ANALYSIS OF THE RELATIONSHIP OF MAJOR AIR POLLUTANT EMISSION LEVELS AND ROAD TRAFFIC FLOW IN METRO MANILA

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Abstract: In Metro Manila, major atmospheric pollutants such as total particulate matter (TPM) and nitrogen dioxide (NO_2) come mostly from motor vehicle emission. The purpose is to analyze the relationship between traffic flow and air pollution. Traffic survey and environmental survey of TPM and NO_2 are conducted in 1998 at 22 roadside locations in Metro Manila. The roadside TPM and NO_2 concentration are modeled by multiple linear regression of traffic volume of various vehicle types including buses and paratransit vehicles such as jeepneys. The emission mass rate is then estimated from the Plume model where the roadside concentration model is incorporated.

1. INTRODUCTION

The problem of road traffic congestion and the corresponding pollution from motor vehicles it brings have become an important issue in developing metropolitan areas lacking a railway network and urban expressway network like Metro Manila. The Metro Manila Urban Transport Integration Study (MMUTIS) reported in 1997 that the source of major atmospheric pollutants come mostly from motor vehicle exhaust emission and it was determined that the suspended particulate matter (SPM) and oxides of nitrogen (NO_x) were found to be the major pollutants. Several air pollution monitoring studies conducted since 1990 support the increasing trend in total suspended particulates (TSP) exceeding the pollution standards, mainly attributed to paratransit vehicles such as jeepneys, buses and some taxicabs. The purpose of this study is to analyze air pollution traffic flow characteristics that affect the traffic environment specifically around signalized intersections and mid-block sections using macroscopic traffic flow variables such as traffic volume classified according to different vehicle classes including jeepneys, buses and trucks.

2. REVIEW OF RELATED LITERATURE AND APPROACH OF THE STUDY

Regarding the prediction of air pollution particulate matter and emission quantity and roadside concentration generated from road traffic, experiments in Japan have been conducted to determine the emission factors according to vehicle type and age. Pollutant generation models, emission quantity and concentration prediction methods derived from the dispersion model have been made by Yuzono, *et al* (1992) and the Environmental Conservation Bureau of the Tokyo Metropolitan Government (1996).

Regarding the studies and survey of air pollution in Metro Manila, Villoria, *et al* (1996) reviewed the pollution monitoring activities of the Philippines and identified factors contributing to vehicular air pollution such as increasing motorization trend, engine performance of vehicle fleet, worsening traffic congestion and motor vehicle composition. Pollution data came from the Environmental Management Bureau (EMB), an agency under the Department of Environment and Natural Resources of the Philippines, and the Asian Development Bank-funded Vehicle Emission Control Planning Project. Diesel-engined jeepneys, taxis and buses were found to contribute to 2/3 of the particulates. The EMB historical annual data, most monitoring stations indicated an increasing trend in total suspended particulate concentration from 1987-1993 (Villoria, *et al*, 1996). In 1996-1997, field investigations have been done by MMUTIS and the National Center for Transportation Studies (NCTS) at the University of the Philippines especially on the atmospheric environment. This included reports of survey of conditions of roadside pollutant concentrations at major arterial roads. Teodoro and Villoria (1997) proposed an empirical model estimating ambient concentration of air pollutant, specifically carbon monoxide (CO) at roadside environment which is a function of traffic volume, vehicle speed, wind speed and direction, using multiple linear regression and non-linear parameter estimation using collected air pollution monitoring data (NO, SPM, CO and wind data) with simultaneous 14-hour traffic flow observation. A sensitivity analysis was conducted to identify the significant parameters and the model was validated by the pollution monitoring data from another site.

However, it could be noted that the analysis of unit emission of air pollutant generated by vehicle traffic is unclear. The determination of vehicle-specific emission factors for jeepneys, large trucks and buses is still very difficult such that the existing research and methods of predicting emission quantity and roadside concentration from emission factors are not applicable to Metro Manila. Given the above constraints, in this research, the traffic flow characteristics and concentrations of representative pollutants such as nitrogen dioxide (NO_2) and total particulate matter (TPM) are understood from the traffic flow and environmental surveys conducted. Also, the special traffic flow characteristics of the mixing of paratransit vehicles such as the jeepney and its influence on air pollution are analyzed and incorporated as factor in the roadside pollutant concentration estimation model. Then, utilizing the roadside pollutant concentration, the possibility to estimate emission mass rate from traffic volume is examined and the method to estimate emission factor from roadside pollutant concentration is proposed.

3. DATA COLLECTION

The data collection, which consists of the traffic flow survey and the environmental survey, was conducted twice in 1998 at 22 locations throughout Metro Manila (Figure 1, Table 1 and Table 2). In the first data collection, conducted on July 13-15, the traffic flow survey involved the observation and collection of traffic flow data from 15 intersections and mid-block sections along arterial roads using 8-mm video cameras. The time periods of taking of footage were set at 8:00-9:00 AM, 11:00 AM-12:00 PM and 2:00-4:00 PM. For the traffic flow survey, vehicles are classified into 5 types: a) Type 1 for passenger cars, b) Type 2 for jeepneys, c) Type 3 for large buses, d) Type 4 for trucks and e) Type 5 for motorcycles and tricycles. 24-hour traffic data was collected by NCTS in March 1998 during the JSPS Filter Badge Survey for NO_x.

In the same period, the environmental survey involved the observation and measurement of roadside pollution in terms of total particulate matter (TPM) weight concentration and

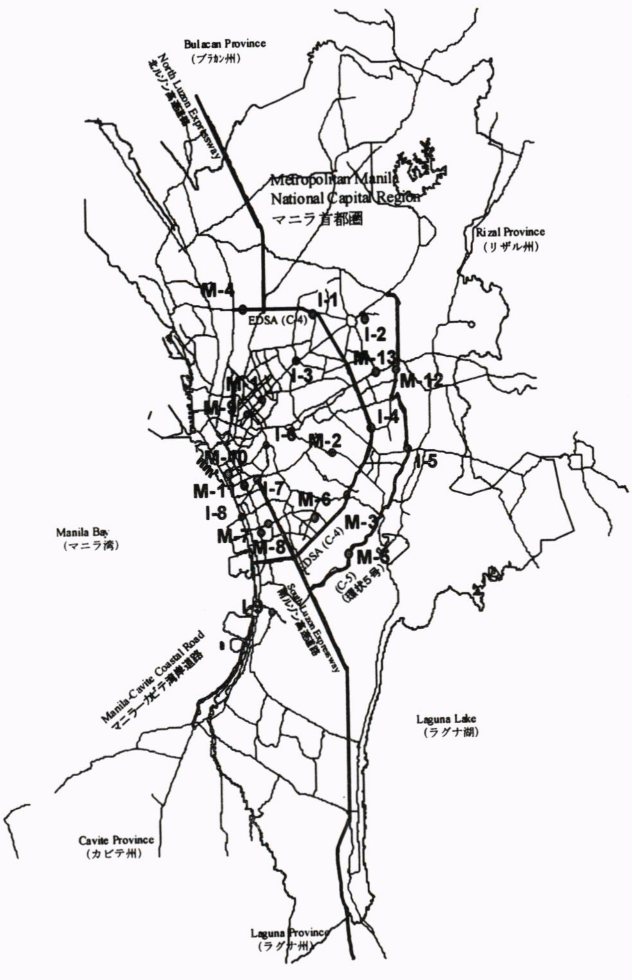

Figure 1. Location of observation points in Metro Manila

Table 1. Locations of Surveyed Intersections

Location Code	Intersection Type	Name
I-1	cross-type	EDSA (C-4) and North Avenue and West Avenue
I-2	T-type	Commonwealth Avenue and Elliptical Road
I-3	T-type	Quezon Avenue and Roosevelt Avenue
I-4	T-type	EDSA (C-4) and Katipunan Avenue
I-5	cross-type	Circumferential Road C-5 and Ortigas
I-6	cross-type	President Quirino Avenue and M. Guazon Avenue
I-7	T-type	South Super Highway and Pres. Quirino Avenue
I-8	cross-type	Roxas Boulevard and Vito Cruz Extension
I-9	T-type	Airport Avenue and Ninoy Aquino Avenue

Table 2. Locations of Surveyed Mid-block Sections

Location Code	Name
M-1	España Avenue (Macaranas Avenue)
M-2	Shaw Boulevard (Sunshine Square)
M-3	EDSA (Guingua Avenue)
M-4	EDSA (Arellano Avenue)
M-5	Circumferential Road C-5 (Villamor Air Base)
M-6	Paseo de Roxas Avenue
M-7	Taft Avenue
M-8	Sen. Gil Puyat Avenue
M-9	España Avenue
M-10	M. Adriatico Street
M-11	Taft Avenue
M-12	Katipunan Avenue
M-13	Aurora Boulevard

atmospheric parameters such as temperature, humidity and wind velocity at 1-minute intervals. In each site, 20-30 samples of TPM measurements at 4 points (located at almost zero distance from outer lane of road) were obtained within a specified hour. The measurement of TPM utilized three portable devices: 1) TPM weight measurement device; 2) TPM distribution monitor and 3) device that measures atmospheric parameters such as temperature, humidity and wind velocity. The first environmental survey covered a total of 9 intersections and 5 mid-block sections. The second data collection was conducted on November 14-19, which involved environmental survey of 7 additional mid-block sections and 1 intersection, and traffic flow survey conducting one-hour classified traffic volume count (one direction) of these sections using manual counters. The second environmental survey consisted of TPM and nitrogen dioxide (NO_2) concentration measurements. The measurement of NO_2 concentration made use of the filter badge method that involved the placing of specified number of badges at specified distances from the roadside at a height of 1.5 m from the road surface and then leaving these filter badges for 24 hours at the sites. After a day, the badges were collected and using a syringe-type measurement device, the syringe was then inserted in each badge filled up with chemical solution where the NO_2 concentration can be read directly from the device's digital display.

4. RELATIONSHIP OF TRAFFIC FLOW CHARACTERISTICS AND ROADSIDE POLLUTANT CONCENTRATION

4.1 Traffic Volume and Roadside Pollutant Mass Concentration

The relationships of the measured roadside TPM and NO_2 mass concentration and all traffic passing through the mid-block road sections are shown in scatterplots in Figure 2 and Figure 3. The measurement time for TPM is 1 minute that corresponds to the hourly traffic volume on the specific hour of measurement. The measurement time for NO_2 is 24 hours that similarly corresponds to 24-hour traffic flow passing through the section. The Philippine daily standards for suspended particulate matter (SPM) mass concentration is 180 $\mu g/m^3$ and NO_2 mass concentration is 0.08 ppm. In this survey, all the observed NO_2 concentration fell below the standard while some TPM mass concentration observations exceeded the hourly standard, as seen in the plots.

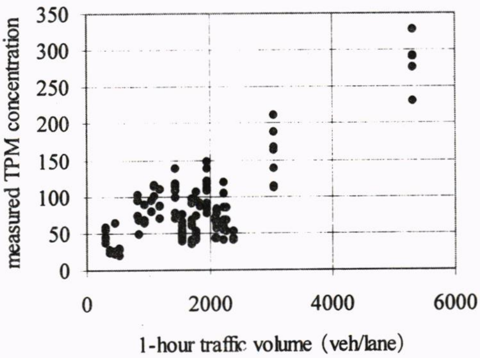

Figure 2. TPM mass concentration and traffic volume

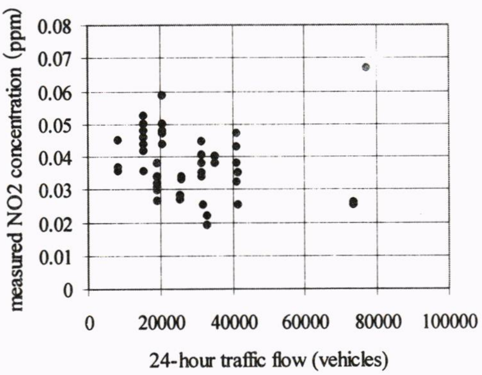

Figure 3. NO_2 mass concentration and traffic volume

4.2 Traffic Flow Characteristics and Roadside Pollutant Concentration

In Metro Manila, the major modes of public transportation are jeepney and bus. The exhaust emission coming from these vehicles contain mostly diesel exhaust particles (DEP) and the moving total particulate matter is generated and then directly becomes part of the concentration. In this regard, the traffic proportion of buses and jeepneys is plotted against the roadside TPM mass concentration (Figure 4). The computation of traffic volume in each location sums the flows in all directions.

4.3 Traffic Flow Characteristics and Particulate Size Distribution

The relationship between the traffic flow of jeepneys and buses and the total number of particulates distributed according to size (5-range in micrometer or μ m) is shown in Figure 5. In Figure 5, for relatively small particle size ranging 0.3-0.5 μ m, it could be observed that as the traffic flow of jeepneys and buses increases, the total number of particulates also increases. This is due to the influence of DEP generated by the internal

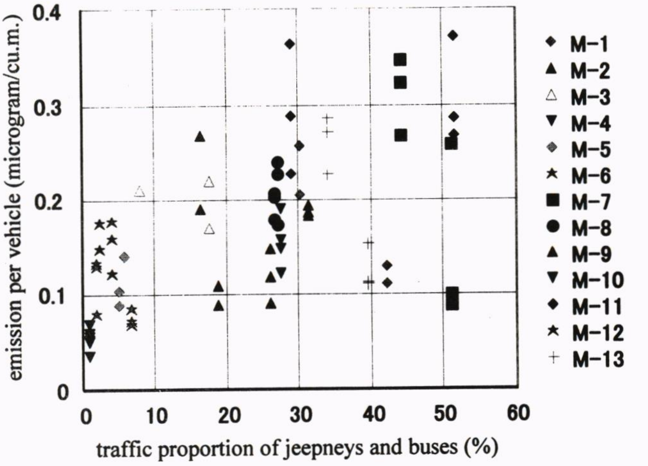

Figure 4. Relationship of traffic proportion of diesel-engine vehicles and roadside TPM mass concentration

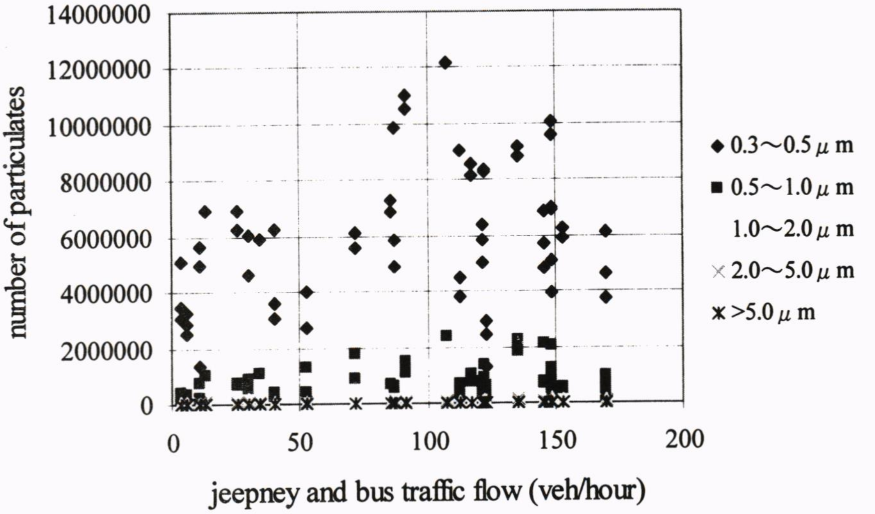

Figure 5. Relationship of traffic proportion of diesel-engine vehicles and particulate size distribution

diesel engine combustion. In TPM, many DEP exist in particle sizes 0.1 μm and smaller (Shimizu, *et al*, 1987). Also, in road sections where there the traffic proportion of jeepneys and buses is high, the number of particulates with smaller particle sizes is large.

5. ROADSIDE POLLUTANT CONCENTRATION ESTIMATION MODEL

In order to investigate what important factors that can explain the measured roadside pollutant concentration, the roadside pollutant concentration model is constructed. Assuming that the roadside concentration is dependent on the absolute volume of vehicle exhaust emission, the roadside pollutant concentration model can be expressed as a function of traffic volume using the linear regression model, as shown in Equation 1. The modeling used the mid-block section data.

$$y = \alpha_0 + \sum_i \alpha_i V_i + \sum_j \beta_j W_j \tag{1}$$

where α, β = parameters
V = traffic volume
W = meteorological information, road geometry

Strictly, traffic speed should be considered because emission level is different by vehicle speed. In this study, this is neglected because travel speeds at all mid-block are almost from 20km/h to 30km/h, in which difference of emission level is not considered to be large.

5.1 Correlation Analysis

In order to assess the adequacy of the factors in the regression analysis, correlation analysis between factors was conducted. Considering the factors contributing to the roadside pollutant concentration, 9 factors and 8 factors are adopted for the TPM concentration and NO_2 concentration, respectively. The main explanatory variable for TPM concentration is the 1-hour traffic volume per lane. For NO_2 concentration, the 24-hour traffic volume passing through the road section is considered as the explanatory variable. Another factor considered for NO_2 concentration is the presence of 1 square kilometer open space in the vicinity of the road section and this is examined using the Metro Manila Street Map. From the results of the correlation analysis, for two factors with high correlation coefficient, only one of them is included in the model estimation.

The specific factors influencing roadside TPM concentration are the hourly traffic volume per lane adjacent to the observation point classified according to: 1) general cars, 2) jeepney, 3) bus, 4) truck, 5) other vehicle types, and 6) total traffic volume in opposite direction, 7) wind speed (m/s), 8) temperature (degrees Celsius) and 9) humidity (%). The specific factors influencing roadside NO_2 concentration are 24-hour total traffic volume passing through the road section classified according to: 1) passenger car, 2) jeepney, 3) bus, 4) truck, 5) other vehicle types, 6) presence of open space, 7) number of lanes and 8) total traffic volume of the direction of the road section farther away from the observation point.

5.2 Model Estimation

While examining the special characteristics of correlation values between factors, model is estimated by the assembly of the factors. The comparison between the results of the 6-

factor model 1 and 5-factor model 2 for the roadside TPM concentration is shown in Table 3 while the comparison between the results of the 7-factor model 1 and 6-factor model 2 for the roadside NO_2 concentration is found in Table 4. In Table 3, it can be seen that the significant factors influencing roadside TPM concentration are the passenger car, jeepney and bus traffic flow parameters. Compared to the value of the parameter for passenger cars, the value of the parameter for jeepneys is approximately 1.5 times greater while the value of the bus parameter is approximately 4 times greater. It can be concluded that there are differences in generated unit emission across vehicle types. However, the parameter value for the truck traffic volume has a negative sign that is due to the bias in the traffic volume data. In Table 4, in the case of the estimation results of model 1, the factors that influence NO_2 concentration which can be seen through their significant parameters, are the traffic volume of passenger cars, jeepneys and buses, and for factors not related to traffic volume, these are the presence of open space and number of lanes in the approach of the road section adjacent to the observation point. Since the NO_2 concentration observations are 24-hour exposure values, the land-use and road geometry of the observation points can be said to influence the observed concentration.

Table 3. Roadside TPM Concentration Model Estimation Results

	Model 1		Model 2	
Variable	parameter	t-value	parameter	t-value
Intercept	6.548	0.284	-5.056	-0.487
Wind speed	3.100	0.594	2.740	0.530
Temperature	-0.199	-0.565		
Passenger car	0.161	9.458	0.158	9.672
Jeepney	0.240	3.481	0.239	3.473
Bus	0.636	6.538	0.641	6.623
Truck	-0.209	-2.198	-0.190	-2.140
Number of samples	131		131	
Regression coefficient	0.792		0.803	

Table 4. Roadside NO_2 Concentration Model Estimation Results

	Model 1		Model 2	
Variable	parameter	t-value	parameter	t-value
Intercept	0.064	11.67	0.046	8.62
Open space	-0.033	-2.60	-0.038	-2.35
Number of lanes	-0.015	-2.99	-0.011	-1.87
Passenger car	1.31×10^{-6}	3.71	6.22×10^{-7}	1.51
Jeepney	2.00×10^{-6}	2.58	1.14×10^{-6}	1.20
Bus	4.97×10^{-6}	9.76	3.25×10^{-6}	6.67
Truck	5.04×10^{-6}	2.06	4.73×10^{-6}	1.54
other vehicle types	-3.05×10^{-6}	-5.20		
number of samples	52		52	
Regression coefficient	0.792		0.803	

5.3 Comparison of Model Estimates and the Actual Measurements

The comparison between the theoretical values derived from the estimated models and the actual values obtained from the observation is conducted. The correlation between the results of calculation of Model 2 of the roadside TPM concentration model, and the actual TPM concentrations resulted to a coefficient of 0.804 while the correlation between the calculated values from Model 1 of the roadside NO_2 concentration model and the observed roadside NO_2 concentrations resulted to a coefficient of 0.848.

6. EXAMINATION OF THE POSSIBILITY OF ESTIMATING THE AMOUNT OF POLLUTANT EMISSION

The main principle in this study is to attempt to propose a calculation method estimating the amount of pollutant emission or pollutant emission mass rate from the measured roadside pollutant mass concentration. A case study is conducted here that estimates the traffic volume using the roadside pollutant mass concentration data from the environmental survey and comparing it with the observed traffic volume. In explaining the dispersion phenomenon of air pollution particulates, the simple Puff model (during without wind or weak wind conditions) and the Plume model (during strong wind conditions) are the usual models. In particle dispersion, the Plume model (Equation 2) is used where the emission intensity is derived from the roadside concentration setting wind speed as a variable.

$$c(x,y,z)=\frac{Q}{2\pi\sigma_y\sigma_z U}\exp\left(-\frac{y^2}{2\sigma_y^{\ 2}}\right)\left[\exp\left\{-\frac{(H-z)^2}{2\sigma_z^{\ 2}}\right\}+\exp\left\{-\frac{(H+z)^2}{2\sigma_z^{\ 2}}\right\}\right] \tag{2}$$

where:

$c(x, y, z)$: concentration of dispersed particle at point (x, y, z) (ppm)
x: distance along the x-coordinate axis with origin at the emission source (m)
y: horizontal distance perpendicular to the x-coordinate axis from emission source (m)
z: vertical distance from the road surface (m)
Q: emission mass rate of dispersed particle (cc/s)
H: emission source height (m)
σ_y: horizontal dispersion width (m)
σ_z: vertical dispersion width (m)
U: wind speed (m/s)

6.1 TPM Emission Mass Rate Estimation Model

A simple modeling is used as shown by the example of road diagram in Figure 6, to derive the TPM emission mass rate from the roadside TPM mass concentration data. In the setting of initial conditions, for example, the road width is 12 meters, the number of lanes is set to 4, wind speed is set to 1 m/s and the measured TPM mass concentration at 0 meter from the edge of the road is 100 μ g/m^3. Under these conditions, it is hypothesized that the roadside dispersion of the pollutant particulates originates from the center of the roadway where the emission mass rate is assumed to be concentrated. Therefore, from the dispersion equation or the Plume model, the emission mass rate is calculated yielding a

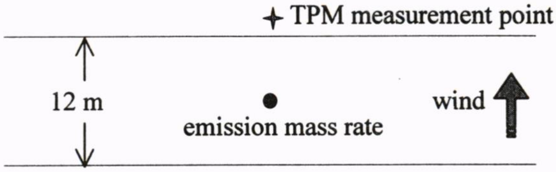

Figure 6. Example of Setting of Initial Conditions

TPM emission intensity value of 0.00341 cc/s.

6.2 Verification of Calculated Emission Mass Rate in Terms of Traffic Volume

The estimated TPM emission mass rate in the previous section is then verified by converting the calculated TPM emission mass rate to traffic volume and comparing it with the actual traffic volume data. The method of conversion to traffic volume needs the following variables: TPM emission factor, E (g/km); vehicle speed, V (m/s); the specific gravity of TPM, d, and length of road section, L (m). Regarding the TPM emission factor, particulate matter emission factor data according to vehicle type is obtained from the report of the Tokyo Metropolitan Government Environmental Conservation Bureau (1996). Initial conditions are that traffic flow is regular and speed-flow is also assumed to be regular. The total quantity of pollutant particulate emission generated from the total traffic passing through the road section L is derived. This is seen in Equation 3. Multiplying the speed V and the traffic density K will result to total traffic passing through section L and if this is multiplied the time it takes for a vehicle to pass through L, the total number of vehicles can be known. Multiplying again this result by the TPM emission factor, E (g/km) which is unit vehicle emission per kilometer run, the quantity of TPM emission per kilometer run for the total number of vehicles passing through section L is obtained. If this result is multiplied again with the length of road section L, the total quantity of TPM emission in grams from the road section L can be obtained.

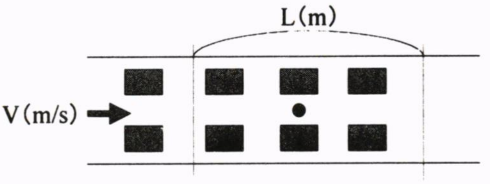

Figure 7. Traffic Volume Estimation

$$\text{(passing time of vehicle)} \times \text{(vehicle speed)} \times K \times (E/1000) \times L = KEL^2/1000 \qquad (3)$$

Also, the total volume quantity of TPM emission is calculated from emission mass rate by multiplying the latter with the time it takes the vehicle to pass the road section of length L, as shown in Equation 4.

$$Q \times \text{(passing time of vehicle)} = Q\,L/V \tag{4}$$

If the right-hand side of Equation 4 is multiplied by the specific gravity *d*, it will then equal to the total mass quantity (in grams) of TPM emission. Equating this with Equation 3, the traffic density, *K*, is derived resulting to Equation 5. If *K* is multiplied by vehicle speed *V*, then the traffic volume is determined.

$$\mathrm{K} = 1000Qd/VEL \tag{5}$$

6.3 Sensitivity Analysis

In the emission mass rate estimation process, the wind speed is treated as a variable in the Plume model equation wherein a variation in the wind speed effects a change in the estimated emission mass rate. Also, in the traffic volume estimation, the emission factor is treated as a variable that also depends on the vehicle speed. Furthermore, the traffic volume is dependent on the converted emission factor (Equation 5) for Metro Manila from the Tokyo vehicle-specific emission factor data. In this section, a sensitivity analysis is conducted where how much the estimated traffic volume varies as the mentioned variables change. The conversion factor for the Metro Manila emission factor is defined below:

$$\text{Metro Manila's Emission Factor} = \alpha \times [\text{Tokyo's Emission Factor}] \tag{6}$$

In the Plume model equation, due to the direct proportional relationship between wind speed and emission mass rate, this means that the emission mass rate increases as the wind blowing towards the observation point becomes stronger, given that the measured roadside mass concentration is fixed. Sensitivity analysis is conducted at the observation point, M-1 along España Avenue fixing the roadside TPM mass concentration at 75.4 μ g/m^3, while the rest of the variables are varied. Wind speed is varied from 0.6 ~ 1.6 m/s while the vehicle speed is varied from 10~60 km/h. Based on the study by the World Bank (Larssen, et. al, 1997) where the emission factor in Metro Manila is predicted to be about 10 times that of the factor in Tokyo, the conversion factor is then varied from 1 to 16.

Part of the results of the case study on M-1 along España Avenue, where wind speed is set to 0.6 m/s, the vehicle velocity varies from 20~40 km/h, the conversion factor α is found to be around 10~11. Setting the wind speed at 0.8 m/s, the vehicle velocity varies from 20~40 km/h, α is around 13~14. From the sensitivity analysis regarding traffic flow, wind speed and the conversion factor is more sensitive to changes compared to the vehicle speed.

7. CONCLUSION AND FURTHER STUDIES

This study has implemented an environmental survey in Metro Manila measuring and understanding the actual conditions of pollutant levels such as roadside TPM concentration and NO_2 concentration. Special traffic flow characteristics such as the presence of paratransit vehicles such as jeepneys and its relationship with the air pollution is analyzed and roadside pollutant concentration is modeled. The pollutant emission mass rate generated by the vehicle traffic is calculated from the measured roadside pollutant mass concentration.

Further studies include additional collection of roadside pollutant concentration data in order to improve model accuracy and the use of the Paramics traffic simulation software to develop the overall Metro Manila traffic environmental simulation.

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