Benchmarking LPG as an Alternative Fuel for Jeepneys

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Abstract: This paper presents a benchmarking study employing on-road and chassis dynamometer tests to estimate mileage of public utility jeepneys using diesel and liquefied petroleum gas (LPG) in the Philippines. Relevant on-road data are measured to estimate mileage and develop drive cycles for chassis dynamometer testing. The drive cycles are developed, involving collection of speed data using GPS. Speed data is processed using the microtrip concept in which a program randomly appends microtrips to generate speed-time data of around 20 minutes duration. Measured on-road mileage (km/liter) at load factor (%) for the diesel and LPG jeepneys, respectively, are: 6.7 at 63.5% and 3.84-4.24 at 59.8%. Drive cycle and constant velocity tests at 100% load factor yielded mileage of respectively 5.1-5.6 and 12.8-8.1 km/liter for diesel, and 2.6-3.1 and 3.0-1.8 km/liter for LPG. Lower LPG mileage is attributed to lesser heating value per liter than diesel and non-optimal tuning of the engine.

Keywords: Fuel Economy, Drive Cycle, Chassis Dynamometer, Alternative Fuels

1. INTRODUCTION

1.1 Background

This paper presents part of the study undertaken by the University of the Philippines National Engineering Center for the Philippine Department of Energy (DOE) in evaluating LPG as an alternative fuel for public transport, in particular, public utility jeepneys. Jeepneys are locally assembled vehicles with shop-fabricated bodies and chassis, fitted with second-hand diesel engines, drivetrain components, and other vehicle parts. They typically are designed for 20-22 passengers. Jeepneys are considered paratransit mode complementing and competing with bus and rail public transport system in Metro Manila and usually form as the main 4-wheeled intra-city public transport mode and public transport between adjacent towns and cities in the rest of the Philippines.

The main objective of the study is to obtain some benchmark fuel mileage range data for LPG and diesel as fuels for in-use jeepneys operating in a selected urban route. In addition, any operational issues with LPG use will be identified. Results of the study will be used in developing programs and strategies for the DOE and related government agencies to enhance their capacity to effectively promote and implement alternative fuels and technology in the country. The study is part of the Fuel Efficiency in Road Transport Program of the DOE.

An earlier study on Auto-LPG jeepneys in Metro Manila has been conducted by Pokharel *et al.* (2013). The drive cycle for the public utility jeepney running on LPG was developed in this study and the full tank method was used in the measurement of LPG consumed. The speed data in the development of the drive cycle were gathered during the Auto-LPG jeepney's operations in Makati City, specifically the Mantrade (Magallanes, EDSA) to Philippine Race Club (PRC) route. The fuel efficiency from the on-road test was estimated to be 3.54 km/liter. The developed drive cycle for Auto-LPG jeepney was used in the chassis dynamometer. The maximum power of Auto LPG Hyundai Theta 2.4 OEM engine was measured to be 51.79 kW. However, this study was not able to conduct fuel economy tests on the chassis dynamometer.

1.2 Objectives

The objectives of this paper are as follows:

a) to benchmark the fuel economy of LPG versus diesel as an alternative fuel for public utility jeepneys plying an existing city route;
b) to conduct limited on-road test runs of diesel and LPG jeepneys to characterize their daily operation in terms of travel distance, fuel consumption, passenger load factor, and speed-time profile;
c) to conduct chassis dynamometer testing of both diesel and LPG jeepneys to determine drive cycle fuel economy; and,
d) to identify operational issues with LPG use in jeepneys, if any.

2. METHODOLOGY

2.1 On-Road Tests

The study utilized in-use Auto-LPG jeepneys of operators belonging to a transport association and a transport cooperative that were granted provisional authority by the Land Transportation Franchising and Regulatory Board to operate and collect fares at the U.P.-SM North EDSA route. Participating diesel jeepneys already with franchise along the route did not need the provisional authority. The route starts at the University of the Philippines (UP) Diliman Campus in the east and ends at SM North EDSA in the west which is a shopping mall. The route is classified as the short urban type of route and the route length is 6.5 km westbound from the university to the shopping mall and 6.75 km. eastbound.

The test jeepneys were assessed for baseline conditions and tuned up by the respective vehicle technicians. The test vehicles had undergone and passed inspection at the North Motor Vehicle Inspection Center of the Land Transportation Office to verify roadworthiness and emission standards compliance.

The duration of the on-road tests was set for a maximum of 72 days. The schedule of the operation usually started at 6:00 AM and ended at 7:30 PM, daily except Sundays to minimize the differences in operation of the test vehicles. All drivers of the test vehicles followed normal work breaks of drivers of other jeepneys operating in the same route.

Daily operational characteristics such as daily vehicle operation information (operation, cost and revenue) and passenger station origin-destination (OD) were collected. All maintenance and repair activities and corresponding costs (and other expenses) borne by the operator were also recorded in the duration of the on-road test.

The refueling of diesel and Auto-LPG powered jeepneys were monitored. The full tank method was used in the measurement of daily fuel consumption of the test jeepneys. Speed-time data were recorded using a GPS device for selected days during the on-road test runs for the drive cycle development for the diesel and Auto-LPG jeepneys.

2.2 Chassis Dynamometer Tests

Fuel economy tests were conducted at the University of the Philippines Department of Mechanical Engineering's Vehicle Research and Testing Laboratory (UP-ME-VRTL) using the AVL AN 40720 48" Chassis Dynamometer where the test jeepney units were run on drive cycles corresponding to the fuel used. These drive cycles, developed from the on-road test data, are shown in Figures 1 and 2. Fuel consumption during the dynamometer runs was measured with the AVL 735 Fuel Mass Flow Meter together with the AVL 753 Fuel Temperature Control unit.

Prior to the chassis dynamometer runs, a pre-test inspection of the test jeepney unit was conducted to reasonably ascertain that the vehicle was in good running condition. This included general inspection of the tires, checking of tire pressures, and checking for smooth and stable running of the engine. The test vehicle was then mounted on the chassis dynamometer, secured, and instrumentation attached. After a pre-set warm up time, the test jeepney was run on its drive cycle at fully-loaded conditions three times and the measurement results averaged. Constant velocity tests at 20, 40 and 60 km/hr were conducted after the drive cycle tests to determine steady-state performance. Maximum wheel power was measured afterwards.

In the case of the diesel jeepney unit, it was tested four times: before and after engine tune-up and calibration done before the on-road runs, after on-road tests using a provisional drive cycle, Figure 3, developed from limited on-road data, and a revised drive cycle, Figure 1, based on the complete on-road test results. The first two tests tried to capture the effect of tune-up and calibration, the third to see the effect of on-road use after calibration, the fourth to update the results of the third test using the final version of the diesel drive cycle developed. Figure 4 shows photos of the diesel jeepney test unit on the chassis dynamometer.

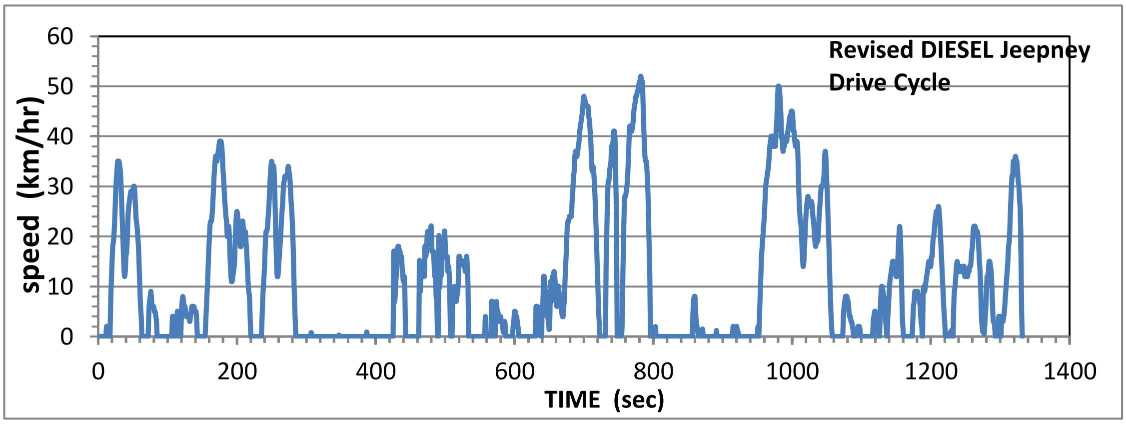

Figure 1. Revised diesel jeepney drive cycle

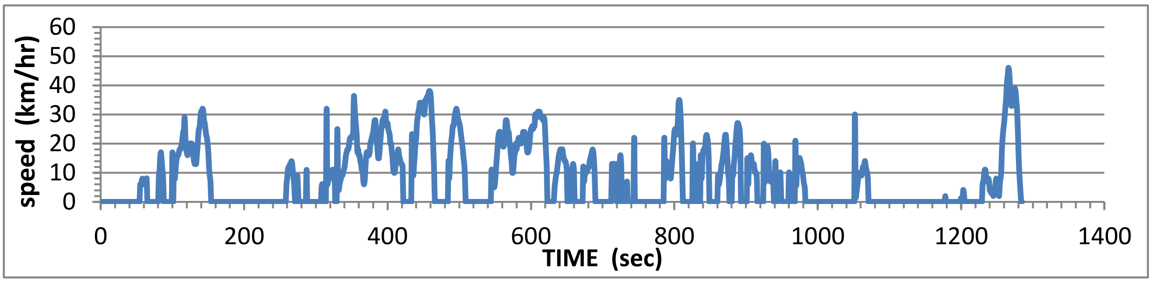

Figure 2. Auto-LPG jeepney drive cycle

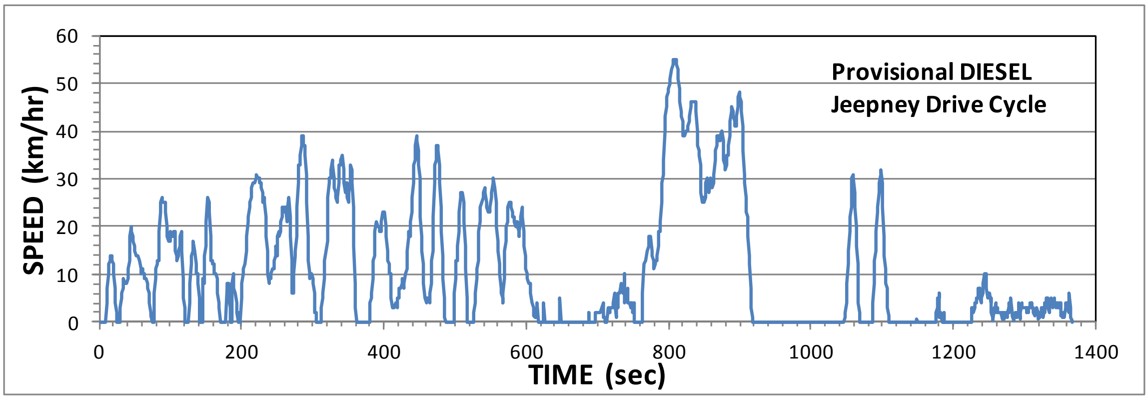

Figure 3. Provisional diesel jeepney drive cycle


Figure 4. Diesel jeepney unit during chassis dynamometer tests

Two LPG jeepney units were tested, one designated as "ZTS 904" (after its plate number) fitted with a Hyundai Theta engine, and the other as "Go LPG" (after its promotional banner) fitted with a Toyota 4RD2 engine. The chassis dynamometer runs were performed after their on-road tests were completed. The Go LPG jeepney unit was not an in-use vehicle as it did not have a franchise to operate at the time of the study. It underwent a short on-road test on the same route using artificial weights to simulate fully loaded conditions. On the other hand, the ZTS 904 had an average load factor of about 60% for the on-road runs.

Figure 5 shows the chassis dynamometer testing of the ZTS 904 LPG jeepney with the LPG fuel weighing system fabricated specifically for the tests.

The 22-passenger Go LPG jeepney unit was initially tested on-road then on the chassis dynamometer after the ZTS 904 LPG jeepney. Because of the limited time available, the Go LPG jeepney was tested not in actual operation but by a special on-road protocol. It was tested with 100% load factor based on its maximum 22-passenger capacity using artificial weights corresponding to 70 kg/passenger. This test vehicle ran along the UP-SM North EDSA route for five days. The driver was accompanied by an on-board surveyor who recorded GPS and vehicle odometer readings and directed the driver where to stop along the route to simulate the on-road test run performed by ZTS 904 LPG jeepney. The vehicle was afterwards tested on the chassis dynamometer using the LPG jeepney drive cycle. Figure 6 shows the jeepney unit on the dynamometer at the VRTL.

Figure 5. Chassis dynamometer testing of ZTS 904 LPG jeepney unit with fabricated fuel weighing system

Figure 6. Go LPG jeepney unit being tested on the chassis dynamometer

3. ON-ROAD TEST RESULTS OF DIESEL AND AUTO-LPG JEEPNEYS

3.1 Operational Characteristics of Diesel and Auto-LPG Jeepneys

This section discusses average daily values of the parameters of diesel and auto-LPG jeepneys. Tables 1 to 6 show the daily averages of parameters of operations namely, start and end of operations, duration, daily fuel efficiency, number of passengers, distance travelled, gross revenue, driver's take-home pay, boundary (rental), fuel cost, terminal and dispatchers' fee and other expenses such as amortization, allowances, fines and food. The number of records considered in the computation of averages is indicated.

Table 1 indicates the daily average fuel efficiency in terms of kilometers per liter (km/li), liter per kilometer (li/km), and fuel cost per kilometer (Php/km). The second diesel test jeepney was the lowest in terms of cost per kilometer out of the five jeepneys tested. The second Auto-LPG test jeepney followed with cost per kilometer 14% higher than the cost per kilometer of the Auto-LPG test jeepney.

Table 1. Average daily fuel efficiency of diesel and Auto-LPG test jeepneys

Fuel Efficiency	1st Diesel			2nd Diesel			1st LPG			2nd LPG			3rd LPG		
	km/li	li/km	Php/km	km/li	li/km	Php/km	km/li	li/km	Php/km	km/li	li/km	Php/km	km/li	li/km	Php/km
Average	6.67	0.17	7.09	6.86	0.15	6.09	3.84	0.27	8.94	4.24	0.24	7.04	3.48	0.29	8.36
Maximum	18.25	0.32	13.51	11.50	0.29	11.97	5.18	0.41	13.82	5.89	0.36	11.03	4.03	0.38	10.86
Minimum	3.13	0.05	2.32	3.48	0.09	3.65	2.42	0.19	6.46	2.74	0.17	4.83	2.62	0.25	7.07
Standard Deviation	2.90	0.06	2.52	1.31	0.03	1.24	0.57	0.05	1.56	0.93	0.05	1.46	0.51	0.05	1.36
No. of Records	34			51			30			35			8		

The first diesel test jeepney had an average of 14 hours and 27 minutes duration of daily operations. The rest of the test vehicles (2nd diesel test jeepney and 1st and 2nd Auto-LPG test jeepneys) had an approximate duration of operation for 13 hours.

The average daily number of passengers transported and distance travelled by the test jeepneys are shown in Table 2. The lowest in terms of numbers of daily passenger carried and distance travelled out of the four test vehicles is the 1st batch auto-LPG with 373 km and 134.8 km, respectively. The 1stdiesel test jeepney had the most number of passengers with 482 passengers. However, it is second to the lowest daily travel distance with a mean of 155.6 km.

The lower values of the 1stAuto-LPGjeepney may be attributed to its frequent downtime due to repairs. Moreover, the 1st test diesel jeepney carried the most number of passengers due to its higher capacity (22 passenger seats).

Table 2. Average daily number of passengers and travel distance

Number Passengers/ Distance Travelled	1st Diesel		2nd Diesel		1st LPG		2nd LPG	
	Pass	Dist (km)	Pass	Dist (km)	Pass	Dist (km)	Pass	Dist (km)
Average	482	155.6	455	179.8	373	134.8	411	170.6
Maximum	658	322.0	720	377.8	653	221.4	601	377.8
Minimum	98	58.1	94	34.5	41	15.9	105	50.6
Standard Deviation	137	52.9	132	69.5	141	49.2	110	63.0
No. of Records	73	37	55	40	62	50	38	40

Tables 3 and 4 show the average daily gross revenue, driver's take-home pay, boundary and fuel cost. The 2nd diesel test jeepney garnered the highest revenue and driver's take-home pay with PhP4,049.95 and PhP1,467.17, respectively. The 1st test Auto-LPG jeepney had the least boundary (rental) cost and the highest fuel cost.

Table 3. Average daily gross revenue, driver's take home pay, boundary and fuel cost (diesel)

Gross Revenue/ Take Home Pay/ Boundary/ Fuel Cost	1st Diesel				2nd Diesel			
	Gross Rev	Take Home	Bound	Fuel Cost	Gross Rev	Take Home	Bound	Fuel Cost
Average	PHP 3,807.89	PHP 1,357.97	PHP 1,389.85	PHP 1,024.59	PHP 4,049.95	PHP 1,476.17	PHP 1,052.63	PHP 1,125.83
Maximum	PHP 5,940.26	PHP 3,900.00	PHP 1,650.00	PHP 1,593.78	PHP 6,390.00	PHP 3,070.00	PHP 1,200.00	PHP 7,208.06
Minimum	PHP 1,100.00	PHP 330.00	PHP 500.00	PHP 200.00	PHP 753.53	PHP 200.00	PHP 600.00	PHP 345.00
Standard Deviation	PHP 1,174.57	PHP 739.23	PHP 331.59	PHP 286.97	PHP 1,116.72	PHP 619.97	PHP 192.76	PHP 831.78
No. of Records	70	67	67	72	62	38	38	61
Ratio of Duration w/ 2nd Diesel	0.94	0.92	1.32	0.91	1.00	1.00	1.00	1.00

Table 4. Average daily gross revenue, driver's take-home pay, boundary (vehicle rental) and fuel cost (auto-LPG)

Gross Revenue/ Take Home Pay/ Boundary/ Fuel Cost	1st LPG				2nd LPG			
	Gross Rev	Take Home	Bound	Fuel Cost	Gross Rev	Take Home	Bound	Fuel Cost
Average	PHP 2,805.22	PHP 825.43	PHP 886.67	PHP 1,413.73	PHP 3,519.72	PHP 935.44	PHP 1,105.26	PHP 1,248.33
Maximum	PHP 5,455.00	PHP 5,405.00	PHP 1,000.00	PHP 1,879.00	PHP 5,038.00	PHP 1,925.20	PHP 1,200.00	PHP 4,347.11
Minimum	PHP 320.00	PHP 130.00	PHP 300.00	PHP 890.00	PHP 1,050.00	PHP 100.00	PHP 300.00	PHP 578.30
Standard Deviation	PHP 1,184.92	PHP 849.52	PHP 157.54	PHP 207.72	PHP 1,018.28	PHP 490.37	PHP 227.74	PHP 610.62
No. of Records	62	45	45	55	44	38	38	40
Ratio of Duration w/ 2nd Diesel	0.69	0.56	0.84	1.26	0.87	0.63	1.05	1.11

Table 5 shows average daily terminal fee and dispatcher's fee, other expenses such as allowance, food, fines and amortization. The data shows the 1st Auto-LPG test jeepney had the lowest terminal and dispatch costs.

The differences in the number of records considered are due to the downtime days of the test vehicles due to repairs and the difference in the number of testing days.

Table 5. Average daily terminal fee, dispatcher's fee, and other expenses

Terminal Fee and Dispatcher's Fee/ Other Expenses (Baon, Food, Fines, Hulog)	1st Diesel		2nd Diesel		1st LPG		2nd LPG	
	TF&DF	Other	TF&DF	Other	TF&DF	Other	TF&DF	Other
Average	PHP 301.64	PHP 236.89	PHP 385.08	PHP 199.85	PHP 292.95	PHP 302.29	PHP 355.77	PHP 483.27
Maximum	PHP 600.00	PHP 1,470.00	PHP 720.00	PHP 850.00	PHP 475.00	PHP 1,145.00	PHP 545.00	PHP 2,050.00
Minimum	PHP 25.00	PHP 0.00	PHP 120.00	PHP 0.00	PHP 30.00	PHP 0.00	PHP 175.00	PHP 0.00
Standard Deviation	PHP 127.09	PHP 231.61	PHP 119.51	PHP 128.42	PHP 92.03	PHP 236.86	PHP 92.68	PHP 363.52
No. of Records	73	73	61	61	58	58	44	44
Ratio of Duration w/ 2nd Diesel	0.78	1.19	1.00	1.00	0.76	1.51	0.92	2.42

3.2 Public Transport Line Demand Parameters

3.2.1 Estimation of Passenger Load Factor

The passenger load factor indicates how fully occupied are the seats of the public transport vehicle and is computed by dividing the number of passengers on board by the passenger seating capacity. The weighted average load factor is computed by the dividing the product of the passenger load factor and transit segment (section between stops) length by the total route distance.

The computed average daily passenger load factors of the second diesel test jeepney, Auto-LPG test jeepney are 63.47% and 59.81%, respectively. The maximum/minimum average daily passenger load factor values for the same tests jeepneys are 69.86%/58.68% and 64.39%/47.99%, respectively.

3.2.2 Estimation of Passenger-Kilometers

Travel demand in passenger-kilometers is equal to the number of passengers multiplied by the trip lengths of passengers. The estimated daily averages of passenger-kilometers from February 2 to 10, 2013 and March 18 to 24, 2013 of the diesel test jeepney and Auto-LPG are 1,906.46 and 1,926.23, respectively. The estimated maximum/minimum daily average passenger-kilometers for the same tests jeepneys are 2,543.90/ 441.05 and 2,786.40/ 509.80 respectively.

The computed average load factor and passenger-kilometers are important considerations and are use in the normalization of the comparison of the measured fuel economies of test jeepneys using the chassis dynamometer to the on-road tests computations.

3.3 Drive Cycle Development

Sigua (1997) developed the first urban drive cycle in the Philippines for private cars. The drive cycle has parameters: maximum velocity, 56 kph; minimum velocity, 0 kph; % idle period, 33.72 %; average running speed, 22.14 kph; duration, 1299 seconds. Sigua developed the drive cycle using 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.

The speed-time data from the on-road test runs using GPS devices were used in the development of the drive cycle for each jeepney. 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 steps in processing are summarized 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.
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;

$$\text{Number of Class Intervals} = 1 + 3.3 \log N \tag{1}$$

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, ρ_{tc} and ρ_{dc} are the matrices of the combined speed-acceleration probability distribution of the target drive cycle and generated drive cycle, respectively;

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

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 7 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;

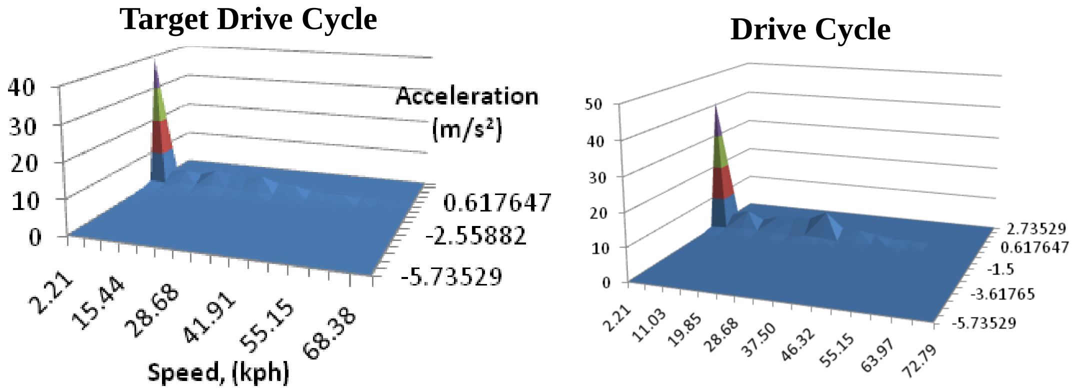

Figure 7. Combined speed-acceleration probability distribution

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) The name of the text file to be processed and the maximum value difference are individually specified before the program runs to generate a candidate drive cycle;
9) For every run, a candidate drive cycle is formed. A total of ten candidate drive cycles are developed for each type of vehicle; The final drive cycle is selected from the candidate drive cycles having the least maximum acceleration.

Figures 2 and 3 show the speed-time graph of the drive cycles used in laboratory tests of the subject vehicles. The different parameters of the drive cycles such as maximum velocity, maximum acceleration, average velocity, average acceleration, minimum velocity, minimum acceleration and percent absolute value difference are also indicated in Tables 6 and 7.

Table 6. Diesel jeepney drive cycle statistics

max. velocity:	57 kph
max. acceleration:	1.86 m/s^2
avg. velocity:	11.95 kph
min. velocity:	0 kph
min. acceleration:	-1.25 m/s^2
percent difference	10.0%

Table 7. Auto-LPG jeepney drive cycle statistics

max. velocity:	51 kph
max. acceleration:	1.11 m/s^2
Ave. velocity:	11.27 kph
min. velocity:	0 kph
min. acceleration:	-3.47 m/s^2
percent difference	8.6%

4. LABORATORY TEST RESULTS OF DIESEL AND AUTO-LPG JEEPNEYS

4.1 Diesel Jeepney

Results of the chassis dynamometer tests of the diesel test jeepney are shown in Table 8. The drive cycle fuel consumption before and after calibration is practically unchanged. During the engine tune-up activities, an engine compression test showed that three cylinders have below-specification compression pressures while the other cylinder could not be tested due to accessibility problems. Tune-up did not include engine repairs to address this problem. The data tend to indicate that calibration works had negligible effects on fuel consumption when engine compression falls below specifications. The fuel economy immediately after the on-road tests improved by approximately by 11% relative to that after calibration. It should be noted from the data that the fuel used after the on-road tests could have a different quality from that after calibration as indicated for instance by an approximately 2% lower density. Change in performance may be partly accounted for by fuel quality differences as commercial diesel used in the laboratory was not strictly controlled and monitored. There were no diesel fuel quality measurements (e.g., heating value, cetane number, etc.) during the tests except density from the coriolis mass flow meter. Tests using the revised diesel drive cycle showed 7.6% less mileage than that after the on-road tests. Overall, the diesel jeepney drive cycle mileage varied from 5.06 to 5.61 km/liter at full load conditions.

Table 8. Drive cycle laboratory test results – diesel jeepney

Unit		Average Velocity		Average Fuel Flow		Fuel Density	SFC	Mileage
	Trial	*(km/h)*		*(kg/h)*		*(kg/m3)*	*(g/km)*	*(km/l)*
BEFORE Calibration	1	11.22		1.856		844.489	165.36	5.11
	2	11.22		1.856		844.489	165.35	5.11
	3	11.22		1.856		844.489	165.38	5.11
	Average	11.22		1.856		844.489	165.36	5.11
AFTER Calibration	1	11.31		1.883		842.136	166.41	5.06
	2	11.31		1.883		842.136	166.40	5.06
	3	11.32		1.883		842.136	166.38	5.06
	Average	11.31		1.883		842.136	166.40	5.06
	Before Calib.	11.22		1.856		844.489	165.36	5.11
	%change	*0.82%*		*1.45%*		*-0.28%*	*0.62%*	*-0.90%*
AFTER ON-ROAD TESTS	1	11.34		1.698		826.088	149.68	5.52
	2	11.29		1.643		825.952	145.48	5.68
	3	11.32		1.656		825.886	146.33	5.64
	Average	11.32		1.666		825.976	147.16	5.61
Revised Diesel Drive Cycle	1	10.94		1.774		824.671	162.16	5.09
	2	10.81		1.705		825.030	157.83	5.23
	3	10.96		1.723		825.399	157.28	5.25
	Average	10.90		1.734		825.033	159.09	5.19
	After On-Road	11.32		1.666		825.976	147.16	5.61
	%change	*-3.69%*		*4.12%*		*-0.11%*	*8.10%*	*-7.60%*

Table 9 shows the constant velocity test results for the diesel jeepney. Except at 20 kph, where calibration indicated a little more than 4% improvement, fuel consumption remained basically similar before and after calibration. A 7 to 9% decrease in mileage after the on-road tests compared to that after calibration is seen from the data. The decreased mileage at steady speeds possibly may be to a certain extent caused by fuel quality differences. Overall, the diesel jeepney running fully loaded at constant speed between 20 and 60 kph yielded a mileage range of about 12.8 – 8.1 km/liter.

Table 9. Constant velocity test results – diesel jeepney

20 kph	**Average Velocity**	**Average Fuel Flow**	**Fuel Density**	**Spec. Fuel Consumption**	**Mileage**
	(km/h)	*(kg/h)*	*(kg/m3)*	*(g/km)*	*(km/l)*
BEFORE Calibration	20.17	1.394	844.378	69.13	12.21
AFTER Calibration	19.99	1.317	840.128	65.88	12.75
AFTER ON-ROAD	20.14	1.445	824.072	71.73	11.49

40 kph	**Average Velocity**	**Average Fuel Flow**	**Fuel Density**	**Spec. Fuel Consumption**	**Mileage**
	(km/h)	*(kg/h)*	*(kg/m3)*	*(g/km)*	*(km/l)*
BEFORE Calibration	40.12	2.652	844.284	66.08	12.78
AFTER Calibration	40.03	2.634	840.022	65.81	12.77
AFTER ON-ROAD	40.15	2.799	824.023	69.72	11.82

60 kph	**Average Velocity**	**Average Fuel Flow**	**Fuel Density**	**Spec. Fuel Consumption**	**Mileage**
	(km/h)	*(kg/h)*	*(kg/m3)*	*(g/km)*	*(km/l)*
BEFORE Calibration	59.95	5.733	844.199	95.62	8.83
AFTER Calibration	59.97	5.756	839.898	95.98	8.75
AFTER ON-ROAD	60.07	6.095	824.021	101.47	8.12

Table 10 shows the maximum power test results. Maximum power is a little over 3% higher after calibration. A subsequent decrease of about 12% is seen after the on-road tests possibly reflecting a combination of fuel quality and engine condition differences since after calibration.

Table 10. Maximum power test results – diesel jeepney

DJ#2 Condition	Power (kW)	% Change
BEFORE Calibration	35.00	
AFTER Calibration	36.16	*3.32%*
AFTER ON-ROAD	31.71	*-12.33%*

4.2 Auto-LPG Jeepneys

Tables 11 to 13, show the drive cycle, constant velocity, and maximum power test results respectively, for both LPG jeepneys.

Based on the drive cycle test results, the ZTS 904 jeepney has a mileage of about 2.6 km/liter while the mileage varies from about 2-3 km/liter at the steady speeds tested. On the other hand, Go LPG jeepney drive cycle mileage was around 3.1 km/liter, which is roughly 19% better than ZTS 904. Constant velocity mileage for the Go LPG jeepney unit is also roughly in the 2-3 km/liter range. It should be noted from the maximum power test results that the Go LPG Toyota engine is more powerful than the Hyundai Theta engine of ZTS 904. Both LPG jeepneys have more powerful engines than that of the diesel jeepney.

Table 11. Drive cycle test results – LPG jeepneys

	Total Distance	LPG Consumed	LPG Density	SFC	Mileage
ZTS 904	*km*	*kg*	*kg/liter*	*g/km*	*km/liter*
1	2.895	0.571	0.520	197.25	2.638
2	2.821	0.556	0.520	197.13	2.639
3	2.811	0.562	0.520	199.92	2.602
Average	**2.842**	**0.563**	**0.520**	**198.10**	**2.626**
Go LPG	*km*	*kg*	*kg/liter*	*g/km*	*km/liter*
1	4.297	0.725	0.521	168.73	3.086
2	4.295	0.706	0.521	164.36	3.168
3	4.295	0.710	0.521	165.33	3.149
Average	**4.296**	**0.714**	**0.521**	**166.14**	**3.134**

Table 12. Constant velocity test results– LPG jeepneys

	Total Distance	LPG Consumed	LPG Density	SFC	Mileage
ZTS 904	*km*	*kg*	*kg/liter*	*g/km*	*km/liter*
20 kph	0.168	0.039	0.520	232.09	**2.242**
40 kph	0.334	0.058	0.520	173.72	**2.995**
60 kph	0.501	0.110	0.520	219.67	**2.368**
Go LPG	*km*	*kg*	*kg/liter*	*g/km*	*km/liter*
20 kph	0.167	0.029	0.521	173.66	**2.998**
40 kph	0.333	0.059	0.521	176.92	**2.943**
60 kph	0.498	0.144	0.521	288.99	**1.802**

Table 13. Maximum power test results (kW) – LPG jeepneys

Trial	ZTS 904	Go LPG
1	*51.86*	*62.62*
2	*49.45*	*61.32*
3	*49.28*	*61.45*
Average	**50.20**	**61.80**

Overall, the LPG jeepney drive cycle mileage varied from 2.6 to 3.1 km/liter at full load conditions. For constant speeds between 20 and 60 kph at full load conditions, the overall LPG jeepney mileage range was about 3.0 to 1.8 km/liter.

5. CONCLUSIONS AND RECOMMENDATIONS

A benchmarking study has been conducted to estimate fuel mileage ranges of public utility jeepneys running on diesel and liquefied petroleum gas (LPG or Auto-LPG) as part of efforts to introduce alternative fuels in public transport in the Philippines. Selected samples of in-use diesel and dedicated LPG jeepneys plying a short urban route were utilized in both on-road and chassis dynamometer tests to estimate “real world” fuel consumption and verify operational suitability of LPG as fuel for jeepneys. On-road speed-time, travel distance, fuel consumption, and load factor data from the test jeepneys were collected and used to develop specific drive cycles for chassis dynamometer testing of the diesel and LPG jeepneys.

On-road mileage for the diesel jeepney was 6.67 to 6.68 km/liter and 3.84 to 4.24 km/liter for the LPG jeepney at average load factors of about 63.5% and 59.8% respectively.

Table 14 summarizes the mileage ranges from the drive cycle and constant velocity tests for the diesel and LPG jeepneys at 100% load factor together with estimated average fuel properties.

Table 14. Summary of diesel and LPG jeepney mileages – laboratory tests

Fuel	Ave. Density	Heating Value	Heating Value	Drive Cycle Mileage	Constant Velocity Mileage	Drive Cycle Energy Use	Constant Velocity Energy Use
	(kg/ltr)	(MJ/kg)	(MJ/ltr)	(km/ltr)	(km/ltr)	(MJ/km)	(MJ/km)
DIESEL	0.835	42.6	35.6	5.1 – 5.6	12.8 – 8.1	7.0 – 6.4	2.8 – 4.4
LPG	0.555	46.6	25.9	2.6 – 3.1	3.0 – 1.8	10.0 – 8.4	8.6 – 14.4

- The drive cycle and constant velocity average mileages of LPG are respectively about 53% and 23% that of diesel.
- LPG mileage for both drive cycle and constant velocity tests are roughly of the same range.
- LPG drive cycle and constant velocity average energy per kilometer consumption are respectively about 1.4 and 3.2 times that of diesel.
- The results of the on-road and chassis dynamometer tests bracket the mileage range for both jeepney fuels between these load factors.

One reason for the lower mileage of LPG versus diesel is LPG’s about 27% lower heating value than that of diesel on a per liter basis. It is also believed that the LPG jeepneys’ more powerful engines may not have been optimally tuned to the load and driving pattern encountered in the tests.

The diesel jeepney’s good constant velocity mileage suggests the jeepney should be run on routes with longer stretches of constant speed operation (e.g. terminal-to-terminal, lesser jeepney stops between source and destination).

The magnitude by which LPG mileage is lower than diesel impacts the financial viability and sustainability of LPG use in jeepneys. Fuel pricing and other financial features of a program to introduce LPG use in jeepneys should robustly address the mileage difference aspect. From an energy use per kilometer standpoint, the data seem to suggest a lot of room for improving the LPG jeepneys’ technical design (engine size and management system, drivetrain components, etc.) to approach the diesel’s performance.

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