23rd ARRB Conference – Research Partnering with Practitioners, Adelaide Australia, 2008

EFFECT OF MOTORCYCLES TRAVEL BEHAVIOUR ON SATURATION FLOW RATES AT SIGNALIZED INTERSECTIONS IN MALAYSIA

Leong Lee Vien, Universiti Sains Malaysia, Malaysia

Wan Hashim Wan Ibrahim, Universiti Sarawak Malaysia, Malaysia

Ahmad Farhan Mohd, Universiti Sains, Malaysia

ABSTRACT

Mixed traffic flow with high composition of motorcycles is a common situation in most Asian countries such as Taiwan, Thailand, Vietnam and Malaysia. To date, there are approximately 7.5 million of registered motorcycles in Malaysia and motorcycle ownership in Malaysia has increased from 0.13 in year 1990 to 0.28 motorcycles per person in year 2006. Observation in the field indicates that motorcycles can traverse through signalised intersections in certain distinctive ways as compared to other motorised vehicles. In this study, motorcyclists' travelling through an intersection was divided into those within the flow and those outside the flow. Motorcycles within the flow follow a first-in-first-out rule, implying that they travel either in front of or behind other vehicles in the traffic stream. Motorcycles outside the flow are those that do not follow the first-in-first-out rule. This study attempts to investigate the effect of these motorcycles travel behaviour on saturation flow rates at signalized intersections. The results showed that motorcycles inside flow should be considered in the estimation of saturation flow rates.

INTRODUCTION

Mixed traffic situation with high composition of motorcycles is common in most Asian countries such as Taiwan, Thailand, Vietnam and Malaysia. A study in Vietnam (Nobuyuki et al., 2005) found that the proportion of motorcycles in Hanoi and Ho Chi Minh city is around 90% while in Korea, authorities have even prepared a special area for motorcycles in front of the signalized intersection stop line to accommodate the high number of motorcycles on the roads. In Taiwan, segregated traffic flow concept was promoted and successfully implemented to improve the performance of traffic situation mixed with motorcycles. Segregation in Taiwan is in the form of two-stage left-turn regulation for left-turn motorcycles and the head start holding zone for motorcycles.

Significant work has been done to understand the effects of mixed traffic composition on the capacity of signalised intersections, but only limited research has taken into consideration the effects of motorcycles: Cuddon and Odgen (1992) have grouped motorcycles travelling within a lane (not between lanes) with passenger cars while Stokes (1989) has indicated that motorcycles and bicycles have very little effect on saturation flow. Branston and van Zuylen (1978) however, suggested that unless the proportion of motorcycles or bicycles in the traffic stream is greater than about 20%, they have very little effect on saturation flow and can be ignored for practical purposes. Hence, in Malaysia, the influence of motorcycles should not be disregarded, traffic volume of motorcycles recorded in major cities or towns throughout Malaysia are very high and the percentage of motorcycles registered annually is approximately 41% (Highway Planning Unit, 2005). Table 1 shows the number of new registration of vehicles in Malaysia from year 1996 to 2005.

Table 1: New registered vehicles by type in Malaysia (1996-2005)

Year	Motorcycle	Motorcar	Bus	Taxi	Hire & Drive Car	Goods Vehicle	Others	Total
1996	322,145	318,765	2,620	4,358	2,545	69,234	30,844	750,511
1997	364,214	372,343	2,947	5,257	1,860	65,160	28,396	840,177
1998	237,776	159,642	797	3,569	552	11,786	6,342	420,464
1999	236,779	296,716	508	1,925	1,724	19,987	8,102	565,741
2000	238,695	344,847	544	2,635	2,883	24,316	11,949	625,869
2001	234,751	395,891	652	3,169	1,348	25,612	13,866	675,289
2002	222,685	419,713	919	4,446	1,242	25,415	16,768	691,188
2003	321,234	424,753	1,014	5,542	1,231	29,975	17,041	800,790
2004	397,977	472,116	1,290	7,746	1,797	33,169	18,268	932,363
2005	422,255	537,900	1,568	5,002	3,411	33,532	16,440	1,020,108

Source: Highway Planning Unit (2005)

It can be clearly seen from Table 1 that motorcycle users in Malaysia are the two largest groups of road users along with car users. In years 1996 and 1998, the newly registered motorcycles even surpass the number of registered cars. There are several reasons why motorcycle is a favourite model choice. One reason is its size that makes it easier to manoeuvre in traffic compared to passenger cars. This could help lessen the travel time between two places especially during traffic congestion. A motorcycle is also relatively inexpensive and is economical in terms of fuel consumption and maintenance, making it affordable to people from the lower income group.

In Malaysia, the most common type of motorcycles on the road is of the small engine type (below 250c.c.). The dimensions for a typical motorcycle found in Malaysia as compared to a typical passenger car are as shown in Figure 1.

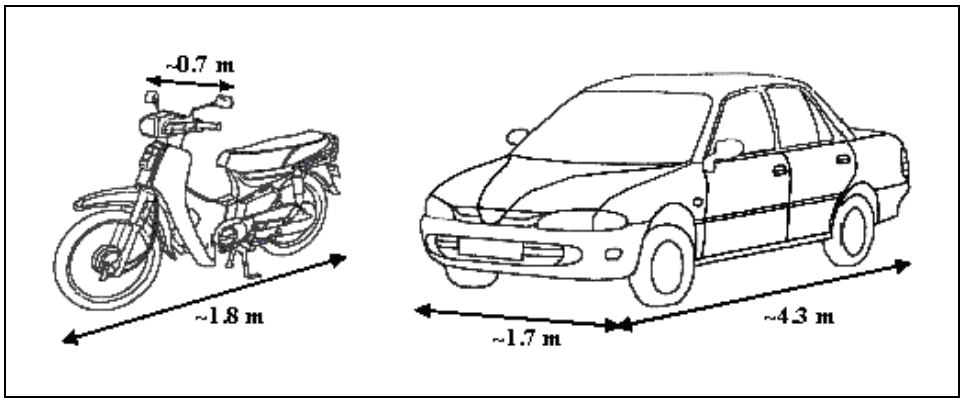

Figure 1: Typical motorcycle and passenger car physical dimensions

Due to its high manoeuvrability, motorcyclists can travel through to a signalised intersection in certain distinctive manner and will often have advantage over other queuing vehicles (Ministry of Works Malaysia, 2006). Typical movements are as follows:

1. Motorcyclists often use the lateral gaps between larger vehicles to weave in and out of a traffic stream to reach the front of the queue during red interval. When the volume of motorcycles is high, motorcyclists will form a group in front of the stop line. They are labelled as “motorcycles in front of stop line”.
2. Most of the approach lanes at signalised intersections in Malaysia are wide enough for motorcyclists to make their way to the intersections along the side of other vehicles within the same traffic lane. They are known as “motorcycles beside other vehicles”.

3. Motorcycles travelling in front of or following other vehicles in a structured discipline.

The above-mentioned travel behaviours of motorcyclists are illustrated in Figure2.

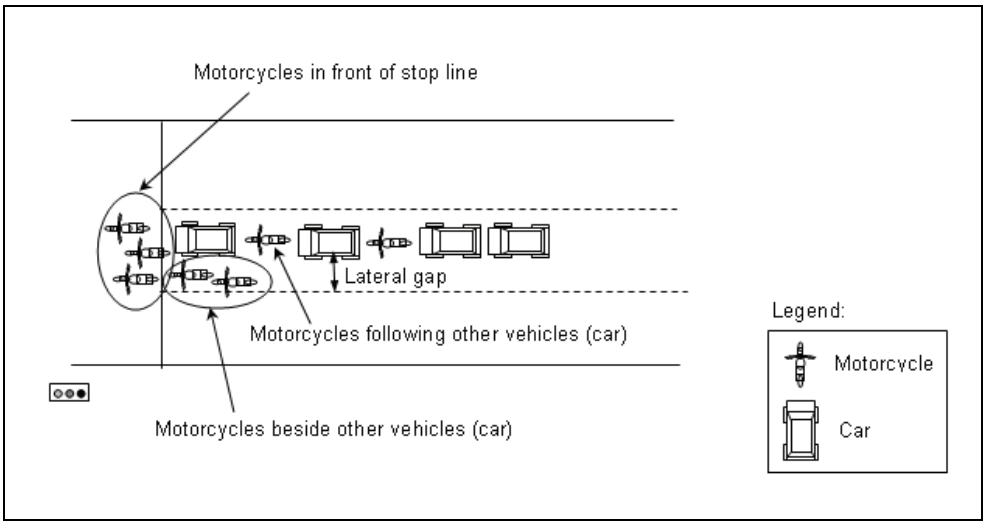

Figure 2: Motorcyclists travel behaviour at signalised intersection

For purpose of analysis, motorcyclists' behaviour at intersection can be regrouped into two categories namely motorcycles outside flow and motorcycles within flow. Motorcycles outside flow are motorcycles that do not follow the first-in-first-out rule. This category consists of "motorcycles in front of stop line" and "motorcycles beside other vehicles". Motorcycles inside flow are motorcycles that follow the first-in-first-out rule implying that they either travel in front of or behind other vehicles within a traffic stream. Both categories will affect the value of saturation flow and consecutively affects the capacity of the road (Ministry of Works Malaysia, 2006). Figure 3 shows the distribution of motorcycles inside flow and motorcycles outside flow that are common in Malaysia.

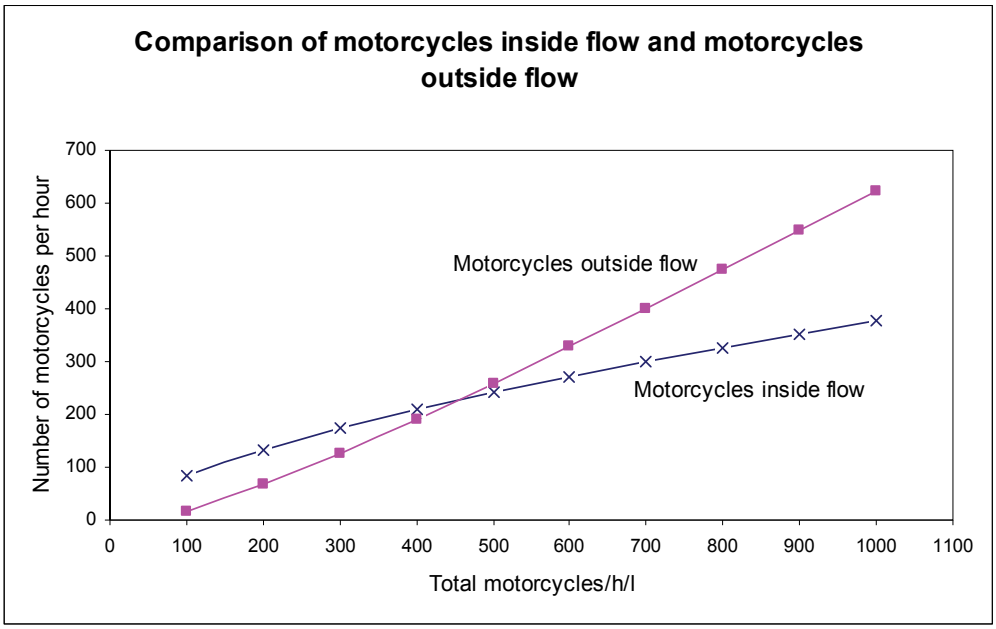

Figure 3: Distribution of motorcycles inside flow and motorcycles outside flow in Malaysia (Ministry of Works Malaysia, 2006)

Even though Malaysia clearly has a higher percentage of motorcycles as compared to other western countries, treatment of motorcycles in Malaysia is rather simplistic such that effective estimation of capacity may not be carried out. Improper treatment of motorcycles on the road

especially at signalised intersections will not only lower the level of service of the junction but may also lead to the increase in road traffic accidents. Therefore, this study attempts to investigate the effect of these motorcycles travel behaviour on saturation flow rates at signalized intersections.

STUDY APPROACH

Significant work has been done to understand the effects of mixed traffic composition on the capacity of signalised intersections, but only limited research has taken into consideration the inclusion of motorcycles in the analysis and design of signalised intersections. In order to investigate the behaviour of motorcycles travelling through signalised intersections on saturation flow, two types of data were collected.

Initially, headway data of vehicles travelling through signalized intersections were collected using the audio recording method. The vehicle types distinguished in this study are in accordance with the Malaysia Highway Capacity Manual 2006 (Ministry of Works Malaysia, 2006), they are as follows:

Class 1: Passenger cars including taxis, small vans and utilities

Class 2: Lorries with 2 axles and mini buses

Class 3: Trailers with more than 2 axles

Class 4: Buses

Class 5: Motorcycles

Saturation flow rates in the unit of vehicles per hour were then computed based on the method described in the Road Research Laboratory Road Note 34/196 (1963). In the method, vehicle discharge pattern are observed and they are used to obtain the number of vehicles discharging from a queue in successive 6 seconds intervals throughout the saturated green period. Therefore, due to this reason, only vehicles that follow the first-in-first-out rule were considered in the computation of saturation flow. This also implies that only motorcycles inside flow were considered in the saturation flow analysis. The flow for each saturated interval except the first and last interval will then be averaged and the saturation flow will be calculated. This will be the observed saturation flow rate.

Apart from vehicles headway data, data of motorcyclists travel behaviour at signalised intersections were also collected at the same time. Motorcycles were segregated into three categories:

- Motorcycles that stopped in front of the stop line.
- Motorcycles travelling along side other vehicles.
- Motorcycles following other vehicles in a structured manner or motorcycles within flow.

Upon obtaining the total motorcycles' volume (veh/h), saturation flow rates were then computed based on the method in Malaysia Highway Capacity Manual 2006 (Ministry of Works Malaysia, 2006). The equations used to estimate saturation flow rates for straight through traffic are as follows:

$$S = S_0 \times f_w \times f_g \times f_a \times (1/f_c) \quad (1)$$

Descriptions of the parameters in equation (1) are as shown in Table 2. Saturation flow rates estimated using this method are based on road traffic volume and in this case, total motorcycles were used because practically, motorcycles are not distinctly segregated to motorcycles inside flow and motorcycles outside flow.

Table 2: Parameters used in the estimation of saturation flow (Ministry of Works Malaysia, 2006)

Parameters		Descriptions
PCE values	Passenger car, e_{car}	1.00
	Motorcycle, e_{motor}	0.22
	Lorry, e_{lorry}	1.19
	Trailer, $e_{trailer}$	2.27
	Bus, e_{bus}	2.08
Ideal saturation flow rate, S_0		S_0 = 1,930 pcu/hr
Area type adjustment factor, f_a		f_a = 0.8454
Lane width adjustment factor, f_w		$f_w = 1 + \frac{w - 3.66}{3.663}$
Gradient adjustment factor, f_g	Downhill	$f_g = 1 - \frac{\%G}{26.34}$
	Uphill	$f_g = 1 - \frac{\%G}{14.39}$

and

f_c = Vehicle composition correction factor ($f_{car} + f_{HV} + f_m$)

$$f_{car} = e_{car}\left(\frac{q_{car}}{Q}\right) \quad (2)$$

$$f_{hv} = e_{trailer}\left(\frac{q_{trailer}}{Q}\right) + e_{lorry}\left(\frac{q_{lorry}}{Q}\right) + e_{bus}\left(\frac{q_{bus}}{Q}\right) \quad (3)$$

$$f_m = e_{motor}\left(\frac{M_T}{Q}\right) \quad (4)$$

where

q_{car} = Traffic flow of car (veh/h)

$q_{trailer}$ = Traffic flow of trailer (veh/h)

q_{lorry} = Traffic flow of lorry (veh/h)

q_{bus} = Traffic flow of bus (veh/h)

M_T = Traffic flow of total motorcycles (veh/h)

and

Q = Total flow (veh/h) = $q_{car} + q_{HV} + M_T$

The observed saturation flow rates which only take into consideration motorcycles inside flow were then compared with the estimated saturation flow rates based on motorcycles volume on the road.

DATA COLLECTION

Vehicles headway data and motorcyclists travel behaviour data were collected simultaneously using the audio recording method during peak periods (morning peak: 7.30 – 9.30 am, afternoon peak: 12.00 – 2.00 pm or evening peak: 4.30 – 6.30 pm) on weekdays when traffic flows at the intersections are typical and saturated. In this study, data were collected at 47 through traffic approach lanes with protected phasing, no side parking and no bus blockage at various signalised intersections throughout Malaysia. On the average, at any one single lane, data were collected for 30 signal cycles.

RESULTS AND DISCUSSIONS

Upon data reduction, the distribution of motorcycles in front of stop line, beside other vehicles and inside flow are as shown in Figure 4.

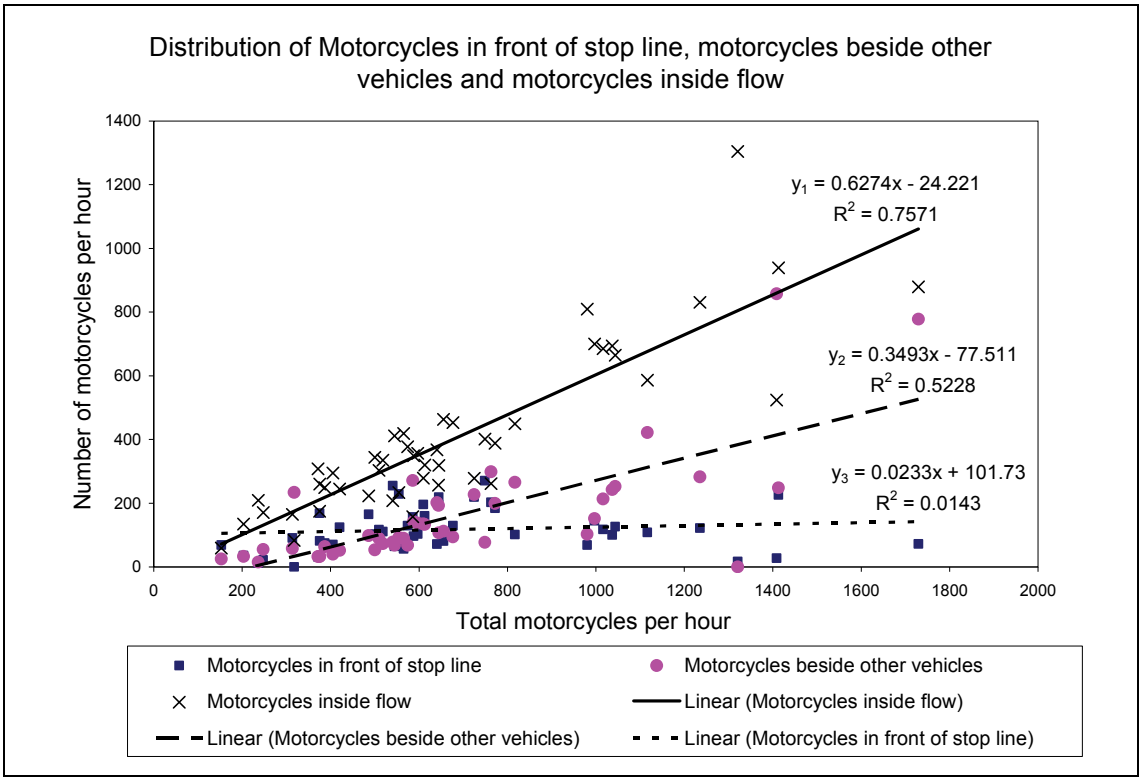

Figure 4: Distribution of motorcycles in front of stop line, motorcycles beside other vehicles and motorcycles inside flow

Based on Figure 4, it can be shown that for motorcycles outside flow, the number of motorcyclists travelling along the side of other vehicles is higher than the number of motorcycles that stop in front of the stop line. This may be due to the limited space available at the front of the stop line as some signalised intersections have pedestrian crossings. Apart from that, the high number of motorcycles beside other vehicles indicates that most of the lateral gaps between vehicles are occupied by motorcycles. This will disrupt the traffic flow as some larger vehicles have to make a slight manoeuvre to the side to avoid collision with the motorcycles.

On the average, there are 41.4% of motorcycles outside flow with 19.8% of motorcycles in the "motorcycles in front of stop line" category and 21.6% in the "motorcycles beside other vehicles" category and there are 58.6% of motorcycles inside flow. This indicates that from the total volume of motorcycles travelling through a signalised intersection, almost half of them are in the "motorcycles outside flow" category. The regression equations shown in Figure 4 can also be used to estimate the volume of motorcycles per hour. The regression equations are as follows:

- $y_1 = 0.6274x – 24.221$ (5)
- $y_2 = 0.3493x – 77.511$ (6)
- $y_3 = 0.0233x + 101.73$ (7)

where

y_1 = Motorcycles inside flow per hour

y_2 = Motorcycles beside other vehicles per hour

y_3 = Motorcycles in front of stop line per hour

x = Total motorcycles per hour

Subsequently, in order to determine the effect of motorcyclists travel behaviour on saturation flow rates in vehicles per hour, observed saturation flow rates which only take into consideration motorcycles inside flow and the estimated saturation flow rates based on motorcycles volume on the road were compared. The result is as shown in Figure 5.

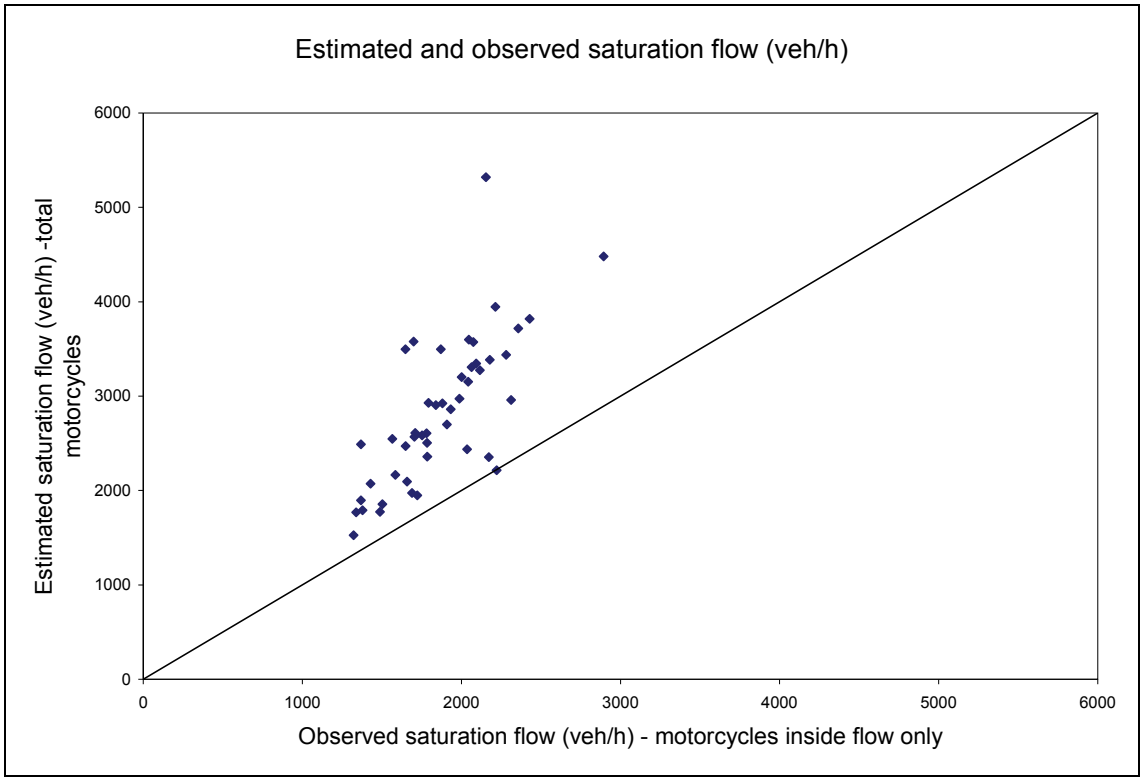

Figure 5: Observed and predicted saturation flow rates

Referring to Figure 5, it can be seen that the estimated saturation flow rates based on total motorcycles volume are higher than the observed saturation flow rates that only takes into consideration motorcycles inside flow. Percentage of differences between estimated and observed saturation flow rates for 47 approach lanes are summarized in Figure 6.

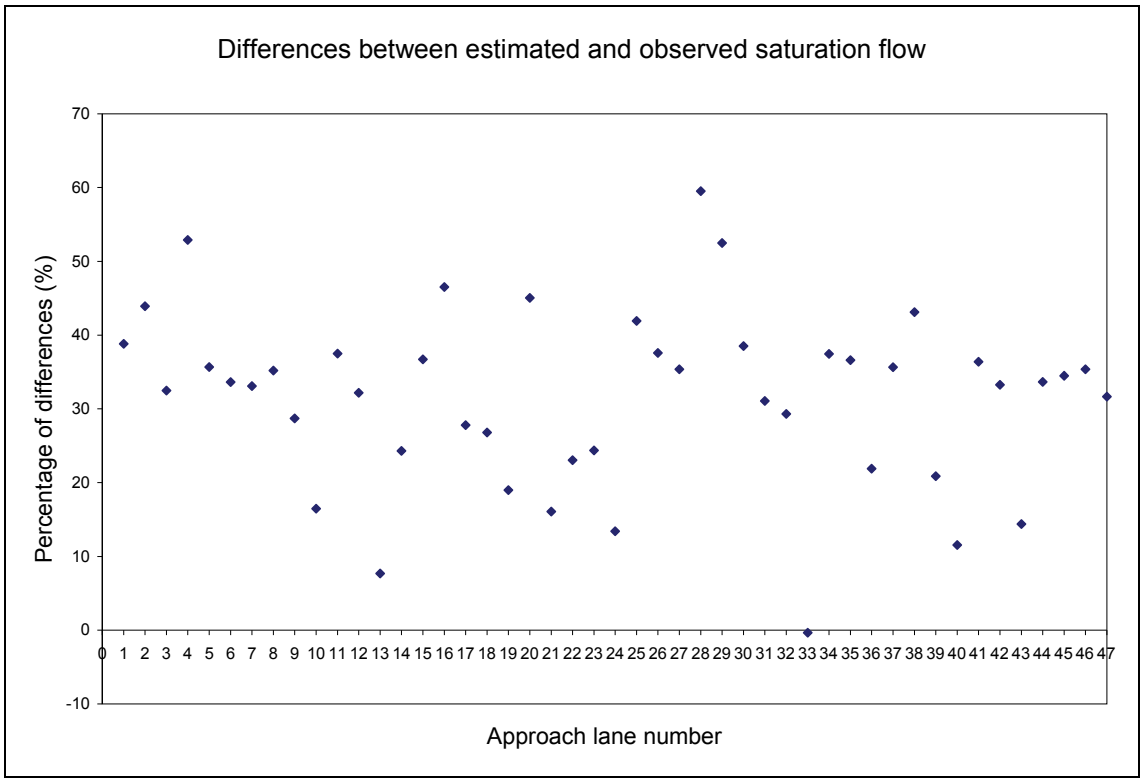

Figure 6: Differences between estimated and observed saturation flow rates

Based on Figure 6, the highest percentage of differences between estimated and observed saturation flow rates computed is 59.5% while the lowest is -0.4%. Therefore, in order to analyse the effects of motorcycles travel behaviour on saturation flow rates, a graph as shown in Figure 7 was plotted.

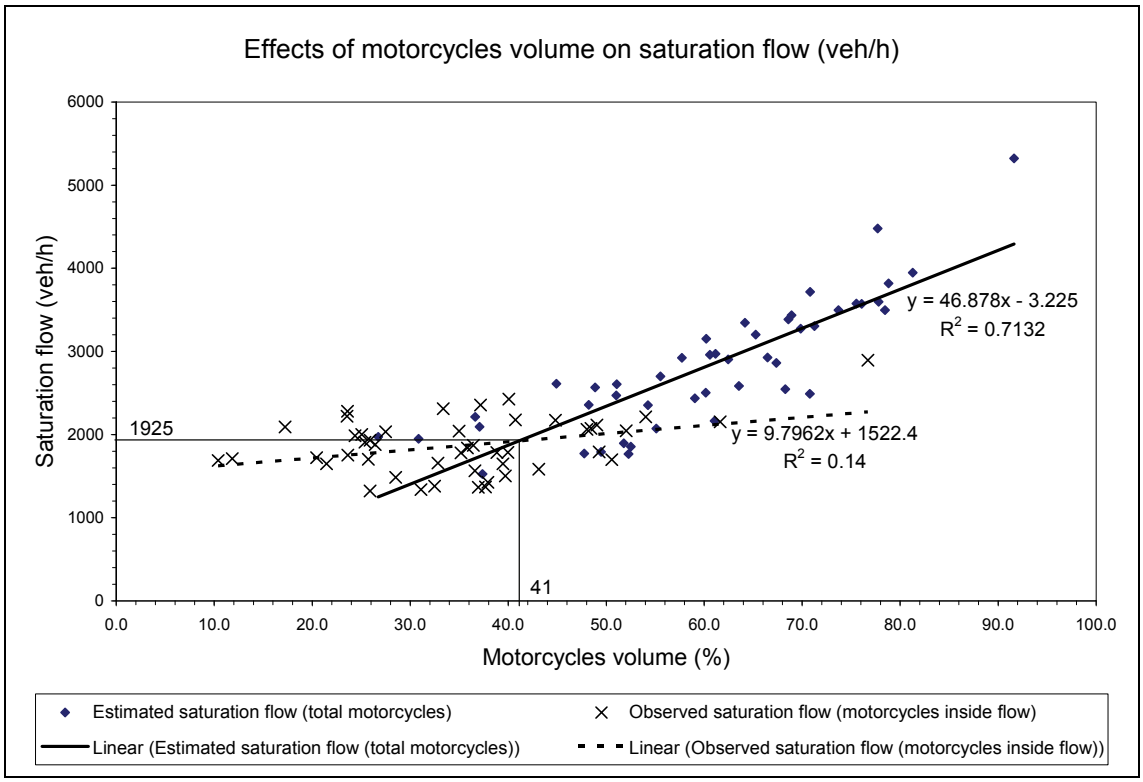

Figure 7: Effects of motorcycles travel behaviour on saturation flow rates

In Figure 7, two trendlines that represent the estimated saturation flow and observed saturation flow are added to the graph. It can be seen that, when the percentage of total motorcycles and motorcycles inside flow are approximately 41%, both the estimated and observed saturation flow values are the same. However, if the percentage of motorcycles is less than 41%, the observed saturation flow is higher than the estimated saturation flow and vice versa when the percentage of motorcycles is more than 41%. This shows that when the motorcycles volume is less than 41%, under-estimation of saturation flow rates will be likely to occur. Therefore, Figure 8 was plotted in order to examine the differences of saturation flow rates estimated based on the volume of motorcycles inside flow with observed saturation flow rates. Based on Figure 8, the estimated saturation flow rates based on motorcycles inside flow are higher than the observed saturation flow rates. The differences are more significant as the volume of motorcycles increased.

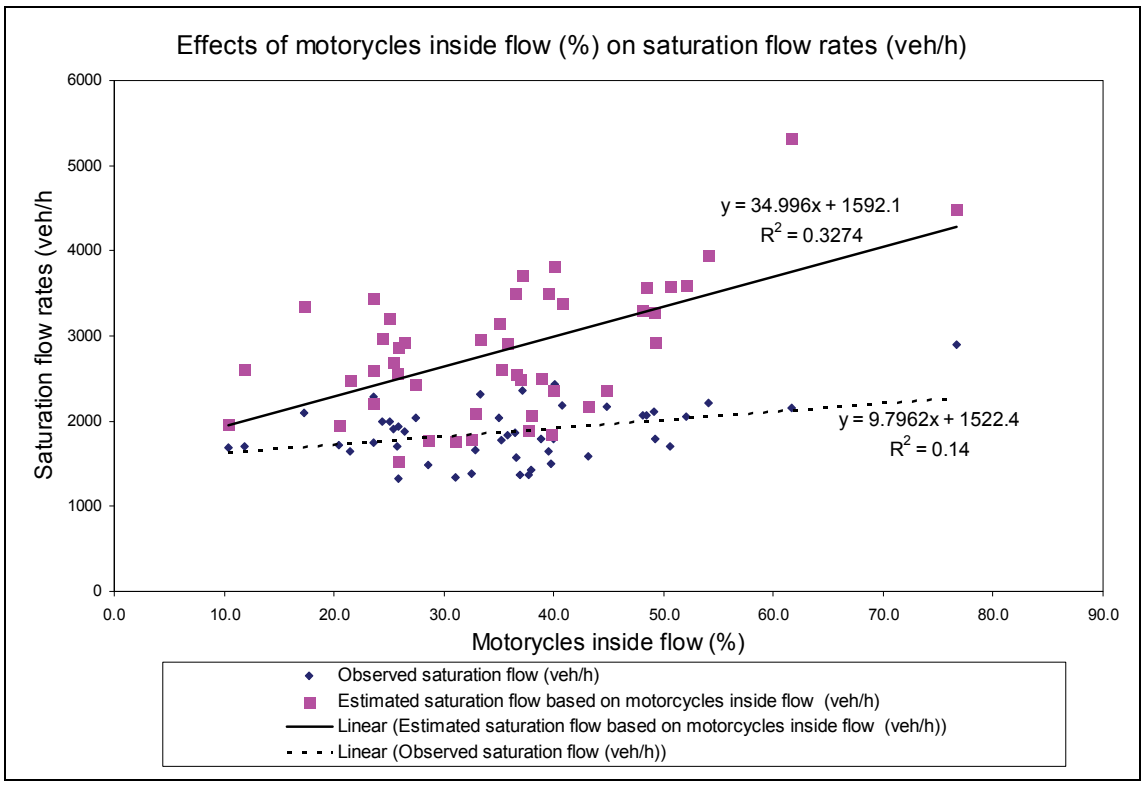

Figure 8: Effects of motorcycles inside flow on saturation flow rates

Figure 9 shows the effects of motorcycle travelling pattern on the estimation of saturation flow rates. Referring to Figure 9, it can be seen that the estimated saturation flow rates based on total motorcycles are higher than the saturation flow rates estimated using only motorcycles inside flow. Nevertheless, the points are scattered close to each other, implying that the differences in the values obtained are not large. The highest percentage of differences between estimated and observed saturation flow rates computed is 33.3% while the lowest is 0.5%.

Therefore, it is recommended to use the volume motorcycles inside flow instead of total motorcycles in the estimation of saturation flow rates. Equation 5 can be used to estimate the volume of motorcycles inside flow per hour based on total motorcycles observed.

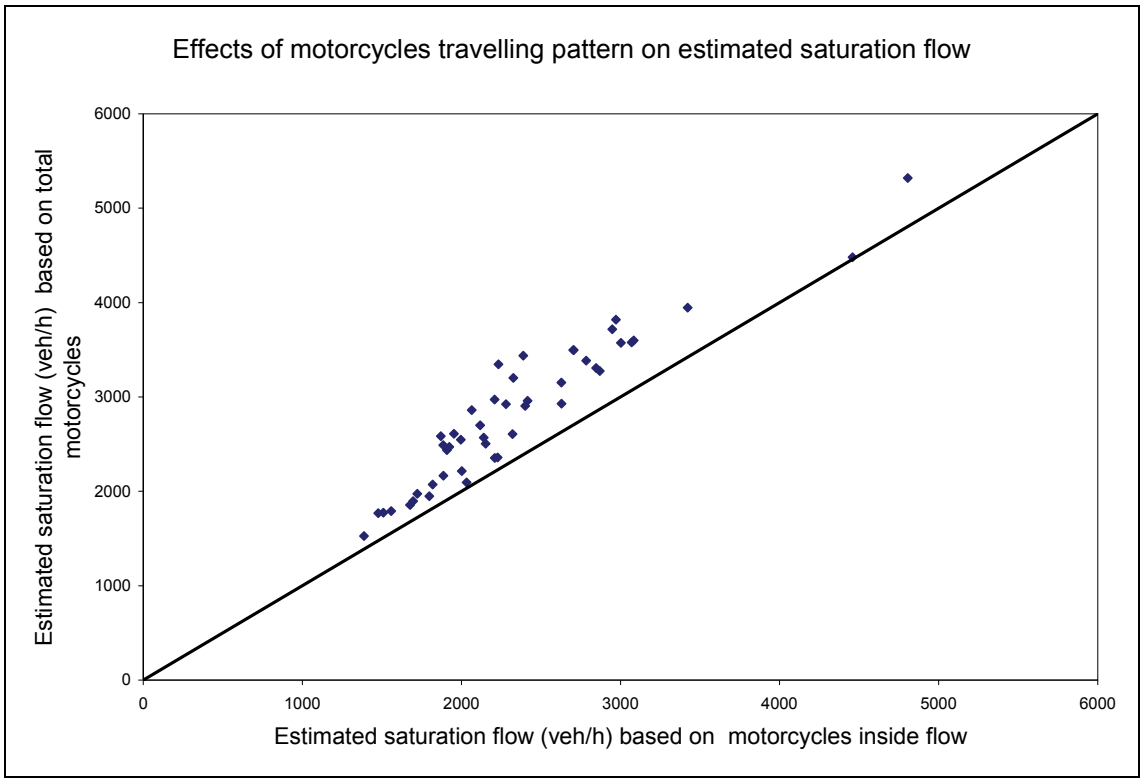

Figure 9: Effects of motorcycles travelling pattern on estimated saturation flow rates

CONCLUSIONS

This paper has discussed the characteristics of motorcyclists travel behaviour at signalised intersections in Malaysia and their effects on the estimation of saturation flow. Saturation flow rates observed at sites and saturation flow rates estimated based on the Malaysia Highway Capacity Manual 2006 were conducted. The observed saturation flow rates only take into consideration motorcycles inside flow while the estimated saturation flow rates are computed based on total motorcycles volume on the road. The results showed significant differences from both saturation flow rates obtained. Therefore, comparisons on the saturation flow rates estimated based on total volume of motorcycles and motorcycles inside flow were then conducted. The comparison showed that motorcycles inside flow should be considered in the estimation of saturation flow rates.

REFERENCES

Branston and van Zuylen (1978). The Estimation of Saturation Flow, Effective Green Time and Passenger Car Equivalents at Traffic Signals by Multiple Linear Regression, *Transportation Research*, Vol. 12, pp: 47–53.

Cuddon, A. P. and Odgen, K. W. (1992). The Effect of Heavy Vehicles on Saturation Flows at Signalised Intersections. *Proceedings 16th ARRB Conference, Part 5*, pp: 1–18.

Highway Planning Unit, Ministry of Works Malaysia (2005). *Road Traffic Volume Malaysia 2005.*

Ministry of Works Malaysia (2006). *Malaysian Highway Capacity Manual 2006*. Chapter 3.

Nobuyuki, M., Tetsuro, H. and Yoki, T., (2005). Image Processing Analysis of Motorcycle Oriented Mixed Traffic Flow in Vietnam. *Proceedings of the Eastern Asia Society for Transportation Studies, Vol 5, (2005),* pp. 929-944.

Road Research Laboratory (1963). A method for measuring saturation flow at traffic signals, *Road Note 34/196*, Department of Scientific and Industrial Research, Her Majesty's Stationery Office, London, pp : 1–13.

Stokes, R. W. (1989). Some Factors Affecting Signalised Intersection Capacity. *ITE Journal (January 1989),* pp. 35–40.

ACKNOWLEDGEMENTS

We would like to acknowledge the Highway Planning Unit of Ministry of Works Malaysia for funding the project 'Malaysian Highway Capacity Study – Stage 1 (Urban and Suburban)' and Universiti Sains Malaysia for giving us the permission to carry out the project.

AUTHOR BIOGRAPHIES

Leong Lee Vien graduated with a Bachelors of Engineering degree (B.Eng (Hons)) from Universiti Sains Malaysia in year 1996 and in year 1999. She then furthered her studies and graduated with a Masters in Science in Highway and Transportation Engineering in year 2000. Due to her great interests in the field of Traffic Engineering, she was offered to pursue a Ph.D. degree in Traffic Engineering in School of Civil Engineering, Universiti Sains Malaysia in year 2001 and in year 2004, she graduated with a Ph.D. degree. Currently, she is working as a lecturer in the School of Civil Engineering, Universiti Sains Malaysia. Her main research interests are highway capacity studies, traffic studies and surveys, capacity analysis of signalised intersections, statistical analysis in traffic engineering, trip generations and traffic impact studies.

Wan Hashim Wan Ibrahim received his Bachelor of Civil Engineering in year 1989, subsequently obtained his M.Sc. in year 1991 and followed by his Ph.D. in Tranportation Engineering in year 1994 from Purdue University, West Lafayette, Indiana, USA. His research interests include highway capacity studies, capacity analysis of signalized and unsignalized intersections and operations and road safety studies. Dr. Wan Hashim Wan Ibrahim has also conducted a number of sponsored research projects funded by national organizations, federal agencies, institutional bodies and industry. Under his guidance, numerous M.Sc. and Ph.D. students have completed their graduate degrees in Civil Engineering. He is also actively involved in consultancy projects, especially in traffic impact assessment studies. Currently, he is Dean of Faculty of Engineering, Universiti Sarawak Malaysia, Kota Samarahan, Sarawak, Malaysia.

Ahmad Farhan graduated with Bachelor of Civil Engineering from Catholic University of America, and subsequently obtained his MSc. and Ph.D. in transport studies from the University of London. Dr. Ahmad Farhan has focused his research on critical areas especially for Malaysia and the region. His research work has concentrated on travel behaviour research, the behaviour of mixed traffic situation and research towards sustainable transport such as defining sustainable transport for Malaysia, enhancement of public transport, especially in relation to the role of paratransit, study on the effects of vehicular traffic on pollution as well as Intelligent Transport Systems. Dr Ahmad Farhan has carried out numerous projects through grants from the federal agencies, institutional bodies, and industry. In addition, Dr. Ahmad Farhan and the team are very active in consultancy projects. Presently, he is the Dean of School of Civil Engineering, Universiti Sains Malaysia.