COMPARATIVE STUDY OF TRAFFIC CONDITIONS AND ROAD CAPACITIES IN SOME ASIAN CITIES

Karl VERGEL
Graduate Student
Department of Civil Engineering
Tokyo Institute of Technology
2-12-1 O-okayama, Meguro-ku
Tokyo 152, Japan
Fax: +81-3-3726-2201

Shigeru MORICHI, Dr. of Eng.
Professor
Department of Civil Engineering
Tokyo Institute of Technology
2-12-1 O-okayama, Meguro-ku
Tokyo 152, Japan
Fax: +81-3-3726-2201

abstract : The study's purpose is to compare intersection traffic flow parameters of Manila, Tokyo, Seoul and Bangkok where the headway, saturation flow rate, starting lost time, and passenger car unit values of certain vehicles are calculated in order to find characteristics of traffic flow, capacity, behavior, social and economic conditions which are unique in each city and determine the their relationship for the formulation of road design standards and transportation policies. Pedestrian and driver behavior in Manila, and buses in Bangkok are only some of the special characteristics which affect headways, saturation flow and starting lost time.

1. INTRODUCTION

In recent years, countries in the East Asian region have experienced the highest economic growth rate in the world where much of the economic activities concentrated in the metropolitan areas. The growth of population in metropolitan areas particularly those in developing countries in the region was observed to be high in the past decade. Accompanying this was the sharp rise in private car ownership as a direct result of economic growth wherein more and more people could afford to buy cars. Consequently, many road facilities have reached their limit in carrying the flow of vehicles resulting to traffic congestion and travel delay in the urban arterials. As policy solution after motorization in this region, developed countries have constructed and improved transportation infrastructure and, developing countries now are building transportation infrastructure, mainly by increasing the capacity of the road network. It is therefore important to provide the basis for estimating the relationship between the demand and the capacity of roads. Initially some years back, the evaluation of road capacity and level of service in the developing countries was based on the capacity manuals of developed countries in the west such as the US HCM although recently, South Korea had just completed its own capacity manual and the Philippines has conducted preliminary research. However, the traffic conditions and policies in developed countries such as the US are different from that of developed countries in Eastern Asia.

The main purpose of this research is to compare signalized intersection traffic flow measures among the cities and determine the special characteristics which may affect them. The relationships among these traffic flow measures and characteristics special to each country would be studied. Characteristics specific to each metropolis include not only traffic flow measures but also behavior, social and economic characteristics. The metropolitan capitals of selected countries in Eastern Asia which include Japan, South Korea, Thailand and the

Philippines are compared in this study. The comparison analysis among countries would result to the determination of those characteristics which are varying and those which are non-varying or stable with respect to the economic level. The importance of understanding this relationship is that it would facilitate the future estimation of traffic flow measures especially in developing countries such as the Philippines and Thailand. With these results, the formulation of transportation policies and design standards which are fit to each country could be possible. These would help solve the current and future traffic problems in each metropolitan area in the study and would provide valuable information to highway capacity manual research in developing countries.

2. DATA COLLECTION

2.1 Intersections Surveyed for the Four Cities in the Study

Data were obtained through the videotaping of intersection flows at various locations in the 4 metropolitan capitals: Bangkok, Manila, Seoul and Tokyo. The focus was on the traffic flow in major arterial roads located at or near commercial business district (CBD) areas of these East Asian metropolises. The videos were taken during morning and afternoon peak periods on regular weekdays. The videos were taken such that the intersection stop line and the rear axle of the vehicle discharging through the intersection could be seen clearly. Table 1 shows the locations of the survey and the corresponding time periods.

2.2 Classification of vehicles

Table 2 shows the classification scheme for various types of vehicles in Manila, Bangkok, Seoul and Tokyo. For all cities, the type 1 vehicle included the private passenger cars, taxis, private and utility vans. Type 2 in general included medium-sized trucks or medium commercial vehicles except for Bangkok where the second type was assigned to be for a kind of paratransit mode which is called the loth. The loth is basically a converted pick-up or medium truck varying from small to medium in size with an approximate seating capacity of 16 passengers for medium trucks and 10 passengers for pick-up trucks. The pick-up was separated from the type 1 vehicle because it might have different performance compared to passenger cars due to its function being a public paratransit mode. Also, very few utility trucks were observed in Bangkok during the surveys which could be due the existing truck ban policy during the day.

Type 3 generally included trucks larger in size than in type 2 which also included ten-wheelers, dump trucks, cargo trucks and trailer trucks. Type 4 basically included motorcycles for all the cities. Type 5 included buses and medium-sized buses for private and public utility. An extra category of vehicle type 6 was added to Manila and Bangkok due to the presence of several forms of paratransit vehicles. For Manila, type 6 was assigned for the jeepney which is still one of the major form of public transportation in Metro Manila especially in radial roads and minor streets where there are no service of buses. The jeepney is basically a modification or extension of the American army jeep used in World War II with the body made locally with available local technology and the chassis and engine imported (Iwata, 1993). The jeepney could generally accommodate 2 passengers in front at the right-hand side of the driver while the seating capacity at the back varies generally from 10 to 18 depending on the length. It could also accommodate "hanging passengers" at the back door where passengers, usually men, hold on to the bars stepping on the entrance platform at the back or at some extension part. The number may vary from 1 to 5 or 6 especially in peak-hour periods. There could be no standing passengers because the structure of the body has a low ceiling and generally it would interfere with passengers riding and getting off the vehicle. In the case of Bangkok, type 6 was assigned to the tuk-tuk or the three-wheeled taxi with a capacity of three passengers. These vehicles are allowed on major arterial roads in Bangkok although restricted against using the expressways (Morichi, 1992).

Table 1. Information on intersection approaches surveyed in the four cities

City	Intersection	Approach	Time of Survey
Manila	Aurora Avenue - Epifanio del los Santos Avenue(EDSA)	Aurora Avenue	7:00 AM-9:00 AM
	Governor Forbes Street- Espana Avenue	Governor Forbes Street	8:45 AM-9:30 AM
	Ayala Avenue-Makati Avenue	Ayala Avenue	7:30 AM-9:00 AM
	Ayala Avenue - Paseo de Roxas Street	Ayala Avenue	7:40 AM-9:20 AM
	EDSA - Pasay Road	EDSA	7:46 AM-9:30 AM
Bangkok	Sukhumvit Road - Phaya Thai I Road	Sukhumvit Road Phaya Thai I Road	4:00 PM-6:00 PM 11:45 AM-1:45 PM
	Phetburi Road - Asok-Dindaeng Road	Phetburi Road	7:00 AM-9:00 AM
	Sukhumvit Road - Asok-Dindaeng Road	Sukhumvit Road	10:15 AM-12:15 PM
Seoul	Mia Avenue-Seongshin Women's University Avenue	Mia Avenue	7:00 AM-9:00 AM
	Kangnam Avenue - Teheran Avenue	Kangnam Avenue	8:15 AM-10:15 AM
	Song'pae Avenue - Olympic Road	Song'pae Avenue	8:00 AM-10:00 AM
	Chung-mu Avenue - Seun Avenue	Chung-mu Avenue	8:00 AM-10:00 AM
Tokyo	Route 20-Sasazuka Intersection	Route 20	5:50 PM-7:20 PM
	Harumi Avenue - Ginza Chuo Avenue	Harumi Avenue	3:50 PM-5:40 PM
	Eitai Avenue-Showa Avenue	Eitai Avenue	8:30 AM-9:30 AM
	Keio Road-Kiyosumi Street	Keio Road	8:25 AM-10:25 AM
	Komazawa Avenue - Meiji Avenue	Komazawa Avenue	9:40 AM-11:40 AM

Table 2. Vehicle classification for the different cities

City	type 1	type 2	type 3	type 4	type 5	type 6
Manila	passenger cars, taxis, vans	medium-sized trucks	large trucks	motorcycles	buses	jeepneys (para-transit)
Bangkok	passenger cars, taxis, vans	pick-ups or loths (paratransit)	large trucks	motorcycles	buses	tuk-tuks (para-transit)
Seoul	passenger cars, taxis, vans	medium-sized trucks	large trucks	motorcycles	buses	
Tokyo	passenger cars, taxis, vans	medium-sized trucks	large trucks	motorcycles	buses	

3. ANALYSIS

3.1 Saturation Period

The most serious difficulty often encountered in the actual calculation of saturation flow rate is the identification of the saturation period. This is also important in the calculation of passenger car unit (pcu) values for various types of vehicles since it is based on the headways between vehicles. The headway values to be used in the computation should be taken from the saturated period of the flow in order to estimate correctly the effect of other vehicle types on the traffic flow as reflected by the pcu. The main difficulty is the determination of position in queue from which the headway is considered to be stable since the principle of saturation flow and lost time is that after the first few vehicles, the headways of vehicles discharging through the intersection become more or less steady or the same. The value in which the headways are supposed to converge is called the saturation headway. But from experience through previous analysis of intersections in Manila, there is no real convergence nor stabilization. The headway plots usually are observed to fluctuate irregularly. Different manuals prescribe different saturation periods based on their empirical research in their respective localities. The ARRB defines its saturation period starting after 10 seconds of green until the end of the green interval. The US Highway Capacity Manual or US HCM (1985) defines it starting from the passing of the rear axle of 4th vehicle in queue until the last vehicle in queue. However, It is not wise to use these prescribed values for application to the East Asian metropolitan capitals selected in this study because of local characteristics which are different for each country such as driver and pedestrian behavior, traffic rules and policies and their implementation.

The saturation flow region of the queue could be determined subjectively by visual inspection of the plot (Stokes, R.W., *et.al.*, 1986b) of the average time headways of a queue of vehicles discharging through an intersection (see Figure 1) by selecting the vehicle storage position in which the headways could be assumed to be equal. The researcher could impose a time tolerance such that if the difference between successive headways falls below this specified value, the queue position coinciding with this can be considered as the start of the saturation period. In this study, the queue discharge position indicating the start of saturation for each lane observed is decided by the difference of mean headway values between successive queue segments which would be discussed next.

The data collection portion produces an initial data of observed headways of vehicles lined up in a queue which are discharged by the change of signal from red to green. These are done for each green interval of each cycle over a number of cycles occurring in the video. With the aid of a computer, these are then used to calculate the mean headways for selected segments of the queue, i.e.,

$$1 \le n_i \le n_k, \ldots\ldots, 5 \le n_i \le n_k$$

where n_i = queue storage position
n_k = number of vehicles queued in a certain lane at the start of the green signal phase

This is patterned after the study of double left-turn saturation flow rates (Stokes, *et.al.*, 1986a). In this study, the preceding procedure is done on a per lane and per intersection approach basis where the departure headway values for all the cycles observed are added and then divided by the corresponding number of headways observed to get the mean for

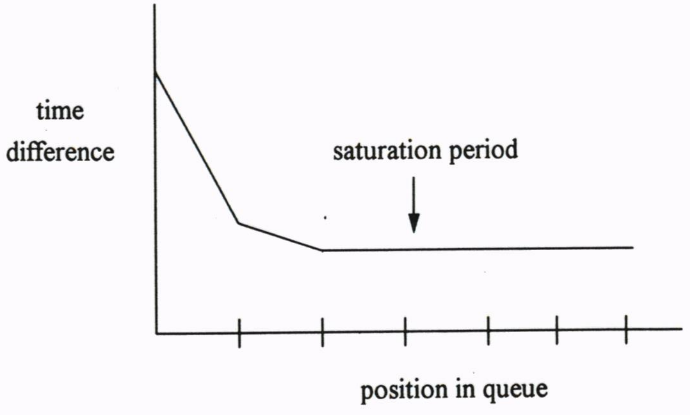

Figure 1. Plot of headway against queue position

each queue segment. The n_k per cycle is determined by observing the length of queue at the start of the green interval including those vehicles joining the queue after the signal change. However, as experienced in this study, due to the limited scope of view of the video footage, the queue length in each cycle is determined subjectively from the video by the observation of the time headway or spacing between vehicles. If it is quite long enough, say more than 5 seconds between passenger cars, the discharge position of the preceding car which passed through the intersection is decided as the queue length n_k for that cycle. The queue position where saturation period starts is decided when the mean headway values between successive queue segments become approximately equal.

3.2 Vehicle Followings Between Passenger Cars and Other Types of Vehicles

An intermediate result before the actual pcu value computation is the average spacing or followings maintained by passenger cars and other types of vehicles considered in this study.

3.3 Calculation of Passenger Car Unit (pcu) Values for Various Vehicle Types

After addressing the problem of identifying the approximate saturation period for each lane in the analysis, the next step is the actual calculation of the pcu values for various vehicle types. There are several methods now being used by researchers from US and UK. The method used in this study is adopted from Scraggs (1964). The pcu for a vehicle type n is found by dividing the mean headway for a vehicle type n following vehicle type n by the mean headway of a car following a car.

$$pcu_n = \frac{\bar{h}_{nn}}{\bar{h}_{cc}} \tag{1}$$

Equation (1) is true only if the effect of vehicle type n is independent of the type of vehicle preceding it and following. The necessary and sufficient condition for this is that the mean headway of cars following cars and type n vehicle following type n vehicle must be equal to the mean headway of cars following type n vehicles and type n vehicles following cars.

$$\bar{h}_{cc} + \overline{h_{nn}} = \bar{h}_{cn} + \bar{h}_{nc} \tag{2}$$

Corrections are applied to the average headways and using Equation (1) by substituting the corrected headways. The main effect of the corrections is to give proper weight to headway measurements. Details of this are shown in the appendix of the paper of Kimber, *et.al.*, (1985).

3.4 Calculation of Saturation Flow Rate and Starting Lost Time

The calculated pcu values for vehicles other than passenger cars are then applied to the cumulative count of vehicles passing the intersection stop line at 5-second intervals. The pcu values are multiplied to the corresponding vehicles to convert the cumulative number of vehicles in Figure 2 into passenger car units. The detailed use of cumulative curves for the calculation of saturation flow rate and starting lost time was explained by Shanteau (1988). The slope of the straight line portion of the graph in Figure 2 represents the saturation flow rate in passenger car units per hour of green per lane and the horizontal intercept derived by regression represents the starting lost time in seconds. In this study, this is done on a per lane basis. The straight line portion of the curve is the saturation period and this is determined by the region between the starting position of headway stabilization and the queue length observed for each cycle. Therefore, the data for the first few vehicles are discarded since they are part of the starting lost time. The points in this region are regressed to find the slope s and y-intercept b. By equating y=0, it is possible to compute for the x-intercept which is the starting lost time.

$$y = sx + b \tag{3}$$

where s is the slope and b is the y-intercept.

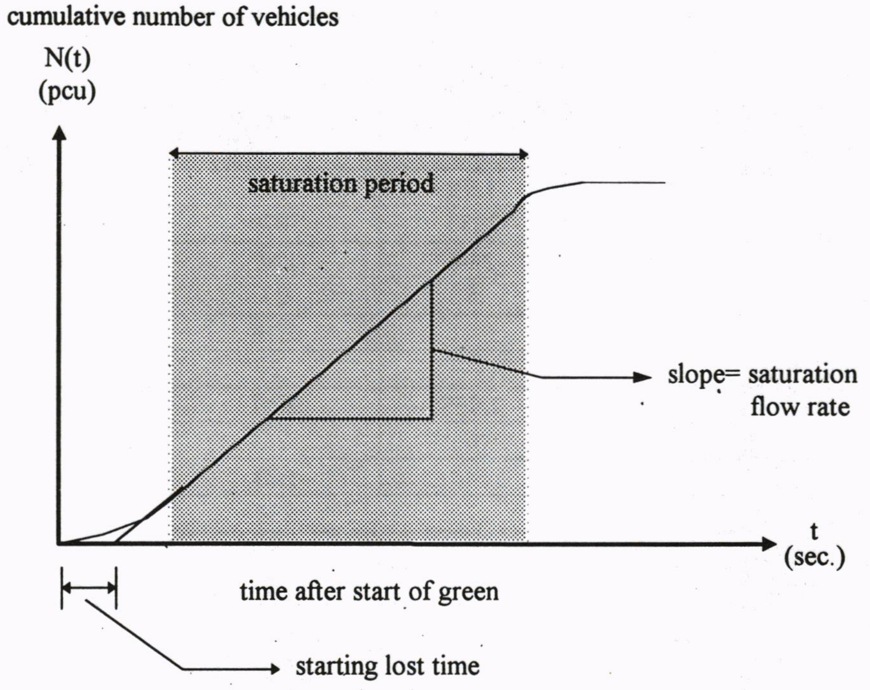

Figure 2. Typical cumulative curve of vehicles discharging against time

In the assessment of performance of signalized intersections, the capacity of an intersection approach is based on a number of variables, namely, the cycle length, allocated green time, and saturation flow rate(defined as the flow rate per lane at which vehicles can pass through a signalized intersection in such a stable moving queue), and can be expressed as :

$$capacity = g/c * s \tag{4}$$

where g = effective green
c = cycle time
s = saturation flow rate

Therefore, the values of saturation flow rate are vital in intersection analysis procedures and these values are directly used in calculating the capacity of an intersection.

4. RESULTS AND DISCUSSION

4.1 Results of Vehicle Followings

4.1.1 Comparison of mean headway between passenger cars

It could be seen in Table 4 that the difference in mean headway of passenger cars between

Table 3. Summary of average vehicle headway followings in the four cities (headway in seconds)

following vehicle - leading vehicle	MANILA	BANGKOK	SEOUL	TOKYO
passenger car - passenger car	**2.02**	**1.99**	**1.79**	**1.93**
	1065	2233	5079	2997
passenger car - large truck	**2.17**	**2.00**	**1.87**	**2.10**
	19	5	27	125
large truck - large truck	**3.79**		**2.75**	**3.10**
	7		2	10
large truck - passenger car	**4.44**	**2.955**	**2.87**	**3.12**
	22	6	26	124
passenger car - medium truck	**2.35**		**1.81**	**1.99**
	58		234	328
medium truck - medium truck	**2.95**		**2.00**	**2.36**
	4		57	56
medium truck - passenger car	**2.69**		**1.98**	**2.31**
	49		232	327
passenger car - bus	**2.18**	**3.04**	**2.19**	**2.17**
	100	73	316	37
bus - bus	**3.39**	**3.55**	**3.30**	**4.14**
	62	33	49	4
bus - passenger car	**3.48**	**2.88**	**2.89**	**3.39**
	86	69	323	44
passenger car - motorcycle	**1.68**	**1.52**	**1.60**	**1.51**
	4	261	69	97
motorcycle - motorcycle		**1.13**	**2.03**	**0.87**
		98	2	12
motorcycle - passenger car	**2.67**	**1.60**	**1.45**	**1.40**
	9	261	68	80

PARATRANSIT VEHICLES - Manila, Bangkok

	Manila	Bangkok	
	jeepney	pick-up	tuk-tuk
passenger car - paratransit	**2.44**	**1.86**	**1.66**
	281	55	20
paratransit - paratransit	**2.90**		
	466		
paratransit - passenger car	**2.62**	**2.23**	**2.26**
	299	58	21

Notes: 1) upper bold figure indicates average headway in seconds
2) lower figure indicates the number of observations

Table 4. Testing the significance of differences of mean headway followings

following vehicle - leading vehicle	Manila vs. Bangkok	Manila vs. Seoul	Manila vs. Tokyo	Bangkok vs. Seoul	Bangkok vs. Tokyo	Seoul vs. Tokyo
passenger car - passenger car	0.0067152	6E-19	1.16E-24	2.69E-11	4.25E-25	6.3E-09
	0.6728775	1.7E-16	0.0002048	4E-24	0.000217	2.7E-22
passenger car - large truck	0.6025505	0.36319	0.144144	0.992313	0.845707	0.60696
	0.5144343	0.08964	0.675292	0.67545	0.735778	0.10623
large truck - large truck	-	-	0.147305	-	-	-
			0.27756			
large truck - passenger car	0.0273687	0.00094	0.003165	0.453488	0.162656	0.11127
	0.0106248	0.00626	0.009799	0.852679	0.73565	0.33437
passenger car - medium truck	-	5.7E-20	1.05E-05	-	-	0.08833
		4.4E-06	0.006833			0.0014
medium truck - medium truck	-	0.57264	0.79868	-	-	0.10413
		0.0388	0.189819			0.00645
medium truck - passenger car	-	0.01095	0.004617	-	-	0.75595
		0.00016	0.029086			2.4E-05
passenger car - bus	1.346E-16	0.71876	0.654976	5.53E-29	1.76E-07	0.79835
	0.0006738	0.97621	0.904888	0.00049	0.001432	0.88117
bus - bus	0.2522901	0.7427	0.158222	0.07715	0.337274	0.0391
	0.5090913	0.66287	0.228061	0.497905	0.429909	0.42951
bus - passenger car	0.001483	3.3E-09	0.417174	0.301433	0.050616	0.00058
	0.014081	0.00423	0.781498	0.943618	0.056201	0.04825
passenger car - motorcycle	-	-	-	0.436656	0.148227	0.66461
				0.481956	0.978972	0.49412
motorcycle - motorcycle	-	-	-	-	0.01486	-
					0.031788	
motorcycle - passenger car	-	-	-	0.64525	0.167827	0.14086
				0.242981	0.067332	0.66903
PARATRANSIT VEHICLES - MANILA AND BANGKOK						
passenger car - paratransit	comparison of jeepneys and tuk-tuks	0.00017	comparison of jeepneys and pick-ups	3.36E-06		
		2.7E-06		2.08E-06		
paratransit - paratransit		-		-		
paratransit - passenger car		0.09956		0.001559		
		0.14855		0.001874		

Notes:

1. upper figure indicates F-test (values of probability) of the differences in variances of headways between concerned cities,
2. lower figure indicates result of t-test (values of probability) between concerned cities

Manila and Bangkok is not significant at 95% level of confidence (5% error level) although the headway value in Manila is slightly larger than Bangkok by about 0.03 second, as seen in Table 3, where the number of observations for cities exceeded 2,000 except for Manila. All the other paired t-tests at yielded significant differences in mean headway values between passenger cars at the 5% level. This generally means that the headway between passenger cars is the least in Seoul followed next by the mean value in Tokyo and then by larger headways observed in Bangkok and Manila. There is no significant difference in mean passenger car headway between Manila an Bangkok which may be due to the similarity in operating capabilities of passenger cars in general. The passenger car headway of Seoul is significantly smaller than the headway in Tokyo. The reason for this may not be the operating capability of vehicles in general since Tokyo implements a strict inspection scheme for the roadworthiness of vehicles. One of the main reasons could be due to wider lane widths in Seoul which allows the smooth flow of mixed traffic of heavy commercial vehicles and passenger cars, specifically reducing the side friction between vehicles by the increase of lateral space. Another reason for this could be the difference in the aggressiveness of the drivers between Tokyo and Seoul. Another reason for the larger passenger car headway could be the relative high percentage of trucks especially medium trucks of varying size in the traffic stream observed in Tokyo.

4.1.2 Comparison of headway of large trucks when following passenger cars

The average headway maintained by large trucks when following passenger cars in Manila is significantly larger than in Tokyo and Seoul due to the low operating capability of trucks due to relatively older fleet age and poorer maintenance level.

4.1.3 Comparison of headway involving passenger cars and medium-sized trucks

The mean headway of passenger cars following medium-sized trucks is significantly greater for Manila, followed by Tokyo with the lowest value for Seoul. Reasons for the larger value in Metro Manila are due to the low operating capability and low level of maintenance of medium-sized trucks which are usually heavily loaded. The main factor for Tokyo's larger headway could be due to the large variation in size of medium commercials in Tokyo as compared to the more or less similar size of the medium truck category in Seoul. The average headway of medium-sized trucks following passenger cars in Manila is significantly larger compared to that of Tokyo and Seoul as explained by the relatively poor operating capability. Seoul has a significantly smaller headway compared to Tokyo which could be explained by the wide variability in the size of medium commercial vehicle category. Another reason is that truck drivers in Seoul could be more aggressive than the drivers in Tokyo.

4.1.4 Comparison of headways involving passenger cars and buses

The mean headway of passenger cars following buses is significantly larger in Bangkok as compared to the other cities. The reason is due to the behavior of buses in Bangkok which often cross the bus lanes making passenger car drivers keep a longer distance from them. The reason for low vehicle performance of buses in Bangkok could not be the explanatory factor for this headway since in the comparison of headway of buses following passenger cars, the results indicate that Bangkok has the lower headway as compared to other cities. The larger value of cars following buses in Seoul could be explained by the behavior of buses observed in Seoul where they were observed to stop suddenly and shift lanes abruptly especially in the vicinity of bus stops which is indicative of poor behavior and the effect is larger headways maintained by passenger cars. There is no significant difference in the average headways of buses among the cities. However, the mean for Seoul is slightly small indicating the high discharge rate of buses in Seoul which could be attributed to the almost ideal physical characteristics of Seoul's main arteries through wide lanes which minimize side friction with other vehicles in flowing through the adjacent lanes and also the aggressiveness of driver behavior. The average headway of buses following passenger cars is significantly higher in Manila and Tokyo compared to Seoul and Bangkok. The factor which causes this result is the earlier-mentioned problem of lane widths with small lateral allowance between vehicles in Manila and Tokyo and the noted aggressiveness of bus drivers in Seoul.

4.1.5 Headway maintained by passenger cars following jeepneys in Metro Manila

The average headway maintained by passenger cars following jeepneys in Metro Manila is significantly larger compared to passenger cars following pick-ups and buses in Bangkok and cars following trucks and buses in Seoul and Tokyo mainly due to the noted behavior of jeepneys which change lanes frequently.

4.1.6 Headway of jeepneys following passenger cars in Metro Manila

The average headway of jeepneys following passenger cars in Metro Manila is larger compared to the pick-ups following cars in Bangkok and medium-sized trucks following cars in Seoul and Tokyo indicating poor acceleration ability and operating capability of jeepneys. In the earlier discussion, this headway is almost similar to the headway of medium commercial vehicles following passenger cars in Metro Manila suggesting the similarity of vehicle operating characteristics which is true because most engines for the jeepneys are secondhand medium-sized truck engines imported mostly from Japan.

4.2 International comparison of passenger car unit (pcu) values of various vehicle types

After a detailed discussion of headways involving passenger cars and various vehicle types within each metropolitan area and the subsequent inter-city comparison, much of the discussion is carried over to this section of comparison of passenger car unit values. The main reason for this is that the method adopted in section 3.2 was a headway-based procedure involving the headway types analyzed and compared in the preceding section.

Table 5. Comparison of computed passenger car unit (pcu) values of various vehicle types in the 4 cities

	medium truck	large truck	motorcycle	bus	jeepney
Manila	1.50	2.43	-	1.87	1.50
	pick-up truck	large truck	motorcycle	bus	tuk-tuk
Bangkok	1.06	-	0.57	2.07	0.95
	medium truck	large truck	motorcycle	bus	
Seoul	1.12	1.67	-	1.84	
	medium truck	large truck	motorcycle	bus	
Tokyo	1.23	1.73	0.52	1.84	

4.3 International Comparison of Starting Lost Time

Table 6 shows the mean starting lost times calculated for the 4 cities in the comparison study. Table 7 tests the difference in variances between cities using F-test and the Table 8 utilizes the appropriate t-test after determining the significance of the difference in variances.

Table 6. Comparison of mean starting lost times of the different cities

	Manila	Bangkok	Seoul	Tokyo
starting lost time (seconds)	5.14	4.28	3.29	2.69
number of cycles observed	39	141	108	112
standard deviation (sec.)	2.81	3.07	1.92	1.64
standard error (sec.)	0.45	0.26	0.18	0.16
95% confidence interval	[4.24, 6.04]	[3.77, 4.80]	[2.92, 3.66]	[2.38, 3.00]

Table 7. F-test of the differences in variances of starting lost time between cities

	Manila	Bangkok	Seoul	Tokyo
Manila		0.2479	0.0163	5.1514E-05
Bangkok			9.4852E-07	2.4530E-13
Seoul				0.0510
Tokyo				

Table 8. t-test of the differences in mean starting lost time between cities

	Manila	Bangkok	Seoul	Tokyo
Manila		0.1153	0.0002	2.1016E-05
Bangkok			0.0021	5.0570E-13
Seoul				0.0185
Tokyo				

A series of paired t-tests for 6 possible combinations resulting from the comparison of four cities is done in Table 8. All the cells in the table indicate significant difference between cities except for the Manila-Bangkok city pair. Table 8 illustrates clearly the significance of the differences in mean starting lost time between cities in the comparison study. In Table 6, the starting lost time is significantly the lowest in Tokyo at 2.69 seconds, followed by Seoul at 3.29 seconds and then by Bangkok at 4.28 seconds with Manila having the highest starting lost time of 5.14 seconds. From the results of the t-test in Table 8, there is almost no significant difference in the mean starting lost times of Bangkok and Manila at the 95% confidence level. The difference in the mean starting lost times of developed cities of Seoul and Tokyo compared with the developing cities of Manila and Bangkok is attributed mainly to: the relative vehicle operating capability which is generally lower for developing cities like Bangkok and Manila compared to Seoul and Tokyo. Additional special factors increasing starting lost time include: (1) pedestrian interference in Manila, and (2) presence of interfering vehicles in the crossing street in Bangkok.

The first factor indicates that Tokyo, with the highest level of economy compared to the other 3 cities in this study, people have enough income to acquire relatively new cars compared to other cities and can practically enforce strict vehicle inspection rules for old vehicles. Most of the vehicles observed in Tokyo are relatively new and even slightly old vehicles are junked since it is more expensive to maintain them than buying a new one.

Tokyo's vehicle fleet are being replaced at a higher rate than other cities and the effects of this are reduced starting lost time in every discharge of queue for every signal cycle, eventually increasing the capacity of intersection approaches. Therefore, for the developing cities where average income is lower, the starting lost times are much higher reflecting the higher average age of the vehicles flowing through the main arterials. In developing countries like Thailand and the Philippines, still many relatively older vehicles are observed running in the streets due to the abovementioned reason of income level where people in general could not afford to easily acquire new vehicles or replace old vehicles. Strict inspection scheme for vehicles would not be practical so lower standards are practically enforced. Jeepneys, which are dominant in the arterial roads in Metro Manila, have second-hand medium-size truck engines and trucks need time to start to accelerate compared to passenger cars. Comparing cycles where 2 or more jeepneys are included in the first four vehicles waiting in queue and cycles where there are no jeepneys, the mean starting lost time for the jeepneys are higher although not significant at the 5% level. In developing cities such as Manila and Bangkok, aside from the bus and regular taxis, the traffic volume of paratransit vehicles developed locally is also significant. Most of these vehicles are lower in operating capability as discussed in earlier sections in this study and thus contribute to larger starting lost times for intersection traffic flow in developing cities.

4.3.1 Pedestrian interference in Manila

This factor which is largely a behavioral characteristic of pedestrians in Metro Manila explains that the interference of pedestrians on traffic flow in some of the intersections is observed to be relatively higher compared to other cities. From the observation of various intersections in Metro Manila, various instances of pedestrian interference were observed. The frequency of these instances was not high in the cities of Tokyo, Seoul and even Bangkok. These include the following:

(a) leftover of pedestrians rushing to cross just before the start of green phase,
(b) deliberate crossing of pedestrians during the green phase,
(c) commuters trying to get on public paratransit vehicles such as jeepneys at the initiation of the green signal, and
(d) spillover of pedestrians at center islands and road sides waiting to cross.

The first three instances could be attributed directly to the violation of traffic rules and regulations by pedestrians in Manila meaning the pedestrians in Manila as compared to Tokyo and Bangkok have less patience and discipline. This is a problem of human behavior which certainly affects traffic flow due to their acts and could be remedied by stricter enforcement of traffic rules and policies and increased awareness and education. The last instance which was observed from many intersections in Metro Manila indicate the lack of capacity of pedestrian facilities. In most of the places observed with high pedestrian activity, there were no pedestrian decks to service the high flow of people crossing the street. In the approach of Aurora Avenue, 2 pedestrians to a maximum of 10 pedestrians were observed to continue to cross even after the start of green phase for the approach. Seoul's starting lost time is also significantly lesser with respect to Bangkok and Manila since many pedestrian facilities were already built to provide service to crossing pedestrians thereby eliminating the pedestrian interference factor which increases the starting lost time for each signal cycle. Many pedestrian decks also serve pedestrians in Tokyo but some approaches still use the zebra crossing. However, pedestrian behavior is better compared to Metro Manila and violations of signal rules were seldom seen in these intersection approaches.

4.3.2 Presence of interfering vehicles in the crossing street in Bangkok

This factor indicates the effect of turning buses is more of a problem of traffic signal control policy implementation and the problem of poor road network.. Comparing the average starting lost time for Tokyo and Bangkok, Bangkok has a significantly higher starting lost time which could be attributed to not only the acceleration capability of vehicles but also due to buses waiting to turn right at the crossing street. In most of the cycles observed from the video of the intersection of Phetburi Road and Asok-Dindaeng Road, there were at least 1-2 buses in Asok-Dindaeng Road waiting to turn right at the end of their green phase and at the start of the green signal for the Phetburi Road, the surveyed intersection approach. This blocking of the intersection by waiting buses increases the starting lost time for the intersection. A comparison of average lost time using t-test with another intersection, the Phaya Thai - Rama I, with low incidence of obstruction by buses, resulted to significantly different means at 5% level. This is a problem of phasing implementation since in this intersection, buses are allowed an opposed right turn phase to Phetburi Road but since straight-through traffic flow along Asok-Dindaeng is high, queuing of buses occurs at the approach almost blocking all the lanes of the Phetburi Road at the start of green.

4.4 International Comparison of Straight-Through Saturation Flow Rates

Table 9 below presents the values obtained for the saturation flow rate for the cities in the study. These are average of the measured saturation flow rate for exclusive straight-through flow lanes surveyed. The values represent mostly the inner lanes near the center island of the arterial road in order to avoid road side friction such as parking and stopping public vehicles. Table 10 and 11 indicate the paired F-test and t-test between cities.

Table 9. Comparison of mean saturation flow rates of the different cities

	Manila	Bangkok	Seoul	Tokyo
mean saturation flow rate (pcu/hour/lane)	1784	1817	2024	1931
number of cycles observed	95	138	219	112
standard deviation	225	233	219	239
standard error	23	20	15	23
95% confidence interval	[1738, 1830]	[1777, 1857]	[1994, 2054]	[1885, 1977]

Table 10. F-test of the differences in variances of saturation flow rate between cities

	Manila	Bangkok	Seoul	Tokyo
Manila		0.72757514	0.74272648	0.28049473
Bangkok			0.42192927	0.09965005
Seoul				0.34075908

Table 11. t-test of the differences in mean saturation flow rate between cities

	Manila	Bangkok	Seoul	Tokyo
Manila		0.28709799	9.9131E-17	9.3194E-09
Bangkok			8.0508E-16	4.7316E-07
Seoul				4.2654E-05

There is almost no significant difference in the mean saturation flow rates of Bangkok and

Manila at 95% confidence level. The difference in the saturation flow rates of developed cities of Seoul and Tokyo compared with the developing cities of Manila and Bangkok is attributed to the following characteristics:

(1) difference in mean headway between passenger cars,

(2) the observed characteristics of lane-changing behavior are different in Bangkok and Manila compared to Seoul and Tokyo, and

(3) the effect of buses.

4.4.1 Difference in mean headway between passenger cars among cities

The first characteristic (1) reflects the general vehicle operating performance especially that of passenger cars which is also indicative of the maintenance level and relative age of the vehicle fleet running in the streets of the city. If assuming that passenger cars are only present in the traffic stream, this time headway reflects how many passenger cars could discharge through an intersection and this indicates the acceleration capability of passenger cars of the city. If the operating capability of passenger cars is relatively poor, this would result to increased headways between passenger cars and a consequent decrease in saturation flow. This headway also is used as the basis for all the pcu values of other vehicle types. The car-car headway is utilized in the headway ratio method as the divisor to normalize the headways of other vehicle types and subsequently results to equivalency in passenger car units of a vehicle type. If the headway increases between passenger cars, the saturation flow rate decreases because all the passenger car unit values would consequently decrease. In Seoul, there are still many old vehicles running in the streets and the vehicle inspection is cheaper and lesser strict than Tokyo. However, the saturation flow rate is significantly higher in Seoul than in Tokyo. The factor which affected the car-car headway is the aggressiveness of driver population in Seoul as explained by the modal split. The values of passenger car headway are also affected by the traffic percentage of certain vehicle types such as jeepneys in Metro Manila and medium-sized trucks in Tokyo, or more directly by the relative frequencies of headways involving the said vehicles as compared to frequency of headway between passenger cars in the traffic stream. In Tokyo, it was shown earlier that the increase in the frequency of medium-size truck-related headways causes an increase in the mean headway between passenger cars in the traffic stream. In Manila, the increase in number of interactions between cars and jeepneys, as reflected by the increase in number of jeepney-related headways, the mean headway between cars consequently increases.

4.4.2 Characteristics of lane-changing behavior

The second factor (2) which is more of a behavioral characteristic is on the lane-changing behavior of drivers in the different cities. The level of lane-changing frequency was observed to be relatively the lowest in Tokyo comparing with the other 3 cities during peak-hour saturated flow conditions. Drivers in Tokyo are generally cautious when changing lanes mindful of the other vehicles in the adjacent lane, as compared to the cities of Bangkok and Manila. There is significant lane-changing frequency for jeepneys in Metro Manila, buses in Seoul, and buses and paratransit vehicles in Bangkok. The manner by which a lane-changing maneuver is done is also important to note from the traffic flow in different cities. From observation, the vehicles were observed to shift lanes gradually in Seoul and Tokyo maintaining the steady flow of traffic such that it could be noted that if even there is a certain frequency of lane-changing in these cities, traffic flow is not disrupted and following this are the saturation flow rate values unaffected by lane-changing. This gradual lane-changing is very similar to lane-changing during low flow rates which generally has no decreasing effect on lane flow rates. In Bangkok and Seoul, it is common to see vehicles abruptly shift lanes without prior signaling to other vehicles and without minding the sufficiency of headway between vehicles in the lanes that they want to enter in. This manner has a very obstructive effect on traffic flow where the following vehicles in the target or destination lanes of a lane-changing activity need from time to time to slow down or sometimes stop completely due to merging vehicles from adjacent lanes. This is especially more significant when the vehicle shifting lanes is a truck, bus or a paratransit vehicle where the acceleration capabilities are relatively lower than passenger cars. Also, if the vehicles which are effectively blocked in the lanes by merging vehicles from adjacent lanes are that of the truck, bus or paratransit vehicle type, the situation is even worse since the sudden stopping and starting again needs more time for these types of vehicles and this shockwave is carried over to the upstream of the queue especially during high flow rates or saturated flow conditions.

4.4.3 The effect of buses

The third characteristic (3) is significant especially in cities where there are few train or subway lines such that public transportation relies mainly on bus transit and paratransit mode. Paratransit mode is only applicable to developing cities such as Bangkok and Manila where own indigenous transport and vehicle technology are developed in light of the current economic level and financial resources. Seoul still relies on bus as a major mode of public transportation in the city while Metro Manila depends mainly on paratransit mode called the jeepneys. Bangkok's main public transport mode is still the bus despite having three types of paratransit modes including the loth, silor-lek or the pick-up, the tuk-tuk and the motorcycles or soi bikes. From observations in Manila and Tokyo, lanes where most buses pass through such as the outer lanes in most cases (where bus lanes are not defined) have insufficient width. Although the design is standard for passenger car size, the lane is just fit for large vehicle such as bus so there is small lateral allowance spacing to avoid side collisions. Therefore, two large vehicles could not be able to run side-by-side simultaneously thereby effectively increasing the headway of one lane or decreasing its saturation flow rate and capacity. Also, speeds of smaller vehicles affected by passing of the bus such that they slow down due to the superior size of the bus manifesting the size effect. The decrease in speed in the approach translates to a decrease in saturation flow rate. From observations, two large vehicles moving simultaneously in the middle and outer lane have very little lateral allowance between vehicles such most of the time, the outer lane dominates due to large volume of buses and trucks and the in the middle lane, headways are increased since simultaneous movement is not possible due to small lane widths consequently lowering the saturation flow rate. The problem of buses in Bangkok going out their designated bus lanes have a lowering effect on saturation flow of adjacent inner lane. This clearly indicated in the Phetburi Road approach lanes where the outer lane with a higher bus flow affects the saturation flow rate of the adjacent inner lane through the observed frequent lane movement of buses. The saturation flow rate for the outer middle lane of Phetburi Road is lowered to the 1700 pcu/hour green/lane level, lower than the average of 1817 pcu/hour green/lane. In Metro Manila, this lowering effect was also observed in the Ayala Avenue approach lanes. The factor being pointed out here is that if buses go out of their designated bus lanes and mix with the smaller vehicle traffic in the inner lanes wherein the lanes are smaller in width, there would be increased side friction because lateral allowance is smaller in these inner lanes.

4.4.4 Problem of lane discipline in Metro Manila

Lane discipline is a major difficulty in Metro Manila which is mainly due to driver behavior and the absence of lane markings on the intersection approaches. In the major arterials of EDSA and Aurora Avenue, the lane markings were already worn off at the time of the survey therefore vehicles lining up in queue overutilize the approach by making a 4-lane approach become a 5-lane approach due to the absence of lane markings. Therefore, when discharge starts, lateral allowances are very small lowering the vehicular speeds and consequently the saturation flow rates. In Ayala Avenue and Forbes Avenue intersection approaches, lane markings are present but the main problem observed here is the behavior of drivers not keeping their proper lanes especially during the discharge.

5. CONCLUSION

Table 12 below shows the summary of the international comparison of some signalized intersection traffic flow characteristics including saturation flow rate, starting lost time, passenger car unit (pcu) values and headways between cars and other types of vehicles.

Table 12. Comparison of some traffic flow parameters measured from the four cities

	Manila	Bangkok	Seoul	Tokyo
mean saturation flow rate (pcu/hour/lane)	1784	1817	2024	1931
mean starting lost time (seconds)	5.14	4.28	3.29	2.69
pcu for medium truck	1.50	-	1.12	1.23
pcu for large truck	2.43	-	1.67	1.73
pcu for motorcycle	-	0.57	-	0.52
pcu for bus	1.87	2.07	1.84	1.84
pcu for paratransit	jeepney=1.50	tuk-tuk=0.95 pick-up=1.06		
mean headway (seconds)				
between passenger cars	2.02	1.99	1.79	1.93
large trucks following cars	4.44	-	2.87	3.12
cars following medium-sized trucks	2.35	-	1.81	1.99
between medium trucks	-	-	2.00	2.36
medium-sized trucks following cars	2.69	-	1.98	2.31
cars following buses	2.18	3.04	2.19	2.17
between buses	3.39	3.55	3.30	-
buses following cars	3.48	2.88	2.89	3.39
paratransit vehicles following passenger cars	jeepney = 2.44	pick-up = 1.86 tuk-tuk = 1.66		
between paratransit vehicles	jeepney = 2.90	-		
passenger cars following paratransit vehicles	jeepney = 2.62	pick-up = 2.23 tuk-tuk = 2.26		

The extensive analysis of vehicle followings at intersection traffic in the 4 cities produced several important results discussed in the following. The average headway between passenger cars is significantly larger in Manila and Bangkok, compared to Tokyo and Seoul. There is no significant difference between Manila and Bangkok. The main reason is the difference in general operating capability due to the difference in economic level. However, the passenger car headway of Seoul is significantly smaller than the headway in Tokyo due to: (a) wider lane widths and approaches in Seoul; (b) difference in the aggressiveness of the driver population; (c) significant percentage of medium trucks of varying size in the traffic stream in Tokyo. The average headway maintained by large trucks when following passenger cars in Manila is significantly larger than in Tokyo and Seoul due to the low operating capability of trucks due to relatively older fleet age and poorer maintenance level. The mean headway of passenger cars following medium-sized trucks is significantly greater for Manila, followed by Tokyo with the lowest value for Seoul due to the low operating capability and low level of maintenance in Manila. Tokyo's larger headway could be due to the large variation in size of medium commercials in Tokyo as compared to the more or less similar size of the medium trucks in Seoul. The average headway of medium-sized trucks following cars in Manila is significantly larger due to the relatively poor operating capability. Seoul has a significantly smaller headway compared to Tokyo which could be explained by the wide variability in the size of medium commercial vehicle category. The mean headway of passenger cars following buses is significantly larger in Bangkok due to the behavior of buses in Bangkok which often cross the bus lanes making passenger car drivers keep a longer distance from them. There is no significant difference in the average headways of buses among the cities. The average headway of buses following passenger cars is significantly higher in Manila and Tokyo due to the problem of lane widths with small lateral allowance between vehicles in these cities and the lower value for Seoul is due to the noted aggressiveness of bus drivers in Seoul. The average headway maintained by passenger cars following jeepneys in Metro Manila is significantly larger compared to passenger cars following pick-ups and buses in Bangkok and cars following trucks and buses in Seoul and Tokyo mainly due to the noted behavior of jeepneys which change lanes frequently. The average headway of jeepneys following passenger cars in Metro Manila is larger compared to the pick-ups following cars in Bangkok and medium-sized trucks following cars in Seoul and Tokyo indicating the poor operating capability of jeepneys.

The pcu values of trucks in general in Manila are higher in Manila compared to Seoul and Tokyo due to lower operating capability and poor maintenance. The pcu of motorcycle in Bangkok is slightly larger than that of Tokyo which reflects frequent weaving and lane-changing behavior of motorcycles. The pcu value for bus is highest in Bangkok followed by that of Manila and then by the common pcu value for Seoul and Tokyo due to the poor behavior of buses in Bangkok. The pcu value of the jeepney is in Manila is greater than the pcu values of the pick-up trucks and tuk-tuks in Bangkok, and the medium commercial vehicles in Seoul and Tokyo due to the poor traffic behavior of jeepney drivers and the low operating capability of jeepneys compared to medium-sized trucks in other cities and almost comparable to the operating capability of medium-sized trucks in Manila.

In this study, the mean saturation flow rates are derived from values obtained from various intersections in each city. The effect of neighboring lanes, lane width, the effect of 3 or more vehicles other than cars running through the traffic are not considered fully although it was computed by the statistical test that the effect of 3 or more vehicles of another type running is same as considering 2 vehicles which is the assumption used in the computation of pcu. There are limitations and difficulties in getting a large number of intersections since this is an international study although best efforts were done to find samples of intersections with almost similar characteristics for purposes of the study. In establishing the highway capacity manual for each country, the government must undertake a large-scale survey of more intersections to obtain the accurate values of traffic flow characteristics such as saturation flow rate. There is almost no significant difference in the mean saturation flow rates of Bangkok and Manila at 95% confidence level. At the same confidence level, the saturation flow rates of Seoul and Tokyo are significantly larger than those of Seoul and Tokyo. The difference in the saturation flow rates of developed cities of Seoul and Tokyo compared with the developing cities of Manila and Bangkok is attributed to the following characteristics: (1) difference in mean headway between passenger cars; (2) the observed characteristics of lane-changing behavior are different in Bangkok and Manila compared to Seoul and Tokyo, and (3) differences in the effect of buses.

The mean headway between passenger cars in a traffic stream is affected by the differences in: (a) relative operating capabilities of passenger cars, (b) aggressiveness of driver behavior, (c) traffic composition; The difference in saturation flow rate between the developed cities of Seoul and Tokyo, and the developing cities of Manila and Bangkok could be explained by the difference in operating capabilities of cars as affected by the economic level. The resulting higher saturation flow rate for Seoul than Tokyo could be explained by the aggressiveness of driver behavior in Seoul and the significant traffic of medium-sized trucks in Tokyo. The lower value in Manila is attributed to the high percentage of jeepney traffic. With regards to lane-changing, the manner by which lane-changing was observed to be generally gradual in Seoul and Tokyo compared to the abrupt manner in Manila and Bangkok. Lower frequency of lane-changing was observed in Tokyo. The general effects of buses on the traffic flow are reflected by observed problems such as:

(a) lane widths are not enough for predominantly bus-flow lanes especially in Manila and Tokyo;
(b) buses going out of the designated bus flow lanes especially evident in Bangkok;
(c) lane discipline especially in some arterial roads in Metro Manila.

The difference in the mean starting lost times of developed cities of Seoul and Tokyo compared with the developing cities of Manila and Bangkok is attributed basically to the relative vehicle operating capability which is generally lower for developing cities. Additional special factors which increase the starting lost time include: (a) pedestrian interference in Manila, and (b) presence of interfering vehicles in the crossing street in Bangkok.

The significant differences in traffic flow parameters between developed cities like Seoul and Tokyo, and developing cities like Manila and Bangkok, reflected in terms of saturation flow rates, starting lost times, passenger car unit values and headways, indicate that the economic growth clearly influences road capacity. Economic growth and development bring in the increase the relative operating capability of vehicles in general, increase the level of transportation infrastructure especially for roads, better traffic control and management system and improvement of driver, passenger and pedestrian behavior in terms of strict enforcement of policy and traffic education.

After a detailed comparison analysis and recognition of the differences in basic traffic flow parameters with the corresponding reasons, the following policies are recommended to be implemented for the improvement of traffic flow especially through signalized junctions in developing cities such as Metro Manila and Bangkok:

(1) the need to have a road infrastructure with clear hierarchy in these metropolises such as the expansion of the urban expressway network similar to Japan in order to distribute traffic flow which currently is concentrated on the arterial roads,

(2) the need for traffic education of drivers and pedestrians alike to improve behavior,

(3) the need for appropriate signal management in order to maximize the capacity of flow at signalized intersections, and

(4) the necessity of implementing a stricter vehicle inspection system to minimize lost time at intersections and reduction in capacity due to breakdowns at main arterials.

ACKNOWLEDGMENT

The authors would like to thank professors, experts and students in Japan, Korea, Thailand and the Philippines for their valuable contribution in this international comparison study. The initial work of Mr. Shigeru Tonaki who graduated from Tokyo Institute of Technology Department of Civil Engineering is acknowledged. The study was made possible through the coordination with Dr. Sigua and Mr. Regin Regidor of the University of the Philippines-National Center for Transportation Studies, Dr. Ieda of the University of Tokyo, Dr. Yasushi Takeyama, visiting professor of the Asian Institute of Technology, Mr. Young-in Kwon and Mr. Atsushi Ogawa, graduate students of Tokyo Institute of Technology Department of Civil Engineering, the Korea Transport Institute, Mr. Seiya Matsuoka of Fukuyama Consultants, Mr. Hari Srnivas, graduate student of Tokyo Institute of Technology Department of Social Engineering.

REFERENCES

Iwata, S. (1993) Development of public transportation in Metro Manila, **Proceedings of the 1st Annual Conference of the Transportation Science Society of the Philippines,** Manila, Philippines, 30-31, July, 1993

Kimber, R.M., McDonald, M. and Hounsell, N. (1985) Passenger car units in saturation flows: concept, definition and derivation. **Transportation Research 19B**, 39-61

Morichi, S. (1993) Comparison study on transportation policies in Bangkok and Metro Manila, **Proceedings of the 1st Annual Conference of the Transportation Science Society of the Philippines,** Manila, Philippines, 30-31, July, 1993

Scraggs, D.A. (1964) The passenger car equivalent of a heavy vehicle in single lane flow at traffic signals. Road Research Laboratory Report LN/573/DAS. Transport and Road Research Laboratory, Crowthorne, U. K.

Shanteau, R.M. (1988) Using cumulative curves to measure saturation flow and lost time. **ITE Journal**, 27-31

Special Report 209: Highway Capacity Manual (1985), Transportation Research Board, National Research Council, Washington, D.C.

Stokes, R.W., Messer, C.J. and Stover, V.G. (1986a) Saturation flow of exclusive double left-turn lanes. **Transportation Research Record 1091**, 86-95

Stokes, R.W., Stover, V.G. and Messer, C.J. (1986b) Use and effectiveness of simple linear regression to estimate saturation flows at signalized intersections. **Transportation Research Record 1091**, 95-101