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PASSENGER CAR EQUIVALENTS AND SATURATION FLOW RATES FOR THROUGH VEHICLES AT SIGNALIZED INTERSECTIONS IN MALAYSIA

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ABSTRACT

Passenger car equivalents are used to represent the varying effects of mixed vehicle types on saturation flows by converting a traffic stream comprising of various vehicle types into an equivalent traffic stream comprising entirely of passenger cars. Procedures for signalized intersection analysis often recommend the use of measured saturation flow rates. However, it is impractical to measure prevailing saturation flow rate for an existing site and it is impossible to measure saturation flow rate for a new signal installation which is yet to be constructed. Hence, the development of a saturation prediction formula based on passenger car equivalents values derived according to local traffic conditions is necessary in order to estimate saturation flow rates accurately at signalized intersections. This paper discusses an investigation on passenger car equivalents and saturation flow rates for through vehicles at signalized intersections in Malaysia. The results obtained shows that the measured saturation flow rates are different from the values computed based on Highway Capacity Manuals in other countries such as U.S. and U.K. as the traffic compositions in Malaysia are different from those in developed countries.

INTRODUCTION

Signalised intersections are an essential part of a road network, particularly in urban areas where traffic congestion has always been a major problem. In the design of signalized intersections, capacity is the key factor and saturation flow rate plays an important role in determining the capacity of individual approaches. Therefore, saturation flow can be defined as the maximum constant departure rate of a queue from the stop line of an approach lane during the green period. This definition was based on the conventional graphical representation of saturation flow as shown in **Figure 1**. It assumes that when the signal changes to green, traffic discharges at a constant rate which is the saturation flow rate until either the queue is cleared or the green period ends. The departure rate is lower during the first few seconds as vehicles accelerate to normal running speed and similarly during the period after the end of green interval as the flow of vehicles declines (Akcelik, 1981; Teply & Jones, 1991).

Saturation flows however, are influenced by the proportion and type of vehicles in the traffic stream. Therefore, passenger car equivalents (pce) are usually assigned to various categories of vehicle in order to normalize the saturation flow to the common base of passenger car units per hour (pcu/hr). The term “passenger car equivalent” was introduced in the 1965 U.S., Highway Capacity Manual (HCM) and defined as “the number of passenger cars displaced in the traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions”. In Malaysia, vehicle types are divided into five categories, specifically passenger cars, motorcycles, lorries, trailers and buses. On average, the percentage of vehicles registered annually consists of 51.2% cars, 39.0% motorcycles, 0.5% buses, 6.3% of good vehicles and 3% of other vehicles. **Figure 2** shows the total registered vehicles in Malaysia from year 1987 to 2004. The number of vehicles registered is expected to grow annually but in terms of the proportion of vehicles, no drastic changes are expected to occur any time soon (based on the trend of vehicles registration for the last 18 years or so). Nevertheless, the pce values currently used in Malaysia are based on the values presented in *Arahan Teknik (Jalan) 13/87* which is the

Malaysian Design Standard document for roads published by the Public Works Department of Malaysia in year 1987. These values were similar to the values determined by Webster in the United Kingdom as shown in Table 1.

Table 1: Pce values for signalized intersections according to Arahan Teknik (Jalan) 13/87 as compared to Webster values

Vehicle categories	*Arahan Teknik (Jalan) 13/87*	Webster (1966)
Passenger cars	1.00	1.00
Motorcycles	0.33	0.33
Medium/ light lorries	1.75	1.75
Heavy lorries	2.25	1.75
Buses	2.25	2.25

Other similar researches were also conducted in Indonesia. In Indonesia, pce were categorised according to the signal phasing, that is protected or permitted (Indonesian HCM (BINKOT, 1996)). The pce for heavy vehicles were the same for both protected and opposed movements but for motorcycles, the pce value for opposed movements were larger than the protected movements. The pce values adopted in Indonesia are as shown in Table 2.

Table 2: Pce values adopted by the Indonesian HCM (1996)

Movement types	Vehicle categories	Pce values
Protected movements	Light vehicles	1.00
	Heavy vehicles	1.30
	Motorcycles	0.20
Opposed movements	Light vehicles	1.00
	Heavy vehicles	1.30
	Motorcycles	0.40

More recently relevant authorities in Malaysia have been referring to the U.S. Highway Capacity Manual (U.S. HCM 1994 and 1997 Update) and the new metric version, HCM (2000) for the design and analysis of signalised intersections. However, due to certain differences such as roadways characteristics, drivers' behaviour and importantly the mixed traffic composition in Malaysia as opposed to dual categories of vehicles specifically light and heavy vehicles (pce for heavy vehicles = 2.0) in the United States, these values may not be representative of local traffic conditions in Malaysia. Therefore, due to the realisation that it is necessary to apply more realistic pce values with respect to Malaysian road conditions in the computation of saturation flows, new pce values were proposed by Leong et al. (2005) and introduced in the newly developed Malaysian Highway Capacity Manual (MHCM) in 2006. The pce values proposed in the MHCM (2006) are as shown in Table 3.

Table 3: Proposed pce values for signalized intersections in Malaysia (MHCM, 2006)

Vehicle categories	Pce values
Passenger cars	1.00
Motorcycles	0.22

Medium/ light lorries	1.19
Heavy lorries	2.27
Buses	2.08

This research will attempt to investigate the effects of the proposed pce values with the values adopted by Arahan Teknik (Jalan) 13/87 and pce values used in the U.S. HCM (2000) as well as the values adopted in Indonesia in the estimation of saturation flow rates.

STUDY APPROACH

In this study, an audio recording method was used to collect the headway data for five categories of vehicles at signalized intersections (Wan Ibrahim and Leong, 2002). Audio cassette recorder was used because the actual time headway between successive vehicles needs to be measured and it was found that the observers might not have enough time to record the actual time headway of different vehicle passing through the stop line if vision is used (Brown and Ogden, 1988 and Teply and Jones, 1991). The vehicle types distinguished in this study were 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

In the audio recording method, the observer will record the detailed vehicle departures with event-recording equipment and the inter-vehicle time headways are calculated by measuring the elapsed time between the crossing of the stop line by the rear axle of the vehicle preceding it and the crossing of the stop line by its own rear axle (Kimber et al., 1985). This method was judged to be efficient and accurate, particularly as the observer had only a single task to perform in the field. The time involved in the analysis is also fairly short, enabling a large number of sites to be studied. The data from a tape could be analysed and checked by one person in only a few hours (Miller, 1968).

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, observed vehicle discharge pattern were used to obtain the number of vehicles discharging from a queue in successive 6 seconds intervals throughout the saturated green period. The flow for each saturated interval except the first and last interval will then be averaged and the saturation flow will be calculated. The effect of varying vehicles in the estimation of saturation flows were then taken into consideration by using a traffic composition factor, f_c as shown in equation (1).

$$S_{(pcu/hr)} = S_{(veh/hr)} \times f_c \quad (1)$$

where,

$$f_c = \frac{\sum e_i q_i}{q} \quad (2)$$

q_i = Flow in vehicles for vehicle type i (veh/hr)
q = Total flow (Σq_i) (veh/hr)
e_i = pce of vehicle type i

Based on equation (5), traffic composition factor, f_c, can then be determined using equation (3).

$$f_c = f_{car} + f_{hv} + f_m \quad (3)$$

where,

$$f_{car} = e_{car}\left(\frac{q_{car}}{Q}\right) \quad (4)$$

$$f_{hv} = e_{trailer}\left(\frac{q_{trailer}}{Q}\right) + e_{lorry}\left(\frac{q_{lorry}}{Q}\right) + e_{bus}\left(\frac{q_{bus}}{Q}\right) \quad (5)$$

$$f_{m} = e_{motorcycle(calibrated)}\left(\frac{M_T}{Q}\right) \quad (6)$$

$$Q = q_{car} + q_{trailer} + q_{motorcycle} \quad (7)$$

Comparisons of saturation flows were then made using different pce values adopted in MHCM (2006), Arahan Teknik (Jalan) 13/87, U.S. HCM (2000) and Indonesian HCM (1996).

DATA COLLECTION

Vehicles headway data were collected 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 but saturated. Traffic flow data were collected at 64 signalised intersections in various states throughout Malaysia. For each signalised intersection, traffic flow data were collected simultaneously at various approach lanes that satisfied the predetermined conditions which were through traffic, protected phasing, no side parking and no bus blockage. On the average, at any one single lane, data were collected for 30 signal cycles.

RESULTS AND DISCUSSIONS

The saturation flows in vehicles per hour observed at various signalised intersections throughout Malaysia are summarized in Table 4. Based on the collected data, majority of the vehicles observed at the signalized intersections are cars and motorcycles. On the average, the traffic flow consists of 60% cars, 30% motorcycles, 5% respectively for lorries and buses and 1% trailers. Therefore, in order to take into consideration the effects of mixed traffic compositions, the observed saturation flows in vehicle per hour in Table 4 were normalized to passenger car unit (pcu) per hour using equation (1). The normalized saturation flows in pcu per hour based on various pce values as compared to the observed saturation flows in veh per hour are presented in **Figure 3**.

Referring to Figure 3, normalized saturation flows in pcu/hr computed based on the U.S. HCM (2000), most of the data points plotted were evenly spread about the 45° line, which means that the effect of traffic composition or pce values are less as compared to the MHCM (2006), Arahan Teknik (Jalan) 13/87 and the Indonesian HCM (1996). Generally, the saturation flows in pcu/hr plotted based on the MHCM are the closest to the values plotted based on the Indonesian HCM (1996). This may be due to the similarity of the road traffic system and traffic composition in Malaysia and Indonesia. However, the saturation flows in pcu/hr computed based on the pce values in MHCM (2006) were slightly different than the values computed based on the Arahan Teknik (Jalan) 13/87. This might be due to the fact that the pce values presented in the Arahan Teknik (Jalan) 13/87 were adopted with slight modifications from the values derived by Webster (1966) which have not been revised since 1987.

Table 4: Summary of observed saturation flows (veh/hr)

No.	Sites	Observed saturation	No.	Sites	Observed saturation

		flow (veh/h)			flow (veh/h)
1	Gama 1	1793	33	Jln Gopeng-Fella2	2222
2	Gama 2	2214	34	Jln Raja Dihilir 2	2093
3	Jln Ampang 1	1933	35	Jln Raja Dihilir 3	2357
4	Jln Ampang 2	1648	36	Jln SAS-Ipoh 5	2312
5	Jln Leong Boon Swee 1	1881	37	Jln SAS-Ipoh 8	2179
6	Jln Pahang 1	2281	38	Jln SAS-Penang 1	2047
7	Jln Pahang 2	1988	39	Jln SAS-Penang 2	1658
8	Jln Raja Musa Aziz 2	2043	40	Jln SAS-Penang 3	1723
9	Jln SAS-Ipoh 2	1785	41	Jln SAS-Penang 4	2429
10	Jln Sultan Iskandar 2-1	2036	42	Juru Site 2-Lrg 1	1650
11	Jln Tun Perak 1	2002	43	Juru Site 2-Lrg 2-1	1689
12	Komtar 1	1753	44	Juru Site 2-Lrg 2-2	1704
13	Komtar 2	2173	45	Pesta P. Pinang 1	1710
14	Mayang Hyper Store 1-1	1786	46	Pesta P. Pinang 2	2895
15	Mayang Hyper Store 1-2	1839	47	Pesta P. Pinang 3	1781
16	Mayang Hyper Store 1-3	1870	48	Jln Imbi 1	1900
17	Medan Tuanku 1-1	1369	49	Jln Imbi 2	1785
18	Medan Tuanku 1-2	1585	50	Jln SS2 24-2	1881
19	Medan Tuanku 1-3	1503	51	Jln T.A.R 1	1641
20	Medan Tuanku 1-4	1368	52	Plaza Ampangan 2	1893
21	Medan Tuanku 1-5	1488	53	Jln Bangsar 1	2455
22	Medan Tuanku 1-6	1379	54	Jln Bangsar 2	1985
23	Medan Tuanku 1-7	1338	55	Jln Bangsar 3	2021
24	Medan Tuanku 1-9	1322	56	Jln Dato Muda Linggi 3	1631
25	Medan Tuanku 2-1	2075	57	Jln Seremban 1	1395
26	Medan Tuanku 2-2	2064	58	Jln Seremban 4	1426
27	Medan Tuanku 2-3	2116	59	Jln Sungai Ujong 2	1407
28	Medan Tuanku 2-4	2154	60	Jln Utara 1	1889
29	Medan Tuanku 2-5	1700	61	Jln Utara 2	1684
30	Wisma Sime Darby 2	1566	62	Makro 3	1547
31	Wisma Sime Darby 3	1428	63	Makro 4	1317
32	Jln Gopeng-Fella1	1909	64	Persimpangan Centre Point 1	1721

Additionally, based on Figure 3, most of the saturation flows in pcu/hr based on the MHCM (2006) and the Indonesian HCM (1996) were much lower than the observed saturation flow values in veh/hr. This is mainly due to the high composition of motorcycles (more than 50%) in the traffic flow. **Figure 4** shows the percentage of reduction in saturation flows in pcu/hr with respect to different percentages of motorcycles.

As shown in Figure 4, high percentage of motorcycles in the traffic stream will reduce the saturation flows in pcu/hr significantly. When the percentage of motorcycles in the traffic flow

exceeds 50%, the percentage reduction in saturation flows in pcu/hr is more than 50%. This is mainly due to the influence of the motorcycle pce value which is less than 1.0. The percentage of reduction in saturation flows in pcu/hr is the largest for the Indonesian HCM (1996), followed closely by MHCM (2006) and then the Arahan Teknik (Jalan) 13/87 and lastly the U.S. HCM (2000). This is actually in accordance with the motorcycle pce values in which the pce value for motorcycles adopted by the Indonesian HCM (1996) is the smallest which is only 0.2, followed by MHCM (2006) which is 0.22 and then the Arahan Teknik (Jalan) 13/87 which is 0.33, whereas in the U.S. HCM (2000), motorcycles were not taken into consideration in the estimation of saturation flows. However, on the contrary, if the percentages of heavy vehicles such as trailers, lorries and buses were high, then the saturation flows in pcu/hr will increase because the pce values for heavy vehicles are more than 1.0. This shows that pce factors have a significant impact on the estimation of saturation flows in the common base of passenger car units per hour (pcu/hr) especially in the presence of high percentage of motorcycles.

CONCLUSIONS

This paper has discussed on the effects of pce values on the estimation of saturation flows based on pce values adopted in the Malaysian HCM (2006), U.S. HCM (2000), Arahan Teknik (Jalan) 13/87 and Indonesian HCM (1996). On the basis of the analysis, it was proven that pce values have a significant impact on the estimation of saturation flows especially in the presence of high percentage of motorcycles in the traffic stream. Therefore, the direct application of pce values adopted in other countries such as U.S. and U.K. were found to be unsuitable due to the different traffic compositions in Malaysia at present.

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AUTHOR BIOGRAPHIES

Leong Lee Vien graduated with a Bachelors of Engineering degree (B.Eng (Hons)) in year 1999 and then furthers her studies to Masters level in year 1999 and graduated with a Masters in Science degree, specializing in Highway and Transportation Engineering (M.Sc. (Highway and Transportation Engineering)) in year 2000 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, Engineering Campus in Nibong Tebal, Penang. 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.

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FIGURES

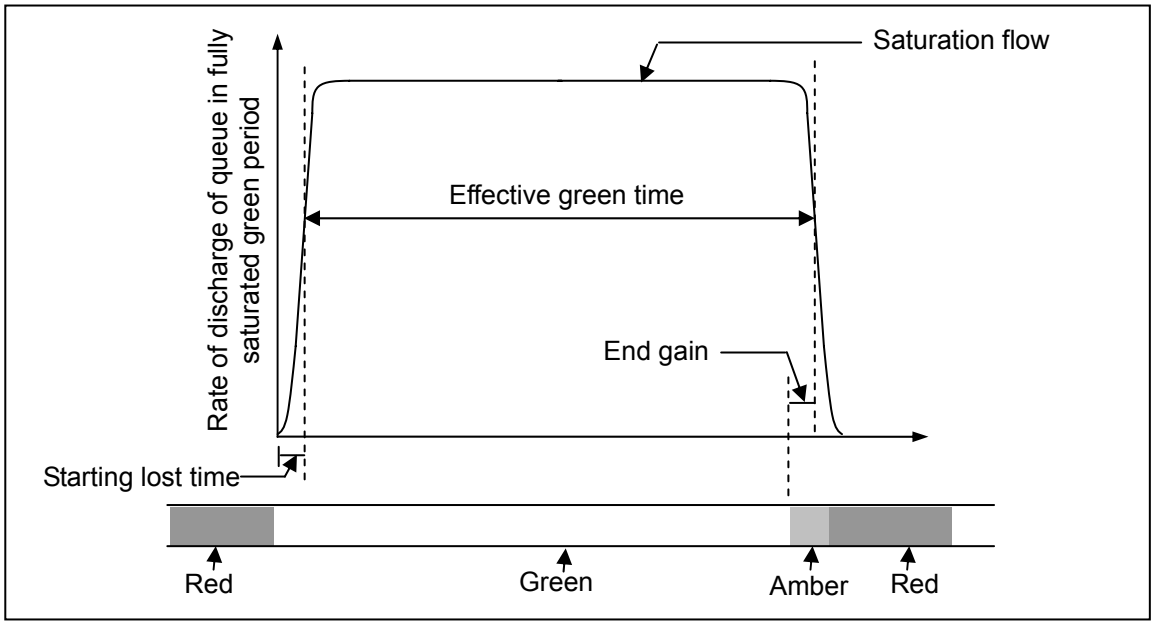

Figure 1: Graphical presentation of saturation flow

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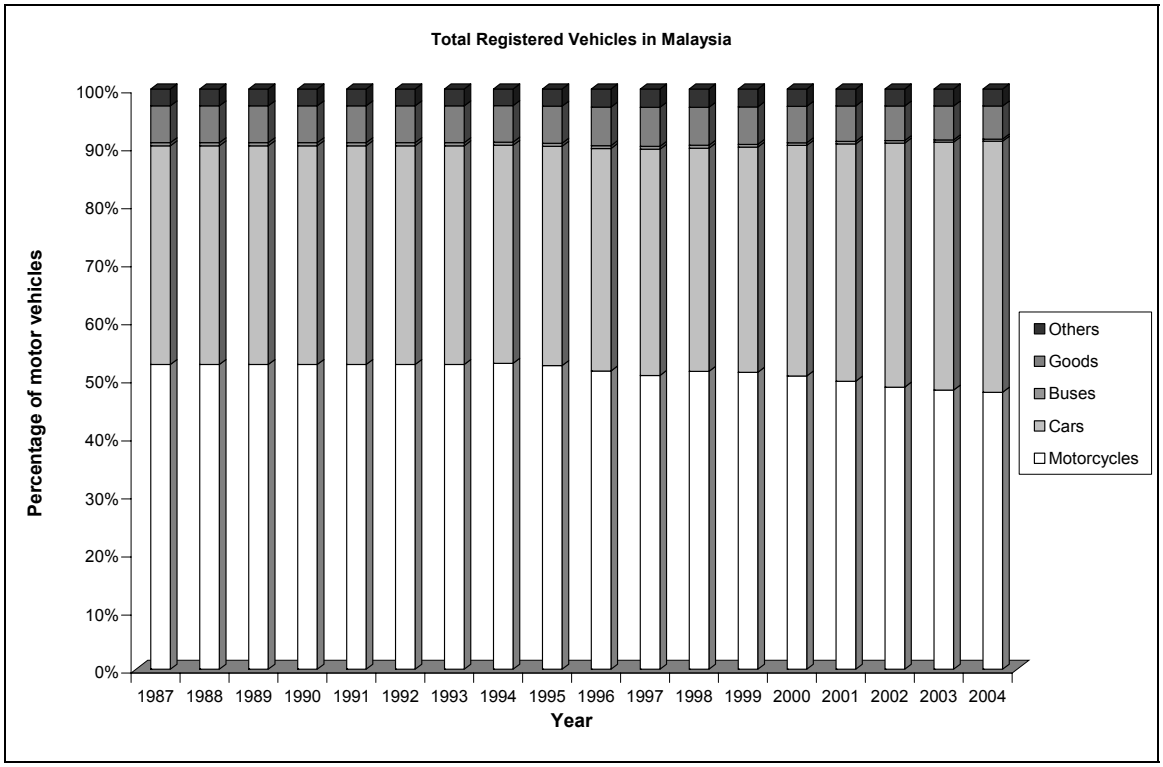

Figure 2: Total registered vehicles in Malaysia

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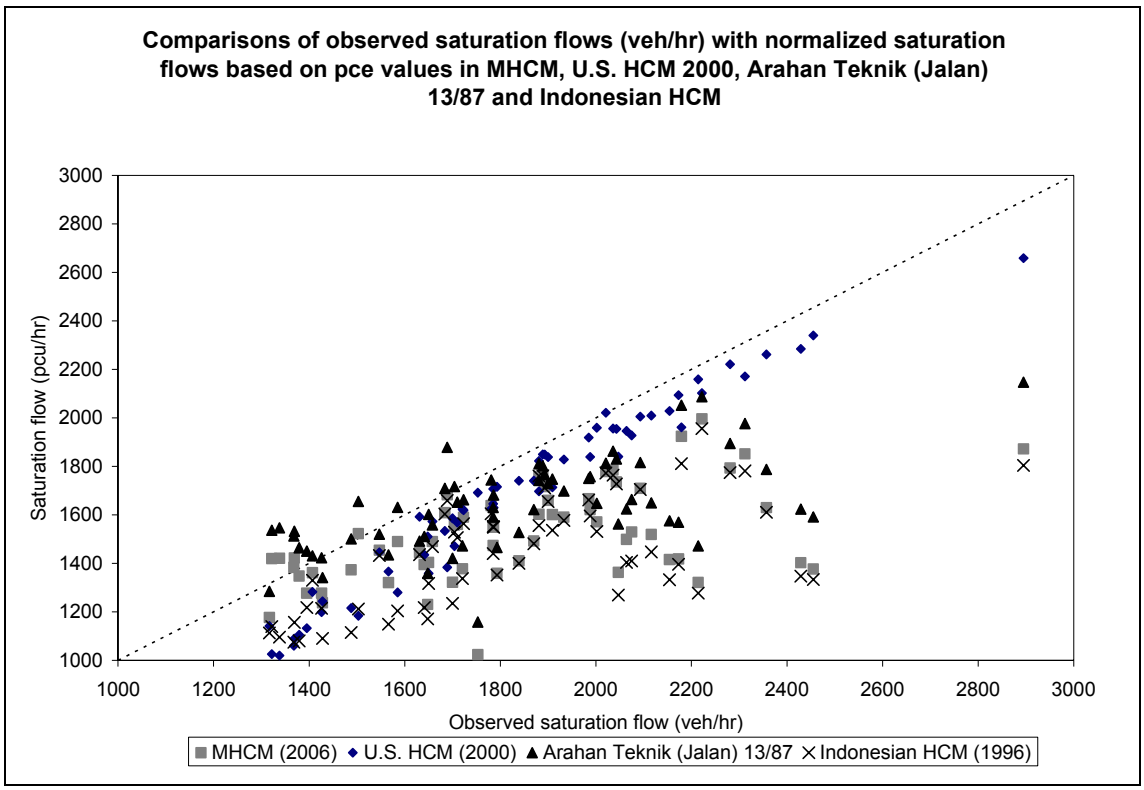

Figure 3: Normalized saturation flows in pcu per hour based on various pce values as compared to the observed saturation flows in veh per hour

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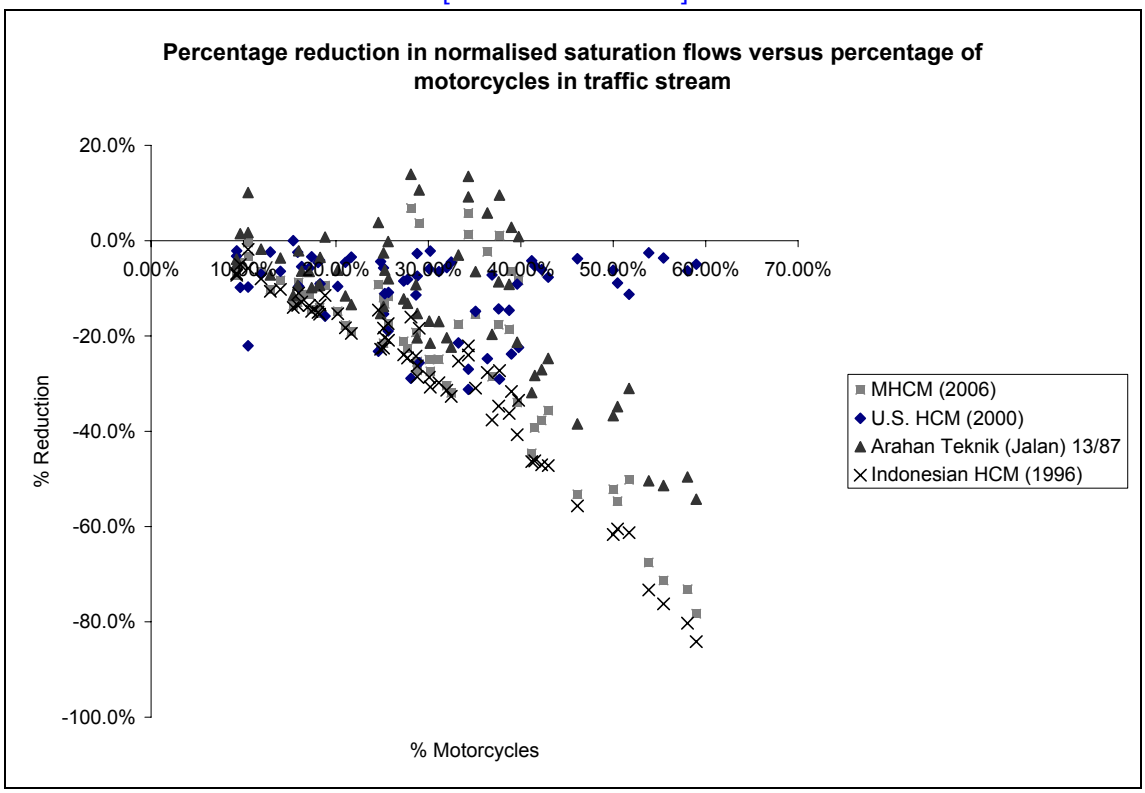

Figure 4: Percentage reduction in normalized saturation flows due to various percentages of motorcycles in the traffic stream

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