Development of Motorcycle Unit (MCU) For Motorcycle-Dominated Traffic

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Abstract: While many developed countries have typically been facing problems related to four-wheeled traffic, developing countries are facing problems related to small motorized vehicles, such as motorcycles. However, very few studies have been conducted to the traffic operation of motorcycles in the existing literature. This study proposes the methodology to estimate the motorcycle unit (MCU) with a consideration of dynamic characteristics of moving vehicles. It expresses the relationship between speeds and occupied spaces with respect to motorcycles and other types of vehicles. A case study is introduced in order to estimate the parameters of proposed formula by using microscopic traffic data at three mid-blocks in Hanoi, Vietnam. Then, the proposed methodology is compared with previous methods. The results show that the proposed formula represents the best among them. The findings provide useful information that can be used to develop the speed-flow relationship, estimate highway capacity, analyze level of service, and formulate effective traffic regulation and control measures.

Key Words: Traffic flow, capacity analysis, mixed traffic

1. INTRODUCTION

Different types of vehicles have different impacts on traffic streams. Traditionally, these impacts have been expressed in terms of passenger car unit (PCU), a common unit used to convert a heterogeneous traffic stream into a hypothetical passenger car stream. However, due to significant proportion of motorcycles in traffic streams in developing countries such as Vietnam, it is better to take motorcycles as the common unit.

Many methodologies have been conducted to estimate passenger car unit in the existing literature. Most of them estimate the common unit upon a homogeneous traffic concept, such as strict lane discipline. Aggarwal (2008) developed a fuzzy based model for the estimation of
PCU values in India traffic conditions. Four identified inputs including width of pavement, type/quality of shoulder, directional split and traffic composition/percentage of slow moving traffic were taken into account in the model. All inputs are classified into Low and High. However, the model did not show the effect of dynamic characteristics of mixed vehicular traffic. According to Chandra et al. (2003), PCU values for different vehicles under mixed traffic situation are directly proportional to the speed ratio and inversely proportional to the space occupancy ratio with respect to passenger cars. The authors did not take the fact that the space occupancy of a vehicle is larger when this vehicle runs faster into consideration. Tiwari et al. (2000) derived passenger car unit for Indian conditions by adjusting the density method to handle heterogeneous traffic. The authors measured the distribution of each traffic type across the pavement width from different highway types. Nevertheless, the authors did not show the relationship between the speed and the density of vehicular traffic streams. Arasan et al. (2008) focused on the estimation and study of the possible variation of passenger car unit values of different categories of vehicles at various traffic volume levels, under heterogeneous traffic conditions on four-lane divided intercity roads using a simulation model. The results of the study provide the complexity of the vehicular interaction in heterogeneous traffic. It has been found that the PCU value of a vehicle type varies considerably with variation in traffic volume.

The urban road system in Vietnam carries heterogeneous traffic, where roadways are shared by many traffic modes with different physical sizes. With the predominance of two-wheeled vehicles in traffic streams, the homogeneous traffic concept has a limitation in application for heterogeneous traffic. The proposed methodology in this study considers motorcycle unit (MCU) as a common unit because the proportion of motorcycles dominates over vehicular traffic streams. The terminology “motorcycle” used in this research refers to motorized two-wheelers. In Vietnam, the engine capacity of motorcycles, including mopeds, scooters, and normal motorcycles, generally ranges from 50 cc to 150 cc.

In order to obtain a proper motorcycle unit, the present study aims (i) to draw the technique applied for collecting and analyzing data, (ii) to develop a methodology for estimating motorcycle unit, and (iii) to validate the proposed methodology with other methodologies in the existing literature.

2. DATA COLLECTION

With a high population of motorcycles, Hanoi, Vietnam was a good representative to conduct this research. Several candidate mid-blocks were observed on-site for the evaluation of traffic and environmental conditions. Finally, three sections at three urban streets satisfied the criteria of data collection, that are (i) sufficient motorcycle volumes; (ii) not near bus stop, petrol station, etc. to keep off modification maneuvers from road users and (iii) easy to observe motorcycles discretely. Three study sites, named 1, 2 and 3, locate on two-lane undivided roadways with two directions. The width of roadways are 11 (m), 7.4 (m) and 7.2 (m), respectively. The traffic is mixed traffic of non-motorized vehicles, motorcycles, cars, vans, buses, etc., in which the motorcycle proportion is more than 85%. The data were collected in December 2006. The operation data determining the need for this study include position, speed, lateral and longitudinal distances and road configuration and characteristics. The digital video recorder was set up overhead at the study site, right angle to the direction of the vehicular traffic. The filming traffic operations converted into video files then replayed in a computer. The positions of vehicles were identified from image video files every one-tenth of a second interval. These instantaneous positions were calculated according to the screen coordinates, converted into roadway coordinates by using the SEV software, which was developed in the traffic lab for specific purposes.
2.1 Data Analysis by SEV Software

The computer software SEV, which developed in the traffic lab for this specific purpose, was used in order to analyze the traffic data. The input files were movie clips with the resolution of 640 × 480 pixels, which captured vehicular traffic at the candidate locations. The output files were Excel compatible files, which had advantages when analyzing the trajectory data, as well as other necessary information about motorcycle traffic. SEV has several advantages over conventional counting techniques, as described below:

- The ability to measure the trajectories of several vehicles simultaneously;
- The ability to measure the position of a vehicle over time intervals as low as one-thirtieth of a second;
- The ability to use multiple repetitions to verify the preceding results or recollect missing data, as well as to filter out unnecessary data;
- Fewer equipment and installation requirements, and few observers required, both on-site and in the laboratory;
- It is user-friendly, simple to learn, and easy to operate.

Figure 1 shows the interface of SEV software at a study location.

2.2 Coordinate Transformation Technique

According to Khan et al. (2001), for every screen coordinate pair \(x_s, y_s\) and roadway coordinate pair \(x_r, y_r\), the following expression may be derived:

\[
x_r = \frac{C_1 + C_7 x_s + C_5 y_s}{C_4 x_s + C_5 y_s + 1}
\]

\[
y_r = \frac{C_6 + C_7 x_s + C_8 y_s}{C_4 x_s + C_5 y_s + 1}
\]

where

\(x_r, y_r\) : Roadway x and y coordinates;
\( x_s, y_s \): Screen x and y coordinates;
\( C_1, ..., C_k \): Coefficients.

In order to match the coordinate between screen and roadway, all coefficients will be computed by solving the above equations. This process required at least four points, so-called base points, from which, all screen and roadway coordinates were determined. The trajectory data for any vehicle were achieved by clicking on the same position at that vehicle over time intervals. Then, the motorcycle’s trajectory data, speeds, accelerations/decelerations and lateral and longitudinal distances between the subject motorcycle and other vehicles were obtained.

3. METHODOLOGY

The motorcycle unit (MCU) for each type of vehicle in this study was developed with a consideration of dynamic characteristics of moving vehicles. That factor expressed the relationship between speeds and effective spaces with respect to a mode taken and a motorcycle as follows.

3.1 Effective Space of a Vehicle

The effective space of a vehicle is defined as the necessary space needed by a vehicle to maintain its current speed. In other words, that is the occupied and necessary space of the vehicle moving with the given speed on a roadway. It is calculated by the product of the effective width and the effective length. Therefore, that value depends on the vehicle speed, mode and other adjacent vehicles. Because motorcycles predominate over traffic stream, the effective width and the effective length are estimated by the distance between vehicles and motorcycles as below:

\[
S_k = S_{w,k} \times S_{l,k}
\]

where,
\( S_k \): Effective space of a vehicle type \( k \), \( (m^2) \);
\( S_{w,k} \): Effective width of a running vehicle type \( k \) \( (m) \);
\( S_{l,k} \): Effective length of a running vehicle type \( k \) \( (m) \).

\( S_{l,k} \), the effective width of a running vehicle type \( k \), is estimated by the summation of the average length of the vehicle and the inter-vehicle spacing. The inter-vehicle spacing is defined as the total distances (i) between the subject vehicle and the leading motorcycle and (ii) between the subject vehicle and the lag motorcycle. This space is necessary for a moving vehicle to travel safely by avoiding the disturbance from the others.

\( S_{w,k} \), the effective length of a running vehicle type \( k \), is calculated by the summation of the average width of the vehicle and the lateral spacing. The lateral spacing is defined as the total distance (i) between the subject vehicle and the left vehicle and (ii) between the subject vehicle and the right vehicle. From Figure 2, the effective space of a vehicle type \( k \) is the summation of the gray area and the red rectangle.
The tabulation of vehicle categories used in this research, along with average dimensions, is illustrated in Table 1.

Table 1 Vehicle categories and their sizes

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Vehicles included</th>
<th>Average width (m)</th>
<th>Average length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cycle</td>
<td>Bicycles</td>
<td>0.45</td>
<td>1.90</td>
</tr>
<tr>
<td>2</td>
<td>Motorcycle</td>
<td>Scooter, Motorbike Mopeds</td>
<td>0.64</td>
<td>1.87</td>
</tr>
<tr>
<td>3</td>
<td>Car</td>
<td>Car, Jeep, Van</td>
<td>1.44</td>
<td>3.72</td>
</tr>
<tr>
<td>4</td>
<td>Minibus</td>
<td>Mini bus, mini truck</td>
<td>2.10</td>
<td>6.10</td>
</tr>
<tr>
<td>5</td>
<td>Bus</td>
<td>Bus</td>
<td>2.43</td>
<td>10.10</td>
</tr>
</tbody>
</table>

Adopted from Chandra et al. (2003)

SEV was applied to estimate effective spaces and mean speeds of different types of vehicles ($S_k$ and $V_k$). The following figures represent the relationship between effective spaces and speeds of different types of vehicles at three locations. It is noted that the sample size at each location is the same.
Figure 4 The relationship between effective spaces and speeds of passenger cars

Figure 5 The relationship between effective spaces and speeds of cycles

Figure 6 The relationship between effective spaces and speeds of mini buses
From those figures above, it is clear that the relationships between speeds and effective spaces at different locations are insignificantly different. Therefore, all data at three locations are pooled and one equation is accepted for each type of vehicles as below:

For motorcycles:

\[ S_{mc} = 0.39(V_{mc})^2 - 2.35 V_{mc} + 12.39 \]

\[ R^2 = 0.63; \]  \hspace{1cm} (4)

For cars:

\[ S_{ca} = 0.26(V_{ca})^2 + 2.01 V_{ca} + 12.32 \]

\[ R^2 = 0.66; \]  \hspace{1cm} (5)

For cycles:

\[ S_{cy} = 0.07 (V_{cy})^2 + 0.96 V_{cy} + 3.72 \]

\[ R^2 = 0.61; \]  \hspace{1cm} (6)

For mini buses:

\[ S_{mb} = 0.37(V_{mb})^2 + 1.74 V_{mb} + 31.99 \]

\[ R^2 = 0.75; \]  \hspace{1cm} (7)

For buses:

\[ S_{bs} = 0.69 (V_{bs})^2 + 3.09 V_{bs} + 49.03 \]

\[ R^2 = 0.79; \]  \hspace{1cm} (8)

where,

\( S_{mc}, S_{ca}, S_{cy}, S_{mb}, S_{bs} \): The effective space of motorcycle, car, cycle, mini-bus and bus category, respectively;

\( V_{mc}, V_{ca}, V_{cy}, V_{mb}, V_{bs} \): The average speed of motorcycle, car, cycle, mini-bus and bus group, respectively;

3.2 Formula of Motorcycle Units (MCU)

The motorcycle unit (MCU) for each type of vehicle in this study was developed with the consideration of dynamic characteristics of moving vehicles and described as below:

\[ MCU_k = \frac{S_k(V_k)}{S_{mc}(V_k)} \]  \hspace{1cm} (9)

where,

\( MCU_k \): Motorcycle unit of vehicle type \( k \);

\( V_k \): The mean speed of vehicle type \( k \) (m/sec);

\( S_{mc}(V_k), S_k(V_k) \): Effective space of a motorcycle and a vehicle type \( k \) at speed \( V_k \), (m^2), respectively.

The above formula identifies the motorcycle unit as the number of motorcycles, which can be replaced by a single vehicle of specified type \( k \) in a given speed. In the other words, motorcycle unit estimates how many motorcycles can be replaced by one vehicle of a specific type running at the same speed.
The motorcycle unit values are archived after computing effective spaces and mean speeds of all vehicle categories. Those values for different types of vehicles at different locations are given on Table 2.

Table 2 MCU factors as estimated at different sections

<table>
<thead>
<tr>
<th>Location</th>
<th>Car Speed</th>
<th>MCU</th>
<th>Cycle Speed</th>
<th>MCU</th>
<th>Minibus Speed</th>
<th>MCU</th>
<th>Bus Speed</th>
<th>MCU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.35</td>
<td>2.20</td>
<td>4.59</td>
<td>0.98</td>
<td>8.89</td>
<td>3.45</td>
<td>6.48</td>
<td>7.27</td>
</tr>
<tr>
<td>2</td>
<td>9.43</td>
<td>2.19</td>
<td>5.07</td>
<td>1.00</td>
<td>9.27</td>
<td>3.33</td>
<td>7.17</td>
<td>6.87</td>
</tr>
<tr>
<td>3</td>
<td>7.42</td>
<td>2.54</td>
<td>3.98</td>
<td>0.94</td>
<td>6.06</td>
<td>4.52</td>
<td>5.66</td>
<td>7.68</td>
</tr>
</tbody>
</table>

The values of motorcycle unit computed from Equation 9 are significantly affected by the ratio between effective spaces of a motorcycle and another mode. Because the average speeds of all vehicle types in location 3 are less than those in location 1 and 2, the MCU’s values are almost higher than those in other locations. It comes from the fact that the effective space is a function of the speed, which means the lower speed a vehicle runs, the higher number of motorcycles can displace that vehicle. The next part validates the concept of the proposed MCU’s estimation.

4. VALIDATION OF MOTORCYCLE UNIT

The proposed method of motorcycle unit estimation was validated based on the validation data set at three study locations. The same data set was also used to test several other methods, including TCXDVN 104-2007 (2007), Chandra et al. (2003), Indian Road Congress (2001) and Anard et al. (1999). The data used for those studies also came from the developing countries, where the traffic conditions are similar to Hanoi, Vietnam.

The first research applied to validate the proposed methodology is TCXDVN104-2007 (2007), the Vietnam specification for design for urban roads. The MCU estimation is converted from recommended PCU in this study and shown as below:

Table 3 MCU’s factors for vehicles by PCU’s conversion of TCXDVN 104-2007

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>MCU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cycle</td>
<td>1.20</td>
</tr>
<tr>
<td>2</td>
<td>Motorcycle</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>Car</td>
<td>4.00</td>
</tr>
<tr>
<td>4</td>
<td>Minibus</td>
<td>10.0</td>
</tr>
<tr>
<td>5</td>
<td>Bus</td>
<td>12.0</td>
</tr>
</tbody>
</table>

Chandra et al (2003) developed the formula to convert other transportation modes into passenger car. The modified formula which was used for MCU conversion is described by equation 10.

\[
MCU_i^{(CHANDRA)} = \frac{V_{mc} / V_i}{A_{mc} / A_i}
\]

where,

\[MCU_i\] : Motorcycle unit of vehicle type \(i\);
$V_{mc}, V_i$: Mean speed of motorcycles and vehicle type $i$, respectively (Km/h);

$A_{mc}, A_i$: The respective projected rectangular area (length x width) of motorcycles and type $i$ vehicle on the road, respectively ($m^2$).

The PCU’s values as recommended by Indian Roads Congress (2001) were converted into MCU’s values and used to compare with the proposed method. However, this report does not explain how these values are calculated. Table 4 shows the MCU’s factors with the percentage of the heavy vehicle type in traffic of less than 5%.

Table 4 Recommended MCU’s factors for vehicles by conversion of IRC

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>MCU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cycle</td>
<td>0.80</td>
</tr>
<tr>
<td>2</td>
<td>Motorcycle</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>Car</td>
<td>2.00</td>
</tr>
<tr>
<td>4</td>
<td>Minibus</td>
<td>4.40</td>
</tr>
<tr>
<td>5</td>
<td>Bus</td>
<td>8.00</td>
</tr>
</tbody>
</table>

Anard et al. (1999) developed passenger car unit values for Malaysia, where traffic is mixed with high proportion of motorcycles. This method considers the effects of mixing traffic, speed and headway. However, the paper did not show the PCU for bicycles. The PCU’s value for bicycles therefore, was developed with the same concept of these authors. The factors including mean speed, mean lower headway of bicycles are assumed to be 4.55 (m/sec) and 0.79 (sec), respectively. The adopted formula for MCU estimation at mid-block sections from Anard et al. (1999) is below:

$$MCU_i^{(ANARD)} = \frac{W_i}{W_{mc}} \times \frac{U_i}{U_{mc}} \times \frac{t_i}{t_{mc}} = F_w \times F_u \times F_t$$

where,

$W_i, W_{mc}$: Transverse gap for vehicle type $i$ and motorcycles, respectively;

$U_i, U_{mc}$: Mean speed of vehicle type $i$ and motorcycles, respectively;

$t_i, t_{mc}$: Mean lower time headway of vehicle type $i$ and motorcycles, respectively;

Table 5 represents the MCU’s values (adopted concept of Anard et al.) for different types of vehicles.

Table 5 Recommended MCUs for vehicles by conversion of Anard et al. (1999)

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>$F_w$</th>
<th>$F_u$</th>
<th>$F_t$</th>
<th>MCU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cycle</td>
<td>1.00</td>
<td>2.00</td>
<td>0.50</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>Motorcycle</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>Car</td>
<td>1.00</td>
<td>1.21</td>
<td>1.35</td>
<td>1.63</td>
</tr>
<tr>
<td>4</td>
<td>Minibus</td>
<td>1.00</td>
<td>1.22</td>
<td>2.10</td>
<td>2.56</td>
</tr>
<tr>
<td>5</td>
<td>Bus</td>
<td>1.00</td>
<td>1.13</td>
<td>1.13</td>
<td>3.79</td>
</tr>
</tbody>
</table>

The concept for validation proposed formula is based on the speed-flow curve (Figure 8). It is understandable that if the mean stream speeds at different time intervals are the same, the volumes (after being converted into MCU) must be the same. Therefore, after calculating mean stream speeds at different time intervals, if two mean stream speeds are similar, the volumes at these intervals are converted into MCUs. If the converted volumes are the same,
the methodology of calculating MCU is correct. Otherwise, it needs to be revised.

Due to the large variation in speed of different types of vehicles, the weighted mean speed is employed as stream speed and calculated by using the following equation:

\[ V_m = \frac{\sum_{i=1}^{k} n_i v_i}{\sum_{i=1}^{k} n_i} \]  \hspace{1cm} (12)

where,

- \( k \) : Total number of vehicle types present in stream;
- \( V_m \) : Mean stream speed (m/sec);
- \( v_i \) : Mean speed for type \( i \) (m/sec);
- \( n_i \) : Number of vehicles of type \( i \).

At every location, data were collected at 15 minutes. The mean speeds of all types of vehicles and volumes at every minute were recorded. The range of mean stream speeds at location 1 is from 6.84 (m/sec) to 10.11 (m/sec), at location 2 is from 8.18 (m/sec) to 10.04 (m/sec), and at location 3 is from 5.89 (m/sec) to 8.02 (m/sec).

The different volumes after being converted into MCU, in which the same stream speed is applied at three locations by different methods (proposed, Chandra et al. (2003), India Road Congress (2001), Anard et al. (1999) and TCXDVN104-2007 (2007) methods), are shown in Figure 9, 10 and 11.
From those figures, it is clear that mean stream speeds are inversely proportion to volumes. An example of different volumes after being converted into MCU per minute are illustrated in Figure 9. Each point stands for the maximum or minimum volume (MCU/min) of each method. The distances between two same-color points (red, blue, cyan, green and violet ones) in the same mean stream speed stand for the maximum difference from volumes (MCU/min) of proposed, Chandra, IRC, Anard and TCVN 104-2007 method. If one distance is longer
than another distance, meaning that the method has worse result than the other. When the mean stream speed is 9.9 (m/sec), the distance of two blue points is longest. It means that Chandra method is the worst among all. The distance of two red points is shortest, meaning that the proposed method is the best. Simply speaking, Figure 12 shows the aggregate data for all methods at all locations. The y-axis is the percentage of difference from volumes of two extreme values at the same mean stream speed. The red column is shortest, meaning that the percentage of difference of proposed method is smallest. The figure indicates that the proposed formula for MCU estimation provides the best estimates at three locations among four methods.

![Percentage of difference volumes at 3 locations and different methods](image)

Figure 12. Percentage of difference volumes at 3 locations and different methods

5. CONCLUSION

In most of the developing countries including Vietnam, mixed traffic conditions are very common on roads and highways. There is a wide variation in the static and dynamic characteristics of different traffic means. The most appropriate way of accounting for this variation for any traffic analysis in traffic stream is to convert all vehicles into a common unit. The most proper unit for Vietnam traffic condition is motorcycle unit (MCU). In this research, the motorcycle unit (MCU) for each type of vehicle was developed with a consideration of dynamic characteristics of moving vehicles. That factor expresses the relationship between speed and effective space with respect to the mode taken and a motorcycle. It depends on vehicle speeds, modes and other adjacent vehicles. The proposed formula is validated by the data set at three study locations. The same data set is also used to test several other methods. The results show that the proposed formula represents the best one among them. The findings provide useful information that can be used to develop speed-flow relationship, estimate highway capacity, analyze level of service and formulate effective traffic regulation and control measures.

REFERENCES


Chandra, S., Kumar, U. (2003). Effect of lane width on capacity under mixed traffic condition in India. *Journal of Transportation Engineering, American Society of Civil Engineers,*


