could not represent the characteristics of real world data. Nonetheless, the test runs were taken randomly in order to compare with the off-peak runs on weekdays. Idle time of was measured 44.5% in the target cycle. The idle time showed the actual delays due to stopping at intersections, waiting for passengers and traffic congestion. As such, the data were gathered during three weekdays (Monday, Tuesday and Thursday). The traffic characteristics in these days were considered to represent the real world data for the development of the drive cycles.

4.1.1.1 Target Cycle Weekday Runs

The results for the weekday runs are presented in Fig. 3 shows the joint velocity acceleration frequency distribution of the target cycle.

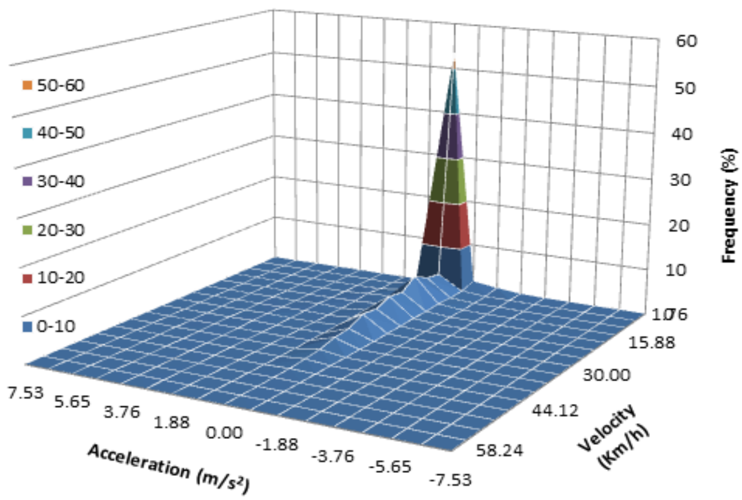


Fig. 3 Joint Velocity Acceleration Frequency Distribution of the Target Cycle for Weekday

4.1.1.2 Candidate Cycle of Weekday Runs

After running the speed profile of target cycle in the program, the top five candidate cycles with least absolute percentage difference within the limit of maximum of 20% (Sigua, 1995) are tabulated in Table 2 below.

Table 2 Comparison of Properties of the Top Five Candidate Cycles with Target Cycles for Weekday Runs

Candidate Cycles	(1)	(2)	(3)	(4)	(5)	**Target**
absolute percent diff. (%)	6.05	6.12	6.17	6.45	6.55	**NA**
max. velocity (km/h)	55	46	39	55	38	**59**
max. acceleration (m/s^2)	5.69	4.44	4.86	5.69	4.44	**7.78**
avg. velocity (km/h)	7.89	7.71	7.7	7.75	7.84	**7.89**
avg. acceleration (m/s2)	0	0	0	0	0	**0**
min. velocity (km/h)	0	0	0	0	0	**0**
min. acceleration (m/s^2)	-4.17	-3.96	-4.03	-4.17	-3.33	**-7.78**
class intervals	17	17	17	17	17	**17**
class width (velocity)	3.52	3.53	3.53	3.53	3.53	**3.53**
class width (acceleration)	0.94	0.94	0.94	0.94	0.94	**.94**
distance (km)	2.793	2.75	2.666	2.495	2.126	**NA**
duration (Second)	1274	1284	1246	1086	1136	**NA**
idle time (%)	53.61	54.75	54.25	54.76	58.54	**53.83**

* Due to congestion, the idle time was found to be 9.3% higher than during the weekends

Since the difference in absolute percentage is less than 1%, the distribution of all the candidate cycles with respect to the target cycle is almost the same.

4.1.2 Comparative Analysis of Target Cycles of Weekend and Weekday Runs

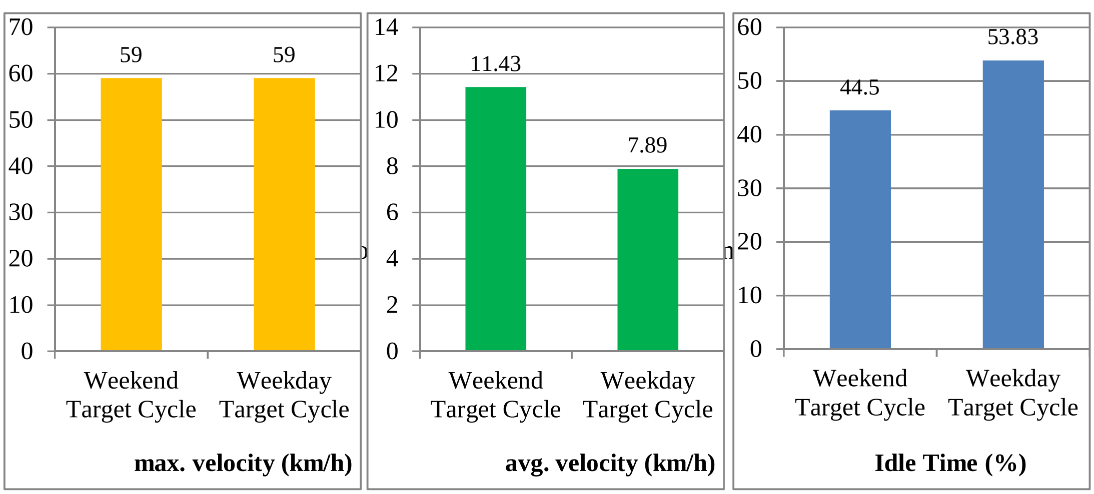


Fig. 4 Comparison of Weekday and Weekend Target Cycles

Data on the target cycle were the actual data collected from the on-road test and hence represented the actual speed, idle time and average speed recorded. As the results obtained from the both target cycles of the weekday and weekend runs were different in traffic characteristics, there were significant differences in properties (Fig. 4). The shares of idle time are 53.83% and 44.5% on weekdays and weekends, respectively. The average velocity on weekdays was 7.89 km/h and 11.43 km/h on weekends. The higher idle time and lower average velocity on weekdays can be attributed to traffic congestion.

4.1.3 Comparison of Candidate Cycles with Local Drive Cycles

Because of similarity, DC 251 (Thaweesak, 2009) for diesel-powered jeepney was used in this study in comparing selected candidate cycles. The result of this comparison is summarized in Table 3 below. As shown, the idle time of Auto-LPG was twice that of the DC 251. DC 251 was 83 seconds longer in duration and 1,271 meter longer by distance. On the other hand, the average speed was more or less the same, that is, 46 km/h.

Table 3 Comparison of Selected Candidate Cycles with Diesel Jeepney Drive Cycle

Parameters	Drive Cycle	
	Auto-LPG	Diesel (DC 251)
Absolute percentage difference (%)	6.12	17.78
Max. velocity (km/h)	46	45.8
Max. acceleration (m/s^2)	4.44	1.972
Avg. velocity (km/h)	7.71	10.59
Avg. acceleration: (m/s^2)	0	0
Min. velocity (km/h)	0	0
Min. acceleration (m/s^2)	-3.96	-2.667
Duration (in Second)	1284	1367
Distance (in meter)	2750	4021
Idle Time (%)	54.75	27.72
Vehicle Weight	Jeepney	Jeepney

4.2 Chassis Dynamometer Test of Auto-LPG Powered Jeepney

Chassis dynamometer test is a reliable tool to analyse the power of vehicles, fuel efficiency and emission. It helps to measure the fuel efficiency of the particular vehicles while running a vehicle on a drive cycle on a chassis dynamometer. Although emission levels would depend upon the speed of vehicle, it is also standardized by driving the vehicle on a drive cycle on the dynamometer.

Since the dedicated drive cycle for Auto-LPG jeepney was developed to run on the chassis dynamometer, the test was scheduled and performed at the University of the Philippines Mechanical Vehicle Research and Testing Laboratory (VRTL), Department of Mechanical Engineering, UP Diliman on February 21, 2013.

4.2.1 Testing of Drivability of New Drive Cycle

The statistical speed data of selected candidate cycle (as shown in Fig. 5) having absolute percentage difference of 6.12% for weekday runs was employed for the chassis dynamometer tests. The study made three runs for simulated 18-passenger capacity and three runs for simulated 23-passenger capacity.

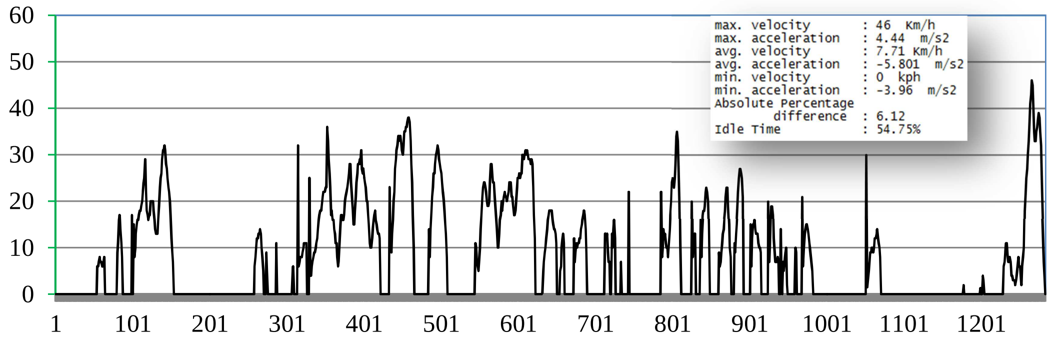


Fig. 5 Selected Candidate Cycle of Auto-LPG Jeepney for Chassis Dynamometer Test

While the chassis dynamometer was started to follow the drive cycle patterns, some locations of speed profile especially at the 315 second and 1054 second were found not to be drivable due to aggressive acceleration to achieve the speed from 0 to 32 km/h in 1 second (Fig. 6). The statistical speed was found to be difficulty to drive during the testing. However, the driving was still able to run within the upper and lower boundary limit of Chassis Dynamometer (AVL) as it was set.

As it was practiced, UP VRTL had set the system with allowance limit ±2 seconds and ±1.5 km/h in time and speed, respectively. Due to the aggressive acceleration, the drive cycle was smoothened using “Moving Average Method”.

4.2.1.1 Smoothening of Statistical Drive Cycle

Applying Eq. 3 (Robertson, 2010) with appropriate window width n, three trials were made with the boundary limit of the chassis dynamometer of ±1.5 km/h for speed and ±2 sec for time.

In order to determine an appropriate window width n, trials of smoothened cycles were computed in odd numbers e.g., 3, 5 and 7 as shown in Table 4. The three smoothened cycles were compared with in the default driving envelope of chassis dynamometer.

Table 4 Comparison of Properties of Smoothened Drive Cycle with Selected Statistical Candidate Drive Cycle and Target Drive Cycle

Properties	Candidate Cycle	Smoothened Cycle		Target
		n = 3	n = 5	
Absolute % difference	6.12	39.15	44.75	N/A
Max. velocity (km/h)	46	43.2	43.2	59
Max. acceleration (m/s^2)	4.44	0.89	0.89	7.78
Avg. velocity (km/h)	7.71	7.77	7.71	7.89
Avg. acceleration (m/s^2)	0	0	0	0
Min. velocity: (m/s^2)	0	0	0	0
Min. acceleration (m/s^2)	-3.96	-0.97	-0.97	-7.78
Idle Time (%)	54.75	44.63	44.63	53.83

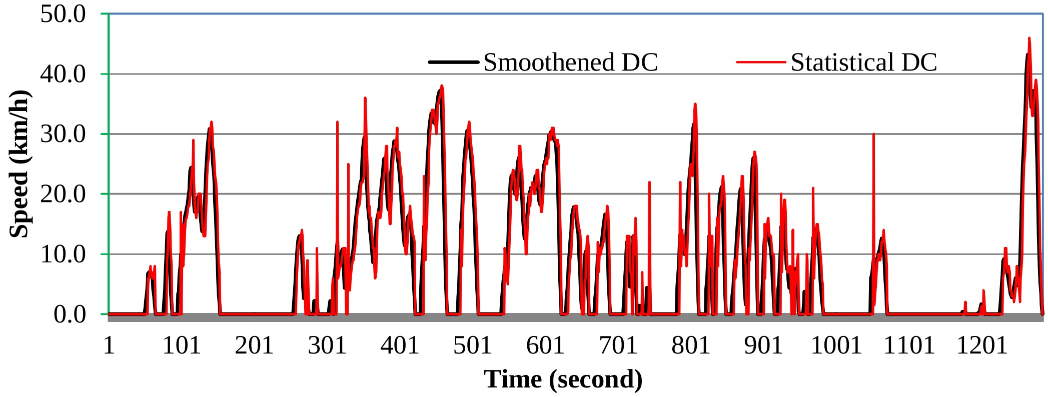


Fig. 6 Comparison of Smoothened Cycle with Statistical Candidate Cycle

After applying Moving Averages Method, the following changes were found in the smoothened drive cycle as compared to the original drive cycle based as indicated in Table 4.8.

a) Decrease in maximum velocity by 2.8 km/h
b) Original aggressive maximum acceleration of 4.44 m/s^2 was reduced to 0.89 m/s^2
c) Minimum acceleration -3.96 m/s^2 was reduced into -0.97 m/s^2
d) New idle time 44.63% was found which was reduced by about 10% after smoothening.

Using n=5 of Eq. 2, Figure 6 shows graph of tempered peaks after smoothening.

4.2.2 **Testing of Maximum Power**

The maximum power of Auto-LPG jeepney was tested for the 18-passenger capacity simulated load. The reading was configured in $1/10^{th}$ second for a total of 5,255 samples.

As shown in Table 5, the computed average maximum power of the Auto-LPG jeepney was 51.79 kW. This value is higher than the tested the maximum power of the PUJ tested in Thaweesak's study (2009) of Isuzu engine 4BEI which yielded 39.02 kW and 39.44 kW for B1 and B3 biodiesel blends, respectively.

Table 5 Maximum Power of Auto-LPG Jeepney Measured in Chassis Dynamometer Test

Samples	Max. Power (kW)	Average Maximum Power (kW)
10 - 3,000	51.99	51.79
3,001 - 4,000	51.83	
4001 - 5,300	51.56	

4.3 **Fuel Efficiency of the Auto LPG Jeepney**

The schedules of the on-road test for fuel consumption survey conducted on February 24, 2012 and from January 31, 2013 to February 07, 3013 in the study route as shown in Table-6 below. The Auto-LPG tank was filled at 80% of its liquid capacity as shown in Fig. 7.

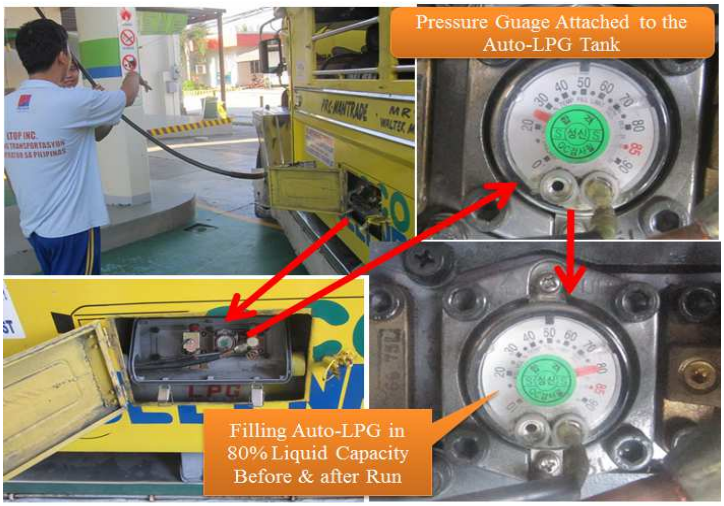


Fig. 7 Filling Up of Auto-LPG Tank at 80% of its Liquid Capacity During On-Road Test

4.3.1 Fuel Efficiency of Auto-LPG Public Utility Jeepneys

Measured on-road fuel consumption was summarized as shown in Table-6.

Table-6 Summary of On-Road Fuel Consumption Survey of Auto-LPG Jeepneys

Test No.	**Date of Survey**	**Sample Vehicle**	**Whole Day Auto-LPG Consumption**	**Total Travelled Distance**	**Fuel Efficiency**
		Plate No.	**litre**	**km**	**km/litre**
A	**B**	**C**	**D**	**E**	**F= *E / D***
1	2/24/2012	TWF 418	21.84	59.02	2.70
2	1/31/2013	TXT 985	20.26	83.86	4.14
3	2/1/2013	TXT 985	20.32	84.26	4.15
4	2/4/2013	TWF 418	28.98	87.34	3.01
5	2/5/2013	TWF 418	26.60	87.34	3.28
6	2/7/2013	TXT 985	19.95	79.40	3.98
Average Fuel Efficiency of Auto-LPG Jeepney					**3.54**

4.3.2 Fuel Economy of Auto-LPG Operation

Fuel economy is directly related to the cost of the operation of utility service, the prevailing price of the fuel, maintenance cost, and other administrative costs. Based on government data from 2011 to 2013 there were fluctuations in the prices of Auto-LPG, especially during the period from February 2012 to February 2013 when the on-road tests took place. The cost of fuel starting 2012 was significantly higher. The analysis of fuel economy in this study is limited to the fuel price and fuel efficiency.

The formula applied in computing for fuel economy is shown in Eq.3. It is expressed in cost per kilometer.

$$\text{Fuel Economy} = \frac{\textit{unit price of fuel}}{\textit{fuel efficiency}} \text{ in Pesos/km} \qquad \text{Eq. (3)}$$

Table 7 shows the computed fuel economy of PUJ operations according to the type of fuels. The price of Auto-LPG fuel was based on actual purchase in February 2013. Figure 8 shows the increments in fuel prices from year 2009 to 2012.

Table 7 Recent Fuel Economy in Public Utility Jeepneys by Fuel Type

Fuel Type	Fuel Efficiency (km/li)	Price of Fuel (Peso/li)	Fuel Economy (Peso/Km)	Remarks
Auto-LPG (On-road Test)	3.54	30.25	8.55	Actual Purchased Rate, Feb. 3013
Diesel	5.54	41.45	7.48	DOE, March 2012
Biodiesel (B2)	5.63	44.00	7.82	Manila Bulletin, Nov. 2012

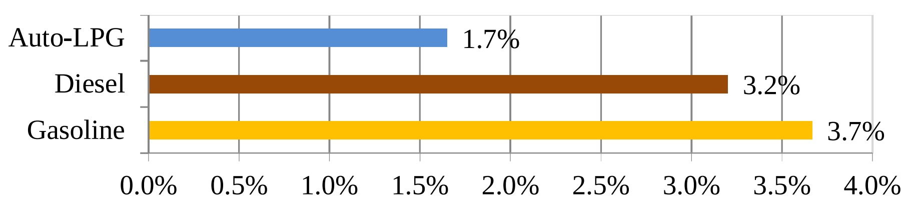
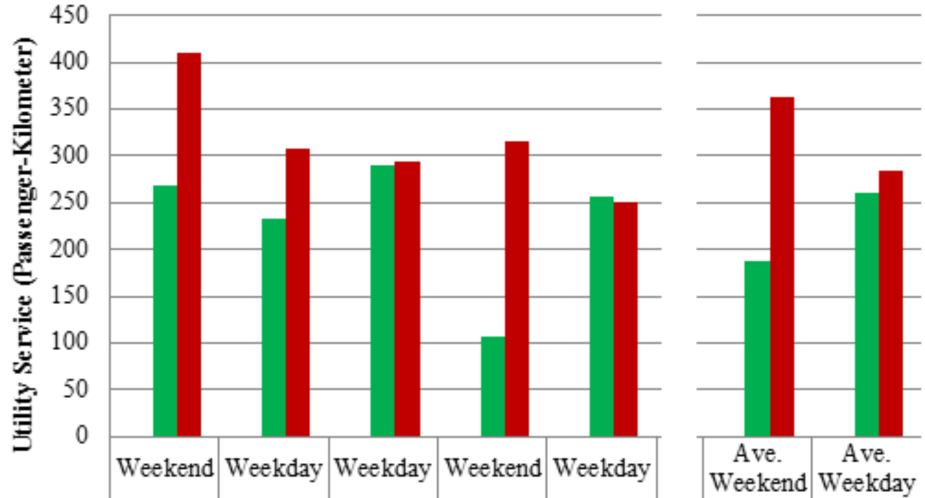


Fig. 8 Increments in Fuel Prices from 2009 to 2012 by Fuel Type (Percentage of Average Annual Increment) [Source: Oil Monitor, DOE]

4.4 Service Utility of Auto-LPG Jeepney in Pasong Tamo

The observed service utility of Auto-LPG jeepneys in the study route was analysed from the boarding and alighting data. The service utility was computed and expressed in passenger-kilometre for each day as shown in Figure 9.



	Weekend	Weekday	Weekday	Weekend	Weekday	Ave. Weekend	Ave. Weekday
Days	1	2	3	4	5		
Northbound	268	233	290	107	257	187	260
Southbound	409	308	293	315	251	362	284

Fig. 9 Daily Service Utility of Auto-LPG Jeepneys

During weekends, the average utility service of Auto-LPG jeepneys was a minimum of 187 passenger-kilometers in the northbound direction and a maximum of 362 passenger-kilometers in the southbound direction. On weekdays, the average utility service varied from 260 to 284 passenger-kilometers in both directions.

5. Conclusions

The drive cycle for the Auto-LPG jeepney (DC ALPG-1) is developed. The parameters of the smoothened, the statistical candidate drive cycle and target cycle are shown in the Table 8 below.

Table 8 Parameters of DC ALPG-1 (Smoothened Drive Cycle), Statistical Drive Cycle and Target Cycle

Parameters	DC ALPG-1	Statistical Candidate Cycle	Target Cycle
Absolute % difference	44.75	6.12	N/A
Max. velocity (km/h)	43.2	46	59
Max. acceleration (m/s^2)	0.89	4.44	7.78
Avg. velocity (km/h)	7.71	7.71	7.89
Avg. acceleration (m/s^2)	0	0	0
Min. velocity: (m/s^2)	0	0	0
Min. acceleration (m/s^2)	-0.97	-3.96	-7.78
Idle Time (%)	44.63	54.75	53.83

The plot of smoothened drive cycle is shown in Figure 10.

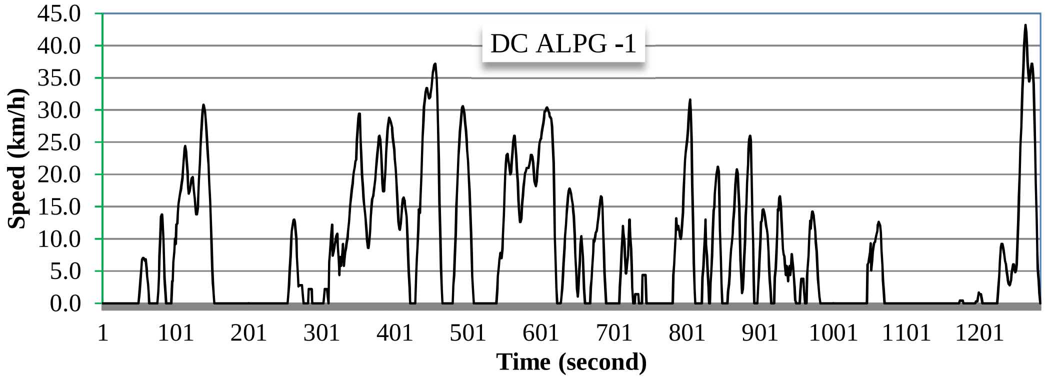


Fig. 10 Drive Cycle DC ALPG – 1 for Auto-LPG PUJ

The fuel efficiency based on the six days of on-road fuel consumption and using "Full Tank Method" is estimated to be 3.54 km/li or 8.55 Pesos/km in terms of fuel economy based on February 2013 pump price of Auto-LPG. As compared to the diesel and biodiesel fuels, the cost is slightly higher (about 14% higher than the diesel and 9% higher than the biodiesel). However as it is shown in figure 10, it would be economical considering the following that the price increase per year for Auto-LPG of 1.7% is less than the price increment of other fuels (3.2% for diesel), thus, in the future, the cost for Auto-LPG operation is expected to be lower than the diesel.

On weekends, the service utility of Auto-LPG Jeepney had a maximum of 409 passenger-kilometres in the southbound direction and a minimum of 107 passenger-kilometres in the northbound direction. During weekdays, the utility service varied from 233 to 315 passenger-kilometres in both directions.

The maximum power of Auto LPG Hyundai Theta 2.4 OEM engine was measured to be 51.79 kW;

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