COMPARATIVE ANALYSIS OF MORNING AND AFTERNOON VEHICULAR OCCUPANCY ENTER AND EXIT THE CITY CENTER

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Abstract: The focus of this research is to study the occupancy rates in passenger cars during the morning and afternoon peak periods of those entering and leaving center city through the at-grade network of roads. Comparative analysis is given in order to determine the difference between occupancy rates of these two peak periods. The occupancy rate of pick-up vehicles is also included into the investigation. Data on passengers in each vehicle was collected along the Cordon line of Ratchadpisek ring road for both entering and exiting in the morning and afternoon periods respectively. Vehicle occupancy rates were analyzed for different types of passenger vehicles, namely, passenger cars, pick-up trucks, and taxis. The occupancy rates of the private, public, and the overall vehicle groups were also analyzed. The comparative investigation was also given to time series analysis of the occupancy rates of each vehicle type for the morning and afternoon trips in order to see the influence of time on occupancy rates during these periods.

Key Words: occupancy rates, comparative analysis of occupancy rates, morning and afternoon peaks' occupancy rates, entering and exiting city center, vehicle occupancy rates.

1. INTRODUCTION

The long queues of vehicles created by congesting traffic on almost every road leading to the city center are the common view that can be seen every morning and afternoon in Bangkok. This problem comes from too many cars on the roads, and most important of all is that there are very few passengers in each car. This research, therefore, was aimed at the study of occupancy rate of passengers in private vehicles that included private passenger cars and private pick-up trucks that are popularly used solely for passenger purposes during the peak hour periods. Taxis, public passenger cars, are also under this investigation. The comparative analysis given to these two peaks' occupancy rates views the difference in occupancy characteristics between the morning and afternoon peaks in entering and exiting Bangkok's city center.

2. SCOPE OF THE STUDY AND DATA COLLECTION

Ratchadapisek Ring Road was used as the Cordon line which surrounds Bangkok's city center. There were 24 at-grade intersections along this ring road that are used to enter and exit the city center. The data for this study was collected on each of these at-grade intersections during the periods of morning and afternoon peak hour between 6.00 am. to 9.00

am. and 3.00 pm. to 6.00 pm. respectively. Data for entering traffic was collected during the morning peak hours, and exiting traffic data was collected during the afternoon peak period. Two types of private vehicles were investigated: the private passenger car, and private pick-up truck. In Thailand, the pick-up is not only used for delivering goods but also for passenger purposes, especially during the peak hour periods in the cities. Another type of passenger car used for public service, the taxi, was also included in this study due to its similar characteristics of passenger usage. Data collection was done for the number of passengers, including the driver, in each type of vehicle. This data was collected at each of the 24 intersections to and from the city center along this ring road.

Vehicle on each traffic lane of the approaching roadway into or out of the city center boundary was observed by at least one observer per lane which accounted for 3-6 persons at each intersection. Traffic counters and pre-designed forms on marking boards were used together with video camera set by the side of roadway for collecting of data. All vehicles entered and exited the cordon intersection were observed by counting the occupied passengers through the front and side windows of the vehicles. Since there were 24 cordon intersections in this study, the data collection was done on the different days for each intersection. However, these observation days were all in the three middle working days of the week, namely, Tuesday, Wednesday, and Thursday in order to avoid any bias on traffic data on the first and last working days of Monday and Friday.

3. OCCUPANCY ANALYSIS

Occupancy rates of vehicles were analyzed in terms of the average number of passengers, including driver, occupying each particular type of vehicle. This study investigated three types of vehicular occupancy rates: specifically occupancy rates of each vehicle type, occupancy rates of private and public vehicles, and finally, the overall occupancy rate of all vehicles.

3.1 Comparison of Occupancy Rate of Each Vehicle Type

The analysis of each type of vehicle's morning entrance occupancy rate and afternoon exit occupancy rate can be mathematically described as follows.

$$OR_{(i)p} = \frac{P_{(i)p}}{N_{(i)p}} \quad (1)$$

where $OR_{(i)p}$ = Occupancy rate of vehicle type i during peak period p (persons/vehicle)
$P_{(i)p}$ = Total number of passengers in vehicle type i during peak period p (persons)
$N_{(i)p}$ = Total number of vehicles in vehicle type i during peak period p (vehicles)
i = Vehicle type i
= (1) Private passenger car (PC), (2) Private pick-up (PU), and (3) Public taxi (TX)
p = Peak hour periods
= (1) Morning peak, and (2) Afternoon peak

and $$P_i = \sum_{\text{all } j} p_{(i)(p)j} \quad (2)$$

where $p_{(i)(p)j}$ = Number of passengers in each vehicle j of vehicle type i during peak period p

j = The j vehicle

Results of this occupancy rate analysis for each type of vehicle together with the summarized results of distribution analyses of number of vehicles in each group of passengers per vehicle (passenger car, pick-up truck, and taxi for both morning and afternoon peak periods) are shown in **Table 1.** The comparison results of mean, variance, and standard deviation of occupancy rates of each type of vehicles are also shown in **Table 2. Figure 1** shows the comparative plot of occupancy rates in the morning and afternoon peak periods of passenger cars, pick-ups, and taxis respectively. In the morning peak period, the lowest occupancy rate of 1.574 passengers/veh appeared in passenger cars. The pick-up's occupancy rate was in the middle of all three types of vehicles under the study with the value of 1.721 persons/veh. Taxis gave the highest occupancy rate of 2.009 passengers/veh, which was due to its public service characteristics and also the high demand of ridership during this peak hour period. For the afternoon period, passenger cars also gave the lowest occupancy rate of 1.555, where pick-ups gave the middle result of 1.835. The highest occupancy rate of 2.068 occurred in the taxi group. In the comparative analysis, both of these two peak periods provided the same trend of occupancy rates from the lowest occupancy rate of passenger cars to pick-ups in the middle, and then taxis as the highest.

In the comparison of individual types of vehicles, occupancy rates of passenger cars in the morning peak were higher than those of the afternoon peak by 1.21%. However, it was in the opposite direction for pick-ups and taxis which the morning peak occupancy rates of these two types of vehicle were lower than those of the afternoon peak by 6.62% and 2.94% respectively.

Table 1. Comparison of Occupancy Rates of Each Type of Vehicles, Groups of Vehicles, and All Vehicles during Morning and Afternoon Peak Periods

Peak Periods	Vehicle Types	No. of Veh. in Each Group of Occupied Persons in A Veh.							Sum Vehicles		Sum Persons		Occupancy Rate (Persons/Veh.)	
		1	2	3	4	5	6	7						
Morning Peak (6.00-9.00 AM)	Private Passenger Car	43,486	28,449	5,514	1,547	303	31	16	79,346	95,631	124,927	152,952	1.574	1.599
	Private Pick-Up	7,174	7,149	1,481	333	113	32	3	16,285		28,025		1.721	
	Public Taxi	4,515	4,761	2,217	657	274	57	10	12,491	12,491	25,098	25,098	2.009	2.009
	All Vehicles	55,175	40,359	9,212	2,537	690	120	29	108,122		178,050		1.647	
Afternoon Peak (3.00-6.00 PM)	Private Passenger Car	38,295	20,805	5,268	1,494	170	19	6	66,057	85,240	102,691	137,885	1.555	1.618
	Private Pick-Up	9,018	6,305	2,455	971	326	69	39	19,183		35,194		1.835	
	Public Taxi	5,072	5,245	3,019	1,131	243	12	2	14,724	14,724	30,444	30,444	2.068	2.068
	All Vehicles	52,385	32,355	10,742	3,596	739	100	47	99,964		168,329		1.684	

Table 2. Comparison of Mean, Variance, and Standard Deviation of Occupancy Rates of Each Type of Vehicles during Morning and Afternoon Peak Periods

Peak Periods	Vehicle Types	No. of Veh. in Each Group of Occupied Persons in A veh.							Occupancy Rate		
		1	2	3	4	5	6	7	Mean	Variance	SD
Morning Peak	Private Passenger Car	43,486	28,449	5,514	1,547	303	31	16	1.574	0.5601	0.7484
	Private Pick-Up	7,174	7,149	1,481	333	113	32	3	1.721	0.6339	0.7962
	Public Taxi	4,515	4,761	2,217	657	274	57	10	2.009	1.0398	1.0197
	All Vehicles	55,175	40,359	9,212	2,537	690	120	29	1.647	0.6465	0.8040
Afternoon Peak	Private Passenger Car	38,295	20,805	5,268	1,494	170	19	6	1.555	0.5816	0.7626
	Private Pick-Up	9,018	6,305	2,455	971	326	69	39	1.835	1.0346	1.0171
	Public Taxi	5,072	5,245	3,019	1,131	243	12	2	2.068	1.0172	1.0086
	All Vehicles	52,385	32,355	10,742	3,596	739	100	47	1.684	0.7698	0.8774

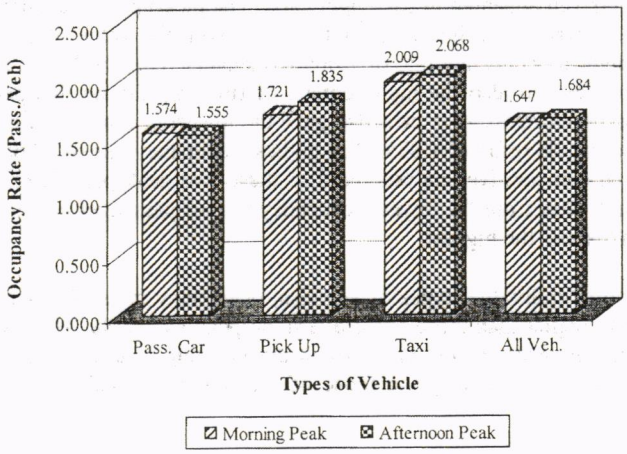

Figure 1. Comparison of Occupancy Rates of Passenger Cars, Pick-Ups, and Taxis in Morning and Afternoon Peak Periods

3.2 Comparison of Occupancy Rate of Private and Public Vehicles

This research also extended into the study for the difference between occupancy rates of private and public vehicles. The mathematical description of this analysis can be defined as follows.

$$OR_{(m)p} = \frac{P_{(m)p}}{N_{(m)p}} \tag{3}$$

and

$$P_{(m)p} = \sum_{\text{all } n} p_{(m)(p)n} \tag{4}$$

where $OR_{(m)p}$ = Occupancy rate of vehicle class m during peak period p (passengers/vehicle)

$P_{(m)p}$ = Total number of passengers in vehicle class m during peak period p (passengers)

$N_{(m)p}$ = Total number of vehicles in vehicle class m during peak period p (vehicles)

$p_{(m)(p)n}$ = Number of passengers in any vehicle n of vehicle class m during peak period p (passengers)

m = Vehicle class m
= (1) Private vehicle (passenger car and pick-up), and (2) Public vehicle (taxi)

n = Any vehicle n in vehicle class m

p = Peak hour period
= (1) Morning peak, and (2) Afternoon peak

The analysis results of these private and public vehicles' occupancy rates during morning and afternoon peak hour periods are shown in **Table 1**. The comparative plot of occupancy rates of private vehicles, public vehicles, and the overall vehicle types are shown in **Figure 2**. From the results of the morning peak analysis, the private vehicle group gave the lowest occupancy rate of 1.599 passengers/veh. This private vehicle occupancy rate was much lower than that of the public vehicle group (taxi), which gave the occupancy rate value of 2.009. This very low value of private vehicle occupancy rate implied that only a single person occupied many of these private vehicles, which included passenger cars and pick-ups, during the morning peak hour period. The average value of 1.599 passengers occupied all of these private vehicles in entering Bangkok's city center during this period of time.

The same trend also appeared in the afternoon peak analysis, which the lowest occupancy rate of 1.618 passengers/veh occurred in the private vehicle group and the highest occupancy rate of 2.068 occurred in the public group.

For the comparative analysis of these two peak periods, the afternoon peak occupancy rate gave the higher value than those of the morning peak in both the private and public vehicle groups by 1.19% and 2.94% respectively. This means that people attempt to pool together in a vehicle from work in the afternoon, where this pooling can not be done effectively in the morning when they are going to work from separate origins.

3.3 Comparison of Overall Occupancy Rate of All Vehicles

The final analysis of overall occupancy rates for all combined types of vehicles during this study period was then analyzed with the following analytical formulas.

$$OR_{(overall)p} = \frac{P_{(overall)p}}{N_{(overall)p}} \quad (5)$$

and

$$P_{(overall)p} = P_{(PC)p} + P_{(PU)p} + P_{(TX)p} \quad (6)$$

$$N_{(overall)p} = N_{(PC)p} + N_{(PU)p} + N_{(TX)p} \quad (7)$$

where $OR_{(overall)p}$ = Overall occupancy rate of all vehicles during peak period p (passengers/vehicle)

$P_{(overall)\,p}$ = Total number of persons in all vehicles during peak period p (passengers)

$N_{(overall)\,p}$ = Total number of all vehicles during peak period p (vehicles)

$P_{(PC)\,p}$, $P_{(PU)\,p}$, $P_{(TX)\,p}$ = Total number of passengers in passenger cars, pick-ups, and taxis during peak period p respectively

$N_{(PC)\,p}$, $N_{(PU)\,p}$, $N_{(TX)\,p}$ = Total number of vehicles for passenger cars, pick-ups, and taxis during peak period p respectively

p = Peak hour periods
= (1) Morning peak, and (2) Afternoon peak

The comparative analysis results of overall occupancy rates and the distribution of the number of vehicles in each group of passengers per vehicle, for all types of vehicles during the two peak hour periods, are also shown in **Table 1** and **Figure 2** respectively. The low overall occupancy rate value of 1.647 and 1.684 passengers/veh as shown in this analysis indicates that there is only an average of 1.647 and 1.684 passengers occupying every four-wheels motor vehicle entering and leaving Bangkok's city center through the 24 intersections during the morning and afternoon peak hour periods. These four-wheeled vehicles account for 108,122 and 99,964 vehicles during these two peak periods respectively. This then is one of the main reasons behind the heavy traffic congestion in the city of Bangkok, especially during the peak hour periods.

The afternoon peak period's overall occupancy rate was also higher than that of the morning peak by 2.25%. Furthermore, the overall vehicle type for these two peak periods were very close to those of the private vehicle group, and much less than those of the public vehicle (or taxi) group. This was due to the large amount of private vehicles which consisted of passenger cars and pick-ups in the traffic stream entering and exiting the city center during these two peak hour periods. These private vehicular volumes account for 88.45% and 85.27% of the total traffic volumes in and out of the city center respectively.

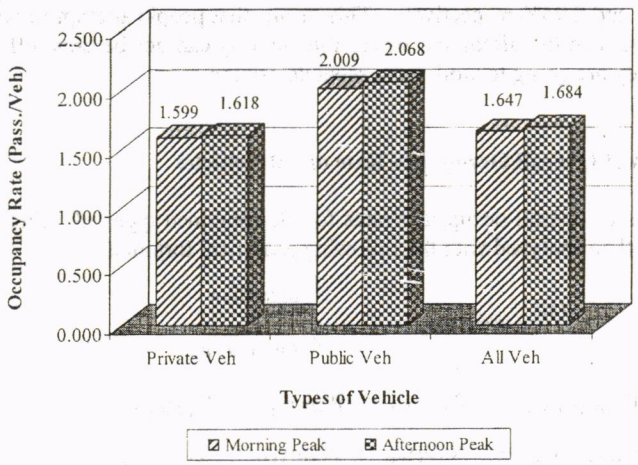

Figure 2. Comparison of Occupancy Rates of Private, Public, and All Vehicle Groups in Morning and Afternoon Peak Periods

3.4 Distribution of Occupancy Rates Over Time

The comparative analysis of the time series of passenger car, pick-up, and taxi occupancy rates, together with the occupancy rates of the groups of private, public, and all vehicles, were analyzed. This analysis was done in order to investigate the distribution characteristics of each particular type of vehicle's occupancy rate in relation to the hourly interval in the morning and afternoon peak hour periods.

3.4.1 Time Series of Each Vehicle Type Occupancy Rates

Comparative results of time series analysis for occupancy rates of passenger cars, pick-ups, and taxis are shown in **Figure 3**. These results show that the occupancy rate of passenger cars decrease with the increase of the time period in the three hour periods of 6.00-7.00 am, 7.00-8.00 am, and 8.00-9.00 am during the morning peak period. For pick-ups and taxis, occupancy rates over time do not show any significant variation during this morning peak. During the afternoon peak, which consists of three time periods of 3.00-4.00 pm, 4.00-5.00 pm, and 5.00-6.00 pm, time seems to have a slight influence on the occupancy rate during the afternoon peak period. There is a slight increase in occupancy rates from the first hour to the third hour with a slight dip in the second hour for passenger cars. The maximum value of occupancy rate of this class of vehicle appears in the third hour. However, occupancy rates of pick-ups rise from the first hour to the second hour, and then drop slightly in the third hour. This creates a low peak of occupancy rate in the second hour for this time period. For taxis, the maximum occupancy rate occurs in the first hour, then it dips sharply in the second hour before jumping up in the third hour.

The comparative plots of occupancy rate versus hourly time periods of each vehicle type are shown in **Figure 4**. For passenger cars, the occupancy rate trend line of the morning peak period decreases with the increase in the time period, where the afternoon trends line shows a slight increase with a dip in the middle. In the first hour, the occupancy rate of the morning peak, with the value of 1.636, is much higher than that of the afternoon peak value of 1.552. In the second hour, the morning peak's occupancy rate of 1.561 is just slightly more than the value of 1.539 of the afternoon peak. However, in the third, or last hour, of the peak periods, the afternoon peak's occupancy rate of 1.570 is greater than that of the morning peak value of 1.507.

For pick-ups, occupancy rates in every hour in the morning peak period are less than those of the afternoon peak period. The minimum difference of occupancy rates appears in the first hour between the values of 1.804 and 1.747, and the maximum difference appears in the second hour between 1.851 and 1.703 for the afternoon peak and morning peak period respectively.

For taxis, the occupancy rates of all three hours in the afternoon peak period are higher than those of the morning peak period. The maximum difference between morning and afternoon appears in the first hour between the highest occupancy rate of 2.107 in the morning peak period and the lowest occupancy rate of 2.002 in the afternoon peak period. The closest value of occupancy rates occurs in the second hour, where the occupancy rate of 2.028 of the afternoon peak period is slightly more than that of 2.018 of the morning peak period. The difference between occupancy rate of these two peak periods become greater in the third hour from the values of 2.073 and 2.009 of the afternoon and morning peak periods respectively.

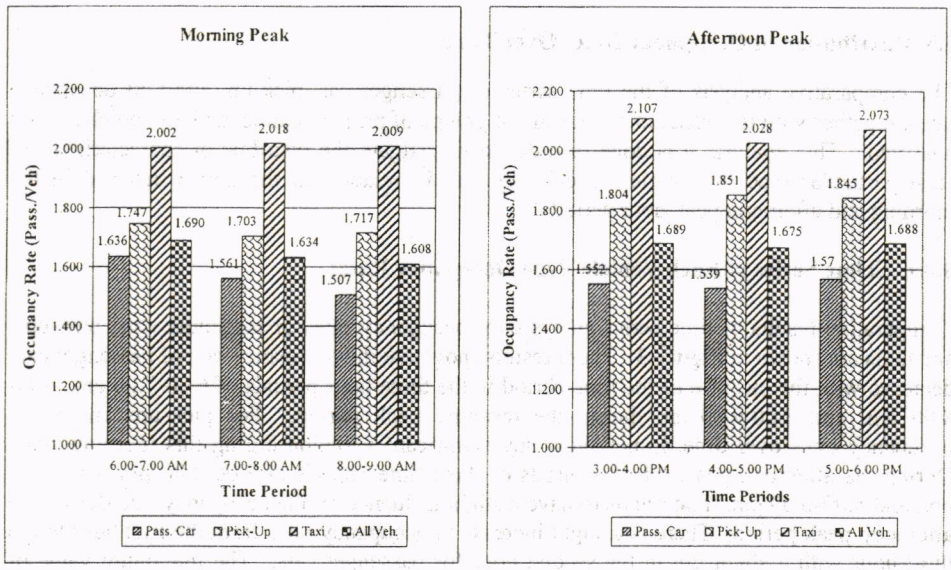

Figure 3. Comparative Time Series Distribution of Occupancy Rates of Passenger Cars, Pick-Ups, and Taxis during Morning and Afternoon Peak Periods

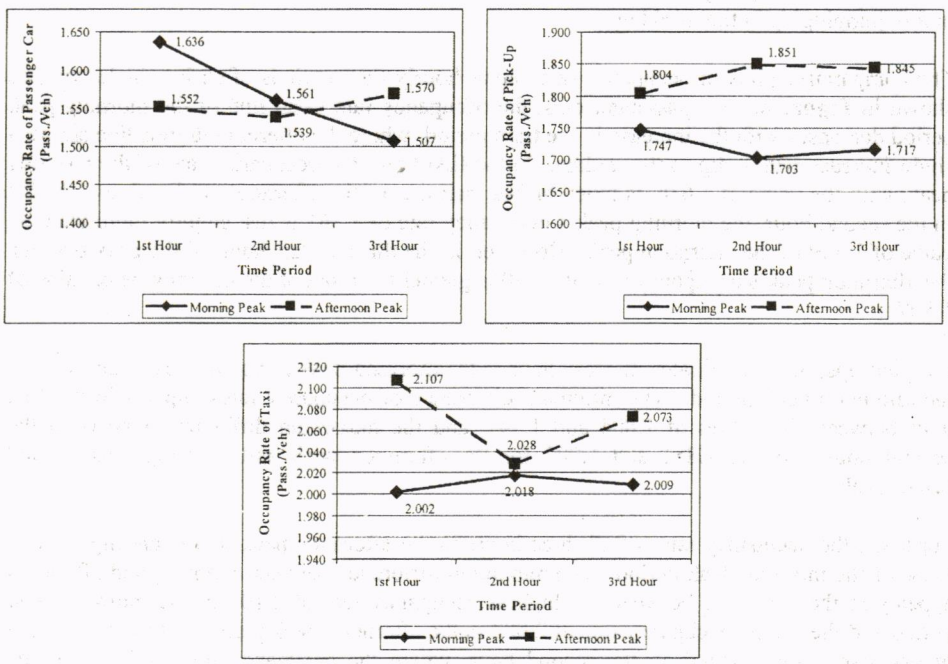

Figure 4. Comparative Distribution of Hourly Occupancy Rates of Each Vehicle Type in Morning and Afternoon Peak Periods

3.4.2 Time Series of Private, Public, and All Vehicle Occupancy Rates

The comparative time series analysis for the groups of private vehicles, public vehicles, and all vehicles are shown in **Figure 5** for both morning and afternoon peak periods. In the morning peak, occupancy rates of private vehicle groups decrease with the increase in time periods. The maximum value of 1.651 occurs in the first hour, it then drops sharply to 1.586 and 1.551 in the second and third hours respectively. However, occupancy rate of the public vehicle group seems to have no influence in regard to time. There is a slight variation of occupancy rates between 2.002 and 2.018 in the form of a crest curve with the maximum value at the second hour.

In case of overall vehicles, the trend of occupancy rates follows that of the private vehicle group in both of the morning and afternoon peak periods. In the morning peak period, occupancy rate decreases with an increase in the time period. The maximum value of the all vehicles' occupancy rates for the morning peak period appears in the first hour, and the minimum rate is in the third hour. For the afternoon peak period, there is only a slight difference between these three hours' occupancy rates with a small sag in the middle hour. The occupancy rate distribution characteristics in both morning and afternoon peak periods of all vehicle types over time are highly influenced by that of the passenger cars. This is due to the large amount of passenger cars in the traffic volume, which account for 73.38% and 66.08% of the total number of vehicles during the morning and afternoon peak periods.

Figure 6 shows a comparative plot of occupancy rate versus an hourly time period of private, public and all vehicle groups for both morning and afternoon peak periods. These results show that during the morning peak period, the maximum occupancy rate of 1.651 of the private vehicle group appears in the first hour and then drops sharply to the second hour with the value of 1.586 and goes to the minimum value of 1.551 in the third hour. Occupancy rate of the first hour in the morning peak period is higher than that of the afternoon peak period with the value of 1.612. However, the second and third hours' occupancy rate of the morning peak period is lower than those of the afternoon. The afternoon peak occupancy rate starts in the first hour with the value of 1.612 and moves to the second hour with almost no change with the value of 1.610, it then goes up slightly to 1.629 at the third hour.

For the public vehicle group, all of the afternoon occupancy rates in the three hour intervals are higher than those of the morning. The maximum occupancy rate value in the afternoon peak period appears in the first hour with the value of 2.107 and dips to 2.028 in the second hour before climbing to 2.073 in the third hour. In the morning peak period the occupancy rate starts at 2.002 and then slightly climbs to 2.018 before coming down to 2.009. The maximum and minimum difference between these two periods' occupancy rates appears in the first and second hours respectively. In the overall vehicle category, both the morning and afternoon periods' occupancy rate trend-line starts at almost the same value in the first hour with values of 1.690 and 1.689 respectively. The occupancy rate of the morning peak period then drops sharply to 1.634 and 1.608 in the second and third hours respectively. However, the occupancy rate of afternoon peak period just dips slightly to 1.675 in the second hour, and then climbs to 1.688 in the third hour. These two occupancy rate values are higher than those of the morning peak period in the same hour. The maximum difference appears in the third hour in favor of the afternoon occupancy rate, and the minimum rate appears in the first hour in favor of the morning peak period with a marginal value.

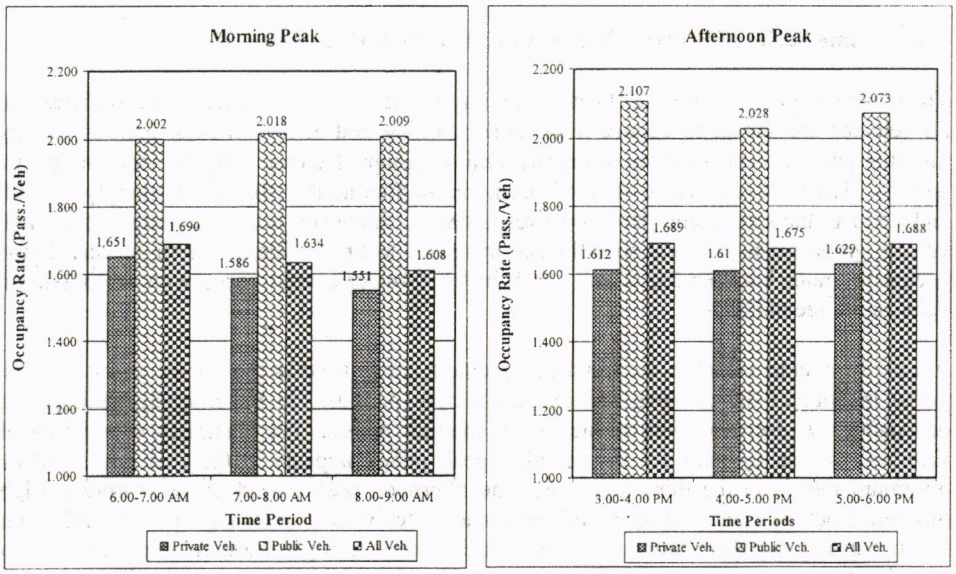

Figure 5. Comparative Time Series Distribution of Hourly Occupancy Rates of Private, Public, and All Vehicles during Morning and Afternoon Peak Periods

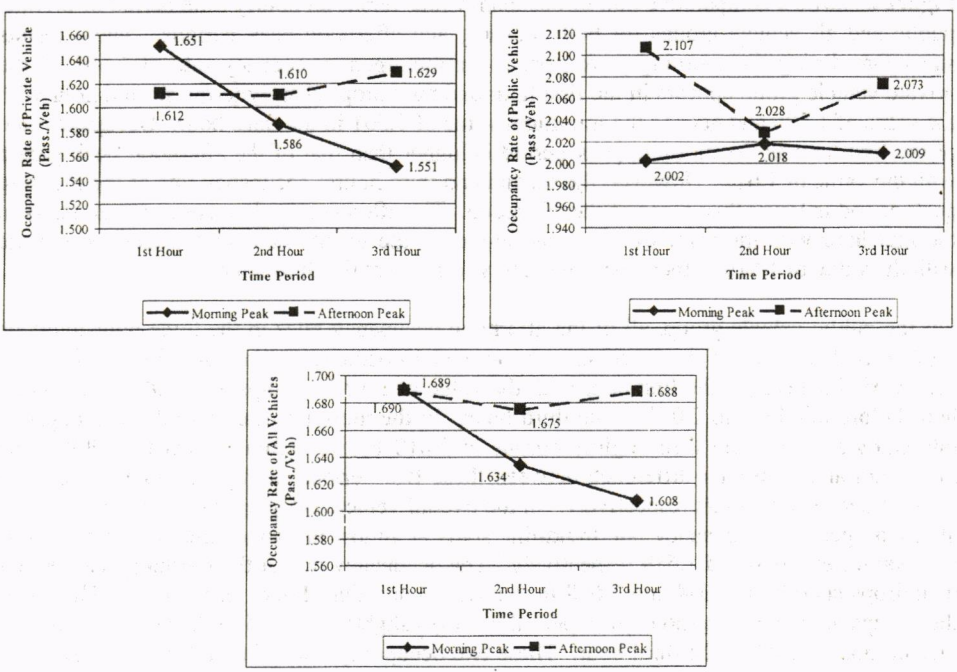

Figure 6. Comparative Distribution of Hourly Occupancy Rates of Private, Public and All Vehicles in Morning and Afternoon Peak Periods

3.5 Comparative Distribution of Number of Vehicles in Each Group of Passengers/Vehicle

Investigation was also applied to the analysis of how many vehicles were in each group of the number of passengers occupying each vehicle. The number of passengers in a vehicle was classified into 7 groups from 1 passenger/veh to 7 passengers/veh respectively. The comparative distribution results of this analysis for both the morning and afternoon peak periods are shown in **Table 1** and **Figure 7** respectively. From this analysis, results from both the morning and afternoon peak periods show that the highest vehicle numbers appear in the group of a single passenger/vehicle for both private passenger car and private pick-ups. The distribution curves of cars and pick-ups for both morning and afternoon then lean to the right of a higher number of passengers. However, the taxis show the highest number of vehicles in the two-passenger group for both morning and afternoon peak periods, and then drops to the side of a higher number of passengers. This characteristic forms the uni-modal curve which leans to the right side of a higher number of passengers for both morning and afternoon distributions.

For the comparative analysis of the individual class of vehicle as shown in **Figure 8**, the morning peak period shows the higher number of vehicles in all of the groups of passengers occupying a vehicle ranging from 1 to 7 passengers/veh. In case of pick-ups, the morning peak period shows a lower vehicle number than those of the afternoon peak period in almost all of the groups of passengers except for the group of 2 passengers/veh. For taxis, the morning peak period provides the lower number of vehicles in the first four groups of passengers ranging from 1 to 4 passengers/veh. But in the range from 5 to 7 passengers/veh, the afternoon peak period provides a higher number of vehicles than those of the morning period. In term of all vehicles analysis, as shown in **Figure 8**, the morning peak period shows the higher number of vehicles in only the first two groups of 1 and 2 passengers/veh in comparison to the afternoon peak period. After that the afternoon peak period provides a higher number of vehicles than the morning peak period for the rest of the groups of passengers per vehicle.

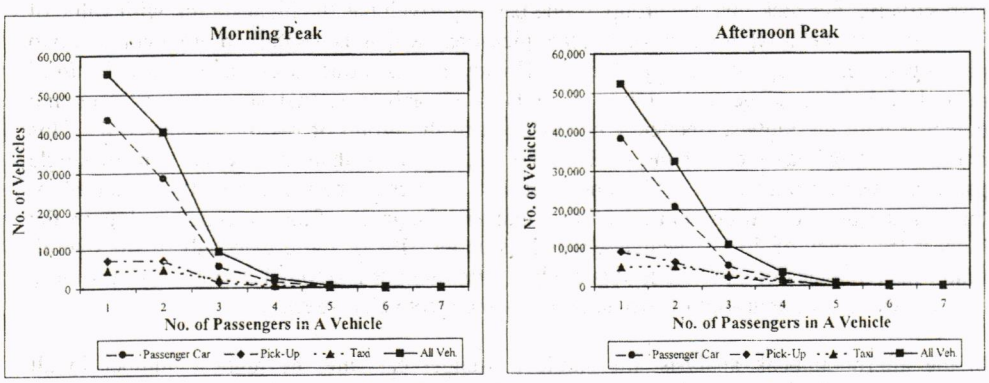

Figure 7. Comparative Distribution of Number of Vehicles in Each Group of Passengers/Vehicle in Morning and Afternoon Peak Periods

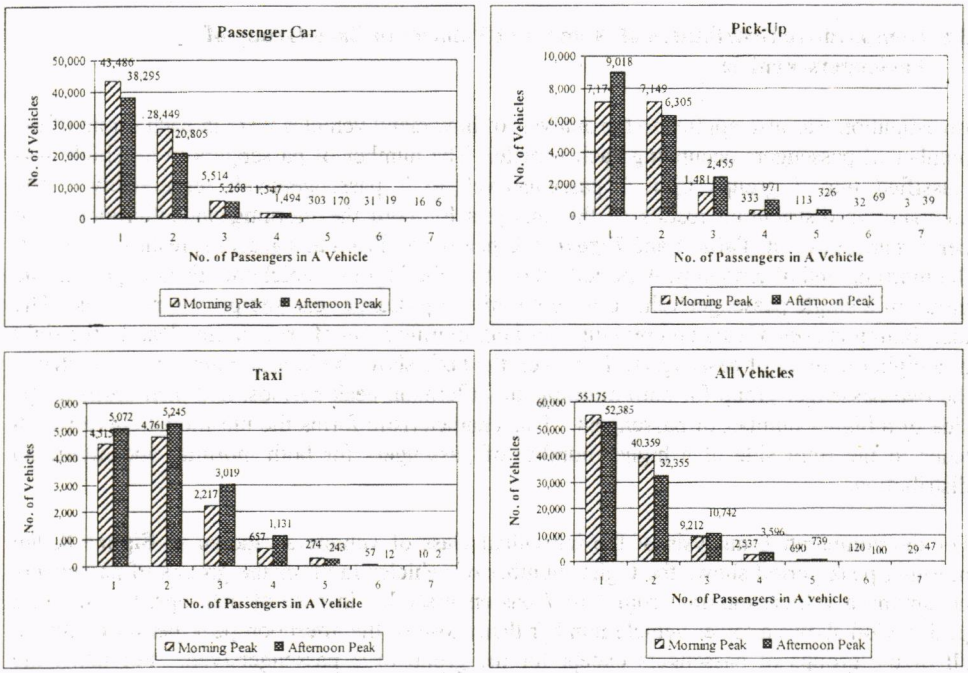

Figure 8. Comparative Distribution of Number of Each Vehicle Type in Each Group of Passengers/Veh between Morning and Afternoon Peak Periods

This analysis also shows that only one passenger, the driver himself, occupies more than half of total passenger cars in both the morning and afternoon peak periods. In the morning peak period, these one-passenger cars account for 43,486 or 54.8% out of the total number of 79,346 cars. This is the highest number in the overall categories under this study and is about 1.5 times and 7.9 times of the second and third ranked of two and three passengers/veh respectively. For pick-ups, the group of one passenger/veh has the highest rank with value of 7,174 out of the total number of 16,285 pick-ups, which is slightly more than the two passengers/veh group of 7,149 pick-ups. However, this value is about 5 times the third ranked of three passengers/veh group. Results from public taxi analysis show an interesting outcome with the highest frequency occurring with the group of two passengers/veh. This number of 4,761 taxis out of the total 12,491 taxis is more than the second rank of single passenger/veh for only about 5.4 %, and is about 2.1 times of the value from the third rank of three passengers/veh group. For all vehicle analysis, the group of one passenger/veh gave the highest frequency of 55,175 vehicles, which is about 51% or more than half of the overall four-wheel vehicles of 108,122 in this study. This number is about 1.3 and 5.9 times more than the values of the groups of two and three passengers/veh respectively.

In the afternoon peak analysis, the single passenger cars are the highest number in all categories and they account for 38,295 or 57.97% of the total 66,057 cars. This number is about 1.8 and 7.3 times the second and third ranks of the two and three passengers/veh respectively. In case of pick-ups, the single passenger/veh group with the amount of 9,018 is

47.01% of the total 19,183 pick-ups. This value is about 1.4 and 3.7 times the values from the groups of 2 and 3 passengers/veh respectively. For taxis, the analysis shows the same trend as that of the morning peak period, which the maximum vehicle number occurs in the group of 2 passengers/veh with the value of 5,245 taxis. This amount is 1.03 and 1.74 times higher than the second and third ranks of 1 and 3 passengers/veh groups respectively. For the analysis of all vehicles, the group of single passenger/veh gives the highest value of 52,385 or 52.40% of the overall vehicles of 99,964. This amount is 1.62 and 4.88 times higher than those of 2 and 3 passengers/veh groups respectively.

There are some interesting points from the comparative analysis of percentage of each vehicle type in each group of passengers/veh between the morning and afternoon peaks as shown in **Figure 9**. There is the high contrast between the percentages of pick-up from these two peak periods. The percentages of pick-up in the morning peak period for each group of passengers/veh show no significant difference between each other with the range from 13.13% to 26.67%. However, in the afternoon peak period, the pick-up's percentages increase with the increase in number of passengers/veh from 1 to 7 with the range from 17.21% to 82.98% respectively. In term of passenger cars, the percentages of these vehicles in the morning peak period drop from the maximum of 78.81% in single passenger/veh group to 25.83% in 7 passengers/veh group. However, the percentages of passenger cars in the afternoon peak drop from the maximum value of 73.10% of single passenger/veh group in an almost straight line to 12.77% in the group of 7 passengers/veh. For taxis, the percentages of this vehicle group in the morning peak period are in the form of a uni-modal curve leaning to the left of the lower number of passengers/veh with the peak of 47.50% appearing in the 6 passengers/veh group. In the afternoon peak period, these percentages are distributed in the form of a normal distribution curve with the peak of 32.88% occuring in the group of 5 passengers/veh, and then decreases to both sides of this peak.

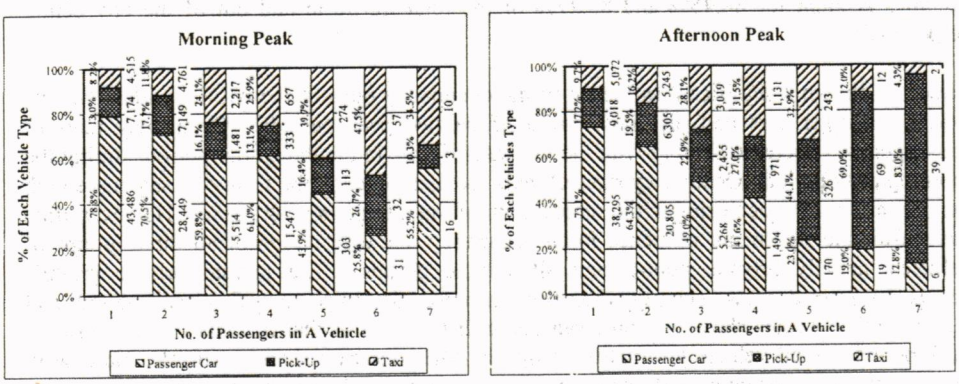

Figure 9. Comparison of Percentage of Each Vehicle Type in the Groups of Passengers/Veh in Morning and Afternoon Peak Periods

4. CONCLUSION

The occupancy rate analysis of private and public four-wheeled vehicles in this study presents the occupancy characteristics of small passenger vehicular usage in entering and leaving the Bangkok city center boundary during the morning and afternoon peak periods respectively. Several conclusions can be derived from the comparative study of these two peaks' occupancy rates as follows. In the individual vehicle type analysis, both the morning and afternoon peak periods provide the same trend of occupancy rates. They rank from the minimum values of 1.574 and 1.555 passengers/veh in passenger cars to the middle values of 1.721 and 1.835 passengers/veh in the pick-up truck group, and then to the maximum values of 2.009 and 2.068 passengers/veh in the taxi group for the morning and afternoon peak periods respectively. The occupancy rate of passenger cars in the morning peak period is higher than that of the afternoon peak period by 1.21%. But occupancy rates of pick-ups and taxis in the morning peak period are lower than those of the afternoon peak period by 6.624% and 2.936% respectively. The private vehicle group gave a much lower occupancy rate of 1.599 and 1.618 passengers/veh in comparison to public vehicles or taxis of 2.009 and 2.068 passengers/veh in both the morning and afternoon peak periods respectively. The afternoon peak period's occupancy rates of private and public vehicles are higher than those of the morning peak period by 1.19% and 2.94% respectively. This means that there are more vehicles pooling in the afternoon home trips than those in the morning work trips.

There is only an average of 1.647 and 1.684 persons occupying each four-wheel motor vehicle entering and leaving Bangkok's city center during the morning and afternoon peak hour periods respectively, and these vehicles account for 108,122 and 99,964 vehicles during these two peak periods. This is one of the main reasons behind the heavy traffic congestion in the city of Bangkok especially during the peak hour periods. The afternoon peak period's overall occupancy rate is also higher than that of the morning peak period by 2.25%. It can be noted that the all vehicles' occupancy rates of these two peak periods are very close to those of the private vehicle group. This is due to the large amount of private vehicles, which consist of passenger cars and pick-ups in the traffic stream during these study periods. These volumes account for 88.45% and 85.27% of the total traffic in and out of the city center respectively.

Time has shown a significant influence in the occupancy rates of the two individual vehicle types, passenger cars and pick-ups, during these two peak periods. Occupancy rates of passenger cars decrease sharply with the increase of time in the three hour periods during the morning peak period. Occupancy rates of taxis are distributed in the form of a sag curve with the minimum value occurring in the second hour of the afternoon peak period. However, time has shown the significant influence in an occupancy rate distribution of all three groups of vehicles, namely private, public, and all vehicle groups. The private vehicle group's occupancy rates decrease sharply when time increases during the morning peak period, and public vehicle's rates show the same sag curve distribution as that of taxis in the afternoon peak period. In all vehicle group, the occupancy rates decrease sharply with the increase in time in the same pattern as that of the private vehicle group during the morning peak period. This is due to the large amount of these private vehicles in the overall traffic stream.

This study also shows that the highest vehicle number appears in the group of single passenger/veh for both private passenger cars and private pick-ups during these two peak periods before they lean to the side of higher number of passengers. However, the taxi group shows the highest number of vehicles in the two-passengers group for both morning and

afternoon in the form of uni-modal curves which lean to the side of higher passengers. Results from the analysis also identify that only a single passenger, the driver himself, occupies more than half of total passenger cars in both the morning and afternoon peak periods. This accounts for 43,486 or 54.8% out of the total 79,346 cars in morning period, and 38,295 or 57.97% of the total 66,057 cars in the afternoon.

There are also some interesting points that appear from the comparative analysis of the percentage of each vehicle type in the group of passengers/veh between these two peak periods in the pick-up truck group. The percentages of pick-ups in the morning peak period for each group of passengers/veh show no significant difference between each other with the range from 13.13% to 26.67%. But in the afternoon peak period, these pick-ups' percentages increase with the increase in number of passengers/veh from 1 to 7 with the range from 17.21% to 82.98% respectively.

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