PHILIPPINE ENGINEERING JOURNAL
PEJ 2004; **Vol. 25 No. 2**:35–52

Development of Drive Cycle and Emission Concentration Models for In-Use Tricycles in Metro Manila

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ABSTRACT

The objectives of the study are to develop the drive cycle for the tricycle, the local three-wheelers used for public transport in the Philippines, and quantify emissions from these vehicles as well as determine some of the factors that affect the emissions. The drive cycle for tricycle is developed with a maximum speed of 43.0 kph, maximum acceleration of 6.97 m/s^2 (minimum acceleration of 6.44 m/s^2), and average speed of 19.94 kph. Results indicate that 4-stroke tricycles have lesser HC and CO emission concentrations compared to the 2-stroke type. Regression analysis revealed that CO concentration is significantly affected by fuel-oil ratio and loading.

Keywords: drive cycle, tricycles, emissions

1. INTRODUCTION

Tricycles (TC) are modified motorcycles with different types of couch (either on the side, center, rear-back, etc.). In 2001, there are 3,865,862 vehicles registered in the Department of Transportation and Communications-Land Transportation Office (DOTC-LTO) where about 1.3 million (34%) are motorcycle/tricycle vehicles and more than half of this number represents the tricycles. In Metro Manila alone, there are 211,450 registered motorcycle/tricycle vehicles. The DOTC indicated that this volume demonstrates a remarkable growth of 13.7% annually from the time the LTO transferred its motorcycle/tricycle regulatory function to the local governments in 1991. Furthermore, the Metro Manila Urban Transportation Integration Study

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Received June 17, 2005
Revised June 16, 2006
Accepted June 23, 2006

(MMUTIS) in 1996 showed that about 27% of the share of motorized vehicle trips was attributed to tricycles.

Motor vehicles burn fuel in the engine to create power and, generally, these are hydrocarbon-based fuels that include gasoline and diesel. Tricycles use gasoline as fuel. Gasoline in particular, emits high levels of suspended particulate matter (SPM) from vehicles with two-stroke engines, lead (in leaded gasoline), carbon monoxide (CO), oxides of nitrogen (NO_x), and volatile organic compound (VOC). On the other hand, since hydrocarbon-based fuels are compounds that contain H and C atoms, hydrocarbon (HC) pollutants are produced. The unburned (incomplete combustion) HCs are emitted as white smoke and the partially burned HCs are emitted as black smoke that are visible exhausts from the engine.

The presence of tricycles in urban areas, particularly in residential subdivisions, threatens the well-being of both children and elderly residents who are susceptible to nasal and lung problems. These problems also arise due to the limited spatial area in urban areas limiting the dispersion of these pollutants (confining them to a limited space thereby delaying the dilution process) in the ambient air.

One of the provisions of the Philippine Clean Air Act (CAA)[4] of 1999 required in-use, rebuilt and imported second-hand motor vehicles to comply with the emission standards (equivalent to Euro 1) starting January 2003. Emission limits for CO at idle mode was set at 6% for motorcycles registered before January 2003 and 4.5% for all motorcycles registered on or after January 2003. Emission limits for HC had been set at 7,800 ppm for urban areas and 10,000 ppm for rural areas since June 2003. However, the standards did not specifically define tricycles that have sidecars which load up to 2 or more passengers.

The implementation of the CAA on tricycles continuously encountered difficulties since January 2003. The organizations of tricycle operators and drivers had continuously opposed the enforcement of the emission standards primarily for the reasons of lack of readiness of the sector, lack of consultation and too strict emission standards. Information has also been lacking on the reasons behind the high emissions from tricycles and their contribution to the total emissions. Government and non-government organizations with development agencies supported by the academe since then had conducted several studies and intervention projects focused on solutions to reduce emissions from tricycles to enable them to comply with the standards.

The study expects to initially establish information on tricycle emission concentration. Mixing lubricating oil in the fuel, overloading of the vehicle, and use of recycled oil have been common practice.

The objectives of the study are:

- to develop the tricycle drive cycle;
- to quantify the on-road emissions from tricycles; and
- to evaluate effects of various engine types, fuel-oil ratios and loads on on-road emissions

The establishment of the tricycle drive cycle will be useful for the development of emission factor and will be more accurately quantify emissions from tricycles which will be important input to emission inventories from transportation. Emission inventories are very useful in the setting of emission standards and their impacts.

2. REVIEW OF RELATED LITERATURE

A study by Manalo [14] indicated that tricycles were legalized in 1985 through Letter of Instruction (LOI) 1482 and in 1988, tricycles were considered as for-hire vehicles. Thus, the present noticeable increase in the volume of motorcycle/tricycle registration was caused by the aforementioned policies that were implemented by the government to legitimize the use of tricycles as a public mode of transport exacerbated by uncontrolled franchising in the local government units.

Kojima *et al.* [13] indicated that vehicular air pollution is severe in South Asia, where about half of the motorcycle population is two-stroke engine type and gasoline-fueled. Prevalently, these are significant sources of visible smoke (white smoke), particulate emissions (PM_{10}, SPM) and gaseous pollutants such as HC, CO, NO_x (MECA, 1999). In addition to this, deterioration of air quality in the region worsened due to poor vehicle maintenance, extended vehicle service life, adulterated fuel and lubricants, excess usage of lubricants, and overloading vis-á-vis the design load capacity of the vehicle. The study also said that 2-stroke vehicles in general are patronized over 4-stroke engines for its advantages in terms of vehicle cost, engine torque and power efficiency, mechanical simplicity, light and small engine design, smooth operation, and low NO_x emission.

Drive cycle is a speed-time history that forms the basis of measurements of vehicle performance and characteristics such as fuel consumption and exhaust emissions (Watson, [19]). Guensler [11] study indicated that 25 representative cycles were developed using three-dimensional Watson plots that show the frequency distribution of vehicle operation at all combinations of speed and acceleration value. The Watson plots of the 25 cycles are produced to typify trips undertaken on various roadway classes under specified levels of service and would serve as new test cycles that are similar to those of the Watson plots of the observed activity.

Another study done by Effa and Larsen [8] detailed that due to the high cost of emission testing, alternative to 25-bin approach was a reduced 10-bin cycle where seven emission-testing cycles were developed for freeways and three for arterials. The freeway cycles were developed by chase car technique. This technique requires an instrumented vehicle to chase cars along the traffic stream in order to determine typical city driving (Carlock, [3]). Each time the observer in the chase vehicle perceives a significant change in the traffic density, the end of a vehicle activity snippet is terminated and the beginning of the new vehicle activity snippet was defined. The determination for the best cycle for each bin was done through a criteria evaluation in terms of mean speed, percent idle, etc., of the random test cycle that were compared to the average characteristics of the total bin. The best match to the average bin characteristics that also achieved 80% or better similarity to the bin speed (in 5 mph increments) and acceleration (in 0.5 mph/sec increments) matrix was deemed the best cycle.

In the Philippines, a study by Sigua [15] for the Department of Energy (DOE) and Department of Science and Technology (DOST) initiated performance testing of vehicles using chassis dynamometer. The study simulated the urban and highway traffic conditions and the drive cycles developed were used to compare fuel consumption of different vehicles and measure the exhaust emissions of vehicles in fixed locations. The methodology of the study involved: 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 (synthetic) or derived cycles by combining microtrips at random, screening of candidate cycles using joint probability density function (criterion) and lastly the generation of drive cycle.

3. SURVEY OF SPEED AND ON-ROAD EMISSION CONCENTRATION

The study is divided to two portions: a) development of the tricycle drive cycle that consists of the acceleration, deceleration, cruise and idle (ACDI) modes; and, b) correlation of measured tricycle tailpipe emission concentration and operating characteristics such as fuel-oil ratio and loading. The first involves the generation of on-road speed-time graphs and the development of drive cycle evaluated by joint probability density function (JPDF). The second involves the development of an emission concentration model for mainly carbon monoxide (CO) using multiple linear regression method.

The study area was at Teachers Village in Diliman, Quezon City. The area was chosen because it has one of the highest registered number of tricycles in Metro Manila with an established organization of tricycle operators and drivers, its road environment is relatively flat (two-way, two-lane road) and the regular trip makers ride the tricycle.

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 stratified-systematic sampling of in-use tricycle population in Metro Manila. The result of the Sloven's formula showed that at a 0.025 margin of error for a total population of 167,848, the sample size requirement is about 1,585 samples. The actual sample size taken for the entire population of tricycles in Metro Manila was 2,257. The result showed that the representative tricycle to be used for the drive cycle test is tricycle model X, a two-stroke in-use motorcycle with a cylinder size of 125cc and a registration age of about two years.

The tricycle speed and speed-emission surveys were conducted in May-July 2002. For the speed survey for the generation of drive cycle, speed data were collected from the runs of the representative tricycle drawn during peak hour periods along the routes of the study area. This involved monitoring of vehicle movement using video camera and cyclo computer instrument. The tricycles for the test runs were checked in terms of the condition of the wheel tires, the gas level in the tank, the auto lube condition, and the soundness of the engine. The baseline load condition of vehicle setup includes one driver and one surveyor, the cyclo computer and the recording equipment. Two 30-minute runs were conducted in the morning and in the afternoon for each day for 7 days.

The application of the "chase car "technique to tricycles for data collection was observed to be effective along secondary roads where movements are quite flexible compared to that of chasing cars along highways. Using the technique was also an advantage since tricycle drivers tend to be less observant of being followed or chased because their focus during driving is usually on looking for (possible) passengers ahead of the route and on unloading of passengers along the road.

The speed-emission survey for the development of emission models involved a second-by-second HC and CO emissions measurement and speed. The survey includes the setup of the cyclo computer, gas analyzer and data-recording setup for the survey runs. In the preparation of the tricycle and cyclo computer, the setup had to follow the same procedure as the speed survey setup for the drive cycle development and a gas analyzer was incorporated for the collection of CO and HC emission concentrations. Conditions of loadings are considered in the survey such that the baseline load condition has one driver and two surveyors while higher loadings happen when the concrete monuments are added (load 1 and load 2). Fuel-oil ratios considered were the following: 1:20, 1:30, and 1:40 and the baseline or auto-lube condition. A survey run is defined as the speed-emission concentration measurement per second, which is collected for at least 30 minutes. The outline of the speed-emission survey is shown in Table I.

4. DEVELOPMENT OF THE TRICYCLE DRIVE CYCLE

The drive cycle development involved a simulation program that adopts the concept of joint probability density function (JPDF) as an initial criterion. The JPDF criterion involves the joint intersection between velocity (Y_1) and acceleration (Y_2) values following the form of the probability function (Equation 1):

$$f_{x,y} = \frac{\delta^2}{\delta x \delta y} f_{x,y}(x,y) \tag{1}$$

$$\begin{aligned} AbsoluteDifference &= /Target - Candidate/ \\ &= \sum_{x_i}^{x} \sum_{y_j}^{y} \left(T_{x,y}(x_i, y_j) - R_{x,y}(x_i, y_j) \right) \end{aligned} \tag{2}$$

The joint events were evaluated in its matrix form to get the frequency of each unique pair of velocity and acceleration intersection. A comparison between a target JPDF (the entire speed traces) and a candidate JPDF from simulation of speed traces is considered. The numerical equivalent of the absolute difference (Equation 2) of the two JPDF of velocity and acceleration pair served as an initial criterion for the acceptance of a candidate. The candidates that fall within the acceptable range of difference (e.g. 25%) are accepted and candidates greater than this value are discarded. Figure 1 shows the comparison of the target and the candidate joint velocity-acceleration probability density functions.

This type of representative vehicle was used for the on-road speed survey data gathering and the development of the drive cycle. A computer program "Drive Cycle Analysis" was developed to perform the work necessary to generate the tricycle drive cycle. The program was segregated by modules represented by the general flow of the program process (Figure 2) as shown below.

Speed data were lumped into one single data file in spreadsheet format and then converted to kilometers per hour (kph) unit and acceleration in meters per square second (m/s^2). The total speed data points collected for the morning peak hour period was about 19,000 and about 17,600 data points for the afternoon peak hour period. The total number of data points for both periods of survey run was about 36,000 representing roughly 10.2 hours of travel. The lumped file is then used for the drive cycle program, where it was converted (to database format) and placed in a temporary file, which represents the first stage of the program flow.

The speed-time data contained in the database of the program represent the target cycle. The second stage involved the processing of the database records (from stage 1) to obtain the distribution of each unique pair of speed and acceleration value traced from the source data. The following statistics were computed: percentage distribution (joint velocity-acceleration

					fuel-oil ratio			
type	model	driver	run	loading	baseline	1:20	1:30	1:40
in-use 2-stroke tricycle	model X	Driver 1	R1	baseload	•	••		
			R2	baseload+load 1	•	••		
			R3	baseload+load 1+load 2	•	••		
		Driver 2	R1	baseload	•		••	
			R2	baseload+load 1	•		••	
			R3	baseload+load 1+load 2	•		••	
		Driver 3	R1	baseload	•			••
			R2	baseload+load 1	•			••
			R3	baseload+load 1+load 2	•			••
	model Y	Driver 1	R1	baseload	•	••		
			R2	baseload+load 1	•	••		
			R3	baseload+load 1+load 2	•	••		
		Driver 2	R1	baseload	•		••	
			R2	baseload+load 1	•		••	
			R3	baseload+load 1+load 2	•		••	
		Driver 3	R1	baseload	•			••
			R2	baseload+load 1	•			••
			R3	baseload+load 1+load 2	•			••
	model Z	Driver 1	R1	baseload	•	••		
			R2	baseload+load 1	•	••		
			R3	baseload+load 1+load 2	•	••		
		Driver 2	R1	baseload	•		••	
			R2	baseload+load 1	•		••	
			R3	baseload+load 1+load 2	•		••	
		Driver 3	R1	baseload	•			••
			R2	baseload+load 1	•			••
			R3	baseload+load 1+load 2	•			••
in-use 4-stroke tricycle	model W	Driver 1	R1	baseload	••	not applicable		
			R2	baseload+load 1	••			
			R3	baseload+load 1+load 2	••			

Notes:
• : one 30-minute run = 0.5 hour monitoring (speed-time data and emissions (CO and HC) data)
•• : two 30-minute runs = 1 hour monitoring (speed-time data and emissions (CO and HC) data)
baseline - fuel only in the tank; auto lube of the engine is working
1:20 ratio is a proportion of 1- 200 ml of 2T oil for every 4 liters of gasoline; auto lube of the engine is working
1:30 ratio is a proportion of 1- 200 ml of 2T oil for every 6 liters of gasoline; auto lube of the engine is working
1:40 ratio is a proportion of 1- 200 ml of 2T oil for every 8 liters of gasoline; auto lube of the engine is working
base load = tricycle driver's weight + constant load (2 surveyors + generator + automotive emission analyzer)
load 1 = 12.26 kg (concrete cylinder 1)
load 2 = 12.26 kg (concrete cylinder 1) + 11.69 kg (concrete cylinder 2)

Table I. Outline of Tricycle Speed-Emission Survey

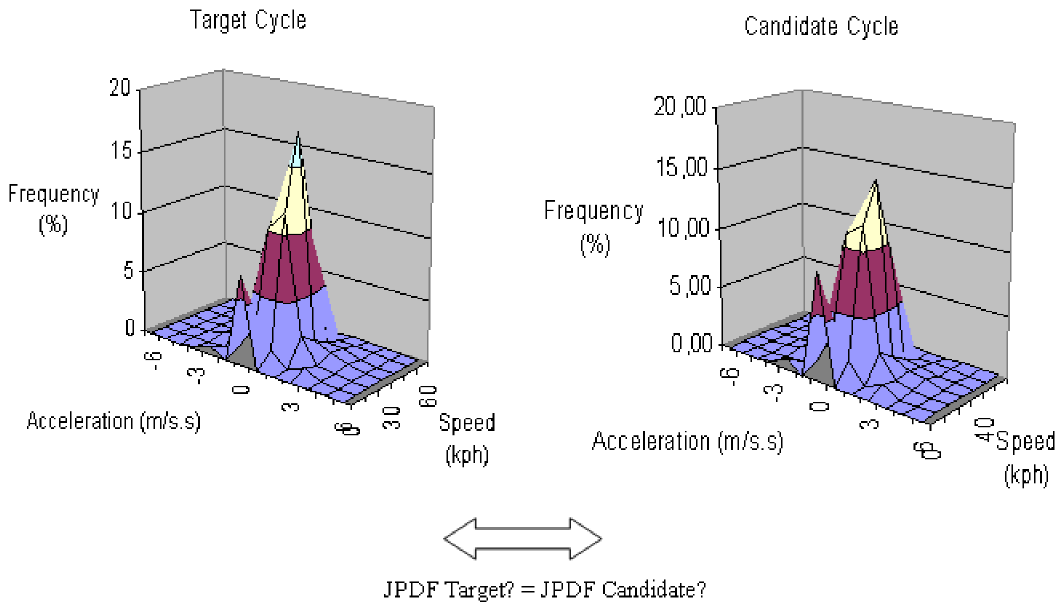

Figure 1. Comparison of Target and Candidate Joint Velocity-Acceleration Probability Density Functions

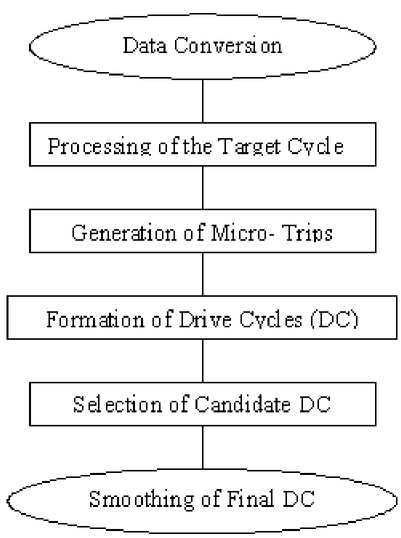

Figure 2. "Drive Cycle Analysis" Program Process

CRITERIA	TARGET	RCF1	RCF2	RCF3	RCF4	RCF5	RCF6	RCF7	RCF8	RCF9	RCF10
Difference		13.15%	13.53%	13.18%	10.83%	12.23%	13.37%	13.59%	11.83%	13.90%	12.98%
MaxSpeed	57.5	47.5	49.0	45.0	43.0	39.5	43.3	53.0	46.5	44.5	45.0
MinSpeed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MaxAccel	11.0	3.8	8.5	6.4	7.0	6.4	5.5	8.8	6.3	4.9	3.7
MinAccel	-13.6	-3.8	-13.6	-7.8	-6.4	-7.8	-5.1	-9.8	-4.3	-6.3	-4.0
AveSpeed	20.2	20.8	20.3	20.3	19.9	20.0	20.7	20.8	20.3	19.5	20.5
AveAccel	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AveRunning	21.0	21.3	20.9	20.7	20.7	20.6	21.3	21.4	20.9	20.3	21.2
IdleTime	3.69%	2.15%	2.47%	2.29%	3.69%	2.85%	2.72%	2.79%	2.85%	3.86%	3.42%

RCF-Random Candidate File

Table II. Ten Candidate Cycles

probability density function), percentage idle (%), maximum and minimum velocity (kph), maximum and minimum acceleration (m/s^2), average velocity (kph), average acceleration (m/s^2), and average running speed (kph). The frequency distribution of each joint speed-acceleration value was then computed to get the corresponding percentage distribution value of the processed data. In the third stage, from the database of the time-velocity traces, micro-trips or small trips with duration of at least two minutes (equivalent to 120 seconds) that start and end at zero velocities, were generated, segregated and stored in a spreadsheet file under a microtrip folder. A total of 138 microtrips were generated.

The candidate driving cycles of the program were then processed by combining at random the microtrips to generate a 20-minute drive cycle (Sigua, [15]). The candidate drive cycles were then subjected to a joint velocity-acceleration probability density function (JPDF) criterion. The JPDF of the candidate and the target cycle are then compared in terms of its absolute difference. The absolute difference of 20% (Effa and Larsen, [8]) was chosen as a criterion for a candidate cycle to be considered as acceptable. Finally, the accepted drive cycle candidates were then processed similar to that of the target cycle to get the corresponding statistics and were converted to spreadsheet format, and filed in the candidate cycle folder. In generating the microtrips, the starting zero (1-zero data point) should be paired with the zeroes detected after the minimum 120 seconds (2-minute microtrip) criterion. However, if within the cycle zeroes are detected but the 2-minute criterion is not met then another set of zeroes would be considered as part of the cycle. When the cycle meets the criteria then the candidate microtrip is selected, the last zero ending this microtrip should then serve as a starting point for the next generated candidate microtrip (serving continuity of data points in the cycle). A total of 10 candidate cycles with the least absolute difference are summarized in Table II. Among all candidate cycles generated, the candidate cycle RCF4 was found to be the most likely choice to serve as representative drive cycle of tricycle driving in Metro Manila. It has the least absolute difference of 10.83% and a maximum velocity of 43.0 kph compared to the target of 57.5 kph (that underestimates the target by 14.5 kph). The profile of the RCF4 time-velocity trace is shown in Figure 3.

The similarity of the target JPDF with the candidate RCF4 JPDF is shown in a three-dimensional graph in Figure 4 and Figure 5, respectively.

In the RCF4 cycle, the speeds of tricycles ranged from 20 kph to 30 kph (between acceleration rates of -2.0 m/s^2 and 2.0 m/s^2) similar to the distribution of the target cycle. The values of

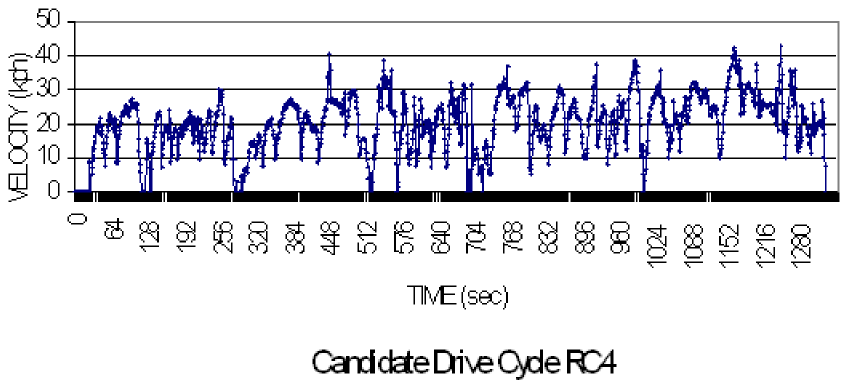

Figure 3. Time-Velocity Trace of Candidate Cycle RCF4

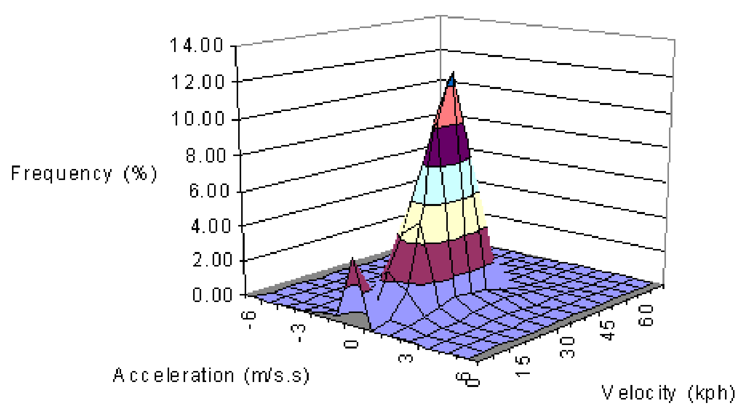

Figure 4. Joint Velocity-Acceleration Probability Density Function of the Target Cycle

idle time in Table II demonstrated very low percentage values in each of the cycles compared to the usual idle time of almost 1/3 of the cycle (Sigua, [15]) in city driving (using cars). This may be attributed to the fact that tricycles ply along residential areas that are generally secondary roads and movements of vehicle in the area are not hampered by long delays and stops at intersections or by traffic congestion. In addition to this, short cruise and stops in the speed patterns are primarily due to the presence of humps along the road network and the loading and unloading of passengers along the route.

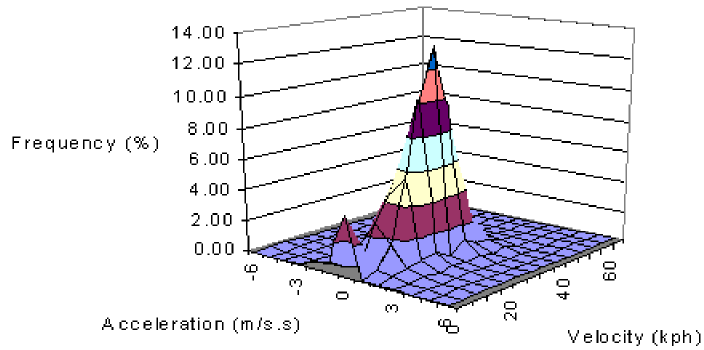

Figure 5. Joint Velocity-Acceleration Probability Density Function of the Candidate Cycle RCF4

5. DEVELOPMENT OF TRICYCLE EMISSION CONCENTRATION MODEL

The results of the speed-emission survey include: a second-by-second reading of speed, acceleration, CO concentration (%) and HC (ppm) concentration by volume. The data were segregated according to different combinations of fuel-oil ratios and loadings on tricycle models W, X, Y, and Z.

The average CO and HC emission concentrations of in-use tricycles with baseline loading and for different fuel-oil ratios (1:20 or 1:30 or 1:40, or auto-lube) are shown in in Figure 6. CO concentrations for 2-stroke tricycle (i.e., model X, Y and Z) range from 1.2% to 5.0% while concentrations of HC range from 3,900 ppm to 8,900 ppm. For tricycles with 4-stroke engines (Model W), the average CO concentration ranges from 1.7% to 2.5%. The corresponding HC concentration ranges from 211 ppm to 388 ppm.

Figure 7 shows the variation of HC and CO emission concentrations with speed and acceleration of tricycles with two-stroke engines. The concentration of CO reached as high as 9% while HC concentration reached as high as 13,000 ppm. The speeds clustered from 5.0 kph to 35.0 kph with corresponding acceleration ranged from -3.0 m/s^2 and 3.0 m/s^2. In addition, the graph also shows that at idle conditions (0 kph), HC concentration reached as high as 13,000 ppm while CO concentration reached as high as 10% by volume. At idle conditions, for all models of the two-stroke tricycles, the CO concentration averaged at 3.73% with a maximum value of 7.93% while the HC concentration averaged at 6,048 ppm with a maximum value of 13,040 ppm. At running conditions, the CO concentration averaged at 3.72% with a maximum of 9.74% while its HC concentration averaged at 6,089 ppm with a maximum value of 13,370 ppm.

The variation of emission concentrations of CO and HC with speed and acceleration for tricycles with 4-stroke engines are shown in Figure 8. Concentration of CO reached as high as 6.0% whereas HC concentration reached as high as 1,300 ppm where speeds clustered around 5.0 kph to 40.0 kph and acceleration ranged from -2.0 m/s^2 to 2.0 m/s^2. At idle conditions, the CO concentration averaged 2.28% with maximum a value of 4.25% while its HC

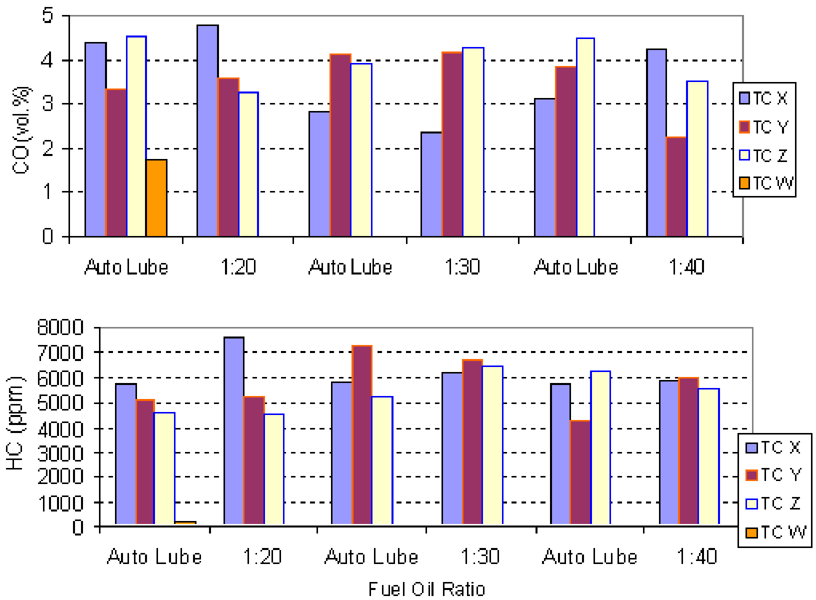

Figure 6. Mean CO and HC Emission Concentrations for Baseline Load

concentration averaged 307 ppm with a maximum value of 620 ppm. At running conditions, the CO concentration averaged 2.29% with a maximum value of 6.16% while its HC concentration averaged 339 ppm with a maximum value of 1,104 ppm. It can be observed that in-use tricycles with 4-stroke engines emit lower volumes of CO and HC than tricycles with 2-stroke engines. The wide range of difference of emission concentration is not simply expected but is also based on the empirical results that were drawn from three samples of vehicle for each tricycle model and engine type. However, noticeable emissions of 4-stroke tricycles showed that in general the CO concentrations were relatively high with relatively low HC concentrations. When vehicles are subjected to varying loads, the emissions for both engine types across all vehicle models (W, X, Y and Z) also vary. There was great variability of CO and HC emissions for various fuel-oil ratios for 2-stroke tricycle models. This variability may be attributed to limitations in the controlling the operating conditions for the test tricycles. Therefore, no specific recommendations for a suitable fuel-oil ratio that will yield lesser emissions can be drawn from the results.

On the other hand, scatter plots of emission versus acceleration demonstrated that the concentrations of pollutants do not vary significantly with acceleration and deceleration. It can be noted that there is an increasing trend of HC concentration with time and CO concentration seemed to vary speed.. These are shown in Figure 9, where the lag in measuring emission was also shown due to the limitations of the equipment and the method of measurement. The emission concentration, Y, is expressed as a function of vehicle speed, loading and fuel-oil

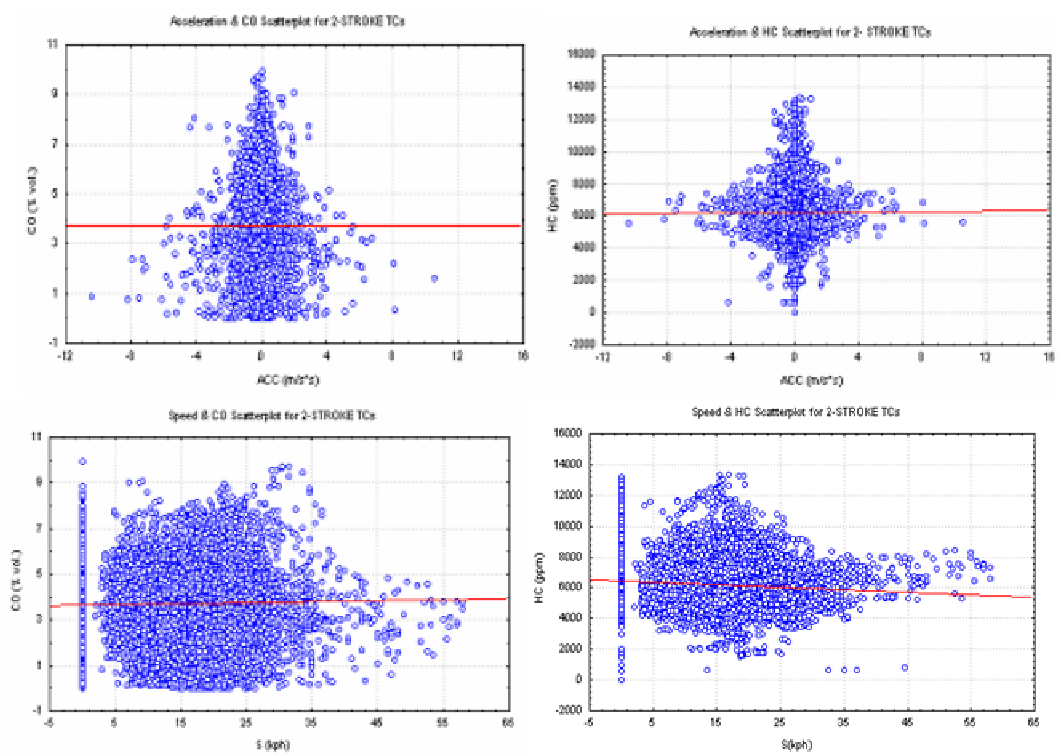

Figure 7. Emission-Acceleration and Emission-Speed Scatter Plots for Tricycles with Two-Stroke Engines

ratio, represented by the multiple linear regression equation (Equation 3):

$$E\{Y\} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 \quad (3)$$

where: Y = emission concentration,
β_0 = intercept of the line on the y axis
$\beta_1, \beta_2, \beta_3, \ldots, \beta_6$ = linear regression coefficients
X_1 = dummy variable for baseline loading = 1 driver + 2 surveyors + equipment
X_2 = dummy variable for baseline loading with additional 1 concrete monument load
X_3 = dummy variable for tricycle with functioning auto-lube device
X_4 = dummy variable for tricycle with 1:20 fuel-oil ratio
X_5 = dummy variable for tricycle with 1:30 fuel-oil ratio
X_6 = speed of the tricycle (km/h)

The results of the CO emission models derived from stepwise analysis of the multiple linear regression estimates are summarized in Table III by tricycle model and engine type. The generated models showed good fits with R^2 values between 0.70 to 0.80, except for tricycle model X at R^2 = 0.60. Across all tricycle models, the regression results showed that the

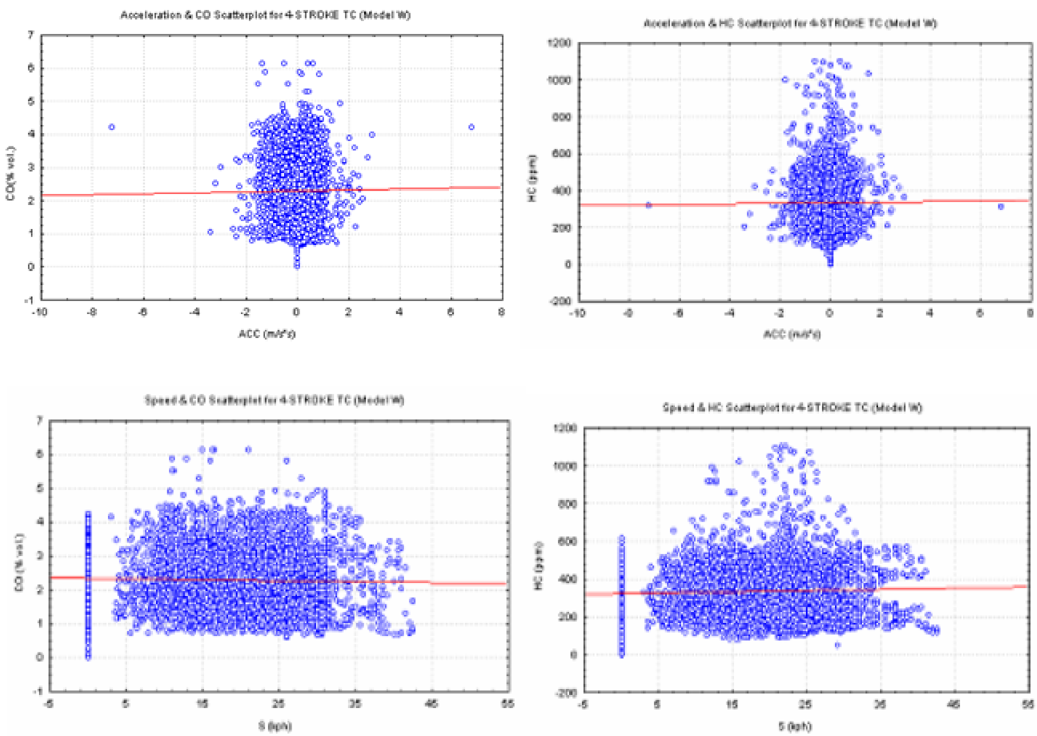

Figure 8. Emission-Acceleration and Emission-Speed Scatter Plots for Tricycles with Four-Stroke Engines

relationship between CO emission concentration and the independent variables (i.e., dummy and predictor) at $\alpha = 0.05$ is significant. Also, loading and fuel-oil ratio significantly affect the emission concentration of CO of tricycles. Results of the regression analysis for 4-stroke tricycle model W show that baseline load (X_1), baseline load + load 1 (X_2) and the speed influence the emissions. The CO emission model for tricycle model X showed that fuel-oil ratio has a negative effect except in the auto-lube condition. Increasing the load (baseline load +load 1) has a positive significant effect whereas the tricycle speed also has a positive effect although it was minimal. For tricycle Y, increasing the loading level of the tricycle bears negatively affects the CO emission while the increasing levels of oil in the fuel including the auto-lube condition of the vehicle has a significant positive effect. For tricycle Z, results show a positive significant association of fuel-oil ratio, auto-lube condition and the emission concentration except for a negative effect of 1:20 fuel-oil ratio. The emission is also positively affected by the speed.

Similar statistical and correlation analyses were also conducted for HC concentration as the dependent variable. Initial results show scatter plots similar to that of CO, however, the correlation between variables was lower. An attempt to correlate HC and CO emission concentration in the case of tricycle model X showed that there is a significant correlation (0.52) between pollutants, although other tricycle models did not behave as such.

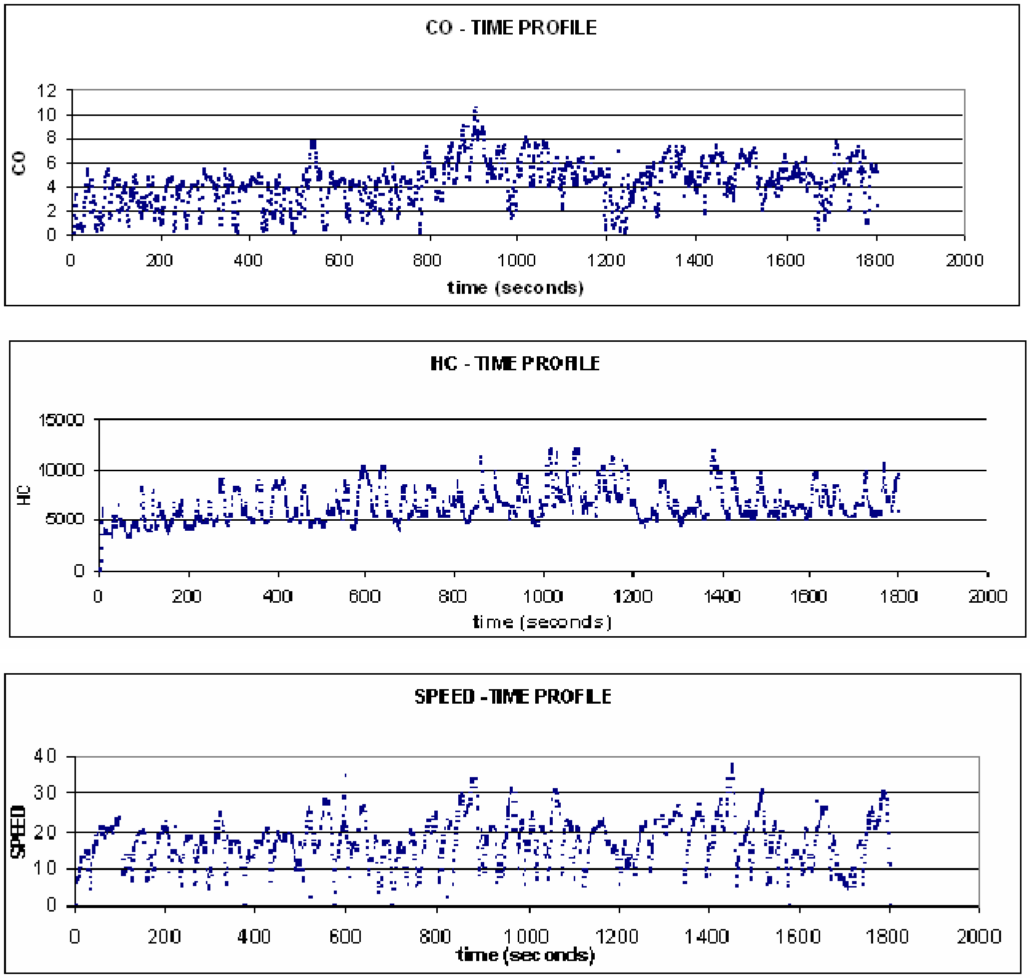

Figure 9. Speed-Time and Emission-Time Plots for 2-Stroke Tricycle Model W

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The tricycle drive cycle for Metro Manila is developed to simulate the movement of the tricycle in urban residential environments. The results of the speed survey in the study showed that for both the morning peak hour run (6:00 A.M. to 7:00 A.M.) and afternoon peak hour run (5:30 P.M. to 6:30 P.M.), the speed values range from 20 kph to 30 kph with corresponding acceleration values that range from - 2.0 m/s^2 to 2.0 m/s^2. The parameters of the developed drive cycle of tricycle are summarized as follows:

Maximum velocity = 43.0 kph

Engine Type	4-Stroke Engine	2-Stroke-Engine		
	Model W	Model X	Model Y	Model Z
Constant/Intercept	1.9112 ($t = 77.45$)	2.6202 ($t = 45.88$)	3.4072 ($t = 99.94$)	3.3224 ($t = 84.79$)
X_1 (baseline load)	0.0254 ($t = 1.56$)			
X_2 (load 1)	0.9265 ($t = 57.73$)	0.8886 ($t = 15.64$)	-0.6539 ($t = -11.02$)	
X_3 (auto-lube)		0.9637 ($t = 20.13$)	0.5850 ($t = 11.87$)	0.3893 ($t = 12.41$)
X_4 (1:20 fuel-oil ratio)		-0.4646 ($t = -9.58$)	0.2098 ($t = 3.04$)	-0.3188 ($t = -7.02$)
X_5 (1:20 fuel-oil ratio)		-0.4464 ($t = -6.56$)	1.1401 ($t = 16.26$)	0.8587 ($t = 19.41$)
X_6 (speed, kph)	0.0043 ($t = 3.42$)	0.0204 ($t = 6.95$)		0.0356 ($t = 13.93$)
Adjusted R^2	0.8082	0.5895	0.7003	0.7036

Table III. Summaries of Carbon Monoxide (CO) Emission Models

Average velocity = 19.94 kph
Minimum acceleration = - 6.44 m/s^2
Maximum acceleration = 6.97 m/s^2
Idle time (percentage) = 4.0%

The improvised procedure for measurement of on-road HC and CO emission concentrations has also been demonstrated in the study. Results showed that for 2-stroke tricycles at idle speed condition, the CO concentration averaged 3.73% with a maximum value of 7.93% while its HC concentration averaged at 6,048 ppm with a maximum value of 13,040 ppm. At running conditions, the CO concentration averaged 3.72% with a maximum value of 9.74% while its HC concentration averaged 6,089 ppm with a maximum value of 13,370 ppm. For 4-stroke type tricycles at idle conditions, the CO concentration averaged 2.28% with a maximum value of 4.25% while its HC concentration averaged 307 ppm with a maximum value of 620 ppm and at running conditions, the CO concentration averaged 2.29% with a maximum value of 6.16% while its HC concentration averaged 339 ppm with a maximum value of 1,104 ppm.

Regression analysis of CO emission concentration of in-use tricycles yielded that richer fuel-oil ratio and loading significantly influence the emission concentration. Correlation of regression models for HC concentration was low; however, there is a significant correlation between HC and CO concentrations.

6.2. Recommendations

The developed drive cycle requires further smoothening in each micro trip for easy handling of the vehicle speed test in the chassis dynamometer. It is also recommended that drive cycle for other vehicle types be developed in order to facilitate development of emission factors and vehicle and engine performance tests which will be useful in the development of in-use vehicle and emission standards for the Philippines. There is also a need to develop or acquire on-board instrumentation for the measurement of vehicle operation characteristics and vehicle emissions at on-road conditions in order to have more accurate estimates of speed, acceleration including other engine parameters and in order to have mass-based emissions measurements.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Institute of Behavioral Sciences (IBS) of Japan which supported the main grant for this research and research fund from the Philippine Council for Industry and Energy Research and Development of the Department of Science and Technology (PCIERD-DOST) for the measurement of emissions from tricycles. The section on emissions measurement is one part of the PCIERD-funded research project entitled "Standards Development for Local Motorcycle/Tricycle Sector". Acknowledgment is also given to the Technical Working Group of the Standards Development for Local Motorcycle/Tricycle Sector, cooperating agencies such as the Filcar Foundation Inc., Philippine Department of Energy, College of Engineering of the University of the Philippines and to the supporting staff members and students affiliated to the National Center for Transportation Studies of the University of the Philippines Diliman during the research project period (April 2002-December 2003) who contributed to this research.

REFERENCES

1. Asian Development Bank (1998) Report and Recommendation of the President to the Board of Directors on Proposed Loans and a Technical Assistance Grant to the Land Bank of The Philippines for the Metro Manila Air Quality Improvement Sector Development Program, Final Report, November 1998.
2. Asian Development Bank (1992) Vehicular Emission Control Planning in Metro Manila, Final Report, July 1992
3. Carlock, M.A. (1992) Laboratory Tests of Modal and Off-Cycle Corrections to FTP-75, **Proceedings on the National Conference on Transportation Planning and Air Quality, ASCE.**
4. Department of Environment and Natural Resources and Environment Management Bureau (1999) RA 8749: The Philippine Clean Air Act, Implementing Rules and Regulations.
5. Department of Science and Technology (DOST), Department of Energy (DOE), Philippine National Oil Company (PNOC) and Department of Transportation and Communication (DOTC) (1998) Performance Testing of Selected Road Vehicles Using the Chassis Dynamometer Under Simulated Urban and Highway Traffic Conditions, Project Terminal Report, March 1998.
6. University of the Philippines National Center for Transportation Studies Foundation Inc. (UP-NCTSFI) and the Philippine Council for Industry and Energy Research and Development (DOST-PCIERD) (2004) Standards Development for Local Motorcycle/ Tricycle Sector, Final Report
7. Domingo, F. S. (2002) Motor Vehicles Registration Forecast, **Proceedings of the 10th Annual Conference of the Transportation Science Society of the Philippines (TSSP)**, Pampanga, Philippines, July 19, 2002.
8. Effa, R., and Larsen, L. (1993) Development of Real-World Driving Cycles for Estimating Facility-Specific Emissions from Light-Duty Vehicles, California Air Resources Board (CARB), September 1993.
9. Environmental Management Bureau of the Department of Environment and National Resources (EMB-DENR) (2001), RA 8749: Philippine Clean Air Act and its Implementing Rules and Regulations, DENR-Public Affairs Office, Dec. 2001.
10. Environmental Protection Administration (EPA) of the Government of the Republic of China (1996) Current Situation of Motorcycle Pollution Control in Republic of China, 1996
11. Guensler, R. (1993) Data Needs for Evolving Motor Vehicle Emission Modeling Approaches, University of California - Transportation Center, Berkeley, California, 1993

12. Japan International Cooperation Agency (JICA), DOTC, MMDA, DPWH, NEDA, and NCTS (1998) Metro Manila's Transportation and Traffic Situation, MMUTIS Study Team, Manila, 1998.
13. Kojima, M., *et al.*(2000) **Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles**, World Bank (WB), Washington, USA, December 2000.
14. Manalo, D.L. (2002) 1980-2001 Philippine Vehicle Registration Characteristics, **Proceedings of the 10th Annual Conference of the Transportation Science Society of the Philippines (TSSP)**, Pampanga, Philippines, July 19, 2002.
15. Sigua, R. G. (1997) Development of Driving Cycle for Metro Manila, **Journal of the Eastern Asia Society for Transportation Studies Vol. 2**, No.6, Autumn, 1997.
16. Sigua, R.G., *et al.*(2005) Development of Engine Performance and Emission Testing Procedures and Sidecar Design Prototyping for Tricycles, University of the Philippines- National Center for Transportation Studies (UP-NCTS) Discussion Paper, Manila, Philippines.
17. National Environment Protection Council (NEPC) (1999) In Service Emissions Performance-Drive Cycles, Proposed Diesel Vehicle Emissions National Environment Protection Measure Preparatory Work, Diesel NEPM Project 2 - Phase 1 (Final Report), Vol. 1, March 1999.
18. Sturm, P. *et al.*(1998) Instantaneous Emission Data and their Use in Estimating Passenger Car Emission, MEET Project- Techische Universitat Graz, Heft, Vol. 74.
19. Watson, H.C. (1985) The Development of the Melbourne Peak Cycle, University of Melbourne, Australia.
20. World Bank (2002) Philippines Environment Monitor 20020-Air Quality, Draft Copy, Metro Manila, Philippines, May 2002
21. World Health Organization (1999) **Urban Traffic Pollution**, edited by Schwela, D. *et al.*London, New York.
22. World Health Organization (2000) Guidelines for Air Quality, Geneva, Switzerland.

