THE EFFECT OF VEHICLE TYPE ON THE SATURATION HEADWAY AT URBAN SIGNALIZED INTERSECTIONS

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Abstract
The capacity of an urban signalized intersection is fundamental importance in designing new intersection and modifying existing one. In *"Highway Capacity Manual"* (HCM) to account the effects of heavy vehicles in the flow at signalized intersections only the proportion of heavy vehicle is considered, queue position of vehicle is not taken into consideration. The presence of taxi in the queue at signalized intersections had significant impact on the saturation headway. For a given number of queue length saturation headway is smaller if proportion of taxi is high. Furthermore, presence of taxi increases the capacity of urban signalized intersections. The presence of small size motorized vehicles (three wheeler auto-rickshaws) had a similar positive impact on the capacity of signalized intersections. So, this factor should be considered for designing the signal timing of urban signalized intersections to reduce the congestion. This paper aims at examining the effect of vehicle type (large vehicle, taxi and small size motorized vehicles) on the saturation headway. This paper also aims at developing saturation flow rate adjustment factor for taxi at signalized intersections.

Keywords: Signalized intersections; Saturation flow rate adjustment factor; Saturation flow; Large vehicle; Small size motorized vehicle; Taxi
Topic area: C3 Traffic Control

1. Introduction

Saturation flow is the basis for the determining of traffic timing and evaluation of intersection performance. Capacity at intersections is based upon the concept of saturation flow and saturation flow rate. Capacity at intersections is defined for each lane group. The lane group capacity is the maximum rate of flow for the subjected lane group that may pass through the intersection under prevailing traffic, roadway and signalized conditions; this is in other words termed as saturation flow rate. The evaluation of capacity at signalized intersections is an important component in the planning operation, and design of urban roadway facilities. The headways during saturation flow are directly related to size and position of the vehicle present in the queue. Headway method is most popular method to estimate saturation flows at signalized intersections. In this method for the first vehicle of a queue, its discharge headway was taken to be the time elapse between the start of a green indication and the time at which the rear bumper of the vehicle cleared the stop line of the intersection. For other vehicles in the queue, headways were taken to be the elapsed time, rear bumper to rear bumper, as successive vehicles passed an intersection stop line. So headway values of queued vehicles are directly related to size of the vehicle present in the queue. Furthermore the position of the vehicle in the queue had a significant impact on the saturation headway at signalized intersections.

This study introduces a methodology for estimating the effects of vehicle type on capacity at signalized intersections. Effects of vehicle type are quantified based on the each queue position of vehicle. Concept of estimation of saturation flow rate adjustment factor for taxi (through and right-turn movement) is introduced and adjustment factors are suggested for different proportion of taxi for the capacity analysis at urban signalized intersections.

2. Previous research

In 1994 Highway Capacity Manual the effects of heavy vehicles are treated by an adjustment factor defined as adjustment factor for heavy vehicle (f_{HV}). This adjustment factor only considers the proportion of heavy vehicles, effects of queue position not taken into consideration although it is very important.

$$S = S_i \times f_{HV} \times \ldots \tag{1}$$

Where: S = saturation flow rate under prevailing conditions, (vphg)
S_i = ideal saturation flow rate, (pcphgpl)

Tsao and Chu, (1995) analyzed data from two intersections of Taipei and concluded that average headways of heavy vehicles in through lanes is smaller than that of left-turn lanes. So they suggested that different adjustment factors for heavy vehicles should be used for through and left-turn lanes. Their results also suggested that in mixed traffic, the average headways for passenger cars and heavy vehicles are indifferent to the type of the vehicles immediately ahead.

Kockelman and Shabih, (2000) analyzed data from two intersections in Austin and Texas and concluded that light-duty trucks (LDT) adversely affect the capacity of signalized intersections and different light-duty-truck categories have different impacts on the capacity. Their results also suggested that if the effect of LDTs on the capacity of signalized intersection is not accounted for in design and other calculations, saturation flows computed using current HCM methodology will produce inflated values of intersection capacity which is likely to result in unnecessarily long queues and additional delays.

Zhao, (1998) introduced a new methodology for estimating the effects of heavy vehicles on traffic performance at signalized intersections. Effects of heavy vehicles are quantified on the vehicular delay perspective. Based on the research results the author suggested that delay-based PCE measurement provides better description of the effects of heavy vehicles than headway ratio methods on vehicular delay perspective at signalized intersections.

Rahman et. al, (2003[a]) introduced a new methodology for accounting the effect of large vehicle (vehicles more than four tire) on traffic performance at signalized intersections. Effects of large vehicles are estimated based on the delay caused by large vehicles considering each queue position of vehicle. The authors introduced concept of new PCE estimation method for large vehicles at signalized intersections. Their results suggested that, total delay caused by large vehicles is significant at the beginning of queue; furthermore, for the same percentage of large vehicles if the position of large vehicle in the queue varies, the increased delay caused by large vehicle also varies.

Steuart and Shin, (1978) analyzed data from twelve intersections of Toronto, Canada and concluded that measurement of headways between vehicles being discharged from a queue at signalized urban intersections show vehicle size to have an effect on headways during saturation flow. Their results also suggested that the shortest headways are found when the preceding and following vehicles are both small cars and the difference in headways is most significant for the early vehicles in a discharging queue.

Rahman et. al, (2003[b]) analyzed data from eight signalized intersections of Yokohama city, Japan and concluded that, when a taxi is the leader of a queue its headway is smaller than a passenger car, this is also true for others queue position. They also developed saturation flow rate adjustment factors for taxi drivers and concluded that, when proportion of taxi increased from 0% to 100% for through traffic, saturation flow rate was increased by 20%, so capacity improvement possible at any intersections with higher proportion of taxi. An overall review of the studies suggested that past efforts were fragmented in terms of study methods, location characteristics and technical objectives. However no similar studies have been done to examine the impact of size of vehicles and position of vehicle in the queue on the capacity of signalized intersections simultaneously. This factor should be taken into consideration for design of signal timing of an intersection to alleviate the congestion at intersections.

3. Data collection

Field data were collected at fifteen intersections approaches located in Hodogaya and Minami ward of Yokohama city Japan. Data were also collected at two signalized intersections of Dhaka metropolitan of Bangladesh. Data collected from Japan were used to analyze the effect of large vehicles and taxi on the saturation flow; on the other hand Bangladeshi data used to analyze the effect of small size motorized vehicles (three wheeler auto-rickshaws) on the saturation flow as this type of vehicle is not available in Japan. All locations were carefully selected so that there was no obvious deficiency of roadway or traffic condition that would affect the saturation headway. The following criteria were used in the selection of data collection location: high traffic volume, no parking allowed, level terrain and insignificant disturbance from bus stops.

Data collection at all sites was conducted by portable digital video camera system. Traffic operation was video taped at each location for a minimum time period of two hours. All fields video taping of traffic movements were conducted in August to December of 2002. In all, more than 20 hours of traffic data were recorded on videotapes for this study. All data were recorded during morning and evening peak. Data reduction was conducted at laboratory using time code (TC) reader software, which gives 1/30 second accuracy. During data processing phase the main manipulation was to input each data element by keystroke while the video tapes were played back.

Reduced data contain data items of vehicle count, vehicle classification, headway and so on. The only platoons containing unimpeded, straight-through passenger cars, taxi, large vehicles and three wheeler auto-rickshaws stopped before entering an intersection were considered as valid cases for the study. The entering headway of the first vehicle of a queue was taken to be the time elapse between the start of a green indication and the time at which the rear bumper of the vehicle cleared the stop line of the intersection. Incase of other vehicles in the queue, the entering headways were taken to be the elapsed time, rear bumper to rear bumper, as successive vehicles passed an intersection stop line. From the data reduction phase, a total of 450 cycles were found to be valid for the study.

4. Methodology

The method of determining the effect of vehicle type on the saturation headway was to measure the headways between vehicles of different type (passenger car, taxi, large vehicle and three wheeler auto-rickshaws) in traffic lanes during discharging flow. In order to examine the effect of vehicle type on entering headways, headway of vehicles is classified into four groups as shown in figure 1;

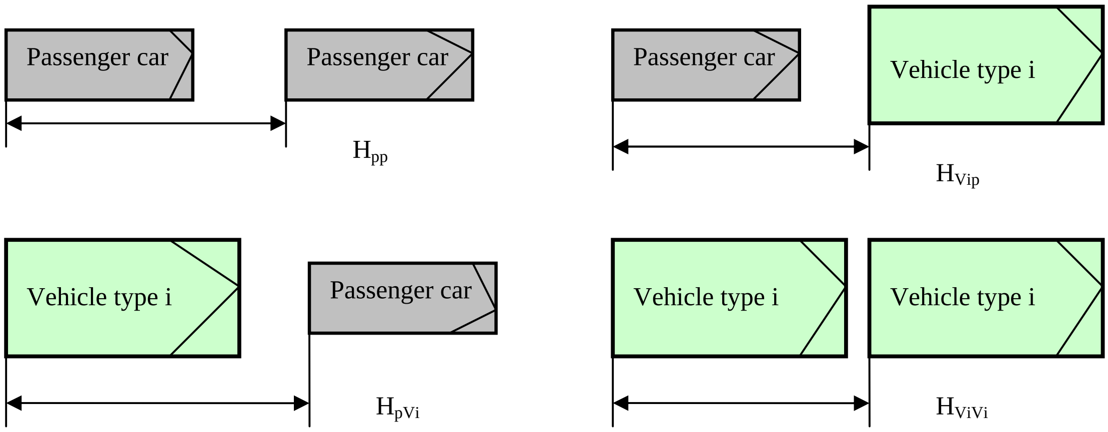

Figure 1: Headway classification of passenger cars and other vehicles

Where;
H_{pp} = headway of a passenger car following a passenger car,
H_{Vip} = headway of a passenger car following vehicle type i,
H_{pVi} = headway of a vehicle type i following a passenger car and
H_{ViVi} = headway of a vehicle type i following a vehicle type i

In this study V1, V2 and V3 are designated as large vehicle, taxi and three wheeler auto-rickshaws respectively. A sample t-test was performed to evaluate the average headway of passenger car and other type of vehicle is not equal when they are the leader of a queue. One way analysis of variance (ANOVA) was performed to evaluate the effect of vehicle type on the saturation headways and finally saturation flow rate adjustment factor was developed by dividing the prevailing saturation flow rate to the ideal saturation flow rate.

5. Effect of vehicle type on saturation headway

The headways during saturation flow are related to the size of vehicles. However, incase of similar size of vehicles the headway values depend on the driving capabilities of driver i.e. driver of passenger car and driver of taxi. The average headway of the first vehicle in the queue is 3.24 seconds for a passenger car, 2.98 seconds for a taxi, 4.14 seconds for a large vehicle and 2.40 for three-wheeler auto-rickshaws respectively. A test of the hypothesis that these mean values of passenger cars and other type of vehicles are equal is not accepted with a sample t-value of 1.66, which establishes, with the large sample size, that the average headways are significantly different. To analyze the effect of vehicle type on headway values a queue length of twelve vehicles considered. The queues were separated in four groups according to the type of vehicles i.e. queue containing passenger cars, taxi, large vehicles or three wheeler auto-rickshaws stopped before entering an intersection for this comparison. The effects of vehicle type on entering headways are shown in figure 2.

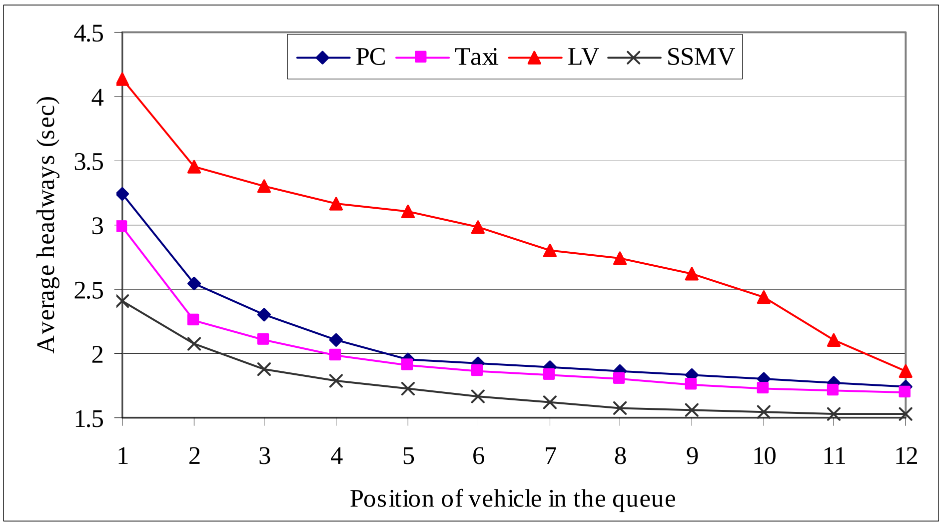

Figure 2: Effect of vehicle type on entering headway

As shown in figure 2, vehicle type has a significant effect on headway values. Maximum headways resulted when all the vehicle of a queue is large vehicle and minimum headways resulted when all the vehicle of a queue is three wheeler auto-rickshaws. This is obvious because the headways value of queued vehicles depends on the size i.e. type of vehicle. But incase of passenger cars and taxi the size of vehicle is similar only difference is the driving capabilities. It was revealed from the figure 2 that headway values of passenger cars are higher than that of taxi and this is true for all queue positions. So during design of signal timing this factor should be considered.

Table 1 summarizes the average headway data according to position in queue for large vehicle and passenger car. For this study large vehicle defines as those vehicles which have more than four tires. As shown in table 1, the headways of passenger cars following passenger cars are small for all the queue positions. A passenger car when following a large vehicle, the headway value is different from that when a passenger car follow a passenger car and this headway value is greater for all queue position. From the observed data (video tape) it was evidenced that when a passenger car follow another passenger car the distance between two vehicles is smaller than the distance of two vehicles when a passenger car follow a large vehicle, which resulted larger headway value. This seems to occur to us for two reasons: firstly the length, height and width of large vehicles are greater which have a physical impact of the following passenger car and a psychological impact on the drivers of the following passenger car; secondly larger vehicles have operating capabilities that are inferior to those of passenger cars, Krammes (1986).

When a large vehicle following a passenger car its headway value is more than that of above mentioned two types of headway as the length of the large vehicle is more. When a large vehicle following a large vehicle that produced the biggest headway value. This effect is most significant for the vehicles at the beginning of the queue. The general relationship among these four types of headways for all queue positions is as follows;

$$H_{pp} < H_{V1p} < H_{pV1} < H_{V1V1} \qquad (1)$$

Table 1: Headway of passenger cars and large vehicles classified by position of vehicle

	H_{pp} (sec)	H_{V1p} (sec)	H_{pV1} (sec)	H_{V1V1} (sec)
Queue position 2	2.37	2.46	2.92	3.45
Sample size	210	75	57	40
Variance	0.17	0.23	0.36	0.32
Queue position 3	2.13	2.28	2.66	3.30
Sample size	178	65	66	27
Variance	0.15	0.20	0.27	0.23
Queue position 4	1.98	2.03	2.54	3.17
Sample size	154	76	54	42
Variance	0.11	0.17	0.29	0.27
Queue position 5	1.91	1.94	2.33	3.11
Sample size	137	63	77	51
Variance	0.09	0.08	0.23	0.28
Queue position 6	1.90	1.91	2.25	2.98
Sample size	124	70	71	36
Variance	0.13	0.09	0.14	0.19
Queue position 7	1.87	1.89	2.14	2.81
Sample size	113	54	73	51
Variance	0.08	0.06	0.08	0.16
Queue position 8	1.83	1.84	2.11	2.74
Sample size	110	61	67	44
Variance	0.07	0.08	0.10	0.21
Queue position 9	1.80	1.81	2.06	2.62
Sample size	96	63	70	41
Variance	0.10	0.04	0.03	0.18
Queue position 10	1.76	1.72	1.96	2.44
Sample size	78	52	60	47
Variance	0.21	0.04	0.08	0.15

The headway value of H_{V1V1} is more than 40% of headway of H_{pp} for all the queue position. In HCM to account the effects of heavy vehicles in the flow only the percentage of heavy vehicle is considered, queue position of vehicle is not taken into consideration. Let us consider the following example: length of the queue is 10 vehicles, with 50% of large vehicles, for case I (first 5 vehicles are large vehicle) and for case II (last five vehicles are large vehicles). The assumption is that the other factors remain the same. This example is shown in figure 3. From 1994 HCM chapter-9 and table 9.6, adjustment factor for 50% heavy vehicle is 0.667, after applying the adjustment factor for heavy vehicle the corrected saturation flow is 1173 (pphpl) and 975 (pphpl) respectively and capacity difference is as high as 16%. So to count the effects of large vehicle properly it is necessary to consider the queue position of large vehicle in addition of the percentage of large vehicles to develop adjustment factor for heavy vehicles in HCM.

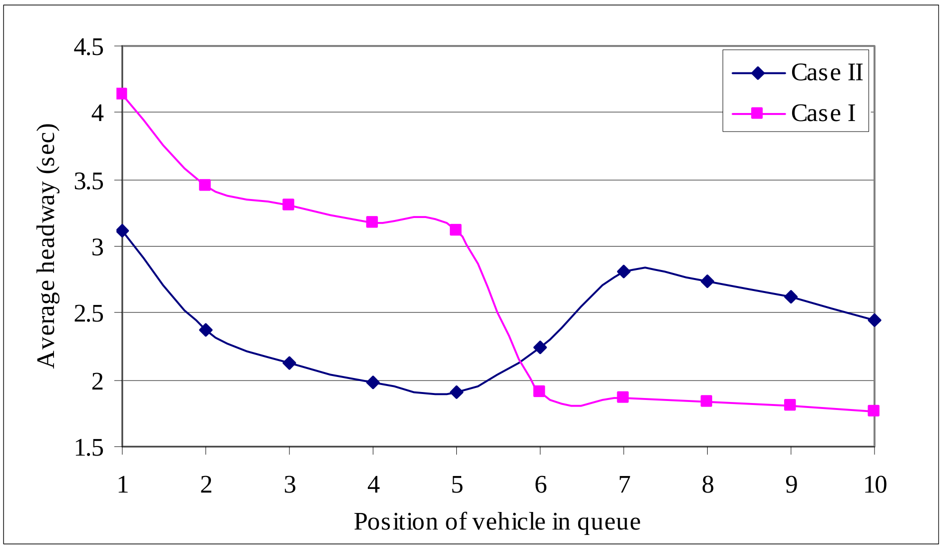

Figure 3: Effect of large vehicle on headway for different queue position

It was evidenced from figure 2 that presence of taxi in the queue had a significant impact on the headway values. One way analysis of variance (ANOVA) was performed to examine whether the impact of taxi on capacity parameters was significant. In order to perform the ANOVA, proportion of taxi were divided into various groups. The hypothesis H_0 of the ANOVA was that the capacity parameter in all the taxi proportions was equal. The results of the ANOVAs for through traffic and right-turn traffic are presented in Table 2. The results indicate that impact of the taxi on the saturation headway was statistically significant at 95% level of significance. Higher proportion of taxi decreased the saturation headway, which means that presence of taxi increased the capacity of signalized intersections. Taxi drivers are professional and they can drive efficiently and safely than ordinary drivers, which resulting the decrease of the headway value.

Table 2: ANOVA results for saturation headway at different proportion of taxi

Capacity parameter	F	$F_{critical}$	H_o
Saturation headway (Through traffic)	17.98	2.35	rejected
Saturation headway (Right-turn traffic)	21.33	2.35	rejected

As discussed in the previous section, presence of taxi in the queued vehicles had significant impact on the entering headway values. When a taxi is the leader of a queue, its headway is smaller than a passenger car. It is also true for other position in the queue. Figure 4; presented the relationship between average headway at different queue position and percentage of taxi. As shown in figure 4; headway value of queued vehicles decreases as proportion of taxi increases.

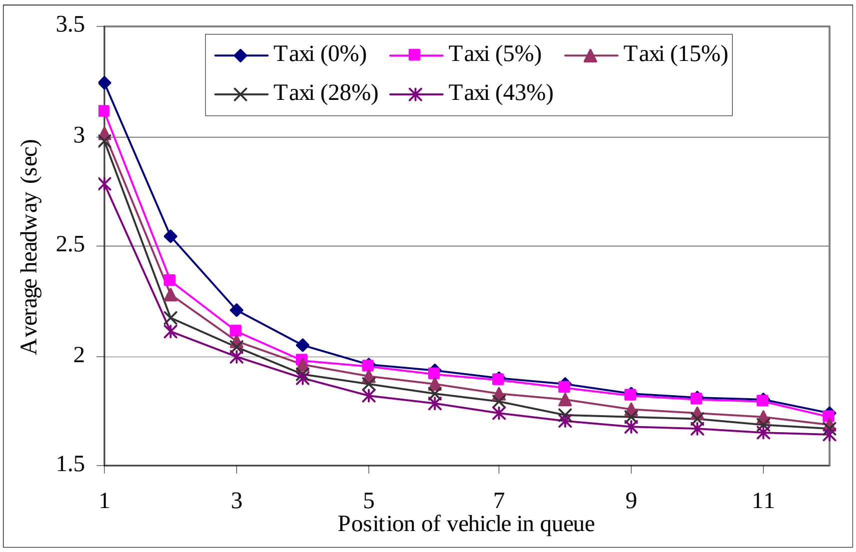

Figure 4: Effect of taxi on entering headway

The headway of vehicles after the queue leader is dependent on the size of the preceding vehicle. Table 3 summarizes the headway values according to the position in queue for auto-rickshaws and passenger cars using the rear bumper to rear bumper definition of headways. Vehicles at the beginning of queue show a significant smaller headway between two auto-rickshaws (small size motorized vehicles) than between two passenger cars. The results indicate that position in the queue has a lesser effect on small size cars than on other vehicle combinations. The average headway in a mixed stream of auto-rickshaws and passenger cars has values consistent with the following observations. The average headway of a passenger car when following a large vehicle is significantly more than the average headway of a passenger car when following a auto-rickshaws (small size motorized vehicle), and at the beginning of the queue this value is more than 10%. The observed data show that when both leader and following cars are auto-rickshaws the average headway is approximately 12% less than when both cars are passenger car. This seems to occur to us for two reasons; firstly the vehicles follow small size motorized vehicles more closely and secondly small size motorized vehicles follow other vehicles more closely. The significant difference between average headways for a pair of passenger cars and a pair of small size motorized vehicles in the queue suggested that capacity improvements are possible with small size motorized vehicles.

One-way analysis of variance (ANOVA) was performed to examine whether the impact of vehicle type (passenger car, large vehicle, taxi and small size motorized vehicle) on entering headway was significant. In order to perform the ANOVA, average headways of passenger car, taxi, large vehicle and small size motorized vehicles are classified separately up to ten queue positions. The principal of an ANOVA table is to compare the F value and $F_{critical}$ value at a given confidence level. The hypothesis H_o of the ANOVA was the average headway of different type of vehicles was equal. The results of the ANOVA for vehicle type are presented in Table 4.

Table 3: Headway of passenger cars and auto-rickshaws classified by position of vehicle

	H_{V3V3} (sec)	H_{pV3} (sec)	H_{V3p} (sec)	H_{pp} (sec)
Queue position 2	2.07	2.18	2.26	2.37
Sample variance	0.08	0.12	0.21	0.17
Sample size	45	39	25	210
Queue position 3	1.88	1.91	2.08	2.13
Sample variance	0.11	0.14	0.18	0.15
Sample size	34	31	21	178
Queue position 4	1.78	1.87	1.96	1.98
Sample variance	0.06	0.11	0.13	0.11
Sample size	51	29	19	154
Queue position 5	1.72	1.81	1.88	1.91
Sample variance	0.11	0.09	0.12	0.09
Sample size	37	26	16	137
Queue position 6	1.66	1.77	1.86	1.90
Sample variance	0.04	0.16	0.23	0.13
Sample size	41	22	14	124
Queue position 7-10	1.61	1.72	1.82	1.85
Sample variance	0.11	0.13	0.22	0.23
Sample size	72	44	32	218
Queue position > 10	1.57	1.68	1.76	1.79
Sample variance	0.16	0.17	0.16	0.16
Sample size	56	38	42	178

Table 4: ANOVA results of headways for different vehicle type

Capacity parameter	F	$F_{critical}$	H_o
Entering headway	1001	2.62	Rejected

The results indicate that impact of the vehicle type on the entering headway was statistically significant at 95% level of significance.

6. Saturation flow rate adjustment factors of taxi

Saturation flow rate is the reciprocal of the saturation headway. In the HCM, saturation headway is estimated by averaging the discharging headway from the fifth queued vehicle to the last queued vehicle. In order to make the research findings compatible with the HCM, saturation headway is calculated according to the HCM procedure. Saturation headways of through and right-turn traffic are estimated from the observed data for different proportion of taxi. A linear regression model was developed to establish the relationship between saturation headway and proportion of taxi and later, saturation headways for different proportion of taxi were calculated from the regression model. Rahman et.al. (2003[b]) described the detailed of this procedure.

In the HCM, adjustment factors are developed by dividing the prevailing saturation flow rate by the ideal saturation flow rate. Thus, saturation flow rate adjustment factor for taxi f_{taxi} were estimated as follows:

$$f_{taxi} = \frac{S_{taxi}}{S_{pc}} = \frac{h_{pc(0\%taxi)}}{h_{taxi}} \tag{2}$$

Where:

f_{taxi} = saturation flow rate adjustment factors for taxi
S_{taxi} = saturation flow rate with a given proportion of taxi
S_{pc} = saturation flow rate of passenger car (0% taxi)
h_{pc} = saturation headway of passenger car (0% taxi)
h_{taxi} = saturation headway with a given proportion of taxi

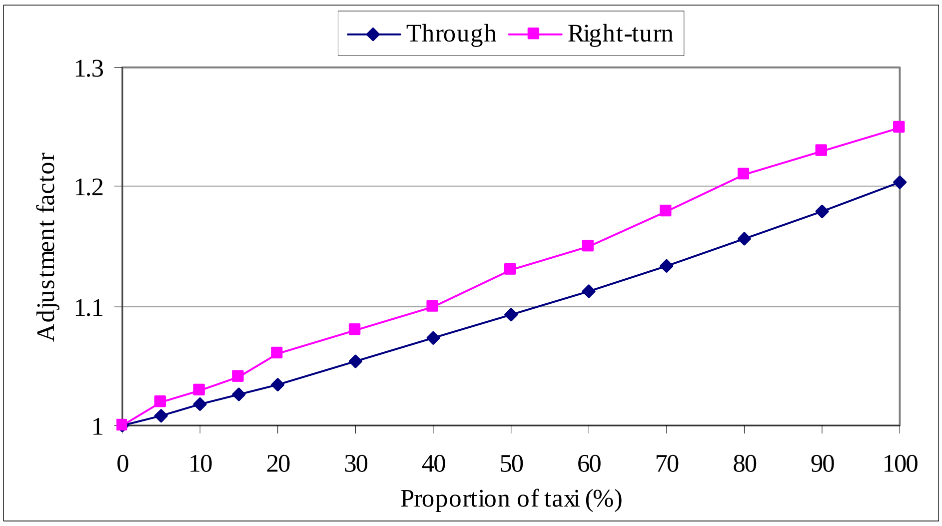

Figure 5: Saturation flow rate adjustment factors for taxi

Saturation flow rate adjustment factors for taxi (through and right-turn movement) were calculated and presented in Figure 5. As shown in figure 5, adjustment factors of taxi increases with increases of proportion of taxi for both right-turn and through movements. Since saturation flow rate was proportional to the capacity at signalized intersections, the capacity of intersection would be increased by 20% (for through movement) and 25% (for right-turn movement) respectively when proportion of taxi increased from 0 to 100 percent. The adjustment factor for taxi (f_{taxi}) given in figure 5 could be used with other adjustment factors in the HCM to perform capacity analysis of signalized intersections with higher proportion of taxi.

7. Conclusions

The average headways between vehicles being discharged from a queue at signalized intersections show that vehicle type to have a significant impact on headway values. The smallest headways are observed when the leader and following vehicles both small size motorized vehicles and the biggest headways are found when the preceding and following vehicles are both large vehicles. It is demonstrated from this study that vehicles follow small size motorized vehicles more closely and on the other hand vehicles follow large vehicles with a substantial distance due to psychological factors. It is suggested by this study that to count the effects of large vehicles properly it is required to consider the queue position of large vehicle in addition of percentage of large vehicles as saturation flow rate varies significantly due to position of large vehicles for same percentage of large vehicles.

It is evidenced from this study that average headway values of passenger car and taxi varies significantly at each queue position, although length of the taxi and passenger cars are equal.

When a signalized intersection was identified with higher proportion of taxi, the saturation flow rate as well as the capacity could be increased by 20 percent for through movement and 25 percent for right-turn movement, which corresponded to an adjustment factor as high as 1.20 and 1.25 respectively based on the observed data. Results summarized in this study may help traffic engineers to perform capacity analysis of signalized intersections more efficiently and effectively.

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