INTERNATIONAL COMPARISON STUDY OF TRAFFIC FLOW CHARACTERISTICS OF BASIC EXPRESSWAY SEGMENTS

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abstract: The study's purpose is to compare traffic flow characteristics of basic expressway segments in Manila, Seoul and Tokyo such as speed-flow relationships, average vehicular speeds and lane utilization of vehicles to find unique traffic and behavior characteristics in each country focusing on Manila to contribute to development of the highway capacity manual. Some findings include the high speed of buses in Manila and trucks in Tokyo compared to passenger cars. In terms of lane use, the inner lane in Seoul is heavily used by cars compared to relatively mixed traffic with trucks in Tokyo and with jeepneys and trucks in Manila.

1. INTRODUCTION

The countries in the East Asian region have been experiencing rapid economic growth and most of these economic activities are concentrated on the metropolitan capital region. Population has concentrated in the metropolis as evidenced by a high population growth rate of the metropolitan area compared to the whole country. The direct result has been the sharp rise in vehicle ownership that is not being matched by the needed transport infrastructure and this had lead to traffic congestion in urban arterials and high-speed corridors such as inter-city and metropolitan expressways thereby increasing travel time and delay. Developed countries like Japan have constructed its metropolitan expressway network in Tokyo while cities such as Seoul, Manila and Bangkok are in the stage of constructing and expanding the metropolitan expressway network. Bangkok's second stage expressway has just been completed and the Metro Manila is planning to build its own skyway. Therefore, it is important to know the relationship of demand and capacity of expressways since in planning and design of expressways, developing countries usually adopt developed countries' manuals such as the US HCM and adjust some parameters for local conditions without careful research.

The purpose of this paper is to study traffic flow characteristics of basic expressway segments especially in the metropolitan areas and compare the characteristics of each city. The characteristics of traffic flow and driver behavior special to each city are determined and some policies and design standards for developing countries are recommended in order to contribute also to the highway capacity manual research in the Philippines. The metropolitan areas of Tokyo, Seoul with focus on Metro Manila are selected and compared in this study due to their differing levels of economic development. The traffic flow characteristics include speed-flow relationships and the effect of percentage of heavy vehicles on the speed-flow relationships, lane utilization, average speed of various vehicle types.

2. REVIEW OF RELATED LITERATURE

2.1 International comparison study on road capacity

Several basic international comparison studies have been done recently in the region of East Asia. Morichi (1993) compared the transportation policies in Bangkok and Metro Manila in terms of level of infrastructure, costs of transportation, and comprehensive policies for paratransit mode of transport, bus transit, rail and road transport. Ogawa, et. al (1995) studied socio-economic and various transport and traffic conditions in Tokyo, Seoul and other Southeast Asian cities including Bangkok and Metro Manila. The following study is the most important basis for this comparative study of traffic flow capacity and traffic conditions. Tonaki (1994) and Morichi, Vergel and Tonaki (1994) investigated international variability in road traffic flow through signalized intersections by computing the saturation flow rate for exclusive straight-through flow lanes, the start-up lost times and passenger car unit values for different classes of vehicles in Metro Manila, Seoul and Tokyo. They found out that saturation flow rates in Manila were lower compared to the ranges of saturation flow rates in Seoul and Tokyo and the start-up lost times were also higher in Manila. Tonaki (1994) attributed this to the relatively lower vehicle performance and high lane-changing rate in Manila.

In expressway traffic flow and capacity studies, several studies dealt usually on one or several locations of one country only. Also, there are theoretical problems concerning the basic speed-flow-density relationship which is the main function describing uninterrupted traffic flow such as in basic expressway segments. Therefore, many researchers in US, Canada, Britain and Japan presented their findings using data from their localities and proposed various models of speed-flow-density relationships. The classical parabolic relationship has been challenged recently by researchers. Hall, Hurdle and Banks (1992) reviewed research of speed-flow-density from 1987-1992 and came up with a model of a generalized speed-flow relationship which contains three segments. The upper level line represents traffic behavior when there is no queue and speeds drop suddenly when capacity is approached. This is already included in 1990 revisions of the US HCM although there are disagreements on the magnitude of speed drop. The second segment which is an arbitrary vertical line at capacity, indicates the queue discharge portion and the third segment is at the low part which is curving upward is the congested portion of the curve. The resulting speed-density relationship is inverted V. Using data from the M6 Motorway in Britain, Hall and Montgomery (1996) proposed functional relationships fitting to the uncongested segment of the earlier-mentioned generalized speed-flow curve.

Koshi, Iwasaki and Okura (1983) using data from Tokyo expressways presented a reverse lambda relationship of flow-density which is different from the inverted V model and the conventional inverted U derived from the parabolic speed-flow relationship. Sigua (1995) analyzed traffic flow on various road sections including expressways in Manila for the development of the Philippine HCM. Mangubat (1995) studied traffic flow characteristics of Philippine expressways specifically on basic segments analyzing speed-flow curves, effects of heavy vehicle ratios on the curves and lane utilization rates. All of the preceding studies concentrated on one country but Hall and Brilon (1994) compared the uncongested speed-flow relationships using data from German autobahns and North American data.

2.2 Relationship between economic growth and capacity

There has been recent increase in the saturation flow rates throughout the years and this trend was noted by Stokes (1988) where the more recent estimates favor the high end of the range of reported saturation flow values. Teply (1991) also noted an increase in the saturation flow in Edmonton, Canada and explained that it was due to the improved economic conditions in recent years. He further emphasized the importance of periodic field saturation flow surveys in providing the most accurate and up-to-date basis for the analysis and design of signalized intersections. The Canadian Capacity Guide included this new feature in its signal design and analysis: the saturation flow values vary with the socio-economic characteristics of a community not just its size (Teply, 1985). Another researcher recognized the significance of social and economic factors. Branston (1979) noted that with improvements in vehicle acceleration and braking capabilities and potential changes in driver behavior, it is important to review, and if necessary modify existing methods of estimating capacity. Although these authors recognized the effect of economy (Teply and Branston) on saturation flow, studies were limited usually localized.

3. METHODOLOGY

3.1 Speed-Flow-Density Relationship

The three most important variables that best describe the traffic condition of uninterrupted flow along the expressway are flow rate (volume), speed, and density. These variables are physically interrelated. The relationships are not only logical but are likewise matched by actual field surveys. The methods data are gathered vary from country to country. In highly developed country such as Japan, detectors installed at regular intervals along the expressways are used to obtain information on these 3 variables (detectors collect information on time occupancy instead of density, but density and occupancy have been shown to have direct relationship). In the Philippines, however, no detectors are installed in the expressway. Instead, footages are taken using video cameras. In the absence of high rise buildings along the expressway, the section covered is limited thereby preventing the researcher to obtain independent measurement of density. Density k, therefore , is estimated from the other 2 variables, namely flow rate q and speed u, based on the relationship

$$q = u \times k \tag{1}$$

Extra care must be given when comparing q-u-k relations for different countries of different driving practices, of different level of economic activities, etc. Specifically, factors to be considered for comparison are the following:

- vehicle performance; vehicle types, age of vehicles, etc.
- drivers characteristics-age, sex, etc.
- road condition - geometry of the expressway section where data are gathered: number of lanes, lane widths, horizontal and vertical alignments; pavement condition, etc.
- traffic condition - bottleneck location whether downstream or upstream, percentage of heavy vehicles, etc.

3.2 Data Collection from Basic Expressway Segments

Data consists of several hours of video recording from Tokyo, Seoul and Manila, as summarized in Table 1, with the basic parameters such as average speed and volume aggregated at 5-minute intervals. Photos of study sites are shown in Figure 1, 2 and 3. In Metro Manila, 23 hours and 10 minutes of morning traffic video footage were collected at the Sucat-Bicutan segment of the South Luzon Expressway for several days in May and June in 1996. This expressway runs south-north from the southern provinces and terminating near the center of Manila with the northbound basic segment consisting of three 3.5-meter traffic flow lanes in one direction and a narrow 3.0-meter shoulder lane. The location of video footage survey is approximately 0.6 kilometer downstream of the Sucat Interchange. This interchange is located at the southeastern portion of Metro Manila at the Paranaque municipality with mixed residential and industrial land-use.

Table 1. Basic expressway segments surveyed

city	expressway	segment name number of lanes	date of survey
Manila	South Luzon Expressway	Sucat-Bicutan 3 lanes	May 3, 10, 13, 17, 20, 24, 27, 31 June 3, 7, 10, 1996 morning traffic
Seoul	Olympic Expressway	Seoul Bridge 4 lanes	September 9, 1996 morning/afternoon
Tokyo	Tokyo Metropolitan Expressway Shibuya Line (Radial Line 3)	Sangenjaya 2 lanes	February 23, 27, 28 1996 morning
	Tokyo Metropolitan Expressway Bayshore Line	Ariake 3 lanes	Februrary 15, 17, 18, 1997 morning

Figure 1. South Luzon Expressway at the Sucat-Bicutan segment northbound morning traffic towards Manila

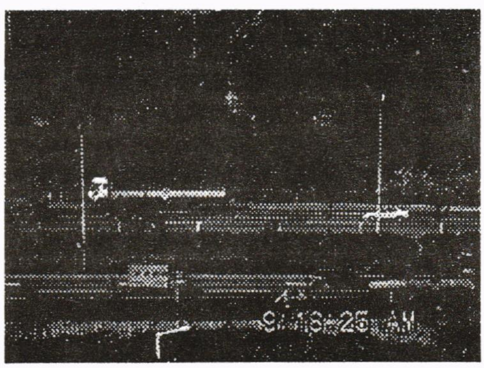

Figure 2. Olympic Expressway segment near Seoul Bridge eastbound morning traffic towards Seoul

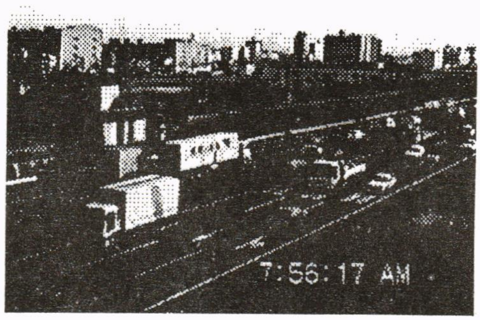

Figure 3. Tokyo Metropolitan Expressway Shibuya Line Sangenjaya segment (left photo) northeastbound morning traffic to Tokyo and Bayshore Line Ariake segment (right photo) westbound morning traffic to Tokyo

In Tokyo, video footage of morning traffic was taken at 2 locations in the Tokyo Metropolitan Expressway. One point is at the southeastern portion of Tokyo at the Shibuya Line No. 3 at Sangenjaya segment totaling 5.5 hours for several days in February 1996 and the other at the northeastern part at the Bayshore Line near the Ariake junction for several days in February 1997 totaling 8.5 hours. The 6-lane Ariake segment is located 120 meters just before the Ariake junction at the Tokyo waterfront area. This expressway runs from northeast to the southeastern points of Tokyo near the coastal area. In Seoul, 6 hours of video footage were taken at 2 points of the Olympic Expressway during the month of September 1996. This facility which runs east to west and consists of 4 traffic flow lanes in one direction. One site is at the Seoul Bridge segment which is around 500 meters before the Seoul Bridge while the other point is at the Han Bridge segment just 200 meters before the Han Bridge.

The videotaping of traffic flow preserves events on tape such as traffic flow where the researcher has that convenience of playing and replaying the data on tape based on his requirements. Video footages were viewed repeatedly to input lane volumes and vehicle speeds. A trap length is drawn by pen on the television screen making use of known standard lengths of white lane marking and spacing between. Trap lengths vary from one footage to the other depending on the range of camera zoom and angle of shooting. Usually, trap lengths range 51-60 meters for Manila's South Luzon Expressway and around 40-60 meters at the Tokyo and 21-31 meters for Seoul. Vehicles passing at the downstream end of the trap length are counted with the corresponding vehicle type inputted to the computer using a program which requires the input of the number according to the vehicle type and outputs vehicle counts by type aggregated at any desired time interval which is 5 minutes in this study.

3.3 Vehicle classification

For each country, there are 5 vehicle types considered. For Japan and Korea, classification is similar which includes passenger cars, motorcycles, buses, large trucks, small/medium-size trucks. For the Philippine classification, all types except motorcycles are included. Motorcycles are usually not allowed to enter Philippine expressways so in this place, a paratransit vehicle type called the jeepney is considered.

3.4 Speed Approximation from Video

Another program was also made to approximate speed of vehicles passing the trap segment. The program asks for a trap length in meters and the output filename before the actual run. When a certain vehicle type passes the upstream end of the trap length, an assigned start key is pressed signaling the start of the vehicle travel inside the trap and then when it passes the downstream end, an assigned keyboard stroke corresponding to the vehicle type is pressed yielding speed value and the corresponding vehicle type.

Speeds measured by the trap length method have errors which are affected by the length of speed trap and the speed of vehicles. In cases where the vehicle runs too fast, there is a little lag in the pressing of the appropriate keys due to reaction time. As the trap length decreases, the errors in speed measurement increase. In the data inputting portion, the longest possible trap length was used which is around 60 meters. In most videotapes viewed, this trap length was used to reduce the errors in speed measurements.

4. RESULTS AND DISCUSSION

4.1 Comparison of Speed-Flow Scatterplots

The following graphs represent the speed-flow curves plotted based on 5-minute observation periods during regular weekday morning traffic at the inner lanes of expressway segments in Manila, and Tokyo and the inner mid-lane in Seoul. The traffic flow values are in terms of vehicles per hour not yet adjusted for the presence of heavy vehicles such as trucks and buses. Figures 4 and 5 indicate the speed-flow relationships with varying percentages of heavy vehicles in Metro Manila and one expressway segment in Tokyo. Figures 6, 7 and 8 show the linear and quadratic functional fitting of speed-flow relationships in the non-congested flow region in Manila, Tokyo and Seoul, respectively. Non-congested flow data points were selected and non-congested flow is defined here as flow where there is no queuing or no influence of downstream congestion indicated by queue discharge, stop-and-go or slowing down of traffic similar to the definition of Spencer Smith, Hall and Brilon (1996).

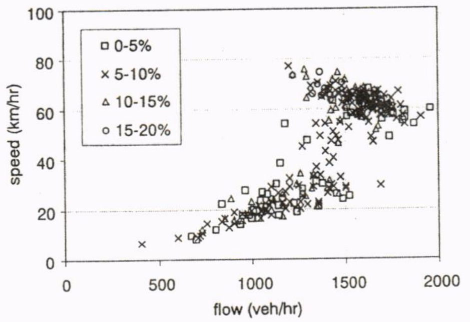

Figure 4. Speed-flow scatterplot of Manila's South Luzon Expressway at Sucat-Bicutan segment for varying percentages of heavy vehicles (inner lane)

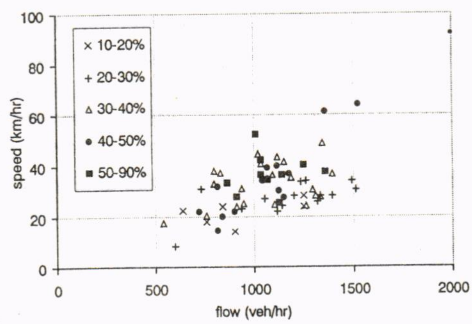

Figure 5. Speed-flow scatterplot of the Tokyo Metropolitan Expressway Shibuya Line at the Sangenjaya segment for varying percentages of heavy vehicles (inner mid-lane)

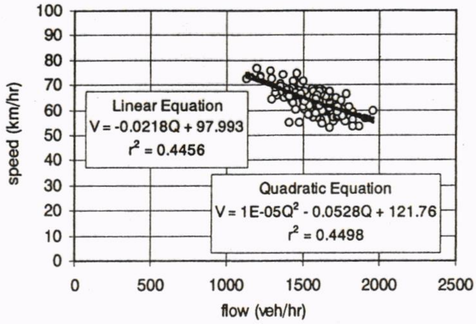

Figure 6. Functional Fitting of the non-congested Q-V region and Q-V scatterplot of Manila's South Luzon Expressway at Sucat-Bicutan segment (inner lane)

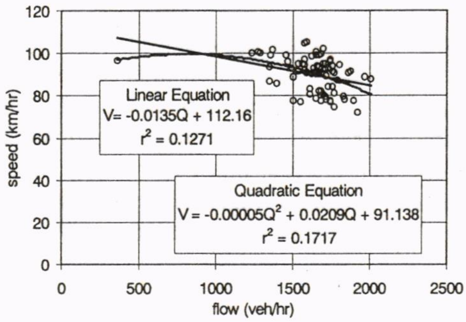

Figure 7. Functional Fitting of the non-congested Q-V region and Q-V scatterplot of Tokyo expressway's Bayshore Line at Ariake Segment (inner lane)

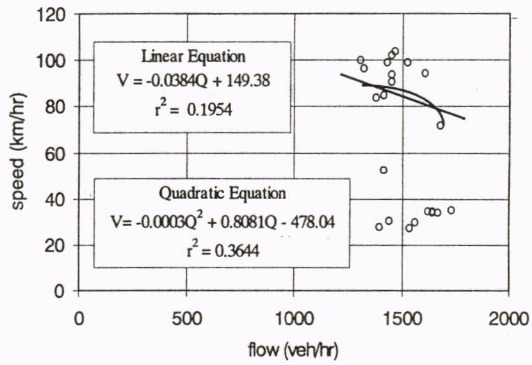

Figure 8. Functional Fitting of the non-congested Q-V region and Q-V scatterplot of Seoul Olympic expressway segment near Seoul Bridge (middle lane)

Few points were observed in the congested part of the speed-flow portion in Tokyo looking at Figure 7. During the time of the video survey at Tokyo Metropolitan Expressway's Bayshore Line, traffic was not congested and average speeds vary from 80-100 km/hr. However, most of the congested traffic was captured by the survey at the Shibuya Line at Sangenjaya segment. In the case of Seoul, parts of free flow and congested regimes were covered by the points although it is still difficult to see the trend of the scatterplot. A time-traced speed-flow plot for the Seoul data which is not shown here indicates that the flow oscillated within the 1200-1600 veh/hr range at speeds from 80-110 km/hr and then the speed dropped the 70 km/hr at a flow around 1700 veh/hr and then further dropped to 55 km/hr at a lower flow and thereafter the speed never recovered and oscillated within the 35-45 km/hr range at still relatively high flows of 1400-1700 veh/hr. The speed-flow curve of Manila contains 278 points which amply covered the congested flow region and part of the non-congested flow near capacity. Although it was difficult to observe points at the high-speed (80-100 km/h) low-flow region, the points could well represent certain trends in the variation of speed with flow. From Figure 4, many points represent the heavy vehicle percentage range of 5-10%. In the Manila curve, jeepneys, small and large trucks and buses are considered heavy vehicles. It is difficult to determine a trend from the scatter of points. Comparing it with Figure 5 representing the Tokyo-Sangenjaya curve, the 50-90% heavy vehicle envelope is enclosed by other envelopes with lower heavy vehicle percentage meaning the percentage of heavy vehicle affects the speed-flow envelope.

Based on limited data in Tokyo (Figure 7) and Seoul (Figure 8), the quadratic relationship yielded a higher correlation although the values are relatively small. Similarly, Manila (Figure 6) follows a quadratic trend with a higher correlation. A piece-wise linear function fitting was also done in the same non-congested flow data in Tokyo but correlation values yielded very low values. In the Manila data, the piece-wise linear functions with were obtained at an optimal breakpoint of 1350 veh/hr. The functions are shown below:

for $Q<=1350$ veh/hr, $V = -0.04Q+119.97$ $r^2 = 0.354$ (2)

for $Q>1350$ veh/hr, $V = -0.02Q+95.64$ $r^2 = 0.326$ (3)

Comparing the simple linear functions derived from the linear regression analysis with flows ranging between 1000 veh/hr and 2000 veh/hr, Seoul has the steepest drop in speed as flow approaches capacity followed by Manila and then by a relatively flat line in Tokyo. Furthermore, in the piece-wise linear function fitting in Manila, the second linear function (after the breakpoint flow) even has a less steep slope than the first linear function. Given the same flow region, the Q-V lines and envelopes (for quadratic functions) of Tokyo and Seoul encompass those of Manila, an indication of higher capacity due to better vehicle performance and due to higher economic level.

Looking at the results of the functional fitting, it can be seen that the values of correlation coefficients are relatively low. For the case of Tokyo and Seoul, the data is limited and speed is relatively scattered and in Manila, it can be said that there are few data on the high-speed low-flow region of the Q-V plot in addition to the relative large scatter of speed.

4.2 Comparison of 1985 and 1996 Traffic Flow Characteristics of Basic Expressway Segment in Metro Manila

Initial collection of data on the traffic flow of the South Luzon Expressway, one of the only two existing expressways in the Philippines, was conducted in 1985. However, the present traffic condition of the expressway is very much different compared to the situation 11 years ago. Favorable economic growth has been observed in the south due to the introduction of industrial zones in the area. A number of satellite cities emerged and several housing areas keep on mushrooming. In terms of road infrastructure however, there have been no corresponding improvements in the expressway or in major arterials connecting the south and Metro Manila. Travel speed has considerably deteriorated during morning and afternoon peak hours. With these improvement in economic activity but a seemingly stagnant development of road infrastructure, it may be asked: Has the *q-u-k* relationships changed? This question is very important since the *q-u-k* relationships are often used to estimate capacity and they are used also to predict traffic condition using the concept of shockwave phenomenon. Several factors may affect the *q-u-k* patterns. For one, new vehicles with better performance have been introduced in the last 3 or 4 years - new cars have been more affordable than before and trucks now have better engines. Some changes in the government policy may have effects in the *q-u-k* relationships. In 1985, the collection of toll fees was relaxed. Truck ban during peak hours was not yet being introduced. However, collection of toll fees has been back since the early 90's to augment to the much needed budget for maintenance and repair of the damaged pavement. Presently also, due to the severe congestion being experienced in the expressway and in Metro Manila, trucks are not allowed along the expressways during daytime including peak periods.

4.2.1 Speed-Flow Relationship

Figure 9 shows the speed-flow relationship for the South Luzon Expressway. Only 24 data points were available in 1985 but they seem to match the 1996 data. It is suggested that more data should be obtained specially for the uncongested and near-congested regions to fully establish the speed-flow relationship.

4.2.2 Formation of Congestion

The graph in Figure 10 gives information on how traffic situation changes from uncongested (early morning) to congested (morning peak) condition for a typical weekday. Both data for 1985 and 1996 were taken for almost two hours from 6:40 AM to 8:40 AM. It can be seen from the figure that at the start of observation (6:40 AM), the condition in 1996 has almost reached capacity while it was still uncongested in 1985. The unstable flow beyond capacity condition can be gleaned from the graph shown by the 'erratic' trajectories beyond the density value of around 40 veh/km. The expressway did not experience any jammed situation that would last for at least five minutes.

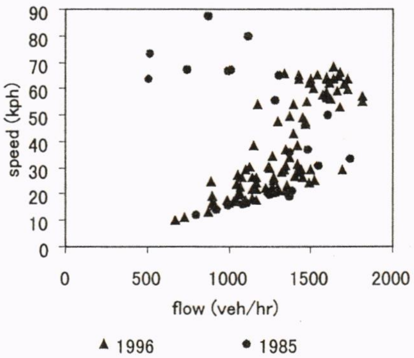

Figure 9. **Speed-flow scatterplots for the inner lane of Manila's South Luzon Expressway in 1996 and 1985**

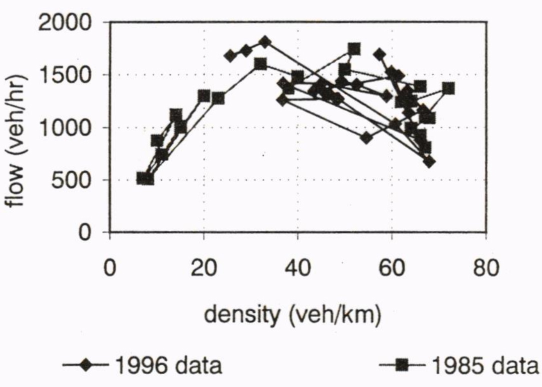

Figure 10. **Flow-density relationships for the inner lane of Manila's South Luzon Expressway in 1996 and 1985 (time-traced plots)**

From the 1996 flow-density graph of the expressway in Manila , after the flow reached a peak 1836 veh/hr within 15 minutes interval, it dropped sharply to 1032 veh/hr indicating an earlier start of congestion compared to 1985 flow-density plot where the flow oscillated within 500-1500 veh/hr around 50 minutes at the non-congested flow region. The large oscillation of flow from 500 veh/hr flow level to 1000-1500 veh/hr range during congested flow (observed from the video) indicates that the observation point is much upstream of the bottleneck which could be the Bicutan interchange, the Nichols Tollgate or the Magallanes Interchange further north. This can be explained by the high-speed shockwave originating from the bottleneck which is amplified as it travels upstream of the bottleneck which is explained in detail in the research of Koshi, et. al (1983) on vehicular flow characteristics and car-following during congested conditions on the Tokyo Metropolitan Expressway.

It is hard to tell whether there is a difference in *q-u-k relations* for 1985 and 1996. The combined data seem to confirm stronger relationships among the three variables. It can be inferred therefore that in the near capacity situation or in the congested situation, better vehicle performance may not improve traffic flow (granted that there are no occurrences of vehicle breakdowns). The effects of heavy vehicles could not be evaluated because of the absence of trucks during daytime period. Comparing the traffic situation in 1986 and 1996, traffic congestion occurs much earlier now than in 1985.

4.3 International Comparison of Average Speeds of Vehicles in Expressway Traffic

Samples of vehicular speed were taken from the non-congested traffic stream of the innermost lane in Tokyo and Manila and the inner mid-lane in Seoul wherein the speed value and the corresponding vehicle type were inputted as basic speed data. Table 2 compares the computed mean speeds of various vehicle types in each of the three cities in this study.

Table 2. International comparison of average speeds of various vehicle types

	Metro Manila	Seoul	Tokyo
passenger car	61.1 (3219)	94.3 (480)	94.3 (684)
bus	72.0 (261)	93.0 (20)	94.5 (38)
small/medium truck	63.0 (216)	89.2 (44)	95.4 (427)
large truck	66.0 (63)	88.0 (31)	94.7 (266)
jeepney	61.4 (351)	-	-

Note: speed values are in terms of kilometers/hour (kph)
values in parentheses ( ) indicate the number of speed observations

F-test and *t*-test were employed to check the significance of the difference between mean vehicle speeds of cities. Initially, the *F*-test is used to check the difference between variances of speed values of cities. This is important prerequisite to the subsequent *t*-test of significance of the difference between cities' mean speeds. Table 3 shows the *t*-test values of probabilities (p-values) which are to be compared to 5% error level.

Speed regulations are similar between cities surveyed in this study. Maximum speed limit is 80 km/hr which is enforced in Tokyo, Seoul and the urban segment of the South Luzon Expressway in Manila.

Table 3. Test of significance of difference of mean speeds between cities using t-test

	Manila vs. Seoul	Manila vs. Tokyo	Seoul vs. Tokyo
passenger car	○ 1.25×10^{-154}	○ 2.1×10^{-272}	✗ 0.947
bus	○ 1.05×10^{-5}	○ 5.46×10^{-30}	✗ 0.705
large truck	○ 6.89×10^{-9}	○ 3.08×10^{-84}	○ 0.015
small/medium truck	○ 2.72×10^{-11}	○ 1.33×10^{-128}	✗ 0.074

Note: ○ - difference is significant at 5% ✗ - difference is not significant at 5%
lower number indicates value of probability (p-values) resulting from t-test

4.3.1 International Comparison of Mean Speeds of Passenger Cars

More than 3,000 speed samples were observed from the inner lane of Manila-bound segment of the South Luzon Expressway in Metro Manila during usual weekday morning traffic which yielded an average speed that is significantly different from the higher mean speeds in Seoul and Tokyo. Difference is around 30 km/hr which is relatively large. The reason is that the average performance of vehicles is better in developed cities which is supported by earlier international research on intersection traffic flow comparison (Vergel and Morichi, 1995). There is no significant difference between the mean speeds of Tokyo and Seoul, although Tokyo's average speed is greater. In Tokyo, the speed samples were taken only from the Ariake basic segment of the metropolitan expressway's Bayshore Line since the Sangenjaya segment of the Shibuya Line was heavily congested during the morning observation periods.

4.3.2 International Comparison of Mean Speeds of Buses

Similar to the results of comparison of passenger car speeds, average bus speed is significantly different from the speeds in Tokyo and Seoul, but this time, the difference is lesser meaning the bus operating capability is not that different from the buses in Seoul and Tokyo. This is supported by the field observation in Manila that relatively new buses acquired by bus transport companies for their inter-city operations. Many of these bus engines came from Japan. It is also interesting to note that in the Manila data, the average speed of buses is greater than those of passenger cars and all the other types of vehicles. Using a one-tailed *t*-test of significance of the difference between mean speeds of buses and other vehicles, all tests yielded significant difference at 5%. Another reason is aggressiveness of bus drivers influenced by the need to arrive at their destinations and turn around as soon as possible and avoid the morning traffic congestion in the metropolis in order to make the required trips.

4.3.3 International Comparison of Mean Speeds of Trucks

As expected, due to the relatively lower operating capability of small/medium trucks compared in Manila compared to those in Seoul and Tokyo, which is indicative of the level of economy, the average speed of small and medium-size trucks in the developing country is significantly lower than the speeds of trucks in other more developed countries. Most of these small and medium-size trucks are observed to be running slow on expressways due to the relatively older fleet age and many of these vehicles were assembled in various small and medium scale auto and truck assembly shops where standards may not be that high as in large-scale truck manufacturing plants.

Average speed is significantly lower in Manila than other cities. Results of one-tailed *t*-test at the 5% error level indicate a significantly higher speed for Tokyo followed by Seoul and Manila. It is indicative that the level of economy in general that affects the vehicle performance in terms of vehicle age and frequency and degree of vehicle maintenance.

4.4 Comparison of Mean Speeds between Vehicle Classes Within Each City

Table 4 indicates the results of comparison of speeds of different types of vehicles in each city. From this table, it is evident that the mean speeds of different vehicle classes in Seoul and Tokyo are almost similar which indicates a relatively smooth traffic compared to the expressway traffic stream observed in Manila. In Manila, the average speed of passenger

Table 4. Tests of significance of the difference of mean speeds between vehicles within each city using two-tailed *t*-test at 5%

Manila		Seoul		Tokyo	
passenger car vs.		passenger car vs.		passenger car vs.	
jeepney	⌘ 0.601	motorcycle	-	motorcycle	-
bus	O 2.00×10^{-59}	bus	⌘ 0.637	bus	⌘ 0.940
large truck	O 1.80×10^{-4}	large truck	⌘ 0.026	large truck	⌘ 0.097
small truck	O 0.007	small truck	⌘ 0.100	small truck	⌘ 0.648
jeepney vs.		motorcycle vs.		motorcycle vs.	
bus	O 5.40×10^{-36}	bus	-	bus	-
large truck	O 1.44×10^{-4}	large truck	-	large truck	-
small truck	⌘ 0.049	small truck	-	small truck	-
bus vs.		bus vs.		bus vs.	
large truck	O 2.24×10^{-5}	large truck	⌘ 0.275	large truck	⌘ 0.574
small truck	O 2.48×10^{-19}	small truck	⌘ 0.444	small truck	⌘ 0.908
large truck vs.		large truck vs.		large truck vs.	
small truck	⌘ 0.04	small truck	⌘ 0.444	small truck	⌘ 0.908

Notes: O - difference is significant at 5% ⌘ - difference is not significant at 5%
lower number indicates value of probability (p-value)

cars is significantly different from the speeds of buses and trucks. Although the speeds of jeepneys and small trucks are not significantly different, the mean speed of jeepney is significantly different from buses and large trucks. The bus speed is significantly different from all the other types of vehicles.

Comparison of speeds of different vehicles in Manila's expressway indicates that the traffic stream is not running smooth relatively. This is supported by video observation that high-speed buses follow slower-moving passenger cars too closely and then either slows down abruptly or suddenly shift lanes to avoid the cars. This is also true for the vehicles in the same class. The variation within each class is discussed in Section 4.5. The driver behavior in Manila contributes to this non-steady traffic flow and aside from lower vehicular performance. The variation of speeds between cities indicates the difference in level of economy but this can be further supported by the speed distributions of vehicles and their relative dispersions and confidence limits which will be discussed in the following section.

4.5 Comparison of Speed Distribution of Vehicles

Using the speed data in the previous section, speed distributions of vehicles are constructed. The dispersions of observed speeds of vehicles running in expressways in the three cities in this study are measured in terms of standard errors. The main purpose is to establish if there is difference in speed of vehicles in each city and between cities. Table 5 indicates the speed statistics of all vehicle classes in the three cities which include the mean, number of observations, variance, sample standard deviation, standard error and confidence limits.

Table 5. Detailed comparison of speed confidence intervals of the three cities

MANILA	all vehicles	passenger car	jeepney	bus	large truck	small truck
no of observ.	4110	3219	351	261	63	216
mean	62.0	61.1	61.4	72.0	66.0	63.0
standard error	0.16	0.18	0.49	0.64	1.05	0.71
68% conf. int.	[61.8,62.2]	[60.9,61.3]	[60.9,61.9]	[71.4,72.6]	[64.9,67.0]	[62.3,63.7]
95% conf. int.	[61.6,62.3]	[60.7,61.4]	[60.4,62.4]	[70.7,73.3]	[63.9,68.1]	[61.6,64.4]
99% conf. int.	[61.5,62.5]	[60.6,61.6]	[59.9,62.8]	[70.1,73.9]	[62.9,69.1]	[60.9,65.2]
SEOUL	all vehicles	passenger car	motor-cycle	bus	large truck	small truck
no of observ.	480	684	-	20	31	44
mean	93.4	94.4	-	93.0	88.0	89.2
standard error	0.71	0.41	-	3.6	2.8	2.96
68% conf. int.	[92.7,94.1]	[93.5,95.1]	-	[89.5,96.0]	[85.2,90.8]	[86.2,92.1]
95% conf. int.	[92.0,94.8]	[92.8,95.8]	-	[85.9,100.1]	[82.4,93.6]	[83.3,95.1]
99% conf. int.	[91.3,95.6]	[92.0,96.6]	-	[82.3,103.7]	[79.6,96.4]	[80.3,98.0]
TOKYO	all vehicles	passenger car	motor-cycle	bus	large truck	small truck
no of observ.	1416	684	-	38	427	266
mean	94.7	94.4	-	94.5	95.4	94.7
standard error	0.26	0.41	-	1.37	0.45	0.54
68% conf. int.	[94.4,95.0]	[93.9,94.8]	-	[93.1,95.8]	[94.9,95.8]	[94.1,95.2]
95% conf. int.	[94.2,95.2]	[93.5,95.2]	-	[91.7,97.2]	[94.5,96.2]	[93.6,95.7]
99% conf. int.	[93.9,95.5]	[93.1,95.6]	-	[90.4,98.6]	[94.0,96.7]	[93.0,96.3]

If the speed distributions of all vehicles are compared, it is clear that the mean speed is lowest in Manila. The mean speeds of Seoul and Tokyo are not so different although the mean of Tokyo is higher and the distribution is most spread in Seoul. At 68%, 95% and 99% speed confidence intervals, Manila is significantly different from Seoul and Tokyo. At 95% confidence limit, the general vehicular speed in Seoul is lower than that of Tokyo.

In Manila, the bus speed distribution is clearly distinct and much higher than all the other vehicle types even up to within 3 standard errors of the mean or 99% confidence limit. This confirms the earlier t-test in sections 4.3 and 4.4 that the bus speed is significantly higher than the speeds of other vehicle The standard error is highest for buses in Seoul followed by large trucks and then small trucks with the least for passenger cars which just indicates the smooth traffic flow for passenger cars in this city. Speed confidence intervals of vehicle classes overlap each other at the 95% indicative of the similarity in deviations of speeds or distribution of speeds which is good for smooth and steady flow of traffic minimizing sudden slowdowns or stops and consequent lane changing behavior. Tokyo has similar results with Seoul. The speed confidence intervals are not distinct from each other especially at the 95% level indicating that the variation of speeds are not so different for all the vehicle types.

4.6 International Comparison of Lane Utilization

Lane utilization indicates how traffic is distributed to all the lanes of a facility. The lane use by vehicles varies with the traffic volume and driver behavior, and in some cases, some traffic regulations such as high-speed vehicles only in the inner lanes. The lane utilization of vehicles is represented in terms of percentage of the total traffic flow for all the lanes in one direction. The lane utilization curves are expected to converge with each other to an almost horizontal line as the total traffic flow increases

4.6.1 International Comparison of Lane Use of All Vehicles

The graphs in Figures 11, 12 and 13 show the comparison of lane utilization of all vehicles. In the Manila expressway segment, the lane utilization curves for the traffic flow lanes converge to the 28% line indicating a congested road facility. The overall utilization rate of

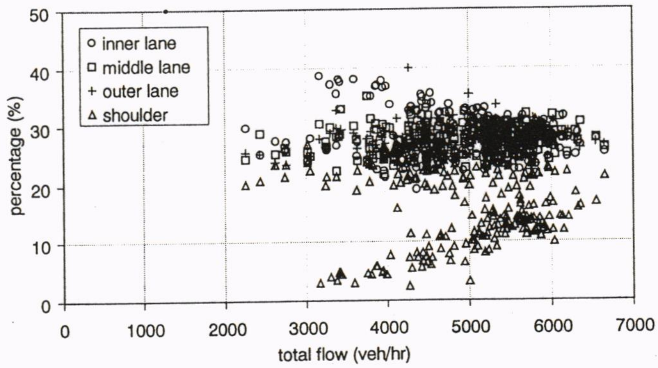

Figure 11. Lane utilization at the South Luzon Expressway Sucat-Bicutan basic segment in Metro Manila

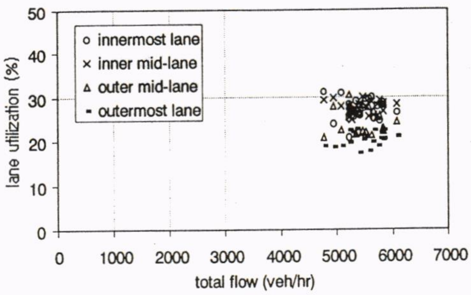

Figure 12 . Lane utilization at the Seoul Olympic Expressway

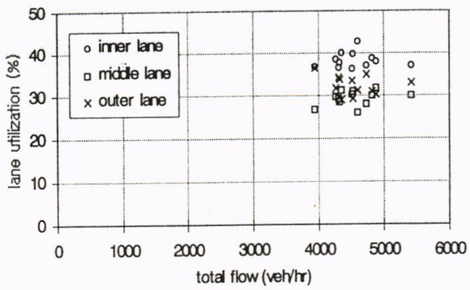

Figure 13 . Lane utilization at the Tokyo Metropolitan Expressway Bayshore Line Ariake Segment

the inner, middle and outer regular traffic flow lanes converge to 27.9%, 27.8% and 28.0%, respectively, using the average of all the lane use rate values falling in the range of total flow rate from 4000 veh/hr. and greater. The shoulder lane usage is significantly high as compared to zero utilization rate in Seoul and near-zero value in Tokyo. This is unique feature of the expressway in Manila where overtaking using the shoulder is allowed by the tollway traffic management. In addition is the impatient behavior where drivers overtake other vehicles using any open lane even including shoulder lanes. In Seoul, no vehicle passed through the shoulder lane which is primarily due to strict regulations against using shoulder with the exception of emergency situations. Although some drivers pass through the lanes in congested flow seasons such as holidays, the police strictly enforce the rule and fine erring drivers.

The innermost and adjacent inner mid-lane in Seoul are the most heavily used lanes with means of 27.3% and 27.6%, respectively, as compared to the 24.8% and 20.3 % lane use rates for the outer lanes. Similarly, in Tokyo, the inner lane is used by passenger cars compared to its use of external lanes which is different from Manila. The lane use of cars in Manila is almost spread equally to around 28-30% across the traffic flow lanes.

4.6.2 International Comparison of Lane Use of Passenger Cars

In Table 6, passenger cars in developed cities such as Tokyo and Seoul occupy the faster inner lanes in contrast to Manila where drivers' choice of lanes is spread to all lanes reflecting the difference in behavior where drivers prefer any faster lane thus the increased tendency to change lanes more often than necessary. It also indicates the basic rule that the faster vehicles running the inner lanes is not being followed in Manila.

4.6.3 International Comparison of Lane Use of Buses

In Manila and Seoul, buses generally use the middle lanes which is also same as the behavior in Tokyo. In Manila, this can be explained by bus driver behavior where they need more freedom to maneuver such as change to lanes in order not to collide with other slower vehicles since the average speed of buses is significantly high as shown in Table 3 in section 4.3. In Seoul, the main factor for the spread of buses to the outer lanes is the earlier result of passenger car flows occupying mostly the innermost lane.

Table 6. Average lane utilization of various vehicle types (non-congested flow conditions and total flows ranging 4000 veh/hr and greater)

Manila	passenger car	jeepney	bus	large truck	small/medium truck
inner lane	32.4	26.1	7.5	16.5	24.1
middle lane	28.3	29.2	33.1	43.0	34.1
outer lane	26.6	34.3	50.3	32.8	33.0
shoulder lane	12.7	10.9	9.1	7.7	8.8
Seoul	**passenger car**	**motorcycle**	**bus**	**large truck**	**small/medium truck**
inner lane	36.4	-	0	0.6	0
inner mid-lane	34.5	-	24.4	8.2	6.8
outer mid-lane	15.6	-	50.2	57.4	54.9
outer lane	13.5	-	25.4	33.7	38.2
Tokyo	**passenger car**	**Motorcycle**	**bus**	**large truck**	**small/medium truck**
inner lane	44.4	-	19.2	34.4	30.5
middle lane	25.5	-	50.6	45.2	47.1
outer lane	30.1	-	30.2	20.5	22.4

4.6.4 International Comparison of Lane Use of Trucks

In Seoul, the outer lanes are used more by trucks. Similarly, because of size and operating capability indicated by the mean speed, which is lowest compared to other vehicle types in Seoul, as shown in Table 6, drivers of these trucks give way for high-speed vehicles. However, the trend is quite different in Tokyo wherein large trucks use the inner lane with a relatively high rate of 34.4%, the highest of all cities. One reason is the relatively high truck traffic percentage in Tokyo's road traffic and also the highest average speed compared to other types as shown in Table 2. It is also shown in the same table that the average speed of large trucks in Tokyo is significantly higher indicative of its high performance similar to passenger cars. With this, they can operate and maneuver thus there is no need for the drivers of these vehicles to stay at outer lanes. The lane utilization of medium trucks in Manila, is similar to that of jeepneys. The lane utilization rate is spread to the outer lanes indicative of driver behavior of using the inner lane despite their low speed that impedes other vehicles running in the faster inner lane. In Seoul, medium trucks use the outer lanes. In Tokyo, the lane use rate is similar to those of large trucks where it is spread across the lanes indicative of the relative high road performance of trucks in Tokyo. These results contribute to the mixing of car and truck traffic for all the lanes in Tokyo's expressways that may be disturbing to drivers of smaller vehicles due to the psychological impact of the size of trucks.

5. CONCLUSION

The study shows that the mean speeds of all vehicles in expressway traffic between Manila and other cities are significantly different while there is no significant difference between the developed cities of Seoul and Tokyo. The speeds seem to increase with level of economy of the country which is similar to the result of intersection starting lost time comparison in an earlier study. It is also interesting to note that the average speed of buses is the higher than other vehicle types in Manila's expressway. This is due to aggressive bus driver behavior and high performance of bus vehicles.

Comparison of overall lane utilization indicate a highly used inner lanes in Seoul compared to other cities due to the almost exclusive use of passenger cars. The use of shoulder in Manila's expressways is significant due to the allowance by toll management and driver behavior. Passenger car drivers usually choose to use the inner lane in Tokyo and Seoul as opposed to Manila where lane use is spread across lanes reflecting the driver behavior difference, and indicates that the faster inner lane rule is not being kept. In Manila, buses tend to occupy the middle lanes for greater flexibility and in case of small/medium trucks, the lane use is spread across the lanes similar to the jeepney lane use which is indication of driver behavior that may impede traffic flow since their speeds are relatively low. In Tokyo, lane use is similar to those of large trucks which contribute to the mixing of truck and car traffic which may be disturbing to car drivers due to the size impact of trucks on these drivers. It is recommended that slower vehicles at the outer lane rule must be strictly enforced to increase traffic capacity and reduce impedance by slow-moving vehicles identified in the speed analysis especially in Manila. In Tokyo, there is a need to limit large trucks to the outer lanes to solve the problems of mixing of trucks and cars the result of which is similar to the Seoul expressway traffic conditions where cars mostly use the inner lane.

Results of the speed-flow relationship can be incorporated directly to the Philippine Highway Capacity Manual (PHCM) as an established Q-V relationship for basic level urban expressway segments. This study plotted 278 points that amply cover the congested flow region and the high-flow near capacity flow region of the speed-flow graph, and could reinforce the existing relationships established for the basic expressway segments by Sigua (1995). Q-V plots of Seoul and Tokyo could be considered as the predicted relationship in the future as economic development brings about improvements in vehicle performance, decrease in paratransit share, increase in share of passenger cars, better traffic behavior such as better lane use, steady traffic flow and lesser lane-changing, improved road design, traffic rule implementation and traffic. The average speed values and lane utilization rates of vehicles shown in the second part of this paper can be incorporated to the section of traffic characteristics in the development of the PHCM. The average speed which is equivalent to the time mean speed can classified as one of the speed characteristics and the lane use as one of the volume characteristics. Furthermore, the average speed according to vehicle type indicate whether there is improvement in vehicle performance.

There is a difference in characteristics of speed-flow relationships based on this study's data coming from the three cities compared to that established in the US Highway Capacity Manual in 1994 particularly the 55-mph (88 kph) non-congested Q-V relationship. The US HCM provides for a 5-mph (8-kph) drop in speed from free flow speed to speed at capacity of 2200 pcphpl. However, in the case of Manila, the speed drop from the free flow speed of 80 kph is approximately 20 kph which is relatively larger than the US HCM values. A speed drop of 15 kph-20 kph could also be observed from the Seoul and Tokyo expressway data. These differences in traffic flow characteristics not only between Manila and Seoul and Tokyo but also with the developed counties like the United States, indicate the need to establish a local highway capacity manual which would take into account these findings.

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