# Traffic Characteristics of Mixed Traffic Flow in Urban Arterials

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**Abstract**: Motorcycles are one of the main transportation modes in some Asian countries because of their advantages, such as better mobility and lower costs, as compared to automobiles. Most of the current designs of roads, such as speed limit and lane markings, are based on automobile traffic and not entirely suitable for motorcycles. Therefore, there is a need to further investigate the traffic characteristics of mixed traffic flow and the interactions of vehicles where the proportion of motorcycles is high. With a proposed novel data collection approach using aerial videography, detailed and accurate vehicle trajectory dataset for traffic stream in urban arterials are collected. The mixed traffic characteristics such as lane choice, distribution of lateral positions, spacing distributions at various level of traffic density are investigated. The characteristics could be useful for the development of microscopic behavioral models and integration with traffic simulation models for the evaluation of mixed traffic environment.

*Keywords*: Mixed flow, motorcycles, macroscopic characteristics, microscopic characteristics

## 1. INTRODUCTION

Motorcycles are one of the main transportation modes in some Asian countries because of their advantages, such as better mobility, fuel consumptions, and lower costs, as compared to automobiles. In Taiwan, the ownership rate of motorcycles and scooters is over 650 per 1000 inhabitants, which is the top among the world. Compared to private cars, motorcycles and scooters are smaller in size, and their road positioning may not follow lane markings and lane disciplines. However, most of the current designs of the road, such as geometry, pavement, and lane markings, are based on the theory and assumptions for automobile traffic, and motorcycles have a much smaller size, and do not necessary follow lane discipline that automobiles follow. Since the lane width is determined based on the size of passenger cars, motorcycles can travel side by side in a lane (Branston *et al.*, 1977) or follow a vehicle obliquely (Robertson, 2002 & 2003; Lee *et al.*, 2008 & 2012). These behaviors would further influence the passenger cars. Hsu *et al.* (2003) presented a comparison study of motorcycles of several Asian countries.

For mixed traffic flow, there is a need to develop better traffic control devices, especially when the traffic density and the proportion of motorcycles and scooters are high. Previous studies investigated the macroscopic characteristics of mixed traffic by representing motorcycles as an equivalent of passenger car using Passenger Car Unit (PCUs), which could be fixed or a variable with the share of motorcycles. Webster *et al.* (1966) proposed a fixed pcu value of 0.33 for motorcycles for signalized intersection in the UK, and Kimber *et al.*

(1982) suggested 0.4 as a proper pcu value for motorcycle. Other fixed pcu values were presented in Turner *et al.* (1993). However, a fixed pcu value might not suitable for diverse traffic conditions. May *et al.* (1986) reported a pcu value as 0 during the first 6 seconds of effective green time, and then the pcu value varies from 0.53 to 0.65 subsequently. Rongviriyapanich *et al.* (2005) described motorcycle influences in a signalize intersection and in mid-block by variable pcu. They investigated combinations of scenarios of flow rates (in 5 levels, i.e. 10-15, 15-20, 20-25, 25-30, and over 30 pcu/minute) and proportions of motorcycles (in three groups, i.e. low share 0-0.3, medium share 0.3-0.6, and high share over 0.6). The value of pcu is suggested to be 0.2 to 0.8 for these scenarios. Other papers also raised omnigenous pcu value ranges (Chandra *et al.*, 2003; Branston *et al.*, 1978; Wigan, 2000; Hossain, 2001; Lan *et al.* 2005).

Some studies developed microscopic simulation models for traffic streams with motorcycles, for traffic modelling purposes. For example, Lan *et al.* (2010*)* simulated the driving behaviors of cars and motorcycles under mixed traffic using cellular automaton, and some rules for the car following, lane change, and lateral drift were proposed. The result can be used to explain the macroscopic traffic phenomena. There are also a number of studies using cellular automata to analysis the properties of traffic flow (Helbing *et al.*, 1999; Menga *et al.*, 2007; Mallikarjuna and Rao, 2009; Mallikarjuna and Rao, 2011; Vasic *et al.*, 2012). A common problem of these simulation models are the lack of real-world data for the model calibration and validation. This is because it is difficult to collect accurate and detailed microscopic data. There are several recent studies analyzing the empirical data of mixed traffic with statistical models (Matsuhashi, 2005; Minh *et al.*, 2005; Tuan and Shimizu, 2010; Ambarwatia *et al.,* 2014; Vlahogianni, 2014; Kanagaraj *et al.*, 2015) and discrete choice models (Lee *et al.*, 2009; Shiomi *et al.*, 2013).

The objective of this study is to investigate the characteristics of motorcycle-oriented mixed traffic flow, which can be further used for the studies of behavior models of motorcycles for micro-simulation purposes. Empirical data is collected in an urban arterial in Taipei, Taiwan. Using a novel data collection approach with aerial videography, accurate vehicle trajectory data for traffic stream of an arterial up to 200m can be collected. This vehicle trajectory dataset coving the whole arterial and intersections at upstream and downstream offers some new opportunities for the investigation of mixed traffic characteristics such as lane choice, distribution of lateral positions, spacing distributions etc at various level of traffic density.

The structure of this paper is organized as follows. Section 2 discusses the traffic characteristics used to illustrate mixed traffic flow with motorcycles. The data collection approach is described in Section 3. The macroscopic characteristics and microscopic characteristics of the traffic are presented in Sections 4 and 5 separately. Section 6 concludes the key findings and further research of this study.

## 2. MIXED TRAFFIC FLOW WITH MOTORCYCLES

In the theory of traffic flow, flow, speed, and density are used to describe the macroscopic characteristics of traffic flow, whereas headway, individual speed, and spacing are used for the microscopic characteristics. These characteristics are good for homogeneous traffic. For motorcycle oriented mixed traffic or heterogeneous traffic in which there is a non-negligible amount of motorcycle and scooters, the classic terms may not be adequate to fully describe the traffic status.

While there are clear definitions in the computation of flow and speed, density is not

well defined for mixed traffic with motorcycles. The definition of density in traffic flow theory, i.e. number of vehicles per distance, assumes that the vehicles have lane discipline and traverse within the lane. However, motorcycles do not follow lane discipline, and usually ride side-by-side with cars or other motorcycles. Therefore, the traditional definition of traffic density is not a good representation of the traffic status, especially in mixed traffic that there are large variations in the sizes of vehicles. Mallikarjuna and Rao (2006) proposed area occupancy, which is a function of vehicle area and speed, as a substitution of density to better represent traffic conditions. Area occupancy computes the road space being occupied by the vehicles, and for this study, the computation of Area Occupancy (AO) is simplified as,

$$AreaOccupancy = \frac{1}{TWL}\sum_{t}\sum_{i \in I_t} w_i l_i \tag{1}$$

where $T$ is the observation period (in sec), $W$ is the width of the study area, $L$ is the length of the study area, $t$ is the index of time instance, $I_t$ is the set of vehicles appeared in the study area at time $t$, $w_i$ and $l_i$ are the width and length of vehicle $i$.

For the microscopic characteristics, motorcycles are small in size, lighter weight and larger horsepower to weight ratio. When a motorcycle rider chooses a vehicle lane to traverse and the lateral position within a lane, not just speed but also safety issues have to be considered. In additional to the longitudinal spacing with the front vehicle, the lateral spacing with the vehicles are also useful characteristics to quantify their acceptable gap when filtering through other vehicles. Based on a review of the literature, a list of traffic characteristics and traffic models for mixed traffic in macroscopic and microscopic approach is summarized in Table 1.

Table 1. Traffic characteristics and models for mixed traffic flow

|  | Macroscopic Approach | Microscopic Approach |
|---|---|---|
| Traffic Characteristics | • Flow<br>• Average speed<br>• Density<br>  ➢ Temporal occupancy<br>  ➢ Area occupancy | • Headway<br>• Individual speed<br>• Spacing<br>  ➢ Longitudinal<br>  ➢ Lateral<br>  ➢ Oblique front<br>• Lane choice<br>• Lateral positions within a lane |
| Traffic Models | • Traffic stream models<br>• Kinematic models<br>• Queuing models<br>• Delay models | • Car following<br>• Lane changing<br>  ➢ Overtaking<br>  ➢ Filtering<br>• Gap acceptance<br>• Intersections<br>• Discharge |

## 3. DATA COLLECTION METHODOLOGY

The study is to investigate the characteristics of mixed traffic flow, consisting motorcycles,

private cars and buses, in urban arterials. The traffic characteristics are analyzed in both macroscopic and microscopic dimensions. For the consistency of data representations, detailed trajectories of vehicles in the traffic stream are recorded and reproduced into variables of interest.

The data is collected by a trajectory extractor developed by Lee *et al.* (2009), which has a function to digitalize a video clip into a vehicle trajectory database, containing the positions, angles, dimensions of vehicles in the road section at every time instances. Basically, the trajectory extractor converts a video clip into second-by-second images and displays the image on the monitor for an operator to record the positions of the vehicles semi-manually. The coordinates on the image are then converted into true coordinates of the road with a projection matrix. This approach has been widely used to collect microscopic data for traffic behavior studies, and the adopted trajectory extractor software is powerful and has also been used by several other recent studies, such as Lee *et al.* (2011), Vlahogianni (2014), and Kanagaraj *et al.* (2015).

Previous studies record the video from a high position on the roadside, such as setting up a camcorder on a tall building or bridge. In the image, the vehicles in the near side are larger and the vehicles far away are smaller in the image, and a projection conversion is implemented to transform the coordinates. However, in practice, when we determine the mapped coordinates of the objects on the ground, error may be introduced if the heights of the moving objects are incorrectly identified due to three-dimensional perspective. In this study, we adopted an aerial videography approach to collect the video using a multicopter (model DJI Phantom 2 Vision+). Since the images by aerial videography are at the top view of the arterial, we can cover a much larger area and the error due to three-dimensional perspective can be ignored. The procedure and the feasibility of using aerial videography for traffic survey are presented in Luo *et al.* (2014).

The survey site is at the Zhongxiao East Road Section 4 in Taipei city, Taiwan. This is a 150m four-lane urban arterial with signalized intersections at both ends. An image of the survey site is shown in Figure 1, in which part of the area considered in this study is cropped for better illustration. The movements of vehicles in the trajectory database are also displayed with an animation player for visualization and error checking, as shown in Figure 2.


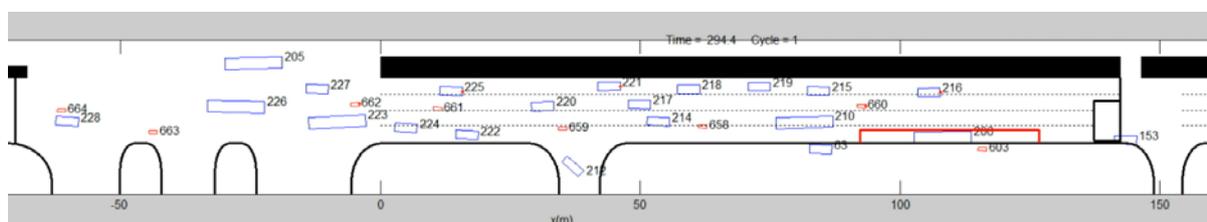Figure 1. An image of the traffic stream from the video


Figure 2. A screenshot of the vehicle trajectory playback

Thirteen pieces of video clips are collected at different time periods of a typical weekday, covering different level of traffic density situations, and total length of the dataset is 120 minutes. The videos were digitalized into vehicle trajectories at a resolution of 1 second. The dataset contained 34498 data points from 1654 vehicles, composed of motorcycles, private cars, taxis, vans, and buses, and the amount of data are shown in Table 2.

Table 2. Vehicle compositions in the database

| | Vehicle mode | | | | | Total |
|---|---|---|---|---|---|---|
| | Motorcycle | Private car | Taxi | Van | Bus | |
| No. of data points | 88785 (23.7) | 161478 (43.2%) | 95242 (25.5%) | 13627 (3.7%) | 14701 (3.9%) | 373833 (100%) |
| No. of vehicles | 3004 (33.9%) | 3386 (38.2%) | 1982 (22.4%) | 225 (2.5%) | 264 (3.0%) | 8861 (100%) |

In the study area, the outermost lane (lane 4) has a stopping area for buses, and there are taxis waiting on the roadside for passengers occasionally, and thus motorcycle riders tend to avoid this lane. The innermost lane (Lane 1) is the fast lane, and a "motorcycle prohibited" sign is marked on the ground. However, there are still a number of motorcycles running on this lane. There is a "motorcycle waiting zone" in front of the stop line for motorcycles waiting for the signal light. A layout of the study area is illustrated in Figure 3.
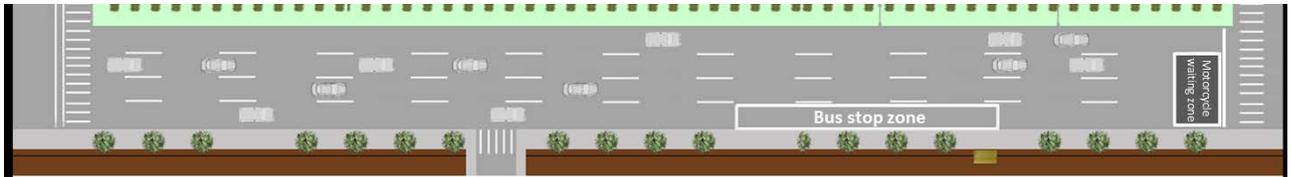


Figure 3. The layout of study area

The vehicle trajectory dataset is useful for generating macroscopic characteristics of the traffic stream and microscopic characteristics of each vehicle for further analysis. The kinematic characteristics of a vehicle, such as longitudinal and lateral speed and acceleration, can be computed by the position differences of the vehicle between consecutive time intervals. The driving environment variables, such as longitudinal spacing and lateral spacing, can be computed by the relative positions between the subject vehicle and the adjacent vehicles. Some distance-related variables are shown in Figure 4. As in the figure, $d_F$ is longitudinal spacing along the traffic direction from the subject vehicle to the vehicle $F$, $d_{LF}$ is the lateral spacing between the subject vehicle and the vehicle $LF$ beside the subject vehicle, and $Gap_l$ and $Gap_r$ are the gap distances that the subject vehicle has to pass through if filtering through two vehicles.
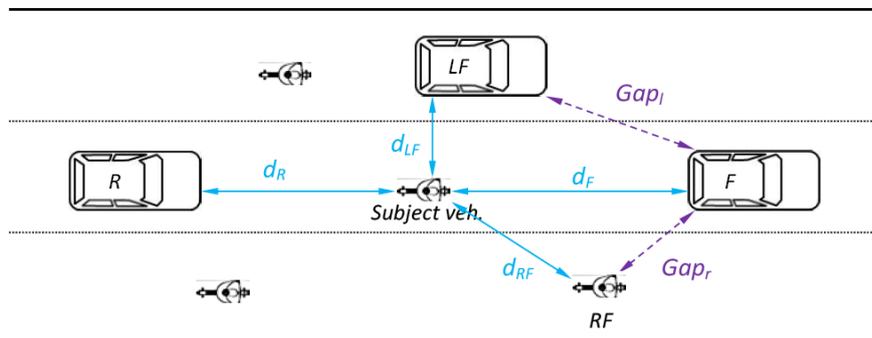


Figure 4. Definitions of interacting vehicles and their relations with the subject vehicle

# 4. MACROSCOPIC CHARACTERISTICS

The macroscopic features of traffic stream are characterized by the relationships of flow, speed and density. For mixed traffic, area occupancy is considered to be a better substitute of density. Figure 5 compares the values of density and area occupancy for the same set of data. As motorcycles occupy a smaller size in the road space compared to cars, it can be seen from the figure that density (i.e. number of vehicles per unit length) can be up to 70% and is an overestimation. It is suggested that area occupancy is a better representation and thus is adopted in this study.

The fundamental diagrams for the relationship between flow, speed, and area occupancy are shown in Figure 6. Since the traffic steam is mainly composed by motorcycles and private cars and their speeds are different, the two speeds are computed separately. It is noted that, as from Figure 5, area occupancy of 15% is corresponding to a high-density level. For the flow-area occupancy diagram, flow and area occupancy increases in proportion and reaches a peak at area occupancy of 7%, and the flow rate decreases with the area occupancy. For the speed-area occupancy diagram, speed decreases with the area occupancy, and the average speed of motorcycles is higher than that of passenger cars. The slope of motorcycle's speed is also less sensitive to the area occupancy that that of private cars, because motorcycles have a small size and better mobility to move through the spacing between vehicles. Similar phenomenon can also be observed for the speed-flow diagram.
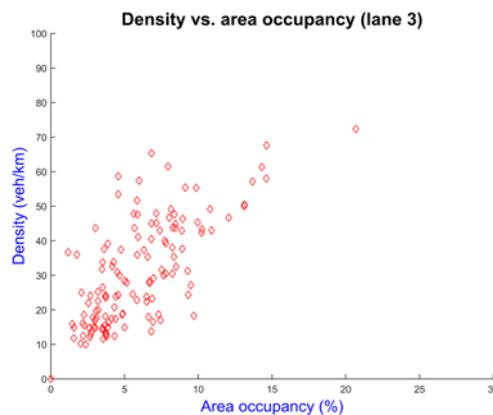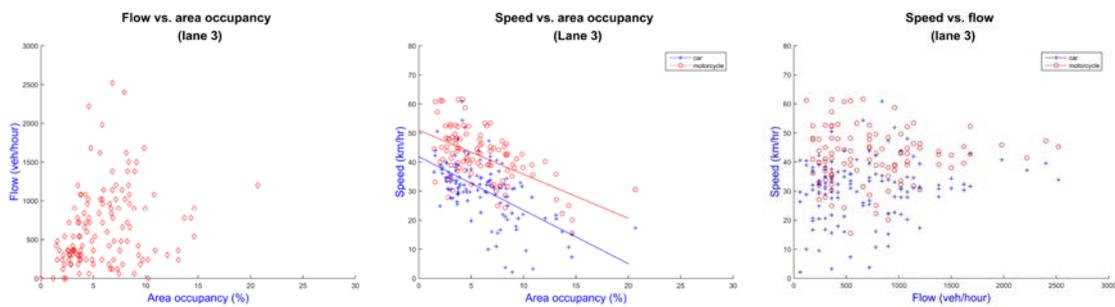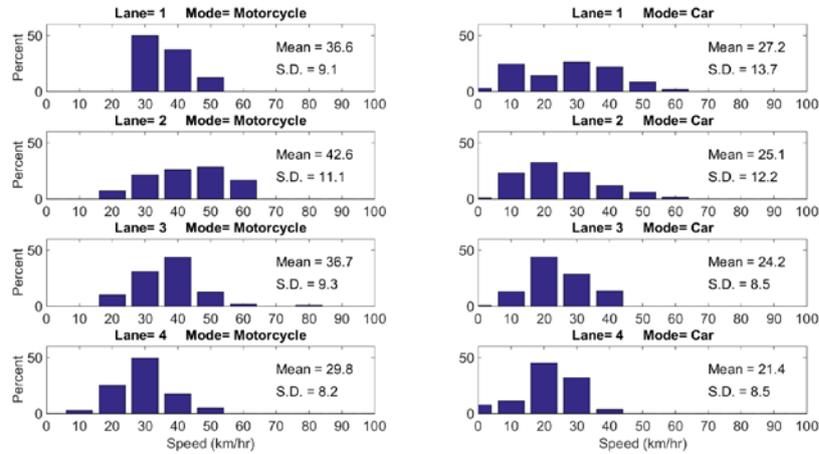


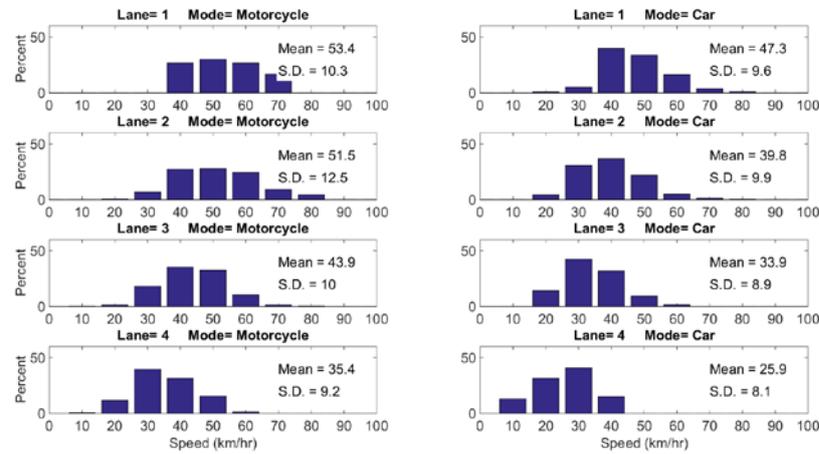Figure 5. The relationship between density and area occupancy



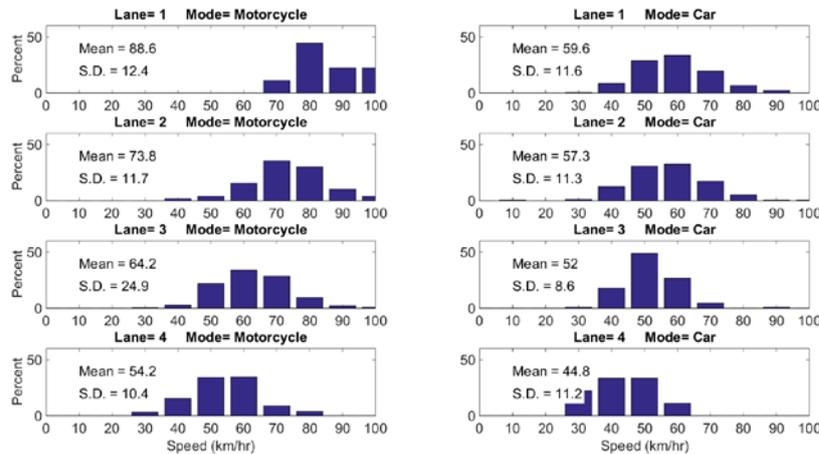(a) Flow vs. Area Occupancy    (b) Speed vs. Area Occupancy    (c) Speed vs. Flow
Figure 6. The diagrams for the relationships of flow, speed and area occupancy

(a) High area occupancy



(b) Medium area occupancy



(c) Low area occupancy

Figure 7. Distribution of speeds of motorcycles and cars at different lanes

Speed distributions of motorcycles and passenger cars at different lanes of the arterials are shown in Figure 7. Since speed decreases with area occupancy, the figures illustrate the scenarios for high, medium, and low area occupancy, for which the area occupancies are 26.7%, 8.1%, and 4.5% for the three cases respectively. In general, the average speed of motorcycles is also higher than that of passenger cars. Among the three scenarios, the vehicles in the low occupancy scenario are faster and the vehicles in the high occupancy scenario are

slower as expected. For the speed differences at across lanes, the average speed on Lane 1 (innermost lane) is larger than that on Lane 2, and the speed on Lane 2 is larger than that on Lane 3, and the speed on Lane 3 is larger than that on Lane 4 (outermost lane). It is noted that, even though Lane 1 is a motorcycles prohibited lane, there are some motorcycles riding on it at a relatively high speed and ever over the speed limit of 50 kph.

Welch's ANOVA are used to test if the average speeds of motorcycle and cars under area occupancy scenarios are equal. For the high area occupancy scenario, the result shows that the average speeds of motorcycles and passenger cars on lane 2 have a significant difference. For the medium area occupancy scenario, the speeds between two vehicle modes on lane 1 and lane 2 are significant different, but no significant on lane 3 and lane 4. For the low area occupancy scenario, the speeds between two modes on lanes 1 to 3 are significant different.

# 5. MICROSCOPIC CHARACTERISTICS

The characteristics of individual vehicles are important for the study of behavior models to be used in micro-simulation. We present the microscopic characteristics of mixed traffic by investigating the lane choice and lateral positions of vehicles, as well as the longitudinal and lateral spacing between vehicles. Since our data collection approach is very comprehensive and detailed vehicle trajectories are recorded, these microscopic characteristics could be extracted and computed from the dataset with a computer coding in MATLAB.

Figure 8 shows the distribution of lateral positions of motorcycles and private cars on the arterial, and the changes of the distributions at different section from the upstream to the downstream along the arterial. In general, passenger cars prefer to use the inner two lanes (i.e. Lane 1 and Lane 2) than the outer two lanes (i.e. Lane 3 and Lane 4). Most of motorcycles use Lane 3 and avoid Lane 1 (motorcycle prohibited) and Lane 4 (bus stop and temporary parking). On the lane discipline, we can also see that the most of the lateral positions of passenger cars are maintained at the middle of a lane, as car drivers follow lane discipline when not performing a lane changing. In contrast, motorcycles do not follow lane discipline, and the lateral positions of motorcycles would not concentrate at the middle of a vehicle lane. The frequency of lateral positions varies with its distance from the roadside, like treating the four vehicle lanes as a single lane. Furthermore, there is significant difference between the two lateral spacing distributions of motorcycles at 0m and 150m (p-value = 0.0023), and the distributions change with the longitudinal position on the arterial, partly because of the roadside interferences. As there is a bus stop from x=80-120m, motorcycles tend to avoid riding on the outermost lane from x=60m.

The comparison of lateral positions at 120 m in various area occupancy scenarios is shown in Figure 9. Riders give priority to use lane 3 when the area occupancy is not high. When the area occupancy becomes high, lane 4 is their second-preferred lane. Besides, there is almost no illegal rider riding on lane 1, a motorcycle-prohibited lane. The Mann-Whitney-Wilcoxon test shows that the distributions of lateral positions in Figure 9 are significant different at different traffic density level.

The distributions of lateral positions can be highly dependent on the level of traffic congestion, especially for motorcycles. To investigate this relationship, Figure 9 illustrates the distributions of lateral positions of motorcycles at the scenarios of low, medium, and high area occupancy. We can see that, for the cases of low and medium area occupancies, motorcycle riders prefer to use Lane 3. And for the case of high occupancy, Lane 4 is also preferred and Lane 1 is barely used. One possible reason is that, when at high traffic density, the inner lanes

are full of private cars and there are little spaces left for the motorcycles to filter through, but the motorcycles can use the outer lanes for which the private cars do not prefer.
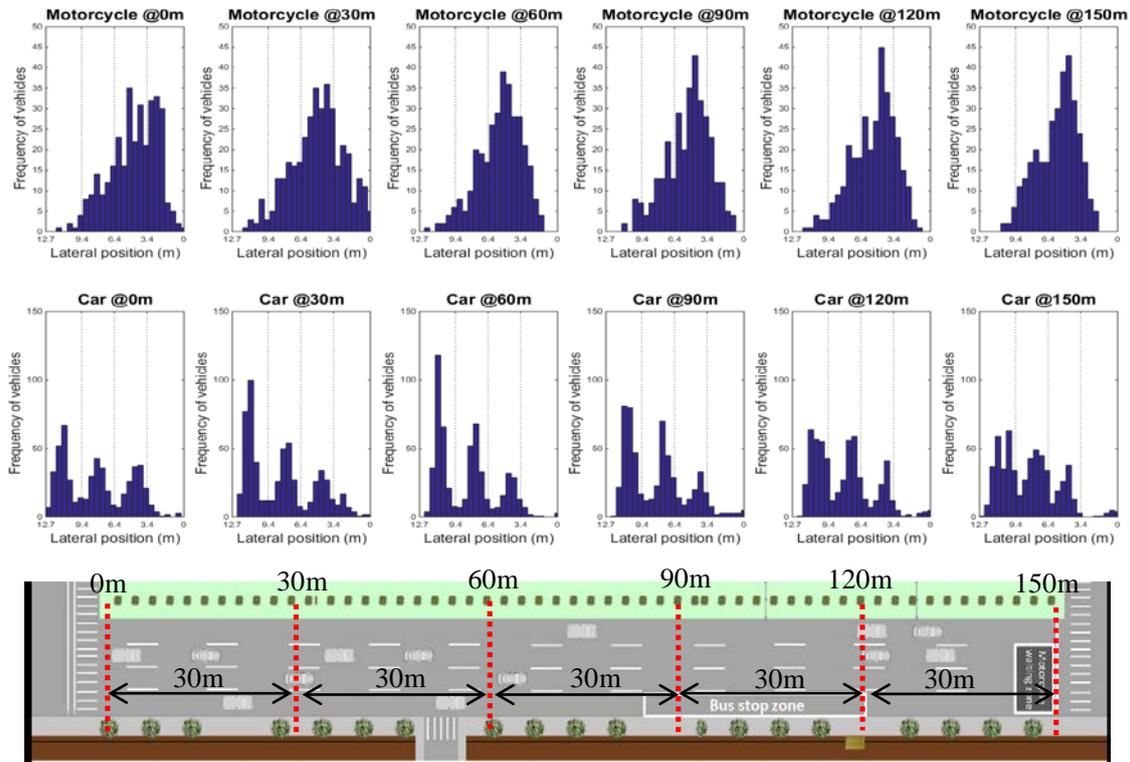


(top: motorcycle; middle: car; bottom: corresponding cross section at the arterial)
Figure 8. Lateral positions of motorcycles and private cars at different section along the arterial
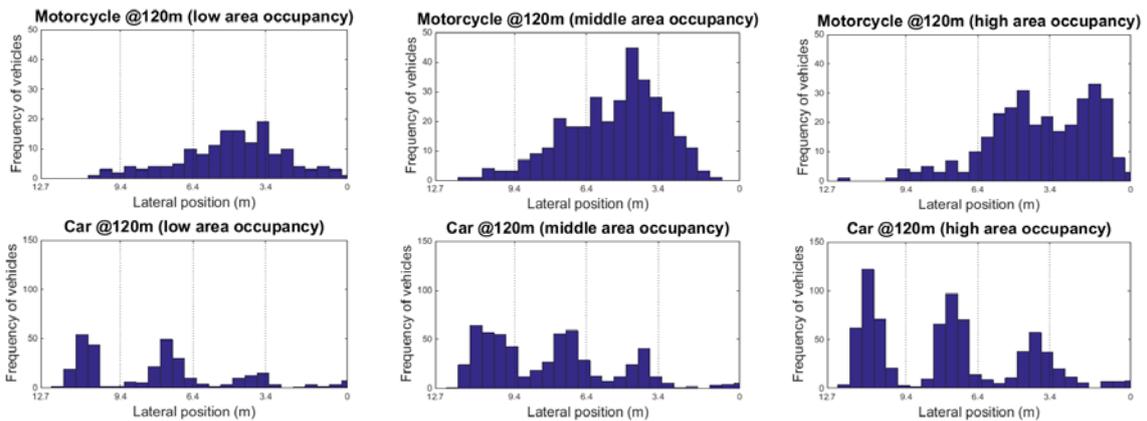


(a) Low area occupancy    (b) Medium area occupancy    (c) High area occupancy
Figure 9. Distribution of lateral positions at different level of congestion

The distributions of longitudinal and lateral spacings are also important microscopic characteristics of interest. The longitudinal and lateral spacing distributions for motorcycles and cars at different speed intervals are displayed in Figures 10 and 11 respectively. Because motorcycles are small in size, they can easily perform a quick lateral movement to do a lane changing and avoid hitting its front vehicle, and therefore motorcycles can keep a smaller longitudinal spacing with its front vehicle. This is verified by the results in Figure 10, which

shows that the longitudinal spacing of motorcycles is smaller than that of passenger cars in general in all cases regardless of the high speed or low speed range. For the speed range below 20 kph, the most motorcycle riders keep 2 to 2.5m from the front vehicle, whereas the longitudinal spacing for passenger cars is at 4.5 to 5m. For both motorcycles and passenger cars, the longitudinal spacing increases with the speed. At the speed range of 40 to 60 kph, the mode interval of longitudinal spacing for motorcycles is 5 to 5.5m, whereas it is 14.5 to 15m for private cars. The results of Mann-Whitney-Wilcoxon test show that all distributions between the two vehicle modes are significant different.
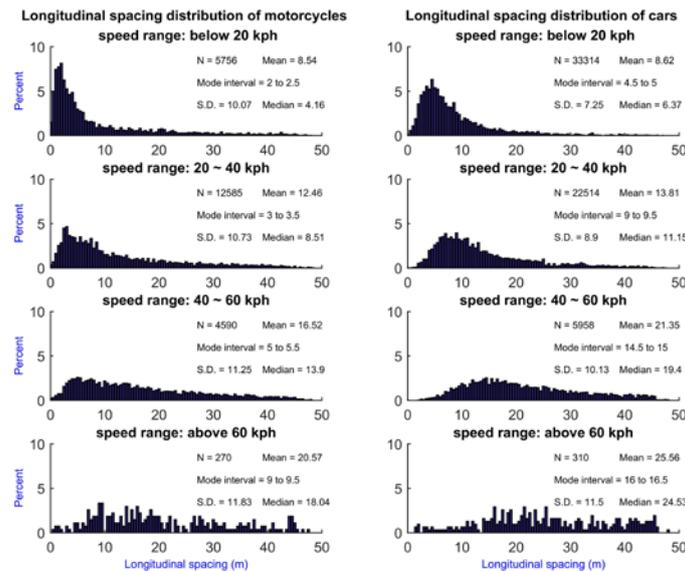


Figure 10. Distribution of longitudinal spacing of motorcycles and cars at different speed intervals

Similar to the longitudinal spacing, motorcycles also keep a smaller lateral spacing as compared to private cars. This is because private cars keep lane discipline, and the lateral spacing between cars on two adjacent lanes is at least 1m apart. Motorcycles may filter through the lateral spacing between two cars, and accepts a much smaller lateral spacing as long as it is safe enough. From Figure 11, at the speed interval of 20 kph, the mode interval of spacing for motorcycle is 0.75 to 1m, whereas it is 1.75 to 2m for cars. The lateral spacing also increases with the speed of traffic, but not as sensitive as the longitudinal spacing, because traffic is moving in the longitudinal but not the lateral direction. The Mann-Whitney-Wilcoxon test shows that the distributions between the two modes for the speed ranges below 60 kph are significantly different.
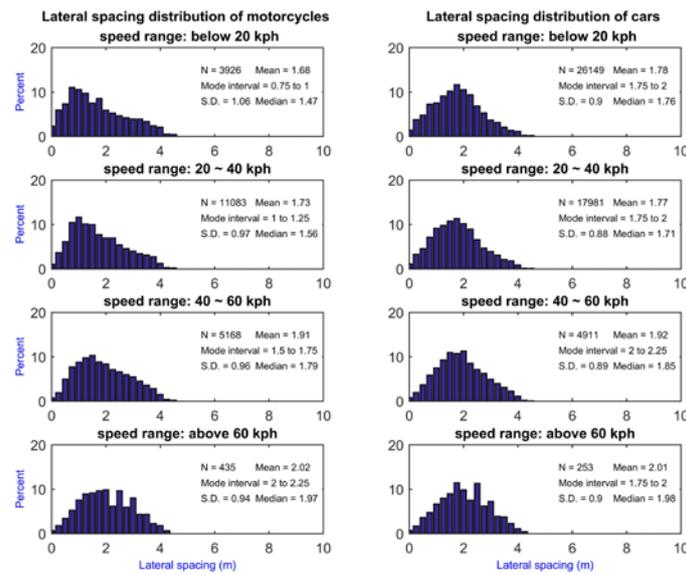
Figure 11. Distribution of lateral spacing of motorcycles and cars at different speed intervals

## 6. CONCLUSIONS

In this paper, some macroscopic and microscopic characteristics of mixed traffic with motorcycles and private cars are presented. We show that the traditional characteristics for homogeneous traffic may not be adequate to fully describe the traffic status of mixed traffic. Thanks to the recent advancement in the technology of aerial videography, some difficulties in video recordings are overcome, and thus a novel data collection approach is proposed. Detailed and accurate vehicle trajectory dataset for traffic stream in urban arterials are collected. This database can be used to investigate all observable movements of vehicles and can be used to derive detailed characteristics such as lateral positions, longitudinal spacing, and lateral spacing etc for different vehicle modes, vehicle lanes and level of traffic density. The derived characteristics can be useful for the development, calibration and validation of behavioral models of vehicles, which can then be integrated to microscopic traffic simulation model for more accurate evaluation of the performances such as capacity and safety of a traffic system due to geometric design. A limitation of the current study is that the dataset is collected from an urban arterial in Taiwan, and future work would be to expand the database for roads with different geometric layout and vehicle compositions.

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