ROADSIDE VEHICULAR EMISSIONS MEASUREMENT AND ESTIMATION AND AIR POLLUTION ABATEMENT STRATEGIES FOR METRO MANILA

Rene Val R. TEODORO
Graduate Student
Dep't. of Civil Engineering
Nagoya University
Furo-cho, Chikusa-ku, Nagoya,
4640814 Japan
Fax: (81-52)-789-5175
E-mail: val@genv.nagoya-u.ac.jp

Ricardo G. SIGUA
Associate Professor
National Center for Transportation Studies,
University of the Philippines,
Diliman, Quezon City
1101 Philippines
Fax: (63-2)-929-5664
E-mail: rsigua@up-ncts.org.ph

Yoshitsugu HAYASHI
Professor
Dept. of Geotech. & Env'l. Eng'g.,
Nagoya University
Furo-cho, Chikusa-ku, Nagoya,
4640814 Japan
Fax: (81-52)-789-1454
E-mail: yhayashi@genv.nagoya-u.ac.jp

Abstract: This paper seeks to examine the air quality at different roadside conditions by conducting series of environmental surveys along major thoroughfares in Metro-Manila. Surveys include simultaneous measurement of criteria pollutants and basic traffic and meteorological parameters. A non-linear parameter estimation model was generated to calculate for carbon monoxide (CO) and suspended particulate matter (SPM) levels. Using the models, pollutant concentrations at different traffic flow and wind speed conditions are evaluated. Diurnal and seasonal variations were also analyzed using field measurements and additional secondary data. Critical conditions given different traffic, wind and temporal variation scenarios were further identified through the conduct of sensitivity and fluctuation analyses. Based on the results, the study identifies the factors contributing to the air pollution problem and formulates appropriate air pollution abatement strategies.

Key Words: air pollution measurement, pollution estimation, control strategies, Metro Manila

1. INTRODUCTION

Motor vehicle emissions affect millions of road users, pedestrians and passengers every working day. Being at the roadside environment, these people are exposed to relatively undiluted concentration of vehicular emissions. People inside dwelling units and work places located near major road sections, particularly those without adequate enclosure are likewise suffering the same fate. In Metro Manila, the jeepney drivers, bus drivers, traffic policemen and aides, and public transport commuters are the population segments most widely exposed to the harmful effects of air pollution. Among them, the jeepney drivers numbering almost 70,000 have the highest exposure (ADB, 1992). An epidemiological study revealed that jeepney drivers have significantly higher prevalence of chronic respiratory symptoms such as wheezing, shortness of breath, chronic cough and phlegm production; have higher incidence of respiratory illnesses such as chronic obstructive pulmonary disease, pulmonary tuberculosis, and pulmonary illnesses; and, have much higher exposure to carbon monoxide and lead than commuters (Subida, 1991).

Further, the current population of approximately 9.4 million in Metro Manila has started to severely strain its existing urban infrastructure and ecology. Traffic congestion in particular worsened the air pollution problem causing enormous social welfare and economic losses. Typically these economic consequences are measured in terms of monetary values assigned to mortality effects; costs of reducing morbidity; reductions in the value of agricultural crops and vegetation; costs of reducing soiling and material damages; and loss in property. Among developed countries, the estimated cost of air pollution ranges from 0.03% to 0.92% of Gross National Product (OECD, 1994). The current losses are expected to increase as vehicle registration marks an average annual increase of 8.66% from 1986 to 1995 outpacing the 2.2% annual increase in road capacity due to road construction and improvement for the same period. A study conducted by the Asian Development Bank in 1992 forecasted that assuming there is no implementation of additional control measures on vehicular emission, pollution load from vehicles in 1990 will at least double by the year 2005.

In this crisis, it is important that transportation planners and environmental analysts should work together in providing mobility and at the same time improving air quality (Wayson, 1992). However, the status of knowledge demonstrates the inability of the current system to bridge the gap between local transportation and air quality issues. This paper is among the fundamental efforts geared towards better understanding of the air pollution problems in relation to transportation.

2. THE STUDY

The study utilizes essential air quality research methodologies such as monitoring, evaluation of measurements and trends, fluctuation analysis, empirical modeling, sensitivity analysis and control strategy formulation. Specifically, the study involves the following objectives:

(1) To assess the air quality condition at roadside environment relative to the National Ambient Air Quality Standards (NAAQS) through actual measurements;
(2) To examine the effects of traffic flow and wind speed to pollutant concentration and analyze observed temporal variations;
(3) To estimate roadside air pollution levels and identify critical conditions at different traffic flow scenarios; and
(4) To identify significant factors contributing to the air pollution problem and formulate appropriate abatement strategies.

The environmental surveys are part of the continuing research of National Center for Transportation Studies (NCTS) aimed to evaluate conditions at different roadside environment. Monitoring in most of the sites was jointly conducted with the Metro-Manila Urban Transportation Integration Study (MMUTIS). The survey includes continuous hourly monitoring of the ambient level of air pollutants using automatic analyzers mounted on a research van. Concurrently monitored are simple meteorological and traffic flow parameters such as wind speed and direction, and total traffic volume and road section spot speed. The classified traffic volume survey was conducted on-site with the aid of manual counters and supplemented by continuous video coverage for indoor traffic count and spot speed processing. Studied thoroughfares are of different width, number of lanes and distinct range of annual average daily traffic.

Analysis of the results of the survey includes the comparison of field measurements to the NAAQS standards for six (6) criteria pollutants, namely: (a) Suspended Particulate Matter (SPM); (b) Sulfur Dioxide; (c) Nitrogen Dioxide; (d) Ozone; (e) Carbon Monoxide; and (f) Lead. Using data from one of the sites, an empirical model was formulated for CO and SPM. SPM in this study refers to PM_{10} and both are interchangeably used in this paper. The models are used to examine the influence of traffic flow and wind speed to the ambient roadside air pollution level. The temporal variation of pollutant concentration was also examined using additional secondary data from yearlong hourly measurements. A sensitivity analysis was also conducted to identify the most significant parameter affecting pollutant concentration. Combinations of traffic level and meteorological conditions that will bring about critical levels of CO and SPM were further determined. In addition, the study made an assessment of the ambient air quality of the study area, identified air pollution problems and their caus1es, and cites workable solutions based on the observed conditions and trends.

3. DATA GATHERING

3.1 Site Selection

Two sets of monitoring surveys sites were selected. The first set which consists of six sites of different road types will be used for ambient air quality assessment, while an additional set consisting of three sites are for the non-linear parameter estimation modeling and analysis. For such purposes, target road sections should ideally be at mid-block of at least 200 meters away from a nearby intersection. This will limit the influencing traffic to that of the immediate road

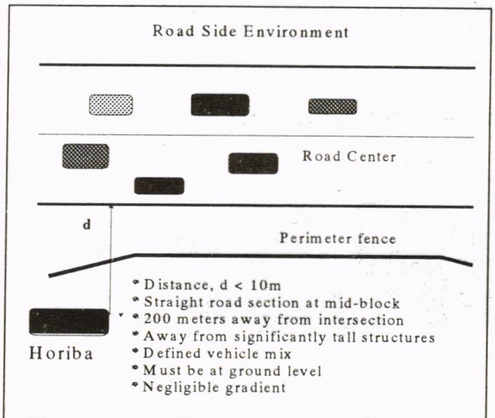

Figure 1. An ideal survey site layout.

section as road of more than 200 meters from the monitoring site technically have negligible pollution contribution due to dispersion. Atop basic requirements such as the availability of power supply, an adequate space to accommodate the equipment and relative security, other requirements in the site selection includes a heavy traffic volume, free access of public and proximity to the cordon line as defined in the MMUTIS study (MMUTIS, 1997). The other requirements are listed in Figure 1 as it presents a diagram showing the characteristics of an ideal survey site layout.1

In addition is the consideration of wind pattern in the selection of the estimation sites so as to collect the most number of data wherein wind is generally blowing from the road towards the receptor. The three selected sites, namely EDSA-Crame, UP-NCTS and Commonwealth-AIT are for the parameter estimation, model validation and background pollution measurements, respectively. The six assessment sites are represented by the names of the studied thoroughfares as presented in Table 1. The annual average daily traffic data was secured from Traffic Engineering Center while the minimum and maximum hourly volumes are based on the results of the traffic survey.

Table 1. List and description of monitoring stations for the assessment of air pollution levels.

Road Name	AADT (1995)	Min.Vol (veh/hr)	Max. Vol (veh/hr)	Remarks (on vehicle fleet)
Taft Avenue (R-2)	92,826	797	3,766	Significant Jeepneys
Quirino Highway	37,762	572	3,003	Along Jeepney / Bus Routes
Quezon Avenue (R-7)	84,771	1,005	7,083	Along Jeepney Routes
Roxas Boulevard (R-1)	92,827	1,595	8,098	Mainly Private Cars
E. De los Santos Avenue (C-4)	158,226	1,880	10,017	Significant Buses
South Super Highway (R-3)	150,034	1,723	11,522	Mix Vehicle Fleet

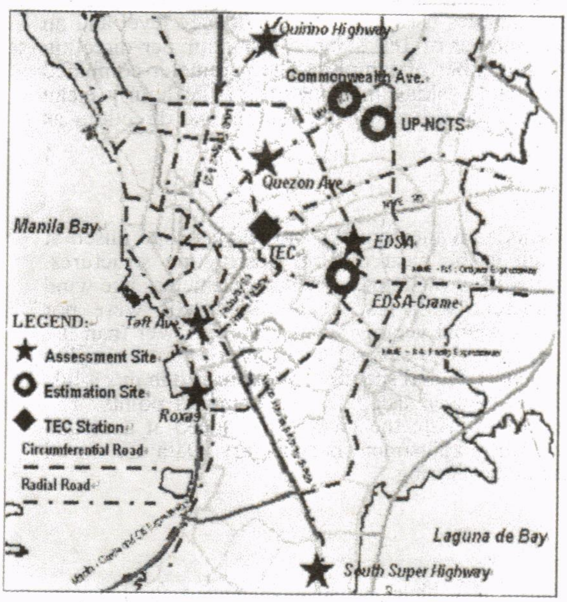

Figure 2. Monitoring site location map.

3.2 Air Pollution Measurements

Hourly air pollution monitoring in the six assessment sites covers all the criteria pollutants while only CO, PM_{10} and NO_X were monitored for the three estimation sites. All pollutants except for lead were monitored using HORIBA 350 Series automatic analyzers. The analyzers feature an automated internal calibration and a computer-based data logging systems. Auto calibration is programmed at an interval of once per week and is likewise conducted at the start of each new setup. The equipment is capable of measuring suspended particulate matter (PM_{10}), sulfur oxides, oxides of nitrogen, ground level ozone and carbon monoxide. Lead monitoring on the other hand utilized a high volume sampler wherein filter specimens are brought to the laboratory for lead content analysis.

Results however are not included, as duration of measurement does not suffice to be compared to the averaging time as required in the NAAQS. Figure 2 shows the locations of the both the assessment and estimation monitoring stations relative to a Metro Manila road map.

3.3 Traffic Surveys

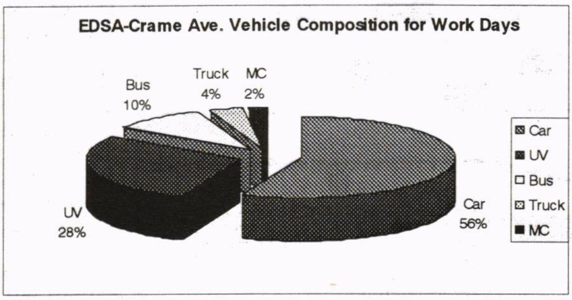

Figure 3. Average composition of traffic along EDSA.

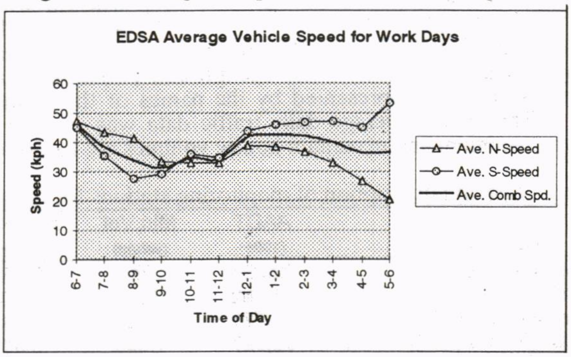

Figure 4. Average vehicle speed of along EDSA.

Traffic flow monitoring includes classified traffic volume count and spot speed surveys. Five general vehicle classes were used in the traffic volume survey, namely: cars, utility vehicles, buses, trucks and motorcycles. Car category includes passenger and taxi; while included with the utility vehicles are light duty vehicles, jeepneys, and light duty trucks. Trucks also include trailers while the bus category includes both conventional buses and mini-buses. Motorcycle includes both the motorcycles and the tricycles. The average composition of vehicle traffic observed along EDSA-Crame is presented in Figure 3. Considerations on fuel type assumed all cars and motorcycles to be using gasoline and all buses and trucks to be using diesel. A 45.7% gasoline against 54.3% diesel fleet composition based on vehicle registration was assumed for utility vehicles. For the speed survey, hourly average traffic speed for the entire direction was determined by taking spot speed samples from the middle lanes with the assumption that it approximately represents the average speed for the entire traffic direction. Selection of number of samples uses a 95.0% confidence level and an allowable error of +/- 2 km/h criteria. A fixed number of 180 samples per hour per direction was found to safely meet the required minimum number of samples. The parameter-combined speed, for both directions was calculated by simply taking the average of the hourly mean speed. Figure 4 shows the average observed speed for the north and southbound directions as well as that of the average road section.

3.4 Meteorological Monitoring

Instruments utilized for wind measurements include an anemometer and anemoscope raised at an elevation of 9 meters, ideally high enough to be cleared from obstructing structures. Meteorological observation only covers the monitoring of simple weather parameters like wind speed and wind direction. Dispersion parameters with respect to the z-axis were not considered thus simplifying wind into a two-dimensional vector. Wind velocity lower than 0.4 m/s was considered calm. Survey sites were subjected to several location criteria to simplify topographical considerations. Hourly measurements of wind speed were expressed in m/s while the most prevalent hourly wind directions is established using the 16 compass points. The power-law function of height commonly used to estimate the mean wind speed at a certain elevation was adopted in cases where in an elevation adjustment is necessary. Data are stored in the same logging system used in environmental monitoring.

3.5 Secondary Data

Among the secondary data gathered are historical vehicle registration record, fuel prices, emission factors and several air pollution measurements. Data from the monitoring station

Table 2. Emission factors by vehicle type. (ADB, 1992)

EMISSIONS FACTORS FOR VEHICLES (grams per kilometer)						
	CO	HC	NOx	SULFUR	LEAD	SPM
CARS	49.5	6.00	2.7	0.011	0.073	0.10
GAS UV	60.0	8.00	3.0	0.014	0.092	0.12
MC	26.0	18.60	0.2	0.004	0.028	2.00
TAXI	1.9	0.65	2.0	0.081	0.000	0.60
JPNY	2.5	0.70	1.4	0.121	0.000	0.90
D UV	2.5	0.70	1.4	0.115	0.000	0.90
TRUCK	12.4	3.70	12.5	0.374	0.000	1.50

being maintained by the Traffic Engineering Center was utilized to establish seasonal variation. Measurements conducted by the Department of Environment and Natural Resources were also referred to in establishing environmental trends. Related studies, environmental laws and government programs were likewise reviewed. Among the major related studies are the 1992 ADB Study (ADB, 1992), which established the vehicle emission factors for Metro Manila as shown in Table 2, and the 1997 World Bank Study, URBAIR (World Bank, 1997), which proposed some abatement measures and management strategies for Metro Manila.

4. RESULTS OF AIR POLLUTION MEASUREMENTS

Air pollution monitoring data indicate that suspended particulate matter (PM_{10}) is the most critical pollutant in Metro-Manila. Taft Ave. records the highest 24-hour average concentration of 285.3 $\mu g/m^3$, exceeding the national standard by a factor of 1.9. Hourly concentration was observed to be as high as 411 $\mu g/m^3$. Two other sites at critical SPM levels were Quirino Highway and Quezon Avenue with maximum 24-hour average of 214.3 $\mu g/m^3$ and 152.1 $\mu g/m^3$ respectively. The busiest thoroughfare, EDSA is at near critical with 139.5 $\mu g/m^3$ daily average.

Another pollutant observed at critical level is sulfur dioxide (SO_2) with measurements at Taft station exceeding the 24-hour air quality standard at a maximum average concentration of 0.076 ppm. High SO_2 concentration along Taft can be attributed to high volume of diesel-engined passenger jeepneys. Jeepney has the highest SO_2 emission factor next to truck as shown in Table 2. Critical level of ozone was also observed in one station, specifically EDSA, exceeding the 1-hour standard concentration by a factor of 1.56. Meanwhile, the 8-hour standard O_3 concentration was exceeded by a factor of 1.97. Ozone (O_3) is a secondary pollutant indirectly generated from NO. With the wind prevalently blowing from the NNE parallel to EDSA, ozone detected at the site could have been due to NO earlier generated in the upstream.

None of the survey sites exceeded the CO and NO_2 concentration standards. At most, the highest average concentration is roughly a factor of 0.2 lower than the ambient air quality standard as in the case of NO_2 24-hour average for Quezon Avenue. Table 3 presents a summary of the air pollution monitoring results.

Table 3. Air quality monitoring results from Assessment Sites and ambient standards.

Pollutants	SPM (μ/m^3)	SO_2 (ppm)		NO_2 (ppm)		Ozone (ppm)		CO (ppm)	
SITE	24 hrs	1 hr	24 hrs	1 hr	24 hrs	1 hr	8 hrs	1 hr	8 hrs
Taft	**285.30**	0.122	**0.076**	0.080	0.038	0.029	0.008	10.90	4.44
Quirino	**214.30**	0.104	0.054	0.086	0.036	0.051	0.017	9.90	3.17
QA	**152.10**	0.105	0.050	0.106	0.065	0.018	0.006	12.40	6.55
Roxas	92.13	0.073	0.022	0.043	0.020	0.019	0.012	4.80	3.08
EDSA	139.50	0.074	0.027	0.048	0.025	**0.109**	**0.059**	6.00	4.28
SSH	108.50	0.094	0.033	0.045	0.014	0.008	0.005	6.30	3.74
Standard	150.00	0.140	0.070	0.210	0.080	0.070	0.030	30.00	9.00

Monitoring results observed in the estimation sites likewise indicates PM_{10} to be the most critical pollutant with all roadside stations registering a maximum 24-hour average of about the 150 $\mu g/m^3$ ambient standard. The third site, which is located away from roads inside the University of the Philippines - Diliman campus, expectedly resulted to significantly low measurements. These measurements roughly depict the background concentration of pollutants being transported from other areas. A notable value is that of background hourly NO_2 being the highest among the estimation sites. Such an unusually high level hints the build up of secondary pollutants in areas away from the source. Roadside hourly CO and NO_2 are at most about a factor of 0.3 of the standard while the respective 8-hour and 24-hour averages are at most more than a factor of 0.5. A summary of measurements from the estimation sites is presented in Table 4.

Table 4. Air quality monitoring results from Estimation Sites and the ambient standards.

Pollutant	SPM ($\mu g/m^3$)	NO (ppm)		NO2 (ppm)		NOx (ppm)		CO (ppm)	
Estimation Stations	24-hour	1-hour	24-hour	1-hour	24-hour	1-hour	24-hour	1-hour	8-hour
EDSA-Camp Crame	149.42	0.403	0.187	0.073	0.0408	0.446	0.227	7.8	5.275
Commonwealth-AIT	152.92	0.352	0.150	0.037	0.0226	0.370	0.167	5.6	2.975
UP-NCTS	78.79	0.123	0.027	0.075	0.0245	0.145	0.049	2.9	1.388
Standards	150	---	---	0.210	0.080	---	---	30	9

The monitoring results are observed to be generally lower than that of the results of previous observational studies. Like the ADB Study for instance with recorded SPM level of twice the 24-hour standard (ADB,1992). The difference can be attributed to the choice of the locations of the monitoring site, as this study selects mid-block sections; the governing seasonal and local meteorological factors, as monitoring was conducted during the prevalence of high northeast monsoon winds; and perhaps the difference in the employed method of measurements.

5. EMPIRICAL MODELING

Formulation of the model structure assumes that pollutant concentration is directly proportional to traffic volume while inversely proportional to wind velocity. Traffic speed, being in general (at volume higher than capacity) inversely proportional to traffic volume, is likewise assumed to be inversely proportional to the pollutant concentration. This convention is consistent to actual emission as results of previous studies shows that vehicles traveling at speed lower than 60 km/h tend to emit a more polluted exhaust (Hamilton, 1991). Based on results of initial statistical analyses, the study adopts the model structure as shown on Equation 1 using monitoring cases wherein wind is generally blowing towards the direction of the receptor. The second term of the equation is very similar to the simplified Gaussian dispersion equation used by Hickman and Colwill (Hickman, 1982), as well as the concentration equation adopted by Manins (Manins, 1991).

$$CO = a + b * (\textit{Traffic Flow Function} / WS) \qquad \text{Eq. (1)}$$

wherein CO = CO level in ppm; a, b = parameter estimates; WS = wind speed in m/s

Several possible traffic flow functions were considered among which include a combination of classified traffic volume and vehicle emission factors. In this study, the *combined volume-speed ratio* (*C-VSR*) was adopted based on its simplicity, applicability and comparative accuracy, among other criteria. *C-VSR* is defined as the ratio between the total traffic volume in a road section (both directions combined) and the corresponding average spot speed. The *C-VSR* is similar in unit to traffic density but different by definition as the latter is defined per lane. A detailed discussion on model formulation is presented in the author's graduate research (Teodoro, 1996) at the College of Engineering, University of the Philippines. Parameter estimates for CO, SPM, NO_X, and NO are generated using the Non-linear Estimation procedure of STATISTICA, a statistical package by Statsoft, Incorporated (Statsoft, 1994). A summary of modeling results is presented in Table 5.

Table 5. Modeling estimates and the fitness tests

Parameters / Indexes		CO	SPM	NOX	NO
a	B	1.376	57.502	0.104	0.067
	t(53)	8.570	9.781	11.845	7.137
	p-level	0.000	0.000	0.000	0.000
b	B	0.012	0.487	0.487	0.001
	t(53)	13.100	12.549	12.549	9.092
	p-level	0.000	0.000	0.000	0.000
	R	0.874	0.865	0.860	0.781

Modeling and fitness tests results as shown in Table 5, generally depict a set of well-fitted models. The *t-statistics* for instance as indicated by the *p-levels* denoted highly significant parameter estimates. The *correlation coefficients, R*, with values ranging from 0.874 to 0.781 for a total of 55 samples surpasses the critical values of the Spearman's Rank Correlation Coefficients of 0.478 for $\alpha = 0.005$ for even a smaller number of samples. For the intercept, CO generates a value very close to results of the background measurement as compared to that of the other models. This can be attributed to CO being primarily emitted from vehicles. As compared to SPM, background pollution with respect to transport involves all other sources, hence may significantly vary from one place to another. The empirical models were tested using measurements along Commonwealth Avenue yielding encouraging results.

6. FLUCTUATION ANALYSIS

6.1 Temporal Fluctuation

Ambient pollutant concentration levels fluctuate over time as rate of emission from sources, meteorological condition, and other influencing parameters vary. Diurnal fluctuations of pollution levels in this study are primarily attributed to traffic flow, being the source, and to wind speed, being a dominant meteorological parameter to trigger dispersion in a tropical atmosphere. Usually, the most significant factor is emission from the source as characterized by a typical double-peak diurnal fluctuation of pollutant concentration with peaks coinciding with that of traffic flow peak hours. This is followed by wind speed and wind direction. Similarly, long-term temporal fluctuations are also affected by seasonal traffic variation and change in climate primarily characterized by the amount of rainfall and the distinct wind patterns.

6.2 Survey Results

For diurnal fluctuation, survey results identify three possible occurrences of air pollution peak hours, namely the morning peak, the afternoon peak and the midnight peak. As shown in Figure 5, occurrence of the morning peak is observed in all three stations between 7 a.m. to 9 a.m. Another is the afternoon peak as observed in Taft and EDSA between 4-6 pm. Both morning and afternoon peaks are primarily traffic attributed as these coincides with the respective peak traffic volume. The midnight peak, as shown in EDSA and Quirino curves occurs at 11 p.m. coinciding with the occurrence of very low wind speed as shown in Figure 6. The morning and afternoon peaks similar to that of the Taft Avenue curve characterize a typical diurnal fluctuation of pollutant level that is primarily influenced by traffic volume.

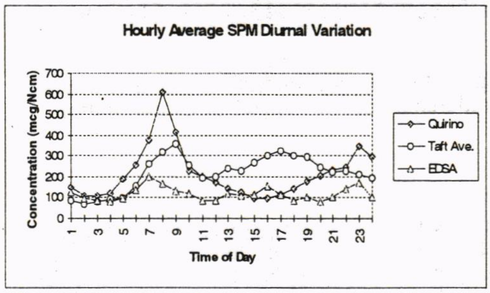

Figure 5. Diurnal average variation of SPM.

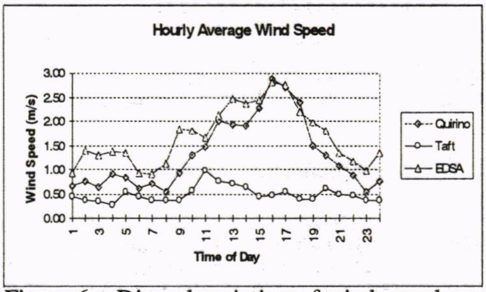

Figure 6. Diurnal variation of wind speed.

Monitoring results in the estimation site EDSA-Crame were characterized by a consistent double-peak pattern among the primary pollutants as shown in Figures 7 and 8. Also referred to as semi-diurnal periodicity (two-maxima) fluctuation, the two maxima were likewise observed to be coinciding with the early morning and early evening traffic peak hours. Nitrogen dioxide on the other hand, though also showing a double peak trend had its peak concentration late in the morning (between 11 a.m. to 12 p.m.) as shown in Figure 9. The lag is attributed to its being a secondary pollutant, as it would take some time for NO_2 concentrations to build up from the reaction created by NO and oxygen gas.

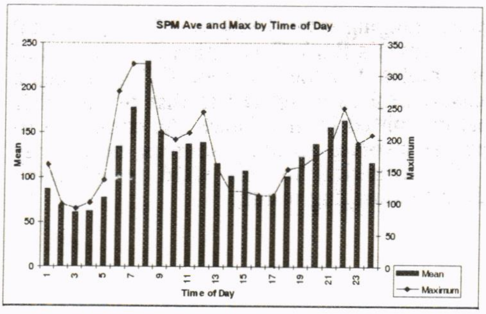

Figure 7. Average diurnal variation of hourly and maximum PM_{10} at EDSA-Crame station.

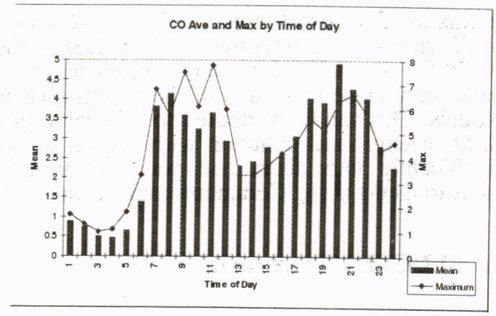

Figure 8. Average diurnal variation of hourly and maximum CO at EDSA-Crame station

The fluctuation of wind as shown is in Figure 10 reveals the occurrence of low wind speed from 1:00 a.m. to 9:00 a.m., then after a gradual rise it is observed peaking between 3:00 p.m. and 4:00 p.m., followed by a decreasing trend which coincides with the early evening traffic. Meanwhile, a trend line generated over a scatter plot of the combined volume-speed ratio (*C-VSR*) data approximated a diurnal fluctuation characterized by a morning peak between 7 a.m. and 9 a.m. and a relatively lower afternoon peak which starts at 5 p.m. coinciding with the end of work hours. It is worth noting that the generated a.m. peak coincides with low wind speed and that the traffic build up at early evening likewise coincides with the decreasing wind speed, there by resulting to high pollutant concentration. Based on the observed diurnal variations, it can be concluded that the most likely occurrence of critical pollutant level will coincide with the identified a.m. and p.m. peak hours. However it is still possible, that for some other factors, low wind speed may occur at mid-day resulting to a pollution peak.

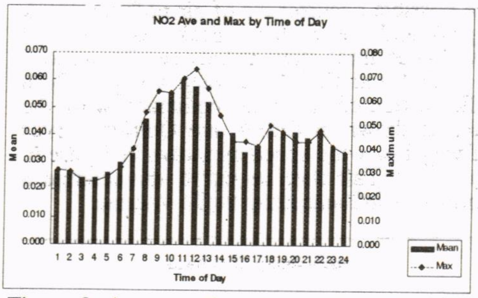

Figure 9. Average diurnal variation of hourly and maximum NO_2 at EDSA-Crame station.

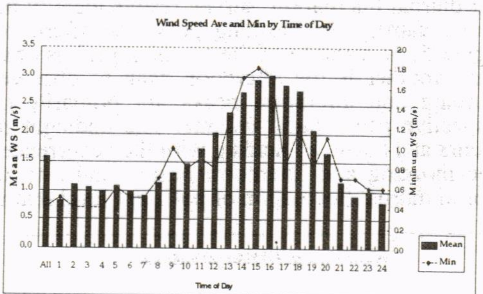

Figure 10. Average diurnal variation of hourly and minimum wind speed at Crame station.

6.3 General Fluctuation Trends

For evaluation purposes, a general fluctuation trend, within a certain period, can be roughly established with respect to the mean of a standard monitoring duration, like 8 hours and 24 hours, using the observed on the hour average hourly measurements. For instance, taking the hourly average diurnal fluctuation of PM_{10} and CO as shown in Figures 7 and 8, the prevailing trend within the period was established by taking each hour's normalized average deviation from the mean of a standard duration, like 24-hour mean for PM_{10} and maximum average 8-hour mean for CO. The resulting values for the case of EDSA-Crame are presented in Figures 11 and 12. This general average diurnal fluctuation trend can be useful in roughly assessing short duration measurements or estimates, say, hourly, to a longer duration standard, say 24-hour average standard, to approximate the supposed 24-hour mean. Employing a similar formulation, the maximum hourly measurement that will exceed the 24-hour and 8-hour ambient air quality standard for PM_{10} and CO is estimated to be approximately 288.5 µg/m3 and 12.72 ppm respectively.

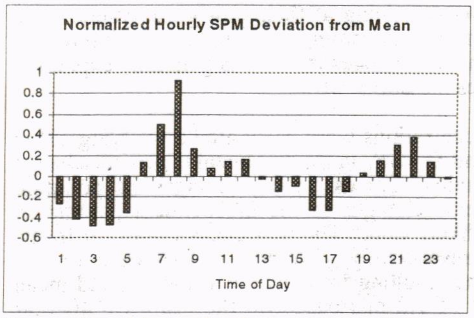

Figure 11. Normalized deviation of hourly average SPM from the 24-hour mean.

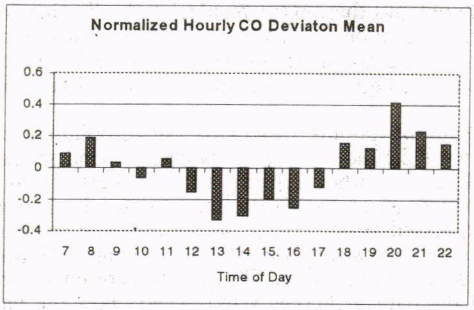

Figure 12. Normalized deviation of hourly average CO from the 16-hour mean.

To further examine longer temporal variation of pollutant concentration, an hourly CO measurement for a span of one year was extracted for data processing from a monitoring system being operated by the Traffic Engineering Center (TEC). The monitoring receptor is situated in the TEC office facing Aurora Boulevard, a major radial thoroughfare in the heart of Metro Manila. Using the data, average hourly CO concentration ratio with respect to a particular mean was generated for a.m. and p.m. peaks and off peaks, monsoon prevalence, and different days in a week and months in a year. Morning peak is defined to be between 7-11 a.m. while that of the p.m. peak is between 5-9 p.m. Daytime off peak is between 12-4 p.m. while the nighttime off peak is between 10 p.m. to 12 midnight. As for monsoon, months between December and March is within the northeast monsoon prevalence while months between June and November is within the southwest monsoon prevalence.

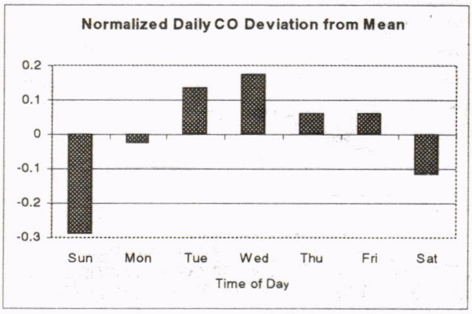

Figure 13. Normalized deviation of daily average CO from the weekly mean.

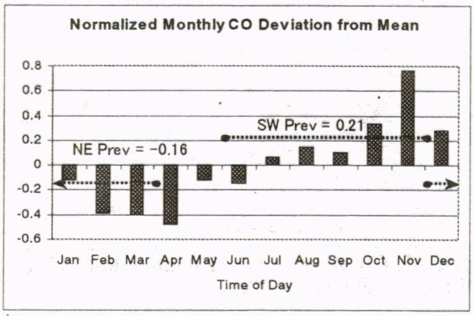

Figure 14. Normalized deviation of monthly average CO from the hourly annual mean.

Results indicate that Wednesday is the day of generally highest CO concentration while that of lowest day is expectedly Sunday as a result of lower traffic volume. As to monthly, November yields the highest CO hourly average while that of the lowest occurs in April. The low concentration in March can be attributed to a combination of relatively higher wind speed and a relatively lower traffic volume due to a long summer school break. Meanwhile, morning peak is observed to be on the average slightly higher than the p.m. peak due to higher traffic volume, while nighttime off peak yields higher average CO than that of daytime due to extremely low wind speed. As for monsoon, CO was observed to be higher during the southwesterly prevalence by a factor of about 1.44 as compared to that of during the prevalence of high northeasterly winds. Summaries of the daily and monthly average fluctuations are presented in Figures 13 and 14.

7. SENSITIVITY ANALYSIS

7.1 Conduct of the Analysis

Sensitivity analysis is conducted by first taking the most likely or best guess value of each inputs and calculating the output value which is taken as a base. Each input value is then altered and the output recalculated, all other inputs remaining at their best guess values. The inputs may be altered to their most plausible high and low bounds or else may be altered by arbitrary amounts simply to see what effects they have. Changes in value is generally expressed as percentage deviations from the most likely values (Jessop,1990).

Using the models for CO and SPM, pollutant concentrations were calculated by varying either one of the independent parameters, wind speed and *C-VSR*, in an incremental percent change while the other remain at their best guess values. Corresponding changes in pollutant concentration are then compared to the incremental changes in the independent parameter, expressed as percentage deviations from the most likely value. The best guess values for traffic volume and speed are 10,000 veh/h and 40 km/h respectively, yielding a *C-VSR* value of 250 veh/km road section. The values were based on the resulting frequency distribution and mean of the data gathered. Wind speed takes the value of 1.2 m/s based on the historical 40-year measurement gathered from a nearest weather bureau monitoring station. PM_{10} and CO concentration are calculated at 159 $\mu g/m^3$ and 4.28 ppm, respectively when independent parameters are at their best guest values.

Sensitivity curves are generated by plotting the percent change applied to an independent variable against the resulting percent change in CO concentration. The sensitivity curves in Figure 15 and 16 show that *combined volume-speed ratio* is more significant than wind speed at independent parameter values higher than the best guess, while wind speed becomes more significant at parameter values lower than the best guess. Wind speed is further observed to becoming less significant as at certain speed, it almost completely disperses pollutants to concentration close to the background level. Based on results as presented in the curves, a 10% increase in *C-VSR* will yield a 6.39% increase in PM_{10} and a slightly higher increase of 6.79% in CO at a most likely wind speed of 1.2 m/s.

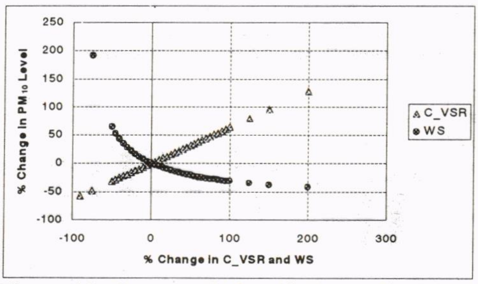

Figure 15. Curves relating % change in *C-VSR* & WS to % change in PM_{10}.

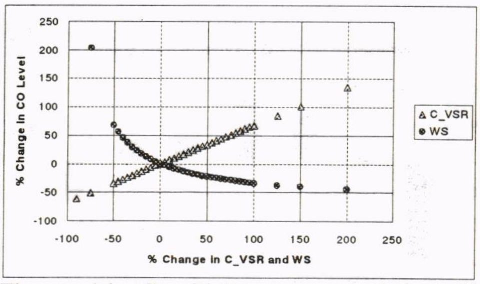

Figure 16. Sensitivity curves relating % change in *C-VSR* & WS to % change in CO.

7.2 Roadside Environment Scenarios

Different roadside environment scenarios were further analyzed by conducting sensitivity using actual and hypothetical initial input values. In particular, average and worst case scenarios were generated by using calm and average wind speed in combination with observed average and maximum *combined volume speed ratio*. The generated sensitivity curves are then used to further identify generated scenarios that may yield critical pollution levels. Critical pollution levels for PM10 were based on the 24-hour standard while that of CO was based on both the hourly and the 8-hour average ambient air quality criteria. The possible occurrence of the critical 24-hour and 8-hour averages was estimated based on the approximate hourly maximum concentration calculated to yield critical averages as presented in Section 6.3.

Pollution levels for the first roadside scenario were generated for the most likely and observed maximum C-VSR value at varying wind speed. The resulting sensitivity curves for PM_{10} and CO as depicted by two linear-inverse curves illustrate the influence of wind speed in pollutant concentration given the two traffic scenarios. Figures 17 and 18 shows the estimated PM_{10} and CO concentrations at varying wind speed for both the observed maximum and best guess *C-VSR* of 560 veh/km and 250 veh/km, respectively. The figures further show the occurrence of critical pollutant concentration at a particular wind speed range. The occurrence of high *C-VSR* at normal wind condition results to hourly concentration that will potentially yield a critical 24-

hour average level as illustrated in Figure 17. Meanwhile, a less critical condition of CO concentration is presented in Figure 18 wherein at normal wind speed, the maximum observed traffic scenario falls way below the maximum hourly and the hourly critical levels. The chance of a possible occurrence of a critical 8-hour hourly maximum level will be as that of the probable occurrence of a rare extreme low wind speed scenario.

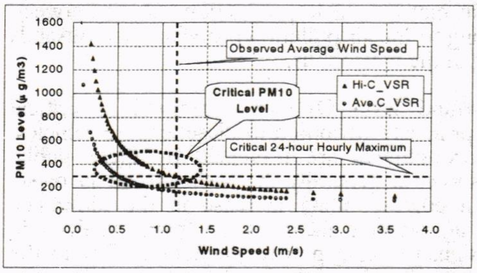

Figure 17. PM_{10} levels for observed average and maximum *C-VSR* at varying WS.

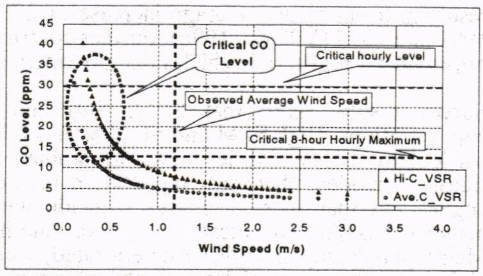

Figure 18. CO levels for observed average and maximum *C-VSR* at varying WS.

For calm and most likely wind scenarios, pollutant concentrations were estimated at incremental change of combined volume-speed ratio so as to examine the influence of traffic flow to the pollutant level. The resulting sensitivity curves for PM_{10} and CO as shown in Figures 19 and 20 are comprised of two linear plots representing the two wind speed scenarios.

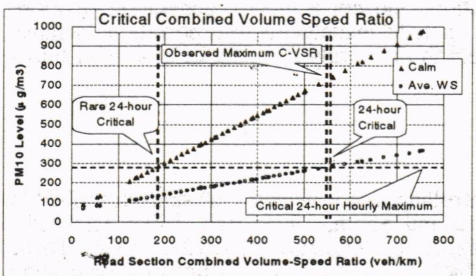

Figure 19. PM_{10} levels for calm and most likely wind speed at varying *C-VSR*.

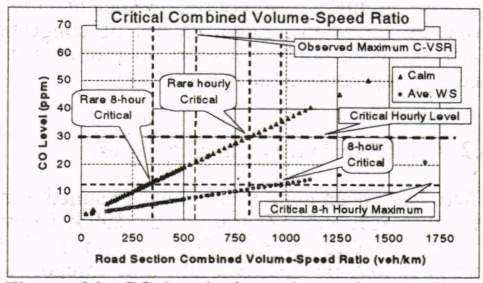

Figure 20. CO levels for calm and most likely wind speed at varying *C-VSR*.

In recognition of the variability of wind speed, a *rare critical traffic condition* was identified to take into account the possible occurrence of extremely low wind speed levels. The rare critical *C-VSR* is defined as the *C-VSR* value that will result to critical pollutant level during rare occurrence of extremely low wind speed. The *rare 24-hour critical C-VSR* for PM_{10} is equivalent to 190 veh/km road section as shown in Figure 19 while the rare 8-hour and rare-hourly critical *C-VSR* for CO are 325 veh/km road section and 820 veh/km road section as shown in Figure 20, respectively. For normal wind velocity, the 24-hour critical *C-VSR* for PM_{10} is calculated to be 569 veh/km as shown in Figure 19. The 8-hour critical *C-VSR* for CO is 974 veh/km road section as shown in Figure 20 while the hourly critical *C-VSR* is 2,460 veh/km which corresponds to the *C-VSR* value when the average wind speed curve in Figure 20 is further extended to reach the 30 ppm hourly critical CO level.

8. CONTRIBUTING FACTORS AND ABATEMENT STRATEGIES

8.1 Factors Contributory to the Air Pollution Problem

Investigation of the secondary data, survey results and observed transportation trends indicates that increasing rate of motorization, poor engine-performing vehicle fleet, and worsening traffic congestion are among the most significant factors contributing to the air pollution problem.

Land Transportation Office (LTO) registration data for 1995 shows a total of 1,055,692 vehicles were registered in Metro-Manila, more than twice the total number of vehicles registered a decade earlier. This momentous growth can be attributed to the government's effort to revitalize the automotive industry. This includes various trade liberalization policies like the formation of the ASEAN Industrial Joint Venture (AIJV) which allows the exchange of products/components under a preferential tariff scheme. These liberalization policies were aimed at making vehicles available and affordable to the greatest number of buyers, thus, resulting to an annual average increase of 27% in motor vehicle production output between 1991 and 1995 (Villoria, 1996). Further contributing to the air pollution problem are thousands of provincial-registered vehicles that are operating in the metropolis.

Survey results show that SPM, SO_2 and ground level O_3 were observed at critical concentrations. High SPM and SO_2 levels can be primarily attributed to diesel engine vehicles, particularly buses and jeepneys, as studied thoroughfares are traversed by these public transport modes. Historical registration record shows a generally increasing trend in diesel engine and that these increases coincide with a corresponding increase in the difference between gasoline and diesel fuel price. Another aggravating factor is that many vehicles in Metro Manila appear to have deteriorated, with signs of being poorly maintained. Due to the high cost of new vehicles and the absence of an effective vehicle phase out policy, the propensity of owners to decommission aging and deteriorated vehicles is very low. Furthermore, importation of second hand buses and engines, particularly diesel engines used for jeepneys, also contribute to the problem of aging and poor engine performing vehicle fleet.

Currently, a major transportation problem of Metro Manila is the expanding peak period congestion as experienced in most of its major thoroughfares (EMB,1990). This is characterized by longer travel time and stalling vehicles in idling mode, thus resulting to increase in fuel consumption, inefficient combustion, and consequently generation of more pollutant emissions. Local causes of congestion include inadequate transportation facilities particularly for public transport operation as evident in the unruly stopping of passenger buses and jeepneys among the study areas.

8.2 Available Abatement Strategies

There have been numerous measures aimed at controlling motor vehicle emissions described in literature (see e.g., Zegras, et al, 1995; Crawford and Smith, 1995; Hall, 1995; Michaelis, 1995; Birk and Zegras, 1993; Bernstein, 1993; Faiz, et al, 1990; and, Horowitz, 1982). These measures may be classified into four categories which define the general strategies for dealing with the motor vehicle emission problem, namely: (a) use of cleaner fuels; (b) use of cleaner vehicles; (c) improvement of traffic flow; and, (d) reduction of travel demand.

In most developing countries, lead content in gasoline and sulfur content in diesel fuel is much higher compared with those in developed countries. Hence, dramatic reductions in particulate, lead and sulfur emissions can be gained within the existing vehicle technology using conventional fuels (World Bank, 1996). The use of unleaded gasoline and low-sulfur diesel can be promoted through fiscal policies like differential taxation and imposition of tax surcharges to favor the use of cleaner fuel. In addition are tax deductions to retrofit vehicles with emission control devices and imposition of stricter emission standards and effective on-road inspection and maintenance (I/M) programs (Faiz, et al, 1990). A typical approach employed in developed countries is the use of alternative fuels.

The use of cleaner vehicles strategy comprises a range of measures aimed to encourage the use of emission reduction devices and to promote less polluting conventional transport such as electric-powered rail transit systems and non-motorized travel modes. Also included are policies aimed to phase out aging and deteriorated vehicles and to develop and use electric cars and buses. In the context of developing countries, the most significant issues typically involve the continued operation of old and dilapidated vehicles, and the local production and importation of second-hand trucks and buses. Therefore, measures aimed at modernizing the aging vehicle fleet, discouraging the importation and local production of substandard vehicles, and arresting the growth in motorcycle usage would significantly reduce motor vehicle emissions.

Improvement of traffic flow strategy includes typical traffic engineering techniques geared to maximize utilization of existing transport supply known as transportation system management (TSM). In particular, measures to improve traffic flow in terms of increased travel speed, lesser vehicle idling, and decreased accelerations and decelerations maneuvers would serve to reduce carbon monoxide and hydrocarbon emissions. Meanwhile, it is now widely believed that traffic congestion in cities cannot be solved by simply providing additional transport capacity, thus the demand for travel has to be reduced using transportation demand management (TDM) measures. In Metro-Manila, there have been very limited applications of TDM measures. Many measures have been considered in the past but only the truck ban and private vehicle traffic restriction, known as the Odd-Even Scheme, have been vigorously implemented. Taxes, license fees, toll fees, parking fees, and the likes are currently imposed but mainly for revenue generation rather than for travel demand management.

8.3 Abatement Strategies for Metro-Manila

Lessons may be learned from the experiences of developed countries over the past couple of decades in dealing with urban vehicular pollution problems. Among the various strategies identified in the earlier section, the most appropriate for Metro-Manila include TDM and TSM measures, along with pricing and other policies in favor of cleaner fuels and vehicles. In most situations, TDM and TSM measures will mitigate the air pollution problem by alleviating road traffic congestion, which is another major problem in the metropolis. Meanwhile, the use of cleaner fuels can be promoted by fuel taxation favoring the use of unleaded gasoline and low-sulfur diesel. Increasing the cost of fuel in general will likewise reduce car usage and even increase government revenue.

Focusing on policies that serve to hasten the phasing-out of old vehicles can best do the promotion of cleaner vehicles. This is in addition to setting emission standards and implementing motor vehicle inspection and maintenance schemes which are deemed insufficient considering that a large proportion of the vehicle population are gross polluters. With the high cost of acquiring new vehicles, the propensity to hold on to aging vehicles is also high, therefore, it is necessary to raise the cost of keeping an aging vehicle to a level that is higher than the price of acquiring a new replacement vehicle. This will result to a newer fleet and at the same time contribute to the car industry. Preferential tax schemes so as to promote cleaner vehicles as well as the use of emission reducing instruments is likewise recommended. Other occasional anti-air pollution campaigns drives will both educate the public and encourage them to participate in the fight against air pollution. Regular campaigns can be scheduled in the identified critical air pollution periods.

A critical step in addressing the serious vehicular pollution problem in Metro-Manila is to strengthen the institutional aspects of urban environmental quality management at the metropolitan level. These aspects include the integration of transportation and environmental plans and policies; the enhancement of vertical and horizontal coordination among relevant agencies; the development of local manpower capability for environmental management; and, the mobilization of the private sector. The formulation of policies and plans related to transportation and vehicular pollution for instance should not be done separately. To enable joint planning for transportation and air quality, there is a need to enhance mutual understanding and communication among transportation and environmental planners.

In line with the effort to devolve several functions from the national to the local government, there is a need to develop training programs on transportation and environmental quality management specifically geared towards building the capabilities of local personnel. The role of the private sector (i.e., individual citizens, business community and constituency groups) in environmental management is also very significant. Being themselves road users, their participation in organized endeavors proves to be crucial.

9. SUMMARY OF FINDINGS

Results of the air pollution monitoring activity conducted along major thoroughfares in Metro-Manila identified Suspended Particulate Matters (SPM) as the most critical pollutant in a typical roadside environment in the metropolis. Measurement shows that SPM levels in four sites exceeded the 24-hour National Ambient Air Quality Standard value of 150 $\mu g/m^3$ by at most a factor of 1.9 along Taft Avenue. Two other sites along EDSA were observed to be at very near critical levels at 139.5 and 149.42 $\mu g/m^3$. Other ambient air quality standards that were exceeded include the 24-hour SO_2 levels and both the 1-hour and 8-hour ground level ozone criteria. Thoroughfares with incident of pollution levels exceeding the national standards are characterized by relatively lower wind speed and are all traversed by public transport routes hinting that buses and jeepneys are among the major sources of high levels of emissions. Most buses and jeepneys are locally assembled using secondhand diesel engines imported from developed countries like Japan. Based on the results, it can be fairly generalized that sections of a major thoroughfare within a densely built up vicinity (low wind speed) and plied by public transport routes are most likely to experience critical air pollution levels.

General factors that are found contributory to the air pollution includes the increasing motorization trend, poor engine performance of the vehicle fleet and the worsening traffic congestion. A review of available abatement strategies identified various measures geared towards the use of cleaner fuels; the use of cleaner vehicles; the improvement of traffic flow; and, the reduction of travel demand. Among the identified strategies, what is deemed appropriate for Metro-Manila are the various TDM and TSM measures and a set of regulatory and fiscal policies aimed towards the promotion of cleaner fuel and cleaner vehicles. Fiscal policies range from an array of appropriate fuel and car taxes. Occasional campaigns are likewise cited to educate and encourage the public to actively participate in government efforts. Moreover, the study recommends institutional strengthening aimed at enhancing working relationship between transport and environmental agencies and coordinating their respective plans and programs. Further training of the existing manpower and pool of experts particularly that of the local government's related agencies as well as organizing and tapping the potentials of the private sector, particularly the stake holders as well as the concerned civil society are likewise recommended.

10. CONCLUSION

Empirical models were also developed to estimate roadside concentration of SPM, CO, NO_X and NO. The model is a function of a wind speed and a traffic flow parameter, C-VSR, which represents the ratio of the combined traffic volume for both direction and the average spot speed. The models are deemed useful in traffic impact assessment and other transport planning applications. Findings of the sensitivity analysis primarily identify the traffic flow parameter as the most significant factor influencing pollutant concentration. This is followed by wind speed, which occasionally becomes even more significant at very low wind speed levels. Fluctuation analysis identifies the occurrence of critical pollutant levels to be coinciding most probably with the morning peak and then followed by the afternoon peak. Based on historical CO measurements, the month of highest CO level occurs on November during the prevalence of the southwest monsoon and observed to be the lowest in April during the long school summer vacation. Pollution level is further observed to be generally lower during the prevalence of strong northeasterly monsoon winds.

Using the models, combinations of wind speed and C_VSR, which might yield critical levels of SPM and CO, were identified. Critical scenarios for 24-hour SPM average concentration for instance were identified to be at hourly wind speed lower than 1.2 m/s for high C-VSR scenario and at wind speed of about 0.5 m/s or lower for an average C-VSR scenario. That 8-hour CO average is at wind speed lower than 0.7 m/s and 0.4 m/s for high and average C-VSR respectively. Average and high C-VSR are based on the average and the maximum C-VSR observed from the survey at values 250 and 560 veh/km road section respectively. The minimum critical traffic flow scenario for SPM ranges from the 190 veh/km road section at extremely calm winds of 0.4 m/s and the hourly C-VSR of 569 veh/km road section at average wind speed of 1.2 m/s. Those of the 8-hour CO average are 325 and 974 veh/km road section respectively. These result shows that SPM is already at near critical at normal wind and realistic traffic scenarios and is most likely to exceed the 24-hour standards during occurrence of low wind speed or higher C-VSR. Results for CO indicates occasional occurrence of the critical 8-hour average at rare instances of very calm winds. It should be noted however that high C-VSR is easily generated at very slow traffic speed.

REFERENCES

a) Books and Books chapters

Bernstein, Janis, D. (1993) **Alternative Approaches to Pollution Control and Waste Management**. The Urban Management Programme, The World Bank, Washington, D.C., USA.

Birk, M.L., and Zegras, C.P. (1993) **Moving Toward Integrated Transport Planning: Energy, Environment, and Mobility in Four Asian Cities**. International Institute for Energy Conservation, Washington, D.C., USA.

Environmental Management Bureau (1990):. **The Philippine Environment in the Eighties**. Environmental Management Bureau, Department of Environment and Natural Resources, Republic of the Philippines.

Hamilton, R.S. and Harrison, R.M. (1991) **Highway Pollution**. Studies in Environmental Science 44; Elsevier Science Publishers B.V., Amsterdam. pp. 8-10

Horowitz, J. L. (1982) **Air Quality Analysis for Urban Transportation Planning**. The MIT Press, Cambridge, Massachusetts, USA.

Jessop, A. (1990) **Decision and Forecasting Models: with Transport Applications**. Ellis Horwood Limited, West Sussex, England.

Organisation for Economic Cooperation and Development (OECD) (1994) **Congestion Control and Demand Management**. OECD, Paris, France.

Zegras, C., Guruswamy, D., Tomazinis, A. and Miller, E. (1995) **Modeling Urban Transportation Emissions and Energy Use: Lessons for the Developing World**. International Institute for Energy Conservation, Washington, D.C., USA.

b) Journal papers

Crawford, I., Smith, S. (1995) Fiscal Instruments for Air Pollution Abatement in Road Transport". **Journal of Transport Economics and Policy**, **Vol. 29, No. 1**, January, 33-51.

Hall, J. V. (1995) The Role of Transport Control Measures in Jointly Reducing Congestion and Air Pollution. **Journal of Transport Economics and Policy, Vol. 29, No. 1**, January, 93-103.

Hickman, A.J. and Colwill, D.M. (1982) The Estimation of Air Pollution Concentrations From Road Traffic. Department of the Environment Department of Transport, **TRRL Report LR 1052**, Transport and Road Research Laboratory, Crowrthorne, Berkshire.

Michaelis, L. (1995): The Abatement of Air Pollution from Motor Vehicles: The Role of Alternative Fuels. **Journal of Transport Economics and Policy**, **Vol. 29, No. 1**, January, 71-84.

Villoria, O.G., Teodoro, R.R. and Jimenez, N.R. (1996) Vehicular Air Pollution Abatement Strategies for Metro Manila. **Journal of the Transportation Science Society of the Philippines (TSSP), Vol.1, No.1**, December 1996.

c) Papers presented to conferences

Wayson, Roger L. (1992) **Transportation Planning and Air Quality. Conference Proceedings.** Urban Transportation Division, American Society of Civil Engineers (ASCE), New York.

d) Other documents

Asian Development Bank (1992) Vehicle Emission Control Planning Project for Metro-Manila. Environmental Management Bureau, Manila, Philippines.

Faiz, A., Sinha, K., Walsh, M., and Varma, A. (1990): Automotive Air Pollution: Issues and Options for Developing Countries. Policy Research and External Affairs Working Paper No. 492. The World Bank, Washington, D.C., USA., August.

Manins, P. (1991) Model for Air Pollution Planning. Environmental Management Bureau, Department of Environment and Natural Resources, Philippines.

Metro Manila Urban Transportation Integration Study (MMUTIS) (1997). Environmental Impact Analysis Study. National Center for Transportation Studies, University of the Philippines.

StatSoft (1994) **STATISTICA for Windows**. StatSoft, Inc. Tulsa, Oklahoma, USA.

Subida, R., Torres, E.B., Borja, M.P. (1991) Epidimiology of Chronic Respiratory Symptoms and Illnesses Among Jeepney Drivers and Commuters Exposed to Vehicular Emissions in Metro-Manila. University of the Philippines – Manila.

Teodoro, R.R. (1996) Empirical Analysis on the Relationship Between Air Pollution and Traffic Flow Parameters (Masters Thesis). College of Engineering. University of the Philippines.

World Bank (1997) Urban Air Quality Management Strategy in Asia: Metro-Manila Report. World Bank Technical Paper No. 380. Shah, J.J. and Nagpal, T, (eds.). The World Bank, Washington, D.C.