

DEVELOPMENT OF A DRIVE CYCLE MODEL FOR TAXICABS IN METRO MANILA

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Abstract: A drive cycle is a speed-time curve that is used in a chassis dynamometer laboratory to assess vehicle performance such as fuel consumption and exhaust emissions. Four days of survey to obtain speed profile of a typical taxicab operating in Metro Manila is conducted accumulating about 20 hours of speed data. The target cycle has a maximum speed of 90.12 kph, an average of 20.84 kph, maximum and minimum acceleration of 2.95 m/s² and -3.35 m/s² respectively. The idle time is 29.17% and the average running speed is 29.42 kph. The chosen drive cycle has an absolute difference of 13.93 percent. It has a maximum speed of 74.03 kph with an average of 20.84 kph. The maximum acceleration is 1.99 m/s² while the minimum is -2.01 m/s². The chosen cycle also has a distance travelled and duration of 7.76 km and 1,375 seconds respectively with 28.95% of the time idle.

Keywords: drive cycle, taxicabs, speed, acceleration

1. INTRODUCTION

1.1 Background

The taxicab is one of the important transportation modes in the Philippines. According to the Land Transportation Office statistics of 2008, there were 33,158 registered sedan taxis in the whole country; this number makes up 3.69% share on all for-hire vehicles in the country, ranking third to tricycles and jeepneys. About 67% of all the taxicabs operate in the National Capital Region. There are also evident number of taxis in some parts of the country such as in Baguio City, Iloilo City, Bacolod City, Cebu, Cagayan De Oro, Davao City, Iligan City and General Santos City. The Department of Transportation and Communications (DOTC) through the Land Transportation Office (LTO) regulates all taxicabs that operate in the country. The Philippine Clean Air Act of 1999 established the emission standards for mobile sources or motor vehicles. Thus, all taxicabs that intend to operate in the country must conform to these standards. To further improve the emission standards, the Department of Environment and Natural Resources (DENR) shall review, revise and publish the standards every two (2) years, or as the need arises.

A drive cycle model can simulate the actual usage of a vehicle. These models were being used as input for laboratory procedure such as in the use of a chassis dynamometer. A chassis dynamometer is a type of stationary laboratory equipment capable of simulating the road operation of a vehicle. The motivation for most dynamometer studies are comparing fuel consumption of different vehicles and determining emission factors of vehicles. For that, different countries and organizations produce a drive cycle to be used in developing emission standards and in testing of vehicles for certification.

1.2 Objectives

This study seeks to develop a drive cycle for taxicabs operating in Metro Manila. The new model for the drive cycle of taxicabs shall be compared to other known drive cycle plots.

1.3 Significance of the study

More than half of all the taxis in the country are in the National Capital Region; however, there were not many details on how they operate in the streets of NCR. Older units, extended daily operation, aggressive driving, and the use of alternative fuels (like LPG) are some of the observable trends in the business of taxis. These points gave motivation in developing a separate drive cycle model for taxicabs in Metro Manila. The model shall be compared to other existing drive cycle models to determine if there is indeed uniqueness in the driving pattern of taxis.

Also, a major output of this study is a computer program that can automatically create a synthetic drive cycle model from a record of speed traces. The program can repeatedly generate a drive cycle that suits a user-preferred criterion. The methodology and the software can be used to develop drive cycle models of vehicles.

1.4 Scope and Limitations

The following are the scope and limitations set forth for this study:

1. The development of the drive cycle only involves taxicabs that operate in Metro Manila.
2. There were only three vehicles with their corresponding drivers were taken as samples for this study.
3. The drivers were expected to operate on normal conditions, i.e. driving behaviors are not affected by the fact that their speed is being recorded.
4. Field surveys were conducted at different periods each day. There were no specific schedules on the time of survey.
5. The recording device logs speed traces in units miles per hour (mph). Data were converted to kilometers per hour (kph) using a factor of 1.609344 and rounded off to two decimal places.
6. The microtrip based methodology is limited to developing a drive cycle that replicates a driving pattern that has frequent stops.

1.5 Framework of the study

The objective of the study is to develop a separate drive cycle for taxicabs. Vehicle sampling was conducted in order to gather speed data. All data were consolidated in a single file for processing by a computer program. The result was analyzed and compared to other drive cycle models. The general framework of the study is shown in Figure 1.

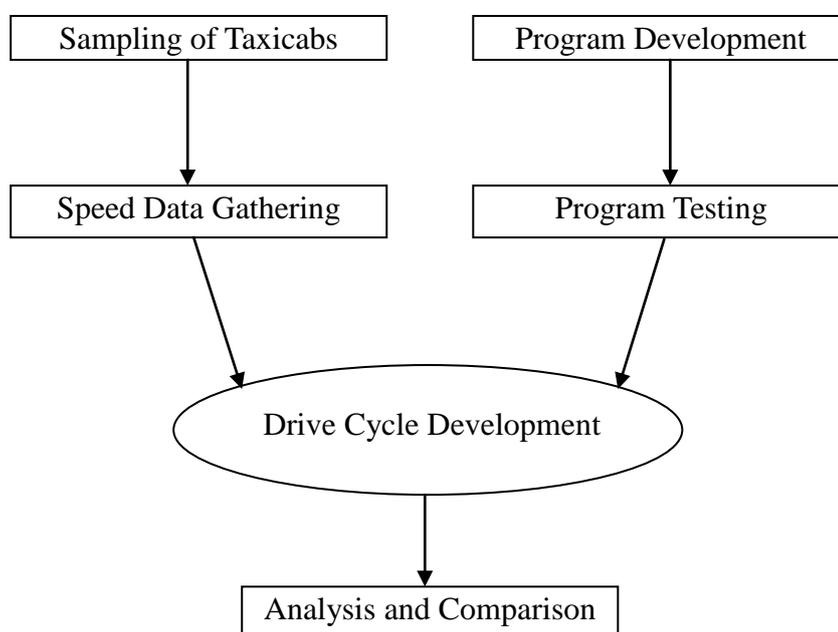


Figure 1. Framework of the study

2. REVIEW OF RELATED LITERATURE

Drive cycle is a vehicle speed-time curve that is used to assess vehicle characteristics and performance such as fuel consumption and exhaust emissions. Drive cycles are produced by different countries and organizations to assess the performance of vehicles. These assessments include fuel consumption analysis and emission factor derivation. Results of such assessments were used in developing policies as well as standards.

2.1 U.S. Federal Test Procedures (U.S. FTP 72 & 75)

The U.S. FTP-72 cycle is also called Urban Dynamometer Driving Schedule (UDDS) or LA-4 cycle. The same engine driving cycle is known in Sweden as A10 or CVS (Constant Volume Sampler) cycle and in Australia as the ADR 27 (Australian Design Rules) cycle. The cycle simulates an urban route of 12.07 km (7.5 mi) with frequent stops. The maximum speed is 91.2 km/h (56.7 mi/h) and the average speed is 31.5 km/h (19.6 mi/h). The cycle consists of two phases: (1) 505s (5.78 km at 41.2 km average speed) and (2) 864s. The first phase begins with cold start. The two phases are separated by stopping the engine for 10 minutes (DieselNet, 2010).

The FTP-75 cycle is derived from the FTP-72 cycle by adding a third phase of 505s, identical to the first phase of FTP-72 but with a hot start. The third phase starts after the engine is stopped for 10 minutes. FTP-75 has a total distance traveled of 11.04 miles (17.77 km), duration of 1874s and an average speed of 21.2 mph (34.1 km/h). The FTP-75 has been used for emission certification of light duty vehicles in the U.S. The emissions from each phase are collected in a separate Teflon bag, analyzed and expressed in g/mile (g/km). The FTP-75 cycle is known in Australia as the ADR 37 cycle (DieselNet, 2010).

2.2 Japanese 10-15 Mode Cycle

The *10-15 Mode Cycle* is currently used in Japan for emission certification of light duty vehicles. A 10-mode cycle has a maximum speed of 40 km/h and covers a distance of 0.664 km at an average speed of 17.7 km/h and lasts 135s. While the 10-15 Mode Cycle is derived from the 10 mode cycle by adding another 15-mode segment of a maximum speed of 70 km/h. The entire cycle includes a sequence of a 15 minute warm-up at 60 km/h, idle test, 5 minute warm-up at 60 km/h, and one 15-mode segment, followed by three repetitions of 10-mode segments and another 15-mode segment. The distance of the whole 10-15 mode cycle is 4.16 km, average speed 22.7 km/h, duration 660 s (or 6.34 km, 25.6 km/h, 892 s, respectively, if the initial 15 mode segment is included). Emissions are measured over the last four segments and are expressed in g/km (DieselNet, 2010).

2.3 Drive Cycles in the Philippines

A local study by Sigua (1997) for the Department of Energy (DOE) and Department of Science and Technology (DOST) entitled "*Performance Testing of Selected Road Vehicles Using a Chassis dynamometer under Simulated Urban and Highway Traffic Conditions*" developed a drive cycle for private vehicles during morning peak periods. The methodology of the study involves: collection of speed traces by chase car technique, development of microtrips (small trips of at least 2 minutes in duration which have to start and end at zero velocity) from on-board data logging, generation of target cycles (actual) and candidates

cycles (synthetic) by combining/concatenating microtrips at random, screening of candidate cycles using joint probability density function (criterion) and lastly the selection of drive cycle.

Another study by Abuzo (2005) established the on-road drive cycle pattern and emission load of tricycles in Metro Manila. The study utilized 2-stroke and 4-stroke in-use tricycles for the conduct of speed survey and speed-emission survey. The representative in-use tricycle model used for the drive cycle test was chosen through random sampling of in-use tricycle population in a certain area.

Also, a study on the effect of Coco-Methyl Ester (CME) blends on fuel economy, engine performance and idle opacity of public utility jeepneys (Thaweesak, 2009) developed a separate drive cycle using spreadsheets for use in simulation of the driving pattern of public utility jeepneys.

3. METHODOLOGY

3.1 Data Gathering

Actual speed data are needed for the development of a drive cycle. An arrangement with a taxi operator was conducted in order to borrow a taxi unit which is going to be the subject of the field surveys. A GPS device was installed on the dashboard of the taxi during survey.

3.1.1 Recording device

A handheld GPS device, the *Garmin GPSmap 76CSx*, has a function of logging tracks of a trip in its default map. It allows for tracing of the routes taken and it also saves the time and date of survey. The device was set to record tracks in time domain of a per-second interval. The velocity at each corresponding time interval was automatically recorded.

The device operates on two (2) AA batteries and can last for about ten (10) hours provided with fresh power source. However, it can only store up to 10,000 track points by default. Since each track point corresponds to 1 second interval, a single survey run has a maximum duration of approximately two hours and forty five minutes. Thus, the data was downloaded to a computer every two and a half hours.



Figure 2. Garmin GPS 76CSx on the Dashboard

3.1.2 Field survey

The driver was instructed to work and drive as if everything is normal. He was also directed to meet up with the researcher every 2.5 hours of run to allow download of the recorded data. The device memory was emptied after each download.

Four (4) days of survey were conducted with a total of 10 different runs. The survey includes two weekdays and two weekends starting from about nine or ten o'clock in the morning with duration of at least two and a half hours (different duration each day). A total of 73,968 (about 20 hours) speed traces were recorded from 3 different drivers and taxi units. The summary of field surveys is shown in Table 1.

Table 1. Summary of Runs

Date	Run	Start	End	Duration	Vehicle	Year Model
1/28/2010 (Thursday)	Run 1	12:07 PM	2:24 PM	2:17	Toyota Avanza	2007
1/29/2010 (Friday)	Run 1	10:39 AM	1:27 PM	2:48	Toyota Corolla	2003
	Run 2	1:35 PM	4:15 PM	2:40		
1/30/2010 (Saturday)	Run 1	9:28 AM	12:16 PM	2:48	Toyota Corolla	1999
	Run 2	12:37 PM	3:01 PM	2:24		
	Run 3	3:06 PM	5:54 PM	2:48		
2/7/2010 (Sunday)	Run 1	8:54 AM	11:40 AM	2:46	Toyota Corolla	2003
	Run 2	11:58 AM	2:45 PM	2:47		
	Run 3	3:38 PM	5:35 PM	1:57		
	Run 4	5:37 PM	6:07 PM	0:30		

3.2 Data Processing

The data gathered from the survey was processed to form a drive cycle model. The goal is to produce a 20 minute drive cycle (about 1,200 seconds). This duration is a practical length for dynamometer testing (Sigua, 1997). All data gathered from the surveys was consolidated in a single file. The technique in creating a drive cycle starts from dividing the data into microtrips. Microtrips are small trips of at least 2 minutes that should start and end with zero velocity. Random combination or concatenation of a few microtrips forms a synthetic drive cycle. In selecting a candidate cycle, the normalized probability distribution of the synthetic cycle was compared to the normalized probability distribution of the bulk data. An absolute difference of less than 20% was accepted as a candidate cycle.

3.2.1 Data preparation

The raw data must be “cleaned” prior to processing. Cleaning implies directly removing erratic data like a sudden jump from 0 to 100 kph in a single second. An example of erratic data is shown in Figure 3. Manual cleaning of the data was implemented in order to carefully examine each data point. The principle regarding data cleaning is that there should be a gradual change in velocity, thus, acceleration values higher than 2 m/s² (put the equivalent in kph per second) were considered questionable. Personal judgment was exercised during the data preparation. Also, idle times that lasted for about 10 minutes or more were reduced to 30 seconds. These were the cases that the driver reported that he took a break during the survey. After cleaning, the taxi data was reduced to 65,233 points (about 18 hours).

Time	Velocity								
1	46.67	1	0.00	1	8.05	1	0.00	1	22.53
2	48.28	2	0.00	2	6.44	2	0.00	2	27.36
3	48.28	3	0.00	3	6.44	3	0.00	3	24.14
4	46.67	4	141.62	4	4.83	4	0.00	4	0.00
5	119.09	5	28.97	5	3.22	5	0.00	5	24.14
6	43.45	6	22.53	6	140.01	6	0.00	6	51.50
7	37.01	7	16.09	7	0.00	7	19.31	7	51.50
8	32.19			8	0.00	8	0.00	8	59.55
9	30.58			9	0.00	9	0.00		
10	30.58			10	0.00	10	0.00		
11	32.19			11	0.00	11	0.00		
				12	0.00	12	0.00		
				13	0.00	13	0.00		

Figure 3. Example of Erratic Data

3.2.2 Development of a Drive Cycle Analysis Program

A program in C++ language was developed for use in this study. The program was compiled using *Bloodshed Dev-C++ Version 4.9.9.2*. All the cleaned data was consolidated and saved in a text file. The program will read this file and store the data in the computer memory. The computer shall process the data to form a candidate cycle. The program algorithm is illustrated in the following sections:

a) Processing of the Target Cycle

The target cycle was derived from the actual speed data of a taxi. It is composed of the speed traces recorded during field surveys. In order to characterize the target cycle, a *Frequency Matrix* from the bulk data was produced using the following equations;

$$C = 1 + 3.3 \log_{10} n \quad (1)$$

$$w_a = \left(\frac{\text{max.acceleration} - \text{min.acceleration}}{C} \right) \quad (2)$$

$$w_v = \left(\frac{\text{max.velocity} - \text{min.velocity}}{C} \right) \quad (3)$$

Where,

- C: number of class intervals
- w_a: class width of acceleration
- w_v: class width of velocity
- n: number of data points

The properties of the target cycle are shown in Table 2.

Table 2. Target Cycle Parameters

Number of data points, n	65,233
Max. velocity:	90.12 kph
Max. acceleration:	2.95 m/s ²
Avg. velocity:	20.84 kph
Avg. acceleration:	0.00 m/s ²
Min. velocity:	0 kph
Min. acceleration:	-3.35 m/s ²
Class intervals:	17
Class width (velocity):	5.35294
Class width (acceleration):	0.411765

The program declares a two-dimensional array with size C x C. This array allocates

memory space for the Frequency Matrix. The program fills up the matrix as it examines each speed values. The Frequency Matrix was then normalized in order to form the *Joint Velocity-Acceleration Probability Distribution Function* of the taxi data. This function shall be the primary criteria in the selection of the candidate cycles.

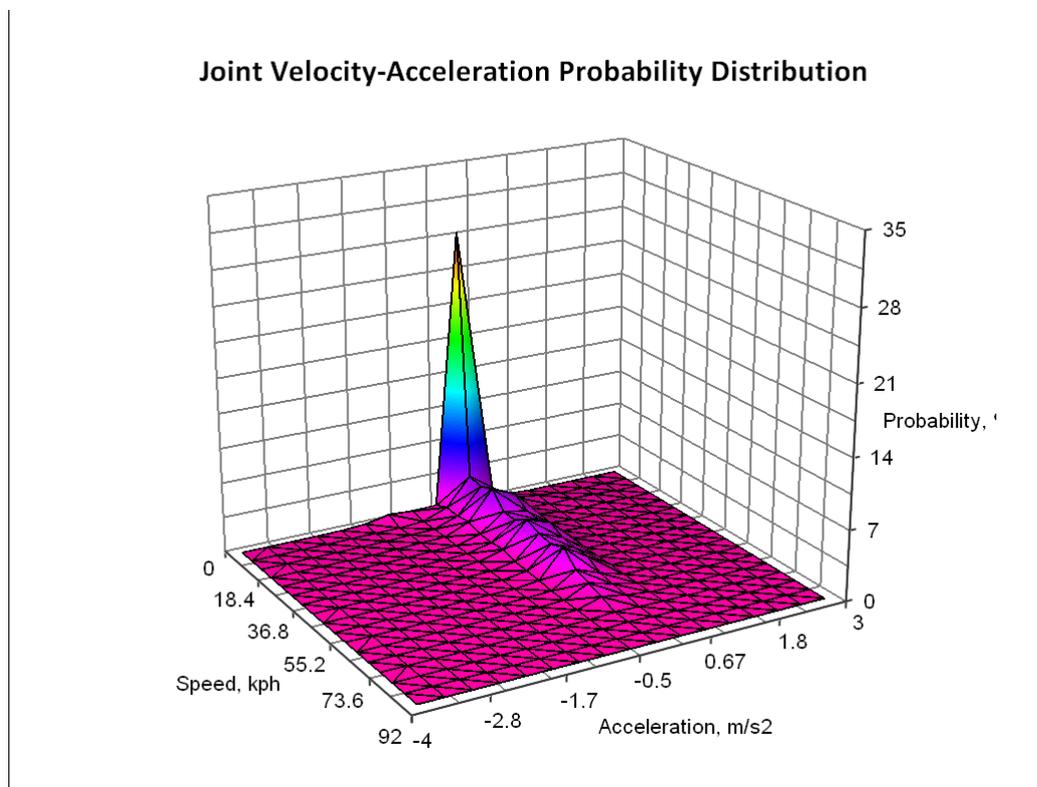


Figure 4. Target Cycle

b) Generation of Microtrips

Microtrips are small trips of at least 2 minutes (120 seconds) in duration which have to start and end at zero velocity. The program will automatically identify these series of points and store them in a two-dimensional array whose row address corresponds to the microtrip number while the columns shall contain the data points. There were 380 microtrips generated from the data of taxi runs. The shortest has duration of 120 seconds and the longest has 930 seconds.

c) Formation of Drive Cycles

A drive cycle was formulated by combining or concatenating, at random order, different microtrips to form a 20-minute drive cycle. The 20-minute cycle is a reasonable duration for a dynamometer testing (Sigua, 1997). The program uses a random function to generate a certain random number. This number shall correspond to the row address of the microtrip array (2D). For one cycle, at most 10 random numbers will be generated which means at most 10 microtrips shall comprise one cycle. A candidate cycle is a synthetic cycle whose probability distribution resembles that of the target cycle. An absolute difference of less than 20% between the two probability distributions (synthetic and target) is generally acceptable. The program shall continue creating a synthetic cycle until a candidate cycle is formed. All

the outputs of the program (i.e. Microtrips, Target Cycle PDF, Candidate Cycle PDF, and Candidate Cycle data points) will be saved as text files. Figure 5 shows the flowchart for the algorithm of the program.

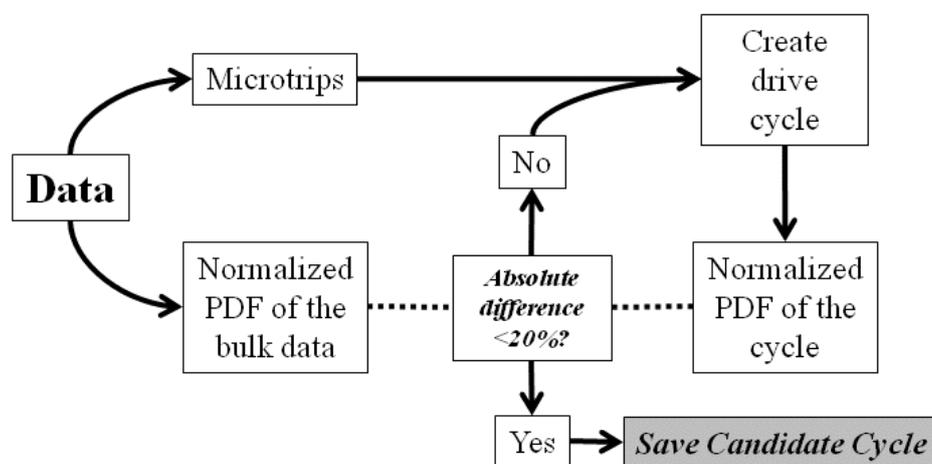


Figure 5. Program Flow

4. RESULTS AND DISCUSSION

There were more than 30 candidate cycles created. Each has an absolute difference of less than 20% with respect to the target cycle. The cycles with the least absolute difference are shown in Table 3.

Table 3. Candidate Cycles

Criteria	Target	C13.93	C15.98	C16.77	C18.00	C19.05	C14.88	C12.40
Absolute difference, %	0.00	13.93	15.98	16.77	18.00	19.05	14.88	12.40
Idle time, %	29.17	28.95	29.60	30.29	30.43	29.95	30.04	28.65
Max Velocity, kph	90.12	74.03	72.42	78.86	62.76	69.20	69.20	74.03
Min Velocity, kph	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max Acceleration, m/s ²	2.95	1.99	2.01	2.91	1.50	2.68	2.68	2.53
Min Acceleration, m/s ²	-3.35	-2.01	-1.79	-2.68	-1.79	-2.68	-2.46	-2.68
Ave. Velocity, kph	20.84	20.31	19.57	20.06	19.95	21.33	20.92	21.04
Ave. Acceleration, m/s ²	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ave. Running Speed, kph	29.42	28.58	27.80	28.78	28.68	30.45	29.90	29.49

For the purposes of this research, Cycle C13.93 shall be taken as the final drive cycle model for taxicabs that operate in Metro Manila. Cycle C12.40 could also be preferred, but the extreme values of acceleration are quite high. Except for the maximum and minimum values, all the other parameters of cycle C13.93 are similar to the target cycle. Cycle C13.93 was selected because it is the second best candidate cycle in terms of percent difference (primary criterion) and it has relatively lower extreme values. Cycle C18.00 have small

extreme values but the percent difference higher compared to *C13.93*. Extreme values (maximum/minimum velocity and acceleration) were considered as secondary criterion because it is aimed that the developed drive cycle can be used in fuel consumption and engine performance studies using chassis dynamometer. It is assumed that a lower acceleration value is easier to manage for a test driver.

The graph of cycle *C13.93* is shown in Figure 6. The three-dimensional graphs of the joint velocity-acceleration probability distribution are also shown in Figure 7 to illustrate the similarity between the target and the synthetic cycle.

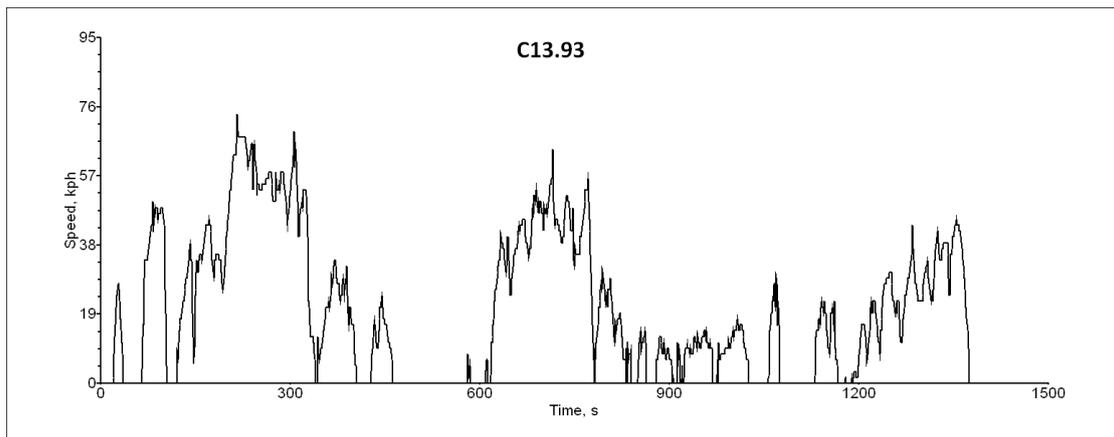
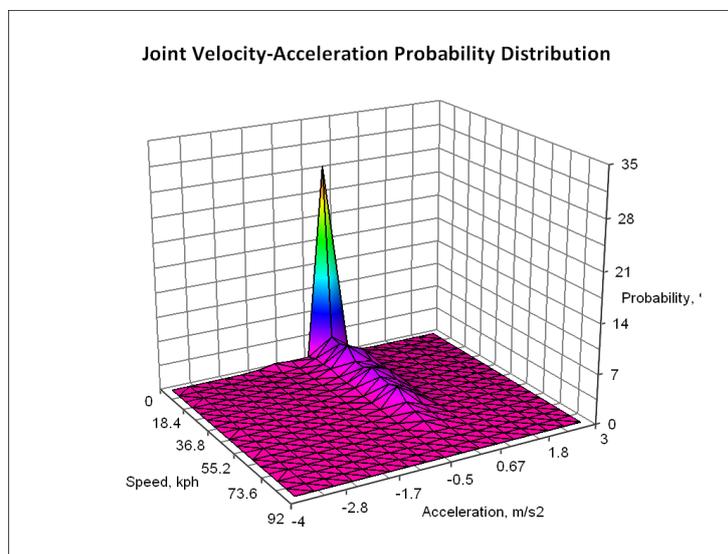


Figure 6. Final Drive Cycle



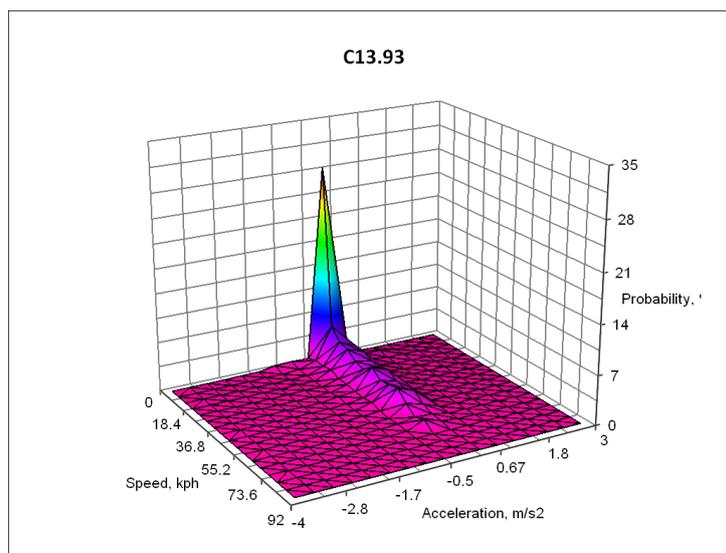


Figure 7. Probability Distributions

Table 4 shows a comparison of three drive cycle models. *C13.93* is the result of this study while *c3638* is the drive cycle from the study done by Sigua (1997) for private passenger cars in Metro Manila in 1997. Some parameters of FTP 72 are also shown in the last column.

Table 4. Comparison of Drive Cycles

Criteria	C13.93	c3638	FTP 72
Idle time, %	28.95	33.72	n/a
Max Velocity, kph	74.03	66.00	91.1
Min Velocity, kph	0.00	0.00	0.00
Max Acceleration, m/s ²	1.99	1.90	n/a
Min Acceleration, m/s ²	-2.01	-2.10	n/a
Ave. Velocity, kph	20.31	14.30	n/a
Ave. Acceleration, m/s ²	0.00	0.00	0.00
Ave. Running Speed, kph	28.58	22.14	31.5

The obvious difference between *C13.93* and *c3638* is the speed. This study shows that on the average, taxicabs in Metro Manila drive faster than other passenger cars.

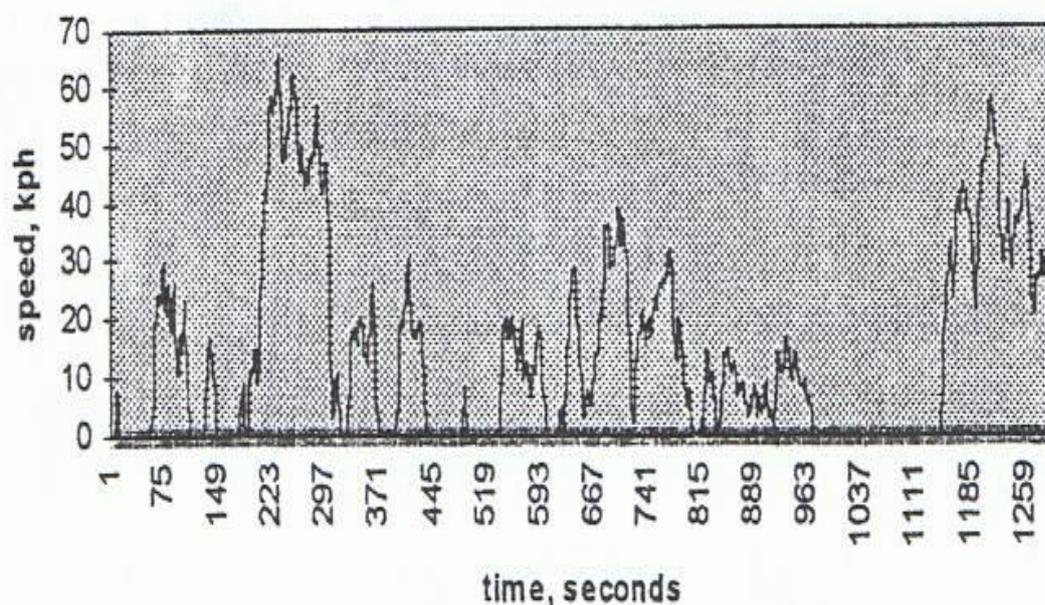


Figure 8. Graph of c3638 (Source: Sigua, 1997)

5. CONCLUSIONS

A drive cycle for taxicabs in metro Manila is developed in this research. The cycle has a maximum velocity of 74.03 kph, with an average of 20.84 kph. The maximum acceleration is 1.99 m/s^2 while the minimum is -2.01 m/s^2 . The final cycle also has an average running speed of 29.42 kph, a distance travelled and duration of 7.76 km. and 1,375 seconds respectively with 28.95% of the idle time.

The result was compared to the Metro Manila driving cycle developed by Sigua (1997). The drive cycle in this study shows that taxicabs drive faster than other passenger cars in Metro Manila. The graphs of the driving patterns also suggest that taxis are more active when it comes to speed changes.

6. RECOMMENDATIONS

6.1 Further Studies

This study can further be improved by acquiring more data on speed traces of taxi. The surveys conducted in this research were limited only to four days at a certain time of day. It is recommended to acquire data for one whole week at a specified time of the day. At least 5 hours per day during peak periods (high travel demand) could be appropriate.

Research extension can be done by using the results of this study in the evaluation of emission factors of taxi with respect to vehicle age and/or model. Also, an elaborative analysis of the alternative fuels being used for taxis may be conducted using the results of this research.

5.2 Use of the Methodology and the Drive Cycle Analysis Program

The methodology used in this research can be applied to any drive cycle development in an urban route. The Drive Cycle Analysis Program can be used to develop any drive cycle model from a set of speed data points provided that the data was gathered from an urban route with frequent stops.

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