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SHOULD MOTORCYCLE BE BLAMED FOR TRAFFIC CONGESTION IN VIETNAMESE CITIES?

Hien Nguyen
Mouchel Group, United Kingdom
Email: hien.nguyen@mouchel.com

Frank Montgomery
University of Leeds, United Kingdom
Email: f.o.montgomery@its.leeds.ac.uk

Paul Timms
University of Leeds, United Kingdom
Email: p.m.timms@its.leeds.ac.uk

ABSTRACT:

In the last fifteen years, along with a rapid change of economy, the number of motorcycles has increased dramatically in Vietnam. Now, motorcycles are considered to be the main mode of transport for most people living in urban areas. However, the motorcycle is also being accused of causing traffic congestion in big cities like Hanoi or Ho Chi Minh.

This paper presents a study of the saturation flow and vehicle equivalence factor at signalised intersections in a traffic environment dominated by motorcycles. A new method to study the variation of these parameters simultaneously was introduced. Motorcycle Unit (MCU) values have been applied rather than conventional PCU in car traffic. The final results show that it is numbers would only reduce traffic congestion if it was implemented in conjunction with other measures that limited private car ownership and encouraged public transport ridership.

RESUME :

Au cours des quinze dernières années, alors que l'économie a connu un changement rapide, le nombre de moto-bicyclettes au Vietnam a augmenté de manière très marquée. Elles sont maintenant considérées comme le principal moyen de transport pour la plupart des personnes vivant dans les zones urbaines. Cependant, on les accuse aussi de provoquer des embouteillages dans les grandes villes, comme à Hanoï ou Ho Chi Minh ville.

Ce document comporte une étude sur la saturation du trafic et le facteur équivalent véhicule aux intersections signalisées dans les zones où le trafic est dominé par les moto-bicyclettes. Une nouvelle méthode d'étude de la variation simultanée de ces paramètres a été présentée. Ses valeurs unitaires (MCU: Motorcycle Unit) ont été appliquées plutôt que les conventionnelles PCU. Les résultats obtenus montrent que les reproches faits aux motos d'être responsables des embouteillages ne sont pas toujours justes. La diminution des embouteillages ne peut être réussie que si plusieurs solutions sont appliquées en parallèle comme réduire le nombre de moto-bicyclettes, le nombre de voitures privées ainsi qu'encourager les gens à utiliser les transports en commun.

1. INTRODUCTION

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Recently, the motorcycle has become a main mode of transport for many cities in the world. It is known as a transition mode between pedal cycle and passenger cars in developing countries while it is serving as a solution to deal with traffic congestion in a number of developed cities. In Vietnam, in the past two decades, the number of motorcycles has increased dramatically, for example in Hanoi with an estimated growth of around 14% per year (Vu and Shimizu, 2005). Unfortunately also throughout that period, the traffic conditions in big cities in Vietnam have become much poorer. Nowadays, traffic congestion is very common in Hanoi and Ho Chi Minh cities. Pollution due to vehicle emission and traffic accidents are other serious problems in these cities. A number of solutions to deal with these issues have been implemented. Furthermore, several other policies have been proposed, including restricting the growth of motorcycle ownership in urban areas. It appears that to gain support for this policy, some recent reports have stated that the increase of motorcycles is the reason for the mentioned-above problems, particularly for traffic congestion.

To ascertain the truth or otherwise of these reports, it is necessary to compare the capacity of different types of vehicles in terms of the number of people/passengers they can transport under the same conditions. Ideally, the comparison should be carried out across a range of traffic conditions and locations. However, within an urban traffic network, signalised junctions are known to be the most capacity constrained and considered as the bottlenecks of traffic streams. Therefore, in a particular network, if congestion happens, it is most likely to occur at traffic signals. The comparison in this paper, therefore is implemented at traffic controlled junctions only.

2. METHODOLOGY

Traffic operation at signalised intersections would be much easier to investigate and analyse if all vehicles in the traffic stream were identical. However, in reality it is very common that the traffic stream is a mixture of vehicles types with different sizes, weights and powers. In this situation, it becomes very difficult to measure saturation flow in veh/h, because different traffic compositions produce different answers. To deal with this issue, a common approach (Richardson et al, 1984 and Kimber et al, 1986) is to convert the mixed flow to a homogeneous one before calculating saturation flow. This conversion is made through the use of vehicle equivalence factors, e.g. Passenger Car Unit (PCU) values.

Saturation flow has been demonstrated to vary depending on geometric, traffic and environment factors in all the above-mentioned studies. Apart from saturation flow, vehicle equivalence factors were also reported not to be constant between locations (Branston, 1979). Nevertheless, by definition, saturation flow and vehicle equivalence factors are closely related because the latter were adopted to take account of mixed traffic composition when estimating the former. Therefore, it is sensible to study the variation of these two parameters at the same time. In the past, however, most research concentrated on the variation of saturation flow and ignored that of vehicle equivalence factors or vice versa.

This paper proposes a methodology to study the variation of these two parameters simultaneously. Note that this study concentrates on traffic dominated by motorcycles, i.e. where motorcycles make up more than 80% of traffic composition. Therefore, the motorcycle was selected as the basis to study other categories of vehicle as well as the whole traffic flow.

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The Motorcycle Unit (MCU) value was introduced in this paper as a vehicle equivalence factor to convert the mixed stream of traffic into an equivalent pure flow of motorcycles.

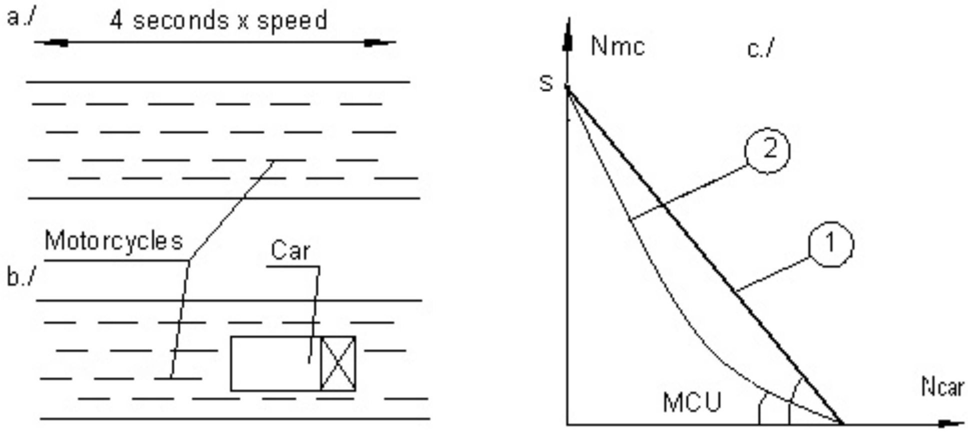

Figure 1: Relation between N_{mc} and N_c – concept of MCU value

As a starting point we take a simple example that there is a homogeneous traffic flow containing S straight-on motorcycles discharging from the queue in a certain time period T as represented in figure 1a. During time period T, it is assumed that S motorcycles discharge from the queue and thus S is defined as the saturation flow during period T. Now, if M motorcycles in this time period are taken out and replaced by N passenger cars as in figure 1b, the saturation flow will be (S-M) motorcycles and N passenger cars (N_c). Equalising the saturation flows between the two situations:

$$S = (S-M) + k \times N_c \qquad (1)$$

Denote $N_{mc} = S - M$ as the number of motorcycles remaining in the traffic stream. Equation (1) can be rewritten as:

$$S = N_{mc} + k \times N_c \qquad (2)$$

where k is a ratio to convert N passenger cars into M motorcycles. In this situation, k is defined as the MCU value of passenger cars (MCU_c) and it is calculated from equation:

$$MCU_c = (S-N_{mc})/N_c \qquad (3)$$

Equation (3) could be rewritten:

$$N_{mc} = S - N_c \times MCU_c \qquad (4)$$

This equation can be represented as the graph 1c and it can be used to assess the variation of saturation flow and MCU_c value at the same time. Specifically, as can be seen from this graph, if MCU_c is fixed, the relation between N_{mc} and N_c is linear as indicated by the straight line No1. However, if MCU_c varies depending on the number of cars in the stream, the relation between N_{mc} and N_c will be non-linear as indicated by curve No 2 in the graph 1c.

While allowing that MCU_c may vary, we have assumed that the variation would be linearly related to the number of cars in the stream, as presented in equation (5):

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$$MCU_c = m + n \times N_c \quad (5)$$

Substituting MCU_c in (5), equation (4) can be rewritten:

$$N_{mc} = S - N_c \times (m + n \times N_c) \quad (6)$$

or

$$N_{mc} = S - mN_c - nN^2_c \quad (7)$$

Equation (7) resembles a multiple linear regression equation, with explanatory variables N_c and N^2_c. Thus if we can obtain sufficient data for N_{mc}, S and N_c, we can test the significance of the coefficients m and n, and thus test (via n) whether MCU_c varies with N^2_c.

The plan was therefore to apply equation (7) to data from several approaches containing straight-on motorcycles and passenger cars only. Note that because the data comes from several locations with different geometric and traffic factors, the value of saturation flow S in equation (7) is not a constant but varies depending on these factors. In homogeneous traffic containing motorcycles only, Nguyen and Montgomery (2007) proposed a model to estimate saturation flow depending on the width of approach, turning radius and proportion of turning motorcycles as in equation (8) below:

$$S = a + b \times (W-3.5) + c \times P_{rt}/R_{rt} + d \times P_{lt}/R_{lt} \quad (8)$$

where - W, P_{rt}, P_{lt}, R_{rt}, R_{lt} are: width of approach; proportion of right/left turning motorcycles; right/left turning radii, respectively; a, b, c and d are coefficients of the independent variables.

Substituting equation (8) in (7) (and assuming that all passenger cars travel the same direction, say, straight-on only), an equation representing the relationship between N_{mc} and other factors can be written as below:

$$N_{mc} = a + b \times (W-3.5) + c \times P_{rt}/R_{rt} + d \times P_{lt}/R_{lt} + \\ - m \times N_{cst} - n \times N^2_{cst} + \varepsilon \quad (9)$$

where N_{cst} is number of straight-on cars in time period T; m, n are coefficients. Other parameters are as explained in equation (8).

As can be seen from equation (9), 'a' is the intercept and it is the standard saturation flow, i.e. flow containing straight-on motorcycles only on a 3.5m wide approach. Other elements in the first line of right hand side of equation represent the effects of geometric and turning vehicle factors. The second characterises the influence of the number of straight-on cars.

When traffic contains all types of vehicles, i.e. motorcycles, passenger cars, vans and buses and all turning movement, i.e. straight, right turners and left turners, equation (9) needs to change to reflect the effect of turning vehicles. The fact is that the impedance of a straight-on vehicle to saturation flow is different from that of right or left turners. Therefore, their effects are represented by three different factors as described in equation (10).

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$$N_{mc} = a + b \times (W-3.5) + c \times P_{rt}/R_{rt} + d \times P_{lt}/R_{lt} + - m_1 \times N_{cst} - n_1 \times N^2_{cst} - m_2 \times N_{crt} - n_2 \times N^2_{crt} - m_3 \times N_{clt} - n_3 \times N^2_{clt} - p_1 \times N_{vst} - q_1 \times N^2_{vst} - p_2 \times N_{vrt} - q_2 \times N^2_{vrt} - p_3 \times N_{vlt} - q_3 \times N^2_{vlt} - r_1 \times N_{bst} - s_1 \times N^2_{bst} - r_2 \times N_{brt} - s_2 \times N^2_{brt} - r_3 \times N_{blt} - s_3 \times N^2_{blt} + \varepsilon \quad (10)$$

In equation (10), N_{cst}, N_{crt}, N_{clt}, N_{vst}, N_{vrt}, N_{vlt}, N_{bst}, N_{brt}, N_{blt} are numbers of straight, right turning and left turning cars, vans and buses, respectively. m_i, n_i, p_i, q_i, r_i, s_i are coefficients of corresponding independent variables representing the relationship between MCU value and the number of vehicles of each type making different turning movements as presented in equation (5).

In homogeneous traffic, equation (8) measured the effect of turning motorcycles in terms of their proportion of the total number of motorcycles. In heterogeneous traffic, this proportion was calculated as the number of turning motorcycles in each movement as a proportion of the total number of MCU units. Therefore, the mixed traffic streams need to be converted into homogeneous flow prior to calculating these proportions. In doing so, a predefined set of MCU values need to be known beforehand. However, MCU values are coefficients of regression models, thus their exact values are only obtained after these regression models are calibrated. Hence an iteration approach was introduced to deal with this ‘chicken and egg’ situation. MCU values of 4.0 for passenger car, 8.0 for vans and minibus and 10 for buses as used in Vietnam (DSUR, 2004) were used as the initial figures. These were used to convert a mixed flow into an equivalent homogeneous stream and proportions of right and left turning motorcycles were computed. The models were run and revised MCU values were obtained. Then, these MCU values were used to recalculate the proportions of right and left turners. The process was repeated until the differences of MCU values from two consecutive loops were smaller than 1%.

3. DATA COLLECTION AND TRANSCRIPTION

Table 1: Main characteristics of selected sites

Factors	Statistics			
	Unit	Range	Mean	STD
Approach width	metre	3.9 to 13.0	8.83	2.80
Right turning radius	metre	7.0 to 23.1	11.12	4.75
Left turning radius	metre	11.0 to 50.0	22.27	12.29
Proportion of right turning	Percent	0 to 40	15.6	13.9
Proportion of left turning	Percent	0 to 85	11.7	17.0

Twelve approaches to fixed-time-control signalised junctions (Cau Giay – CG, Nguyen Cong Tru – NCT, Nguyen Thai Hoc – NTH, Phan Boi Chau – PBC, Pho Hue – PH, Quan Thanh – QT, Ton Duc Thang – TDT, Cat Linh – CL, Kim Ma – KM, Lang Ha – LH, Thai Ha – TH and Ba Trieu – BT) were selected for the data collection in Hanoi, Vietnam. All sites are

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located in a flat area (grades less than 1%) near the city centre (but not actually in the city centre so as to avoid heavy pedestrian flows). There were few conflicts, either with pedestrians or vehicular traffic. Nevertheless, all periods and signal cycles affected by such conflicts were excluded during the data transcription. Main characteristics of traffic and geometric factors are shown in table 1. Approach width varies from 3.9m to 13.0m. The traffic stream was composed of passenger car, light van, minibus, bus, coach, motorcycle and bicycle; however, motorcycles made up the majority, accounting for 80% to 95% of traffic composition as can be seen in figure 2.

For the data transcription, Road Note 34 method (Webster, 1963) was used, counting the total number of vehicles discharging from the queue during a certain period of green time. As such, the green interval was divided into smaller periods and the number of vehicles crossing the stop-line during every period was recorded. In Webster's paper a period of 6s was selected. However, in traffic dominated by motorcycles, a smaller period of 4s was found to be more useful For every time 4s period, vehicles were classified according to turning movement (straight, left turning and right turning) and five vehicle categories (cars and small vans; medium vans & minibuses (12-16 seats); buses & coaches (no less than 24 seats); motorcycles and bicycles).

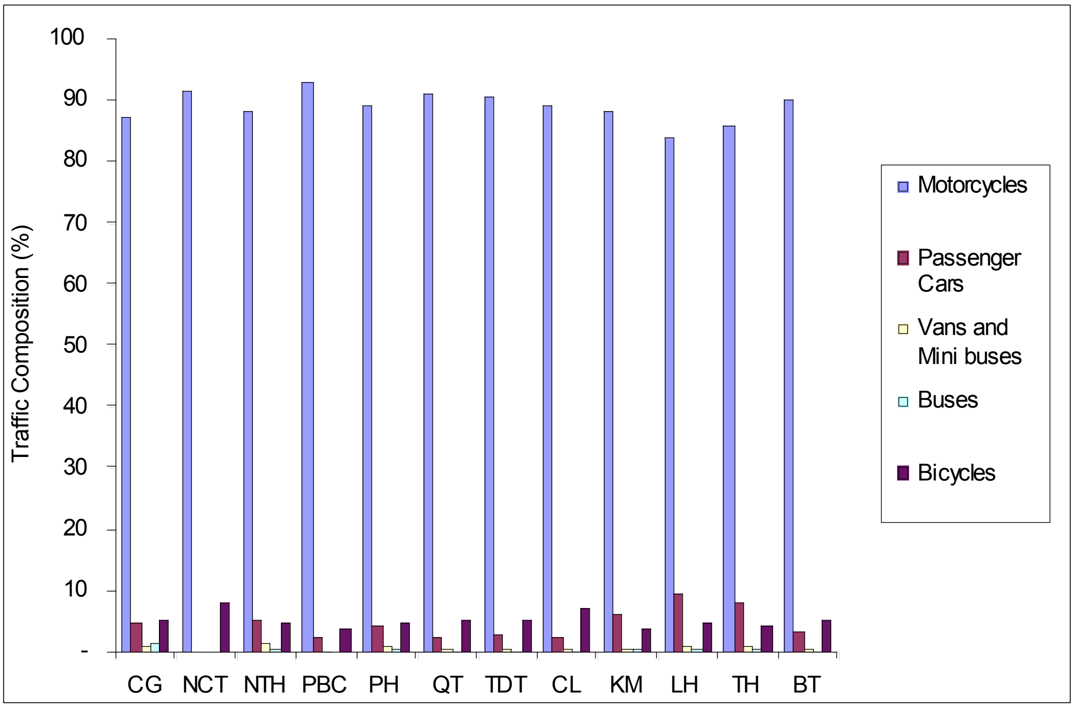

Figure 2: Traffic compositions at twelve selected links

During the process of data collection and transcription, it was found that there was a close similarity in the performance and behaviour of motorcycles and pedal cycles in the queue as well as when they discharged from the queue. T tests comparing the saturation flow between periods containing motorcycles only and those composed of motorcycles and bicycles at two approaches most dominated by two wheelers, Phan Boi Chau (PBC) and Nguyen Cong Tru (NCT) also showed insignificant results. Therefore, a small proportion of pedal cycles (around 5% to 10%) in traffic stream was included in the 'motorcycle' data analysed.

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4. VARIATION OF SATURATION FLOW AND MCU VALUES

The study of variation of saturation flow and MCU values used equation (10) as the starting point. This equation was applicable when vehicles were transcribed in fixed time periods, such as 4s as in section 3. Firstly, ordinary least square (OLS) regression with the stepwise method was used. One of the assumptions of linear regression is that the variance of the distribution of the dependent variable is constant (homoscedasticity). The plot of dependent variable N_{mc} and residuals showed heteroscedasticity and it was also found that the factor of (W-3.5) was the main culprit. One of the methods to remedy this violation is to use weighted least square (WLS) regression. Weight estimation process with independent variable (W–3.5) based on SPSS (Norusis, 2003) was executed and an estimator, β = 0.8, was obtained. WLS regression with stepwise method with this weight estimator was then applied. At both steps, three iteration loops were used. The coefficients of the final loops are written as shown in equation (11) below:

$$
\begin{aligned}
N_{mc} = 12.28 + 2.15 \text{ x } (W-3.5) - 62.60 \text{ x } P_{rt}/R_{rt} - 34.05 \text{ x } P_{lt}/R_{lt} \\
- 3.81 \text{ x } N_{cst} - 5.70 \text{ x } N_{crt} - 5.81 \text{ x } N_{clt} \\
- 4.82 \text{ x } N_{vst} - 8.56 \text{ x } N_{vrt} - 6.67 \text{ x } N_{vst} \\
- 7.96 \text{ x } N_{bst} - 9.07 \text{ x } N_{brt} - 10.21 \text{ x } N_{blt}
\end{aligned} \qquad (11)
$$

The relationship between studentised residuals and unstandardised predicted values of the WLS model were examined and they were found to have a random distribution and constant variance. This suggests that the WLS model is reliable and the weight estimator, β = 0.8, was accurately calculated. The models were also validated with data from two approaches, CG and TH. The plots of relationship between unstandardised predicted value and unstandardised residuals (observed – predicted values) in these two links also show a random distribution. Therefore, it can be concluded that the coefficients in equation (11) above are accurate and reliable.

Table 2: Model summary in different traffic combinations

Statistics	Data size	R2	Adjusted R2	Standard Error	Durbin-Watson
Values	1132	0.86	0.86	1.38	1.33

Table 2 summarises all the main statistics of the regression analysis. As can be seen from this table, the value of adjusted R^2 of 86% is relatively high. It suggests that the final regression model is reliable and coefficients in the equation are highly representative.

5. DISCUSSIONS

From equation (11), the standard saturation flow of a 3.5m wide approach is 12.28 MCU per 4 seconds. This figure is equal to more or less 11,000 motorcycles per hour of green time. During the time of data collection in Hanoi, it was observed that almost all motorcycles carry one person. An average occupancy value of motorcycles of 1.14 was obtained. Therefore, it is easy to work out that in one hour, a homogeneous flow of motorcycles can accommodate around 13,000 people (11000 x 1.14) to pass through one 3.5m wide signalised junction approach.

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Table 3: MCU values of straight on vehicles

	Passenger cars	Van and Minibus	Bus
MCU values	3.81	4.82	7.96

In order to compare this capacity (number of people passing through the stopline of one approach in one hour of green) of motorcycle with other means of transport, firstly it is necessary to compare the capacity in terms of number of vehicles. Table 3 shows MCU values of straight on passenger cars, vans and buses as 3.81, 4.82 and 7.96, respectively. These values are extracted from coefficients in Equation 11 above. From these figures, an equivalent homogeneous capacity (vph) of these types of vehicles is calculated as presented in Table 4 below. As such, in one hour of green, a 3.5 wide approach at a traffic signal can accommodate either 2887 passenger cars, 2305 vans/mini buses or 1396 buses. It is noted that the value of saturation flow of 2887 passenger cars is significantly higher than that found in developed countries where traffic streams are dominated by cars. For instance, Kimber et al (1986) proposed a value of 2080 PCU/h for a 3.25 wide approach or HCM (2000) recommended a saturation flow of 1950 vph for 3.65m wide arm of a traffic signal. The greater value of saturation flow in motorcycle-dominated traffic compared to that in car traffic can be explained by an amount of motorcycles make use the gap between lanes allocated for larger vehicles such as cars or buses.

Table 4: A conversion of capacity and occupancy

	Motorcycle	Passenger cars	Van /minibus	Bus
Equivalent capacity (vph)	11,000	2,887	2,305	1,396
Equivalent occupancy (people/vehicle)	1.14	4.50	5.64	9.31

To compare the capacity (in terms of number of people) of cars or buses with that of motorcycles, their (required) equivalent occupancies (people/vehicle) are computed as indicated in Table 4. As can be seen from these figures, a pure flow of passenger cars could convey the same number of people through the junction as a pure flow of motorcycles only if each passenger car carried 4.5 people. However, this is obviously neither practical nor likely and in reality the average occupancy of passenger cars is usually more or less 1.5 (National Statistics, 2000). In other words, a homogeneous flow of passenger cars could only accommodate one third of the number of people through a signalised junction compared to motorcycles.

Also as can be seen from table 4, a homogeneous flow of buses with average occupancy of 9.31 people is able to accommodate the same capacity as that of motorcycle stream. This means that if bus occupancy is higher than this figure, say more than 10 people per bus, a flow of buses will increase the throughput capacity of the junction. Similarly, from the figures in table 4, it is also noticeable that the junction capacity (number of people per hour) will be improved if the average occupancy of minibus is more than 7 people/vehicle.

From these calculations, it is obvious that the increase of private cars will reduce significantly (threefold) the throughput capacity of junctions in terms of number of people. In contrast, the

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growth of buses and minibuses in traffic stream can improve the capacity provided its average occupancy is higher than 10 people/bus or 7 people/minibus.

6. CONCLUSION

A methodology was introduced for studying the variation of saturation flow and vehicle equivalence factors in mixed traffic dominated by motorcycles. The concept of MCU value was applied instead of conventional PCU value to take into account the effect of mixed traffic dominated by motorcycles. A regression model has been derived to describe the variation of saturation flow. Overall, saturation flow of a 3.5m wide approach is as high as 11000 MCU/h. The impacts of geometric and traffic factors on saturation flows were also investigated.

MCU values of passenger cars, vans and buses making different movements were determined. Based on these, a comparison of the junction capacity (in terms of number of persons per hour) using different modes of transport was made and the final results indicated that:

- The argument that the increase of number of motorcycles is the reason for traffic congestion is not always appropriate.
- In practice, congestion will become much worse if the decrease of motorcycles is accompanied by a growth of private cars.
- An increase in the number of buses or minibuses would be able to reduce traffic congestion provided the occupancy of buses and minibuses was greater than 10 people/bus or 7 people/minibus.
- Current measures to reduce the number of motorcycles will only successfully cut congestion if they are implemented in conjunction with other policies to limit private car ownership and encourage public transport ridership in urban areas.

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