ANALYSIS OF ROAD TRAFFIC FLOW AND TRAFFIC ENVIRONMENT IN METRO MANILA

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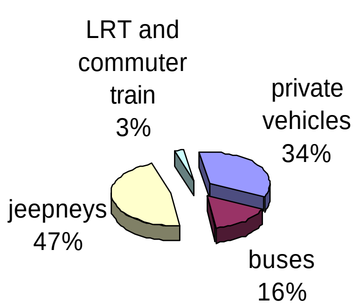
Abstract: Driver behavior, vehicle performance and physical environment factors are determined to have significant influence on saturation flow rate in Metro Manila. Effects of these factors on traffic flow and traffic environment are confirmed by international and locational comparison and the improvement and application of the Paramics microscopic traffic simulation system.

1. INTRODUCTION

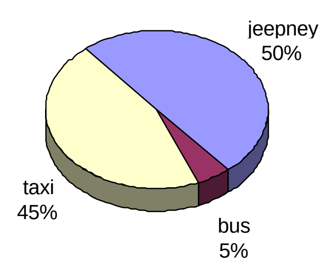
Rapid motorization, high-density urban development, population concentration, and concentration of economic activity in Metro Manila had contributed to high traffic demand causing congestion in major arterials especially in major conflict points such as signalized intersections. However, road capacity has not increased significantly in the past years thereby unable to catch up with the rapid rise in traffic flow. This congestion also produces the negative effects of worsening air quality especially in the vicinity of the road traffic environment. At present, the methodologies in analyzing road traffic flow and traffic environment are still under development.

There is a need to develop road design standards for the development of the Highway Capacity Manual (HCM) in Metro Manila. There is a necessity for the analysis of traffic flow characteristics especially the signalized intersection saturation flow rate and an equally increasing concern to improve the traffic environment in Metro Manila. Focus is also given on the presence of low-performance vehicles such as the jeepney contributes to the increasing levels of pollutant emissions. **Figure 1** shows that trips in Metro Manila



1996 MMUTIS Data: 18.4 million daily person trips

Figure 1. Mode Share in Metro Manila



Source: 1996 MMUTIS Survey

Figure 2. Metro Manila road-based public transport vehicle share

still are heavily dependent on public transportation (66%). **Figure 2** shows that the number of jeepney vehicles total to 89, 304 jeepney units in 1996 survey by the Metro Manila Urban Transport Integration Study (MMUTIS).

The objectives of this paper are to:

- determine and analyze the special factors that affect traffic flow on arterial roads in Metro Manila focusing on saturation flow rate;
- analyze the relationship between traffic flow and the pollutant emission level from roadside pollutant concentration;
- evaluate the impact of the change in vehicle performance, driver behavior and traffic control measures on traffic flow and the traffic environment through the modification and application of the existing traffic flow simulation system.

With the background and objectives, the review of related studies in traffic flow especially at signalized intersections, the traffic environment and traffic simulation is done in Chapter 2. Chapter 3 compares the traffic flow characteristics in selected East Asian cities and after understanding the differences and similarities, the study then focuses on the analysis of traffic flow characteristics of road facilities especially signalized intersections in Metro Manila in Chapter 4. Chapter 5 deals on the analysis of the traffic environment in Metro Manila focusing on major roadside pollutants such as TPM and NO_2. In Chapter 6, studies are conducted on the Metro Manila traffic flow and traffic environment simulation system to analyze various specific countermeasures or improvement measures on driver behavior, vehicle performance in general (including jeepneys) and traffic and geometric conditions and the corresponding impacts on traffic flow characteristics and on the traffic environment in terms of TPM emission levels.

2. REVIEW OF RELATED LITERATURE

Research on saturation flow rate and traffic flow characteristics and factors affecting these had started more than 70 years ago with pioneering scientists such as Dr. Greenshields and Normann (US HCM, 1985). Research on highway capacity accelerated with the publication of the US Highway Capacity Manual in 1965. The US HCM (1965) identified simple factors affecting saturation flow rate and capacity through signalized intersections including physical and operating conditions, environment, traffic conditions and control methods. This has been followed by revisions in 1985 and new circulars in 1994. The Australian Road Research Board (ARRB) identified the factors affecting saturation flow rate in 1968 (Stokes, 1988) followed by the ARRB Report 123 dealing on traffic signal capacity and timing analysis (Teply, 1993). In Britain, there were continuing studies on saturation flow rate through the studies of Branston (1979) and Kimber and Siemmens (1982) in the Transport Research Laboratory (TRL) test track in Crowthorne. The Canadian Capacity Guide (CCG) defined clearly the concept of saturation flow rate and enumerated three types of saturation flow rate: a) basic; b) initial and c) adjusted. Basic saturation flow rate is defined as the number of passenger car units that can discharge across the stop line of an "ideal" intersection lane (width 3.0 to 3.5 m) and move straight through without any additional traffic friction such as parking, and bus stops (Teply, 1985). It can be seen that studies are continually conducted on saturation flow rate and traffic characteristics since traffic conditions are changing with level of development.

Studies on the traffic environment ranges from the macroscopic to the microscopic. The level of analysis depends on how each study approximates the movement of vehicles in a road section, whether mid-block section or an intersection. In general, two approaches are used to study the traffic environment:

1) modelling of pollutant emissions by roadside pollution measurement
2) modelling of pollutant emissions from vehicle-specific fuel consumption/emission rate

In the first approach, Peace, *et. al* (1998) developed a model to test the exponential relationship between traffic flow and carbon monoxide concentration in order to predict roadside emissions from traffic flow data. Balogh, et. al (1993) analyzed resuspended particulate matter $PM_{2.5}$ (with size of 2.5 micrometers and less) at 2 meters from roadway. The second approach can be best explained by the study of Taylor, et. al (1995) on modelling emissions and fuel consumptions for road traffic streams, which is a component of a super-model for environmental impact analysis named IMPAECT (Impact Model for the Prediction and Assessment of the Environmental Consequences of Traffic). The last sub-model relates emission or fuel consumption to the performance of an individual vehicle driven in traffic. The emissions and consumption model is composed of the traffic stream composition sub-model, congestion functions and sub-models of vehicle energy and emissions performance under different traffic conditions. Taylor, et. al (1995) presented the Biggs-Akcelik family of four models of fuel consumption and emissions modelling that consists of an instantaneous model, elemental model, running speed model, and average speed model. The emission factors that are needed to be estimated for the use in these microscopic models are derived from on-road data using inbuilt flowmeter in the car and laboratory vehicle testing using the chassis dynamometer. Lee and Lee (1984) conducted a study on simulation of traffic performance, vehicle emissions and fuel consumption at intersections using the TEXAS-II model.

Microscopic traffic simulation models can express movement of individual vehicle or group of vehicles. There are three general types of models for microsimulation: a) waiting queue microsimulation model, the Q-K type microsimulation model. The car-following model handles individual vehicle movement and the running speed of the vehicle is decided by the difference in speed and acceleration with respect to the leading vehicle. This is frequently used for quite microscopic range simulation for the determination of traffic capacity fpr evaluation of line-type roads. Examples of this model are the Paramics and MITSIM. After review of the past studies, the scope of this study includes:

a) continued studies of saturation flow rate;
b) trial of an alternative estimation method of emission factors;
c) simulation analysis of traffic flow and environment.

3. INTERNATIONAL COMPARISON STUDY ON ROAD TRAFFIC FLOW

Traffic flow characteristics such as saturation flow rate and starting lost time on signalized intersections were measured for 4 East Asian cities. Comparison of saturation flow rate values is shown in **Figure 3**. There is significant difference in the mean saturation flow rates of developing and developed cities. Saturation flow rate in Seoul is significantly greater than that of Tokyo. Saturation flow rate increases with economic level and then drops off after reaching a certain stage in development. **Figure 4** compares the starting lost times of vehicles at intersections. There is significant difference in the mean starting lost times of developing and developed cities.

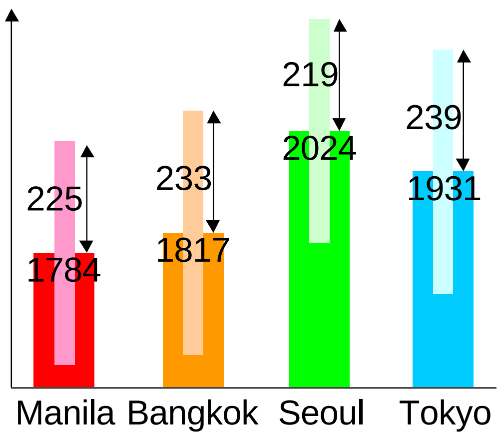


Figure 3. International comparison of saturation flow rate

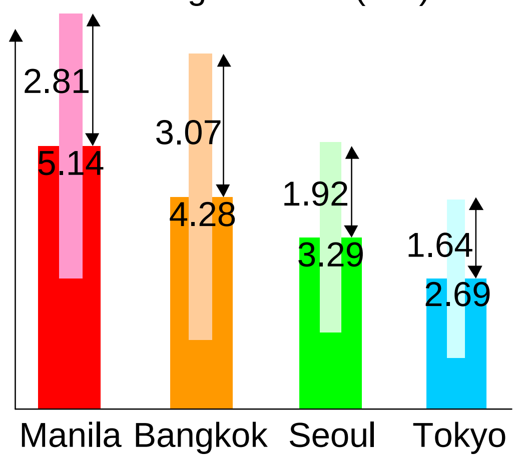


Figure 4. International comparison of starting lost time

4. ANALYSIS OF ROAD TRAFFIC FLOW CHARACTERISTICS IN METRO MANILA

4.1 Data collection and input

Traffic survey by taking of video footage was conducted on 6 signalized intersections and 5 mid-block sections in Metro Manila on July 14-16, 1998 at time intervals of 8:00-9:00 AM, 11:00-12:00 PM, and 2:00-4:00 PM. Exact names of locations and codes for each location can be found in **Figure 5**. Traffic data are then extracted from the video to the computer though viewing of the tapes. Basic input data include classified headway, start and end of green phase, approximate queue length for intersections and classified headway, classified speed and classified lane-changing frequency for mid-block sections. The following vehicle types are considered for this study: passenger cars, jeepneys (paratransit), buses, large trucks, medium trucks, motorcycles.

4.2 Estimation of saturation flow rate

Basic data consist of headway between vehicles and the fundamental plots of headway according to the queue position can be seen in Figure 6.

The queue post indicating the start of the saturation period is determined by successive comparison of mean headways of queue positions and the end of the saturation period per signal cycle is determined by the queue length or if the headway exceeds by 5.0 seconds. The accurate determination of the saturation period of the flow through the intersection is critical in determining the basic or ideal saturation flow rate. In this study, the concept of cumulative curves is used to estimate saturation flow rate for each discharge of vehicles during green time. A typical cumulative plot is shown in **Figure 7**. The start of the saturation period is determined by the time after start of green corresponding to the starting queue position in **Figure 6** and similarly, the end of saturation period is determined by the time corresponding to the ending queue position or queue length in the headway-queue position plot in **Figure 6**.

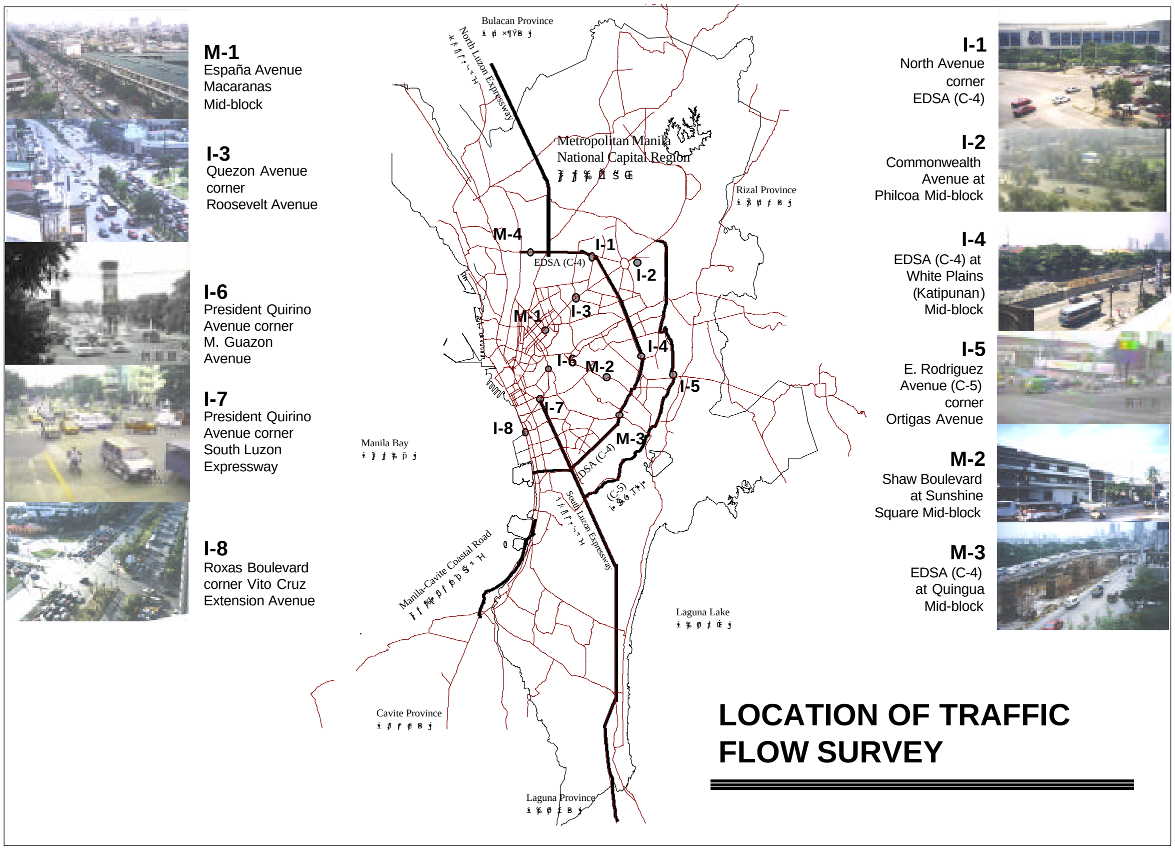


Figure 5. Location of 1998 traffic flow survey

The passenger car unit (pcu) values [jeepney=1.5, bus=1.87, big truck=2.43, medium truck=1.5] computed in Chapter 3 are used to convert the cumulative flow in Figure 7 from vehicles per hour green per lane (vphgpl) to passenger cars per hour green per lane (pcphgpl). In the typical intersection traffic flow, the first few vehicles in queue experience starting lost time and after this, headways become constant of slope becomes constant in the cumulative curve. Saturation flow rate s is the slope of the line $N(t)$:

$$N(t) = s \times (t - L_s)$$

Where L_s indicates starting lost time and t is any time t while $N(t)$ indicates cumulative number of vehicles at time t. Saturation flow rate (pcphgpl) is equal to s (pc/s) × 3600 s/hr.

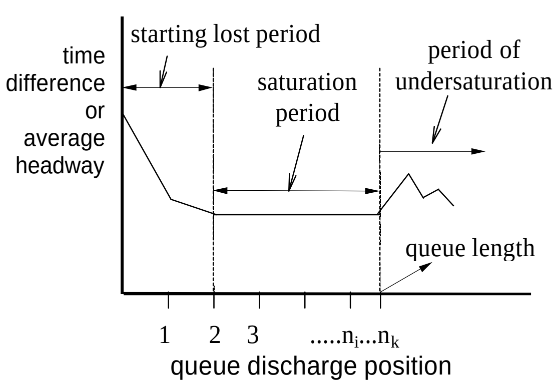


Figure 6. Theoretical plot of headway according to queue position

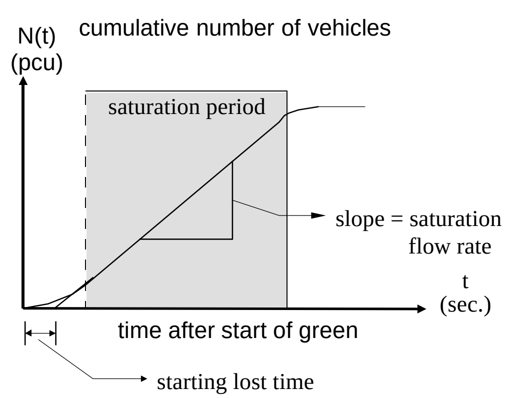


Figure 7. Theoretical cumulative curve of vehicles passing through an intersection

4.3 Speed-Flow Relationship and Mean Speed at Mid-Block Road Sections

Speed-flow relationships according to proportion of various heavy vehicle types such as buses, jeepneys or trucks are plotted and an example of a Q-V plot for mid-block M-3 is shown in **Figure 8**. Despite the high percentage of buses in the middle lane in M-3 (**Figure 8**), the speed-flow relationship is unchanged indicating the high vehicle performance of buses in Metro Manila. Non-congested speed data at mid-block sections are pooled to check the differences of mean vehicle speeds in general. In **Figure 9**, the mean speed of buses is similar to that of passenger cars while the mean speed of jeepneys is relatively low and similar to large trucks indicating its poor operating performance.

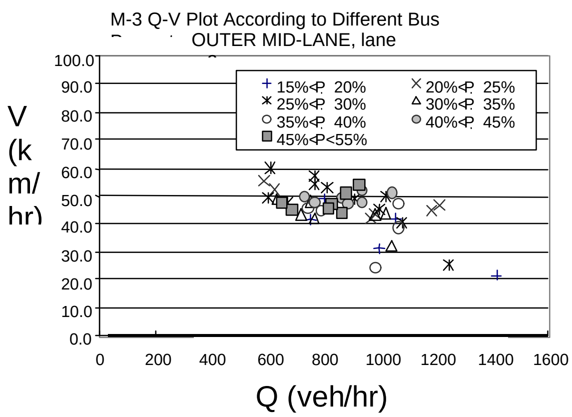


Figure 8. Speed-flow relationship(observed) at M-3

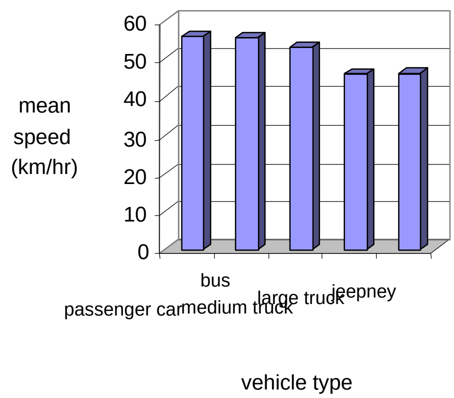


Figure 9. Mean vehicle speeds at mid-block road sections

4.4 Traffic composition of public transport vehicles according to lane

Figures 10 and **11** show the traffic percentages of buses and jeepneys according to lane for various mid-block sections and intersections surveyed in this study. In road sections with jeepney routes, the traffic composition of jeepneys is usually highest at the roadside. In road sections with bus routes, the traffic composition of buses is usually highest at the lane next to the roadside lane.

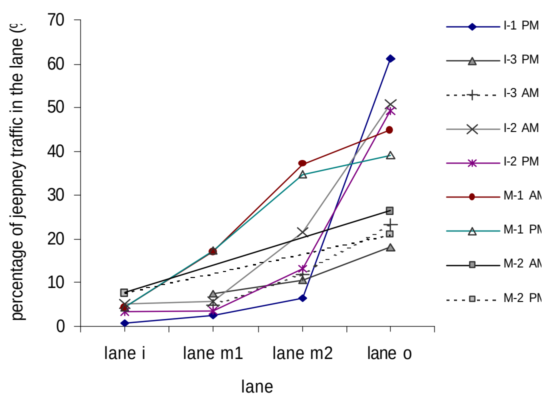


Figure 10. Traffic composition of jeepneys according to lane

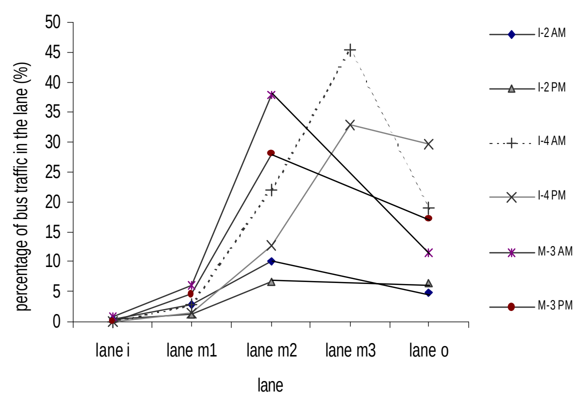


Figure 11. Traffic composition of buses according to lane

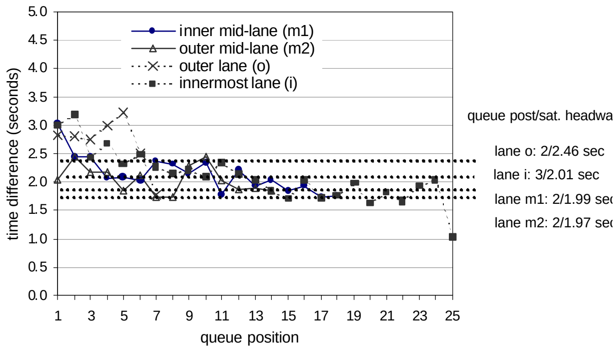


Figure 12. Headway-queue plot of intersection I-1

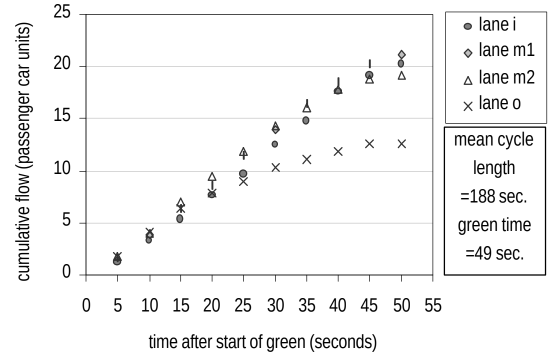


Figure 13. Cumulative curve of vehicles passing through intersection I-1

Figure 12 shows the variation of headway with queue post in intersection I-1. The higher outer lane saturation headway is influenced by the high proportion of jeepneys in the outer lane. **Figure 13** shows the cumulative curve corresponding to the headway-queue plot in Figure 13 for intersection I-1. It can be understood that there is failure to fully utilize the green due to mixture of heavy right turn traffic and high jeepney ratio. Many other intersections are observed to have periods where the green times are not fully utilized.

4.5 Special factors affecting saturation flow rate in Metro Manila

After extensive and detailed viewing of the videos of traffic flow, the following special factors are found to have influence on saturation flow rate (**Table 1**).

Table 1. Special factors affecting saturation flow rate in Metro Manila

main factor	details of main factor
1. vehicle performance	1.1 slow start-up reaction of passenger cars 1.2 slow start-up reaction of trucks 1.3 slow start-up reaction of jeepneys
2. driver behavior – vehicles running in the middle of lanes	
3. driver behavior – vehicles changing lanes	3.1 merging 3.2 diverging
4. public transport operation	4.1 effect of jeepneys 4.2 effect of trucks

Table 2. Influence of special factors on saturation flow rate in Metro Manila

factor	saturation flow rate (pcphgpl)	t-value (compared to no influencing factor)
lane-changing-diverging (3.2)	1607	2.02
combination of slow-start vehicles and vehicles running in the middle of lanes (1+2)	1609	3.72
combination of factors 1, 2 and 3.2 (1+2+3.2)	1547	3.46
no influencing factor	1767	-

Results of comparison of saturation flow rates with and without the influence of special factors (Table 2) indicate that the combined effect of factors, including slow-start vehicles, vehicles running in the middle of lanes and vehicles changing lanes, is significant, indicating the importance of vehicle performance level and driver behavior on traffic flow characteristics.

5. ANALYSIS OF THE ROAD TRAFFIC ENVIRONMENT IN METRO MANILA

5.1 Collection of air quality data

A total of 9 signalized intersections and 13 mid-block road sections were surveyed in July and November of 1999 to collect roadside concentration of suspended particulate matter (SPM) and nitrogen dioxide (NO_2) using portable pollution monitoring equipment. Meteorological and physical data were also obtained.

5.2 Roadside pollutant concentration and traffic volume

Figure 14 shows the plot of the SPM concentration as a function of the hourly traffic volume per lane. Initial results show a direct proportional relationship between traffic volume and roadside pollutant concentration.

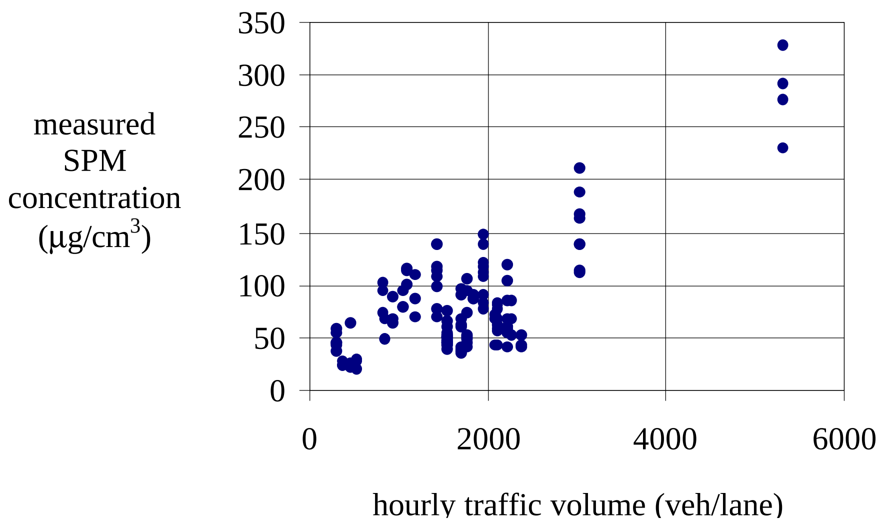


Figure 14. Variation of suspended particulate matter concentration with hourly traffic volume

5.3 Roadside pollutant emission concentration model

The pollutant emission mass concentration is modelled as a multiple linear regression of traffic volumes of various vehicle types, meteorological information and road geometry.

$$y = a_0 + \sum_i a_i V_i + \sum_j b_j W_j$$

where y = pollutant emission mass concentration (µg/m^3)

a_i , b_j = parameters

V_i = traffic volume of vehicle type i (veh/hr)

W_j = meteorological information, road geometry

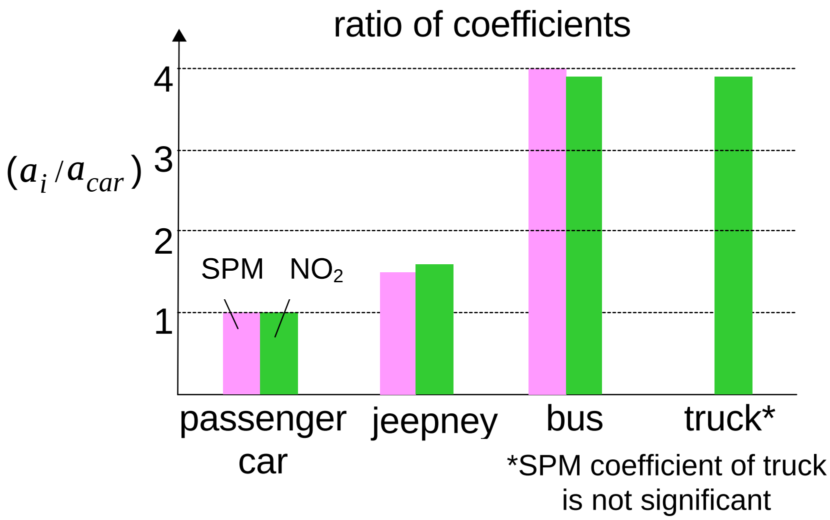


Figure 15. Ratio of the coefficients of the regression model

5.4 Jeepney engine characteristics

A questionnaire survey was conducted on 100 drivers of jeepneys in the Cubao terminal area in Quezon City, Metro Manila on July 15-16, 1998 in order to study the characteristics of jeepney engines including model type, frequency of breakdowns and others. **Figure 16** shows the proportion of engine models used in jeepney vehicles where most of them are Japan-made truck vehicles (Isuzu=88%). **Figure 17** meanwhile shows the periods of manufacturing of various engine models used in the jeepneys and by simple weighted average, the average engine age was found out to be 19 years.

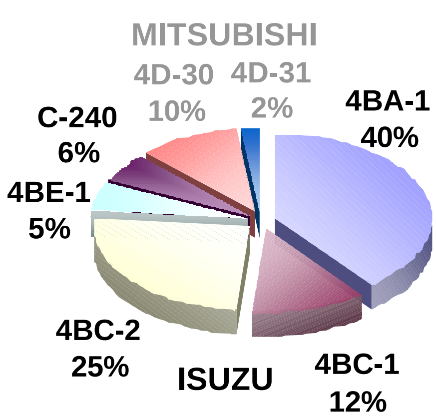


Figure 16. Proportion of engine models used in jeepneys

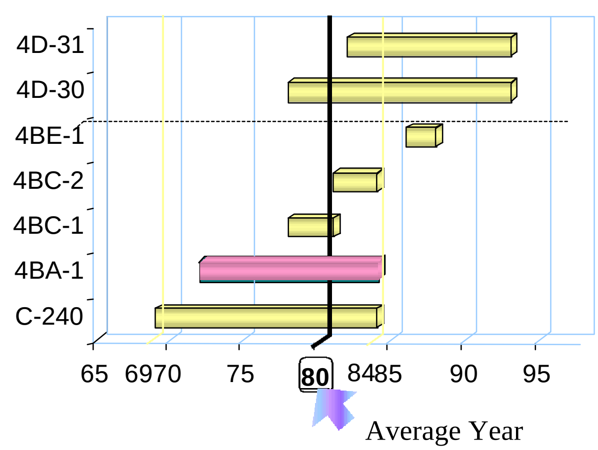


Figure 17. Periods of manufacturing of jeepney engine models (Mitsuhata, 1999)

6. STUDY ON THE METRO MANILA TRAFFIC FLOW AND TRAFFIC ENVIRONMENT SIMULATION SYSTEM

6.1 Introduction

There is a need for simulation analysis since there is difficulty in obtaining the factors affecting traffic flow by statistical analysis only and it requires microscopic analysis. Usually, there is need to analyze the impacts of new transportation policies or measures and there is relative ease in the application of simulation especially to environmental impact study. In this section, the existing microscopic simulation system "Paramics" is utilized and then improved considering the presence of paratransit vehicles such as jeepneys which is special in Metro Manila. This initial study is focused on the point-level study, that is the traffic simulation of an intersection approach in order to analyze changes in driver behavior, vehicle performance, physical road environment and some traffic countermeasures and the corresponding impacts on traffic flow and the environment.

6.2 Advantages of using the Paramics for the study

The major advantage of Paramics is its capability to model individual vehicle movement where headway, lane-changing, individual vehicle speeds can be determined and analyzed in detail. It is based on the car following model with additional models on lane-changing, gap acceptance and driver aggression. There is also high potential for development of the models through addition or modification of the parameters of existing driver-vehicle models.

6.3 Improvement of simulation system

The simulation system is improved through the modification of parameters based on video and site observation of an actual signalized intersection in Metro Manila (denoted by I-1), as shown in **Figure 18** and **Figure 19**. The improvement of the system is summarized on **Table 3**. Basic input is the actual hourly traffic volume from 2:00 to 3:00 PM. The following components of the system are improved: a) vehicle characteristics; b) public transport operation; and c) geometric and traffic characteristics. For vehicle characteristics, top speeds and acceleration of jeepneys and other vehicles are lowered and a low-performance passenger car type is introduced. The jeepney vehicle type is simulated

Figure 18. Photo of actual intersection (I-1: North Avenue-EDSA (C-4)-West Avenue)

as a minibus vehicle class in the Paramics system. In public transport operation, minibus routes and stops are set up and characteristics such as headway and capacity are modified to simulate jeepney/paratransit behavior. For geometric and traffic characteristics, speed limits, road widths and signal timing are modified and are based on actual conditions in I-1.

Table 3. Summary of improvement of the simulation system to base traffic conditions

initialization (configuration)	
right hand drive, simulation time 14:00:00, units metric	
road category (categories)	
speed limit setting	50 kph
number of lanes	4
road width	12.8 m
median width	1.0 m
intersection (junctions)	
cycle length	191 seconds

	green time (seconds)	red interval (seconds)	movement
phase 1	52	3	West Ave. → EDSA West Ave.→ North Ave.
phase 2	47	3	EDSA Northbound EDSA Southbound
phase 3	33	3	EDSA Southbound EDSA → West Ave.
phase 4	47	3	North Ave. → EDSA North Ave. → West Ave.

vehicle class and composition (vehicles)

actual vehicle type	vehicle type in simulation system	top speed (km/h)	acceleration (m/s^2)	proportion (%)
passenger cars	type 2 car	51.50	2.50 (default)	91.400
slow start-up passenger cars	type 3 car	51.50	1.60	2.900
jeepney (paratransit)	type 12 minibus fixed route	46.10	1.60	
medium truck	type 14 OGV1	49.00	2.50 (default)	5.200
large truck	type 15 OGV2	46.80	2.50 (default)	0.500

public transportation operation (busroutes)

routes	no. of companies=1/headway=0 sec./capacity=20
stop	stop set at 80m before stop line

traffic demand (demands)

O/D in vehicles/hour	**1**	**2**	**3**	**4**
1	**0**	**1329**	**875**	**217**
2	**1755**	**0**	**223**	**0**
3	**693**	**419**	**0**	**877**
4	**538**	**46**	**559**	**0**

driver aggression level (behaviour)

multiplier	4 (x4) – default								
aggression level	0	1	2	3	4	5	6	7	8
distribution of probability (normal) – default	1	4	11	21	26	21	11	4	1

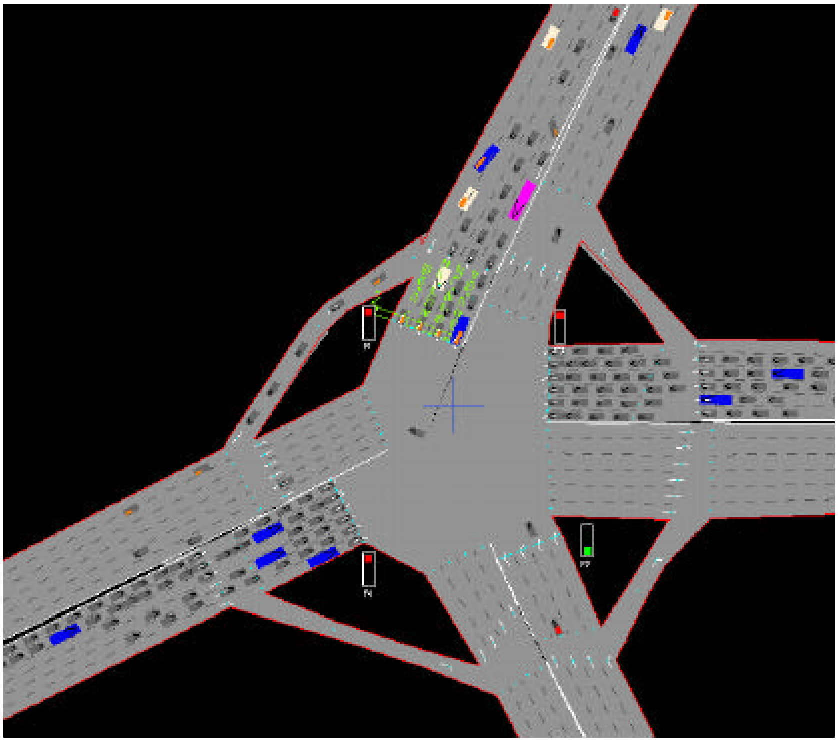


Figure 19. Snapshot of Paramics simulation of intersection I-1

6.4 Traffic simulation experiment of intersection I-1

The base case (actual traffic conditions in I-1) analyzes the following characteristics: stability; output of traffic flow characteristics; and comparison with observed traffic flow characteristics. The base case is then compared with: improvement of driver behavior; low performance level of vehicles; and improvement in physical environment/traffic policy.

6.4.1 Stability of simulation system

The stability of the simulation system should be analyzed first before doing experiments because in the initial time of simulation run, vehicles are still filling up the network and this causes instability or fluctuations in the traffic flow. **Figure 20** and **Figure 21** show the stability of the input and output values, respectively. From Figure 21, the stability of the mean headway is attained at approximately 47 minutes or around after 15 signal cycle

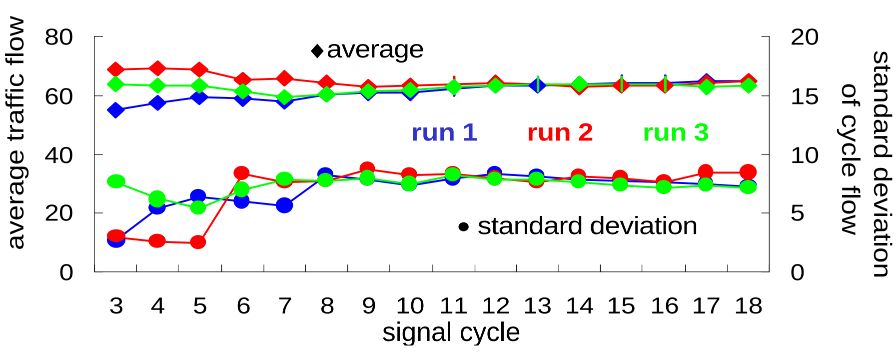


Figure 20. Stability of input value

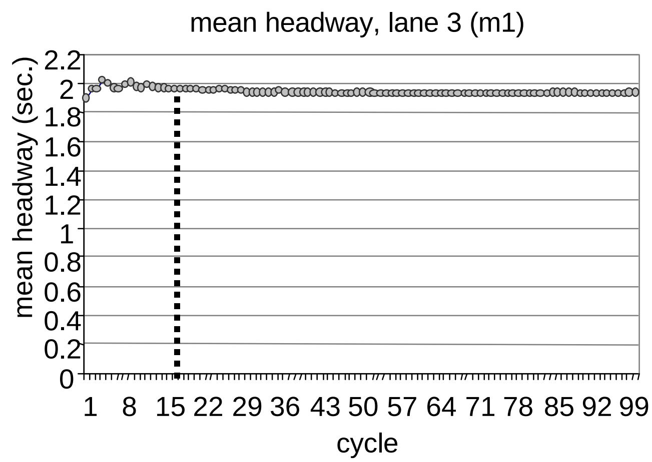


Figure 21. Stability of output value

lengths after the start of simulation run. Therefore, all analysis are conducted based on the simulated output data after 47 minutes of run.

6.4.2 Simulation results of the base case and comparison with actual observations

Figure 22 shows the comparison of the observed and simulated headway of the outermost lane (lane 1), where there is high percentage of jeepneys, and the adjacent lane (lane 2). Results of simulation indicate close agreement with the observed headway in I-1.

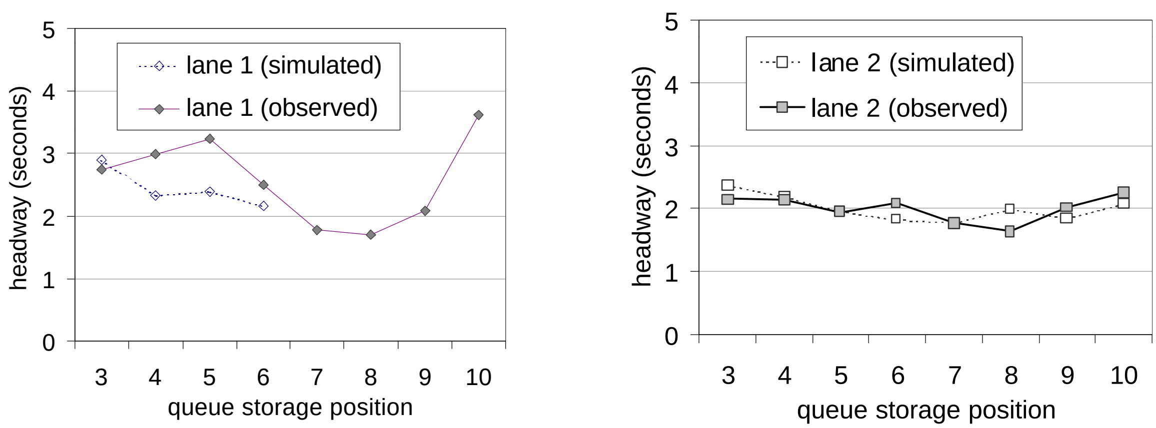


Figure 22. Comparison of simulated and observed headway in lane 1 and lane 2

6.4.3 Simulation analysis-comparison of base case and 3 scenarios

Firstly, driver behavior is improved by reducing the overall driver aggression to 25% of the values in the default normal distribution, as seen in the lower part of **Table 3**. This results in the smoothening of the peak of the normal distribution of driver aggression. **Table 4** shows the results of simulation of base traffic conditions (volume, speed and headway) for lane 1 (outermost lane) to lane 4 (innermost lane). **Table 5** shows results of simulation when driver behavior is improved. Although the mean traffic flow decreased, the speed increases in general since there is less lane-changing thereby making the traffic flow smoother than the base case.

Figure 23 shows the increase in headway and the decrease in speed in the presence of high percentage of low-performance vehicles such as jeepneys and other old vehicles. Figure 24 shows the increase in average speed of the outermost lane when the jeepney stop is relocated farther away from the intersection approach.

Table 4. Simulation results for base traffic conditions in I-1

base traffic conditions (detector D1)	volume (veh./hr.)	headway (sec.)	speed (km./hr.)	trip time (zone 3 to 4)
lane 1 (outermost lane)	107	2.5	26.45	
lane 2 (outer middle lane)	330	2.05	37.61	
lane 3 (inner middle lane)	496	1.94	39.76	
lane 4 (innermost lane)	483	1.91	41.23	
total	1416	2.00	38.75	0:03:57

Table 5. Simulation results from driver behavior improvement

driver behavior improvement (D1)	volume (veh/hr)	headway (sec)	speed (km/hr)	trip-time (zone 3 4)
lane 1 (outermost lane)	103	2.54	25.83	
lane 2 (outer middle lane)	346	1.97	38.75	
lane 3 (inner middle lane)	446	1.94	39.35	
lane 4 (innermost lane)	475	1.88	41.19	
TOTAL	1370	1.97	38.82	0:05:08

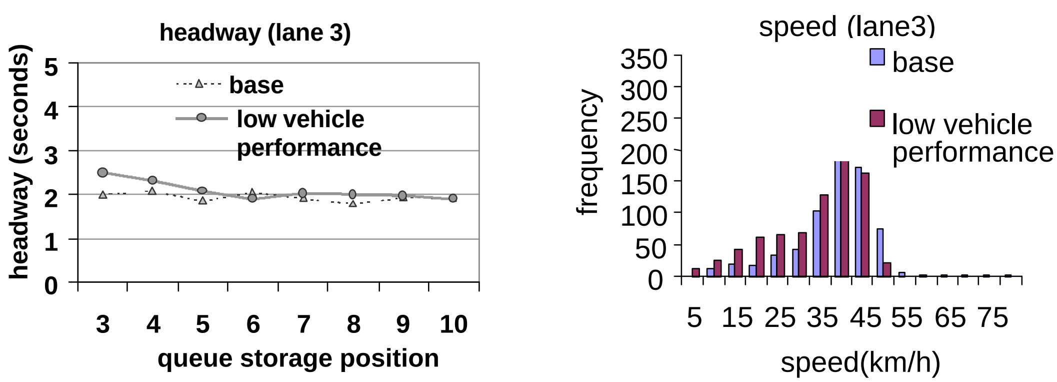


Figure 23. Comparison of base case and low-performance vehicle case

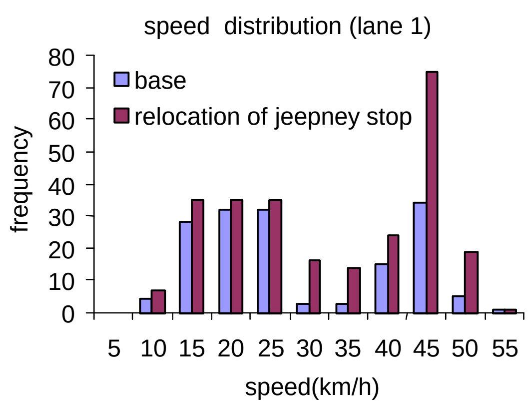


Figure 24. Comparison of base case and relocation of jeepney stop

6.4.4 Analysis of traffic environmental impact using simulation system

Figure 25 shows the positive impacts on the traffic environment in terms of SPM emissions for the 3 cases of improvement in driver behavior, vehicle performance and the physical/traffic conditions.

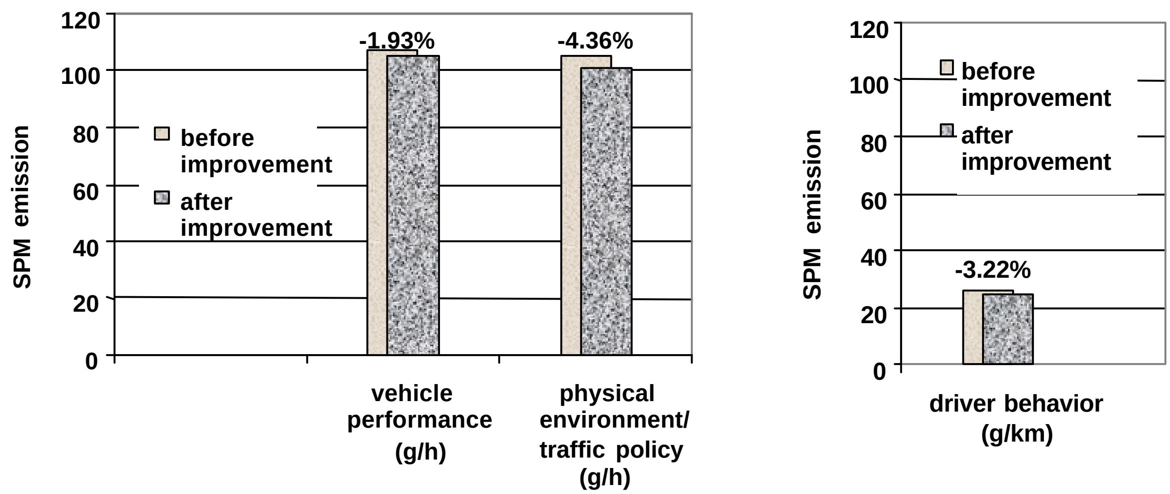


Figure 25. Analysis of traffic environmental impact of various scenarios through the use of simulation system

Based on the results of traffic flow analysis and traffic environment simulation, the strict and proper enforcement of traffic rules and regulations along roads coupled with hard traffic engineering measures are the most effective policies in reducing the traffic congestion and the motor vehicle emissions. In the traffic analysis, higher saturation flows could be obtained if lane-changing, vehicles running outside of the proper lanes and slow-start vehicles are minimized. Results of simulation show that traffic policy/countermeasure and driver behavior are the effective measures in reducing emissions. If the rules against lane-changing and maneuvering as well as rules on jeepney/transit stops are enforced and implemented properly, together with the installation of barriers and traffic signs to prevent lane-changing, and facilities for jeepney stops, it is possible to reduce the traffic congestion and emissions not only in one section but for the rest of the road network.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The study identified that vehicle performance and driver behavior significantly affect the traffic flow in Metro Manila especially the saturation flow rate through signalized intersections. The study analyzed the traffic environment through the measurement of roadside SPM concentration levels in the metropolis and the investigation of jeepney engine characteristics. Considering some major factors related to driver behavior and vehicle performance, the microsimulation sofware was improved and the stability of the simulation system was established. Although the car-following and other driver behavior models were not modified, the study was able to calibrate vehicle, geometric and other traffic operational characteristics to local conditions.

The factors affecting saturation flow rate such as vehicle performance, driver behavior and public transport operation were confirmed by traffic flow analysis and traffic flow simulation experiments using the Paramics microscopic traffic simulation software. The impacts of driver behavior, vehicle performance and the physical environment or traffic policies on traffic flow and the environment are quantified in terms of changes in simulation output values of traffic flow parameters and SPM emission levels.

7.2 Recommendations

This study recommends that gradual implementation of vehicle inspection be implemented that will include emission rate regulation together with detailed refinements in the guidelines in registration fee, taxes and improvement of vehicle classification for this purpose. There is also a need for stricter implementation of the licensing of drivers and the long-term traffic education to reduce driver aggression. There is also need to improve jeepney stops by expanding and allocation of spaces in order to reduce blockage of the outer lanes. There is also a need to optimize the use of traffic signals by reducing the period of undersaturation through variable signal timings, vehicle-actuated or coordinated areawide signal control to reduce unnecessary delays and congestion in the major arterial roads.

7.3. Further Studies

There is a need to for more accurate calculation of the saturation flow rate from yhe microsimulation system through the counting of heavy vehicles to express saturation flow rate in passenger car units. Aside from the basic traffic characteristics such as headway, speed and volume, there is a need to compute the major indicator of level of service of signalized intersections, that is, the intersection delay. This will be another good indicator of various countermeasures or changes in vehicle performance, driver behavior and traffic operations.

A more detailed tracking of vehicle movements (time-space) to more accurately estimate vehicle emissions based on different running modes is necessary in future studies. Of course, the automation of pollution counting would be very much helpful in calculation of vehicle emissions. After establishing the simulation system for intersection-level analysis, future studies would include expansion to a road network, even a sub-network, in order to analyze overall and areawide traffic and environmental impacts of various changes in vehicle performance, driver behavior, traffic operations, physical environment and other transport countermeasures.

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