REVISITING FUNDAMENTAL CHARACTERISTICS OF MIXED TRAFFIC FLOW; FOCUSING ON INTERACTIONS BETWEEN PASSENGER CARS AND MOTORCYCLES

Hiroaki NISHIUCHI*, Yasuhiro SHIOMI**, Kazushi SANO*, Tomoki WATANABE*
Nagaoka University of Technology*
Ritsumeikan University**

ABSTRACT**:** Motorcycle is well known as one of the main transport modes in south-eastern Asian countries especially due to the rapid increase of individual ownership and motorization in parallel to the economic growth. Therefore, road traffic condition in main cities in those countries is mixed by passenger cars and motorcycles. Under the mixed road traffic situation, traffic characteristics of each vehicle is different and it leads to a complex situation if the traffic control strategy such as traffic signal, lane and rules are not functioning adequately. Further, the risk of traffic accidents and traffic capacity reduction have also increased. Therefore, investigating road traffic control and management under mixed traffic flow is required to provide safer and more efficient transport system especially for south-eastern Asian countries by considering the characteristics of the interactions between passenger cars and motorcycles. Purpose of this study is to verify whether the traffic speed decreases under the same level of traffic density but different types of vehicles in mix interactions. Data used for the analysis were collected by video camera at Hanoi city, which is well known for higher share of motorcycles, on September 29, 2009 from 9:00 am to 11:00 am. The speed-density relationship was analyzed using vehicle position, speed and density data obtained from video observations. Then, this information was used to verify whether the traffic speed reduction has a relationship with the different type of mixed characteristics. Voronoi division was applied to describe interactions between passenger cars and motorcycles, and multiple regression analysis was conducted to confirm the relationship between traffic speed change and the interactions. Sensitivity analysis was also performed using a developed model. The sensitivity analysis showed that traffic lane and stop area for motorcycles at signalized intersection is possible to create smooth mixed traffic condition.

KEYWORDS: mixed traffic flow, transport management, voronoi division, motorcycle

1. INTRODUCTION

1.1 Background

In recent years, proportion of motorcycle for all transport modes has been growing up rapidly with the economic growth in south-eastern Asian countries. Therefore motorcycle has become one of the most important transport modes in those countries. However development of related legal systems for motorcycles is not adequate enough to control safe and efficient handling of motorcycles especially in transport facility design and urban transport planning domains. In fact, motorcycles have not considered as a main subject in road traffic management. Further, increasing the number of motorcycles has led several traffic problems such as traffic accidents, congestion, and air pollution.

In addition to these issues, motorization is also growing in many cities in south-eastern Asian countries. Further, mixed traffic conditions, i.e., mainly motorcycle and passenger car mix, can be observed in those cities. This situation may cause decrease of road traffic capacity and an increase of traffic accident risk due to occurrence of complicated traffic conditions by different size of vehicles and different running characteristics. Investigating of road traffic operations and controls under mixed traffic flow is fundamental to understand its characteristics. There are several existing studies on the above issue. Van (2009) et al. analyzed four different situations by changing proportion of passenger cars and buses under mixed traffic situations in Ho Chi Minh City in Vietnam using traffic simulator VISSIM. Meng (2007) et al. proposed cell-automaton model to simulate mixed traffic situation, and pointed out the necessity of introducing a motorcycle lane that separates motorcycles and passenger cars, because the lane-changing behavior of motorcyclists disturb smooth traffic flow of passenger cars. Lee (2008) developed a multivariate logit model to describe passing behavior that motorcycles overtakes the one in front by faster speed. This model assumes that motorcycles move on virtual lane as distinct from actual traffic lane. However there are some further issues such as data collection of motorcycles trajectories by obscure rule, and definition of virtual lane. Nguyen (2011) et al. proposed a motorcycle running behavior model based on the social force model that is not lane specific to understand the mechanism of interaction between motorcycles under congested situations. However the proposed model, which has not considered the interactions between motorcycles and passenger cars, may affects the accuracy of the social force model. Minh (2005a, 2005b) et al. analyzed passing behavior of motorcycle and behavior of tandem riding, and relationship between average speed and traffic flow based on the speed of motorcycle and the number of passing monocycles. The results were expected to be used for more accurate traffic simulations and enhance the quality of motorcycle lanes. Nail (2011) et al. developed a mixed traffic flow model by introducing the concept of porous as space between vehicles. The porous was defined and calculated the space by Delaunay diagram. If there is a suitable space for a motorcycle or a passenger car, driver will make decision for their direction at the next time step according to size of the space. Since motorcycle can occupy a smaller space than a passenger car, this model can analyze the differences in behaviors between motorcycles and passenger cars. However the study by Nail et al. was entirely based on simulations and they did not validate their approach with real data. Therefore the validation of the behavior based on traffic data measured in the real world is required. References mentioned above suggest that several previous studies have attempted to investigate mix traffic situations, however, those studies have mainly focused on microscopic characteristics. No significant studies have investigated mix traffic conditions in macroscopic point of view.

1.1 Research purpose

As discussed in previous section, validation of mixed traffic flow characteristics with real data is necessary. In addition to that, macroscopic traffic flow model under mixed situation may suite to evaluate whole road network. Therefore, this paper investigates macroscopic traffic flow characteristics with special focus on the shape of mixed pattern and interaction between motorcycles and passenger cars. Further, the relationship between the pattern and condition of aggregated traffic flow, with special reference to the change of average speed at the study site, is also explaned.

2. DATA COLLECTION

Vehicle trajectory data was collected from a video survey conducted under mixed traffic conditions in Hanoi-City, Vietnam in 2009. Details of this video survey and the collected data are described below.

2.1 Video survey

Video survey was conducted on one of the main streets (Nguyen Chi Thanh St) which is located between the city center and Noi Bai airport in Hanoi-city, Vietnam. The survey was conducted at off peak hours (from 9:00am to 11:00am) on 29th September 2009. Geometric features of the surveyed section (road width, section length), speed, traffic density, coordinates of passing vehicles and mixed situation were recorded from video data.

2.2 Data collection

To determine vehicle trajectories, position coordinates of all vehicles (motorcycles and passenger cars), which passed the target section, were collected. The position coordinate data was

Figure 1. Example of data collection (red dot is defined as passenger car)

collected at 1 second intervals. Three periods, during which the large trucks are not mixed, were purposefully chosen for video scene as this paper aims to identify relationship between type of mixed traffic situation and fundamental traffic characteristics, especially speed. It is difficult to identify the position of passenger car if the car is located at the back side of a large truck that may be affected the results of analysis. Then three periods from video data in total 164 seconds, that is, 67 seconds, 38 seconds and 59 seconds durations, were analyzed. Figure 1 shows an example of video data which used to collect vehicle trajectory data. Two of red dots nearby passenger car in the figure describes that position coordinate of the car which is defined at that moment. Using these movement information dots, speed of each vehicle at a given moment was estimated. Further, trajectories of all vehicles during this period (164 seconds) were also extracted using these vehicle position information.

2.3 Data cleansing of parking car

To determine vehicle trajectory, position coordinates of vehicles were collected from video recordings. However there were some cars parked in the study site. With parked cars, effective road width becomes narrower and it may affect traffic flow characteristics. Therefore this study assumed that side of the road has role of parking as usual and then the section surrounding by red line in figure 2 was defined as the parking space and not the space for through

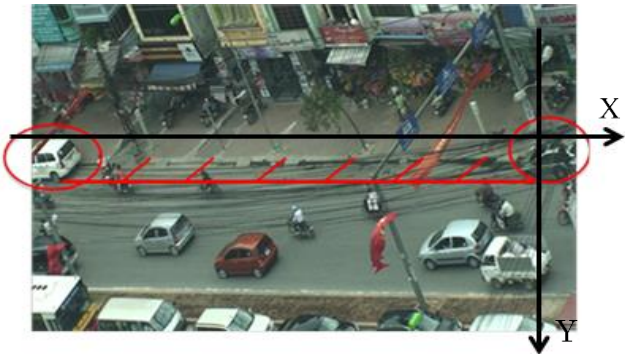

Figure 2. Definition of the car parking space on study site (red line space is defined as car parking)

traffic. After data cleansing as mentioned above, size of the study site becomes 8 meter for road width and 42 meter for section length.

3. VARIABLES TO DESCRIBE MIXED TRAFFIC SITUATION

3.1 Voronoi division

This paper proposes voronoi division to describe the condition of mixed traffic flow. Voronoi division is well known for drawing kind of influence area of a given main point by collecting the nearest other points if many points are located around the main point. In addition to that the area is defined by drawing perpendicular bisector for the line connected between neighboring points as shown in figure 3. Figure 3 shows an example of voronoi division used for this analysis. Each point represents a vehicle location at a given period of time. The power area in this study is assumed the space can be used for infill by higher speed vehicles. Therefore if the congestion is growing by higher demand, the area becomes smaller and smaller especially when demand of motorcycle becomes higher.

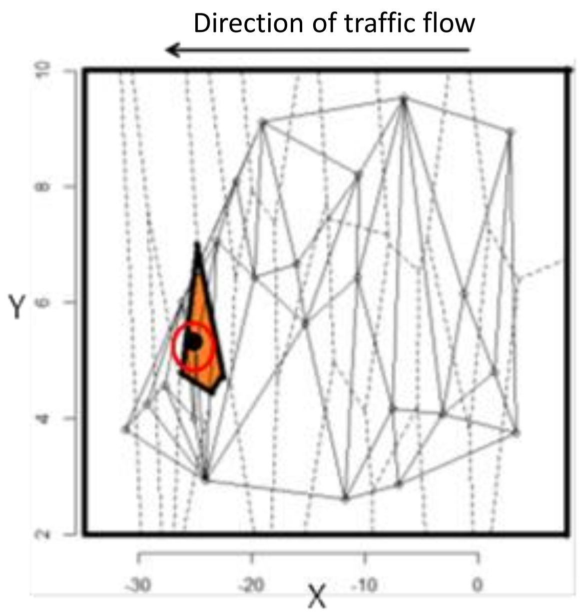

Figure 3. Example of calculation results of power area by voronoi division

3.2 Standard traffic density

Voronoi division can define the space, such as personal space of a vehicle, considering the vehicle as a point. Therefore it is not directly considering the vehicle size which is an important factor to consider in mixed traffic situation. This research proposes standard traffic density to use voronoi division as an explanatory variable of impact analysis in next section. Standard traffic density is defined as how a vehicle occupies its power area defined by voronoi division that is proportion of size of vehicle against to power area of the vehicle. By defining standard traffic density, it can compare the density of a motorcycle and a passenger car and condition of allocation of each vehicle. Value of standard traffic density varies from 0 to 1, that is, it describes congested situation when the value approximates to 1. Figure 4 shows the relationship between standard traffic density and average speed for motorcycles and passenger cars. Average speed was measured at 1 second interval. Figure 4 depicts how the average speed of both transport modes decreases with increasing value of standard traffic density. This tendency is similar to the k-v (density-velocity) fundamental diagram used in traffic engineering field to understand traffic characteristics, such as road traffic capacity, congestion / free flow condition and so on, on a road section. This paper utilizes calculated standard traffic density as explanatory variable to understand the impact of mixed traffic situation for speed changes.

3.3 Spreading level of x-y direction

To describe mixed traffic situation, vehicles' spreading level of x-y direction is defined as a variable affected for speed change. Figure 5 shows the definition of spreading level in x and y directions. It was assumed that the average speed becomes higher if the vehicles' speed is not influenced by other vehicles. It was further assumed that spreading

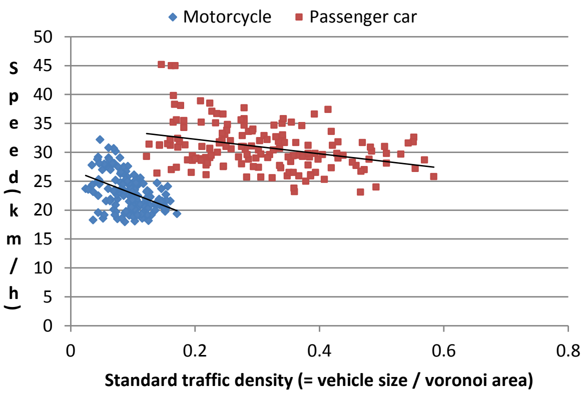

Figure 4. Relationship between standard traffic density and averaged speed

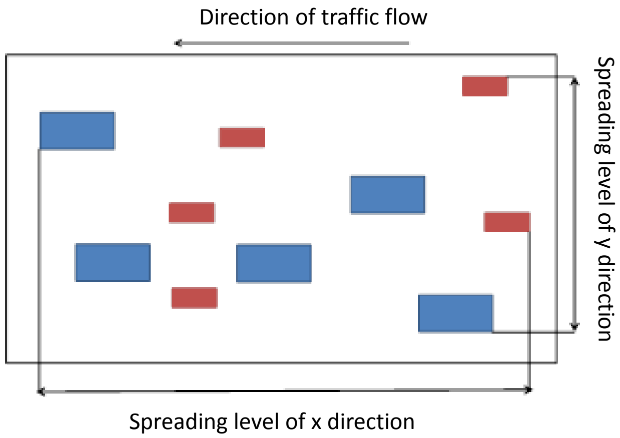

Figure 5. Definition of spreading level of x-y direction

level should be lower at the moment. Spreading level of x-y direction was used for impact analysis as described in next section, because spreading levels of both x-y do not have direct relationship with each other. Sometime spreading level y (x) is possible to be wider even if the one of x (y) directions become shorter, and same for the case of opposite relation.

3.4 Other variables

In addition to the above mentioned variables, entropy and ratio of number of passenger cars per one motorcycle were considered. For Entropy, it is assumed that it may affect to speed change according to deviations by utilization of road section by vehicles. And speed of vehicles may be controlled by speed of other surrounding vehicles. And this paper has assumed that average speed for passenger car may increase when motorcycle is not really mixed. Therefore Ratio of number of passenger car per one motorcycle is assumed as explanatory variable of analysis on next chapter.

4. IMPACT ANALYSIS OF TRAFFIC SPEED CHANGE UNDER MIXED TRAFFIC

4.1 Parameter estimation of speed change model

To determine the impact of traffic speed change of passenger cars and motorcycles under mixed traffic conditions, multiple regression analysis was employed with explanatory variables mentioned in the previous section. Explanatory variable was considered as a average speed at the moment. Table 1 shows the results of parameter estimation for both passenger cars and motorcycles. Signs for both estimated parameters were acceptable. Both models showed standard traffic density has a negative impact on average speed. The area of passenger car becomes smaller if the value of standard traffic density is higher. Therefore higher standard traffic density value refers to a situation when it is difficult to increase the speed of a given vehicle as there are many other surrounding vehicles. Model of passenger car shows that spread level is a significant factor with a positive sign. Higher spread level means passenger car tends to use the space widely without being disturbed by other vehicles. Moreover, model of motorcycle shows that the ratio of the number of passenger car per one motorcycle is also a significant factor. Higher ratio of number of passenger car per one motorcycle refers a situation that motorcycles have to follow the behavior of passenger cars. Therefore, motorcycles face difficulties to pass the section freely, and compile to reduce the speed. From this interpretation on the developed model, it can be derived that the patterns of mixed condition between passenger car and motorcycle may affect their average speed and it shows the importance of considering this fact in mixed traffic flow analysis.

4.2 Sensitivity analysis

To check speed change correspondent to the changes of explanatory variables, sensitivity analysis of the developed model was conducted with especially focus on standard traffic density for the model of passenger car and the ratio of the number of passenger car per one motorcycle for the model of

Table 1. Parameter estimation for speed change

	Passenger car		Motorcycle	
	Coefficient	t-value	Coefficient	t-value
Intercept	31.74	32.538	25.803	15.809
Traffic density [veh/m2]	-0.561	-2.648	-0.403	-7.375
Standard traffic density	-13.487	-5.509	-7.825	-2.097
Spread level of x direction [m]	0.112	-2.671	-	
Spread level of y direction [m]	1.056	-4.338	-	
Ratio of number of passenger car per one motorcycle	-		-8.243	-7.906
Entropy [J/K]	-		20.617	4.083
Number of samples	144		159	
R2	0.399		0.460	

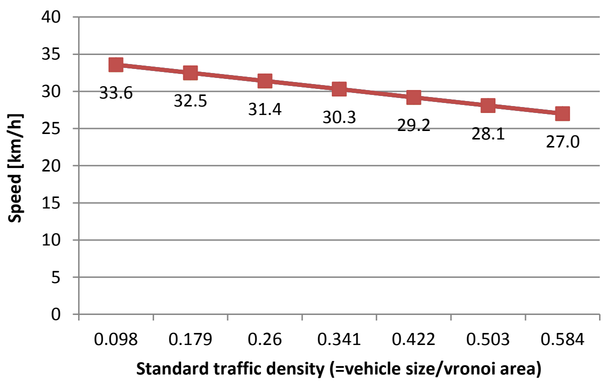

Figure 6. Sensitivity analysis for standard traffic density (passenger car)

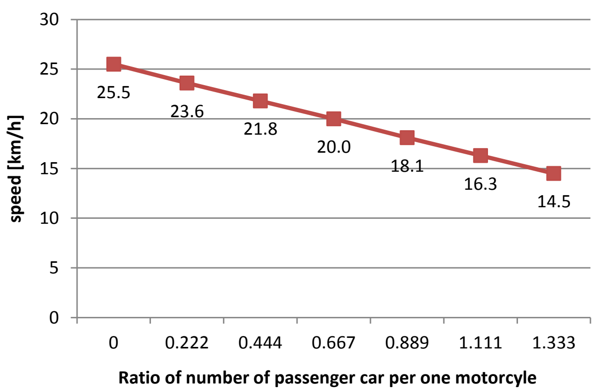

Figure 7. Sensitivity analysis for ratio of number of passenger car per one motorcycle (motorcycle)

motorcycle. Figures 6 and 7 show the sensitivity analysis for passenger cars and motorcycles respectively. Both figures show that average speed is decreasing with increasing the values of explanatory variables according to coefficient shown on table 1.

According to figure 6, decreasing standard traffic flow contributes to increase in average speed of passenger cars. To achieve this situation, providing a stop area for motorcycle in front of stop line for motorcycle at signalized intersection is assumed. Because passenger cars can be speed up without any impact from motorcycles when the duration of green light of the signalized intersection is started. Figure 7 indicated that average speed of motorcycle increases with decrease of ratio of number of passenger car per one motorcycle. To enable this situation, setting-up of motorcycle lane is proposed because that supports motorcycle to control their speed freely without being controlled by the movements of passenger cars.

Through this discussion, traffic controlling scheme for motorcycles as mentioned above can be recommended. Such scheme has already been installed in Taiwan which is well known for higher proportion of motorcycles. Therefore a traffic flow model which can evaluate such schemes should be developed.

5. CONCLUSIONS

This paper analyzed the speed change of motorcycles and passenger cars under mixed traffic situations. Traffic density using voronoi division to consider power space for both transport modes were proposed. Further, other indices related to describing mixed traffic situation were also proposed. In addition to that average speed change is abalyzed through multiple regression analysis using those indices. Results of parameter estimation revealed that those indices have significant impact for average speed changing under mixed traffic situations. The estimated model suggested that a traffic control scheme for motorcycles similar to the one that has already been installed in Taiwan is possible as an effective way to achieve smooth traffic flow under mixed traffic situations.

For further work, using traffic data that is collected for a longer duration is recommended to consider more patterns of mixed situations since the data used this paper was limited. In addition to this, traffic flow modelling should be developed to evaluate traffic control scheme with especial consideration to mixed traffic situations.

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