Internet Journal of Society for Social Management Systems Vol.12 Issue 2 sms19-8641
ISSN: 2432-552X
ORIGINAL ARTICLE

Relationship between Inter-vehicle Space and Two-wheeled Vehicle Behavior in Mixed Traffic Conditions

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***Abstract*:** In Southeast Asia, traffic congestion is increasing with rapid economic development. However, motorcycles and passenger cars are traveling without comprehensive traffic control schemes, such as lane markings, and effective traffic control signals. As a result, traffic congestion caused by interactions between motorcycles and passenger cars is a serious social issue, and the risk of traffic accidents is known to be higher in Southeast Asian cities, including Ho Chi Minh City, Vietnam. Therefore, improving traffic conditions from a macroscopic point of view is required to improve the entire road network. To address these issues, existing studies have proposed a mixed traffic flow model to describe the mixed traffic condition by assuming that inter-vehicle space reflects traffic density. However, the proposed model in existing studies has been evaluated only with numerical analysis. Therefore, understanding whether assumptions in the existing model are correct requires the use of real data. This study analyzed the relationship of space between vehicles and traffic conditions as average speed on a specific road section with mixed motorcycle and passenger car traffic. The results, confirmed that average mixed traffic speed decreased according to reductions in the size of inter-vehicle spaces, which supports the proposed phenomena in existing studies.

Keywords: Mixed traffic, Southeast Asia, Inter-vehicle spacing, Vehicle behavior

1. Introduction

1.1 Research background

Southeast Asia is as having problems with serious traffic jams because of rapid economic development. In addition, drivers in these countries have no concept of traffic lanes, which causes mixed traffic flow of motorcycles and passenger cars (Figure 1). Among such countries, since because of high rates of motorcycle usage, is Vietnam, which should consider suitable traffic control based on motorcycle driving behavior to improve safety and traffic conditions. Ho Chi Minh City has 300 video cameras where traffic jam (Figure 2). They form a network that provides information on road congestion in real time, with the intention of alleviating traffic congestion in the city. Under mixed traffic conditions, motorcycles can operate in a narrower space compared to that needed for passenger cars. Because of this motorcycle mobility, many riders pass other vehicles recklessly. More often than not, motorcycles block other

Received: 2019.07.31/ Accepted: 2020.05.19

Figure 1 State of Le Van Viet Street

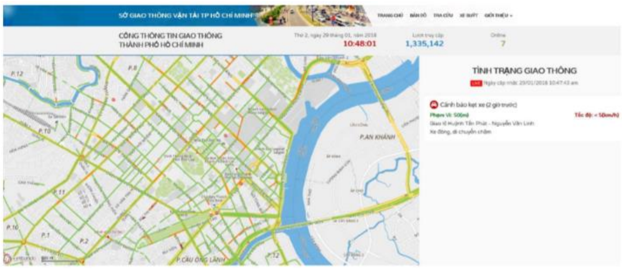

Figure 2 Ho Chi Minh City Transportation Bureau Road Traffic Status Delivery Website[1)]

passenger cars because of this reckless behavior. In addition, motorcycles find it difficult to drive at high speed when following passenger cars. In this way, the mixed traffic flow condition is very complex, making it difficult to analyze traffic over an entire road network while considering the movement of each motorcycle. Nevertheless, in the future, with continued economic development, it is important to microscopically consider the operation of road networks. However, it is necessary to evaluate macro road networks based on complex motorcycle movements to properly build the road network infrastructure of Southeast Asian countries. Nair et al[2)]. made a proposal to evaluate traffic conditions in consideration of motorcycle movements. Therefore, highly accurate evaluation of mixed traffic flow may be possible. However, Nair's model was examined only with numerical calculations rather than being demonstrated using real data. Therefore, an applicable model should be built for a road network based on real data.

1.2 Purpose of research

The purpose of this study is to make it possible to evaluate the traffic situation of mixed traffic flow using observation data from Ho Chi Minh City, Vietnam, with a focus on the inter-vehicle space. Specifically, we analyzed the inter-vehicle space following idea of Nair's theory and a simplified Delaunay diagram, as described in Figure. 3. In the future, our approach aims to grasp the traffic condition of the road network over a wide area by video camera.

1.3 Structure of this paper

This paper is composed of 8 chapters. chapter 1, described the background and purpose of this study. Chapter 2 describes previous studies of mixed and motorcycle traffic. In Chapter 3, we clarify the positioning of this research by identifying methods and social needs from past research. Chapter 4 describes the survey outline and data acquisition method. In Chapter 5, the traffic condition is evaluated using a flow–density (Q-K) diagram. Chapter 6 introduces and discusses a method to analyze the relationship between traffic conditions, traffic speed, and spacing gap size in the target road section. Chapter 7 describes an expression used for speed prediction obtained from analysis of speed and gap size, and identifies input data for the expression. Chapter 8 summarizes the results of this research and specifies future issues.

2. Existing study

Hanamori et al. [3)] created a model that took into account the unique behavior of two-wheeled vehicles, which was impossible with conventional methods that considered the driving behavior of two- and four-wheeled vehicles in the same way. This model allows one to predict a destination based on the motorcycle behavior of each condition. Hanamori et al.[4)] proposed a safety evaluation index that accounts for the characteristics of motorcycles. Evaluating traffic with this method allows clarification of situations where the collision risk is high in mixed traffic flow. Nair et al.[2)] focused on the inter-vehicle space and mixing ratio of vehicle types to build a model that predicts traffic conditions using these factors. Therefore, it became possible to obtain more accurate evaluations of the state of macro traffic flow according to the mixture of motorcycles and automobiles. Matsuhashi et al. [5)] studied the expected traffic flow and traffic conditions and evaluated them by simulation, assuming that the penetration rate of vehicles will increase in Vietnam in the future. As a result, it was clarified that the motorcycle has a great influence on other vehicles. In Fukuda et al.[6)], motorcycles in future urban transportation problems were assumed to have traffic effects. Nishiuchi[7)] built a traffic model to solve traffic problems, such as traffic accidents, traffic jams, and traffic pollution, in mixed traffic flows. Hsu et al.[8)] proposed a concept and countermeasures for separation of traffic based on the effects of motorcycles on other vehicles and the traffic volume of motorcycles. Their results suggested a new road layout for mixed traffic flow and other road improvements. Nakanishi et al.[9)] described the safety dissemination activities of Honda that target motorcycles in developed countries, and clarified the current situation and issues for such activities in developing countries. Nguyen et al.[10)] performed a comprehensive saturation flow analysis at a signal-controlled intersection in a city that relies on motorcycles and proposed a calculation procedure to determine the saturation flow value for each specific traffic situation. As a result, an index was established for mixed traffic flows to calculate saturation flows at signal-controlled intersections. Meng et al.[11)] proposed a single-lane cellular automaton model to simulate mixed traffic with motorcycles. As a result, it was clarified that the flow rate is better if a lane separated four-wheeled and two-wheeled vehicles.

From the previous section, it has been clarified that a model that considers the behavior of motorcycles must be constructed because an evaluation method suitable for mixed traffic flow has not been established. In the study of Nair et al. [2)], which was used as a reference in this study, only a model for numerical calculation was constructed, and the applicability of the model as a real phenomenon is not clear. Therefore one of purpose of this research is to grasp the relathionship between the speed and the inter-vehicle spaces using video data observed in Ho Chi Minh City, Vietnam.

3. Macroscopic mixed traffic flow model

In this section, the macroscopic mixed traffic flow model proposed by Nair et al. is described. Previously simulation studies assumed that motorcycles and passenger cars have the same movements[2)]. Therefore, they proposed a mixed traffic flow model that evaluated traffic conditions considering the inter-vehicle space. In particular, their model simplified the space between vehicles as a triangular shape that connected the tip of each vehicle in a Delaunay diagram. A Delaunay diagram from their study is shown in Figure 3. They developed the model to grasp the traffic conditions by means of the space between vehicles using Figure 3 which accumulated the length of one side of triangle. The proposed model was tested by situation analysis to determine whether it could represent the fundamental diagram. Then, they confirmed that the assumed traffic flow condition can be evaluated with higher accuracy according to the situation of mixed motorcycle and passenger car traffic.

However, although Nair et al. proposed an

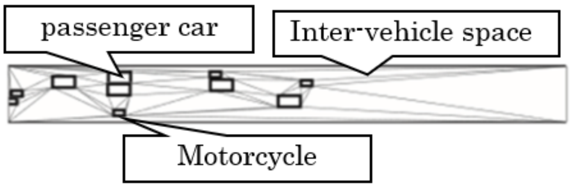

Figure 3 Delaunay diagram for mixed traffic[2)]

Figure 4 Traffic conditions on Vo Van Ngan Street

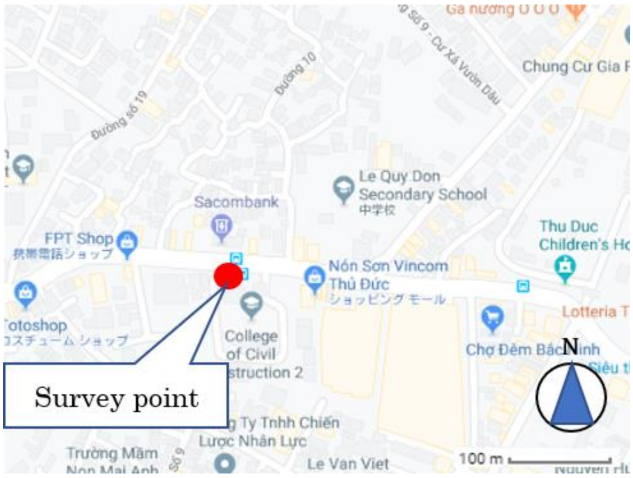

Figure 5 Survey point on Vo Van Ngan Street

Figure 6 Traffic conditions on Le Van Viet Street

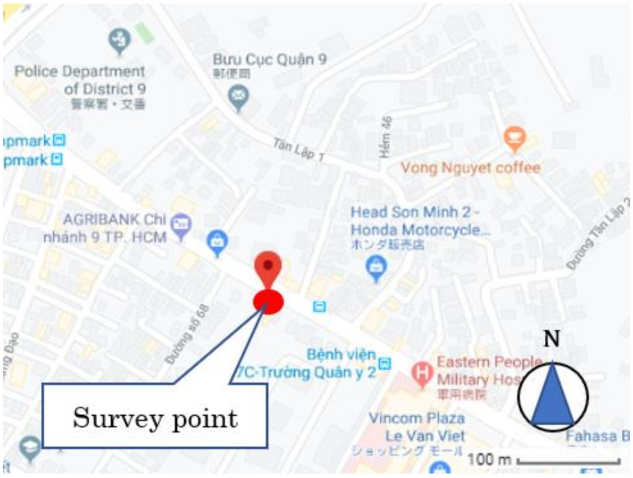

Figure 7 Survey point on Le Van Viet Street

appropriate mixed flow model, they did not conduct testing with real field data to verify whether the proposed model is applicable in a real mixed traffic situation. Therefore, in this research we used observed video data obtained in Ho Chi Min City, Vietnam, to try to perform this verification. The data we used to clarify whether it is possible to grasp traffic conditions by vehicle spacing and mixture ratio following concept of Nair's model.

4. Collection of mixed traffic flow data

4.1 Survey outline

We conducted a video survey of Vo Van Ngan Street (Figure 4 and 5) and Le Van Viet Street (Figure 6 and 7) in the suburbs of Ho Chi Min City on 18 Dec. 2017. Tall buildings were selected for the video camera installation because these locations can observe the situation where cars and motorcycles run together. Both survey locations observed roads with two-way traffic flow. Observation time was 7:40 a.m. to 10:00 a.m. and 4:50 p.m. to 6:00p.m. on 1 day.

4.2 Method for aggregating basic data

To understand traffic conditions, we obtained traffic volume, traffic density, and mixing ratio from video data after defining the target sections (Figure 8 and 9). Next, a line to count the number of vehicles was defined (Figure 10). Traffic flow, traffic density, and mixing ratio were aggregated with the following measurement method. Traffic flow was calculated by counting the in 10 seconds. Traffic density was calculated by stopping the video every 10 seconds and

Figure 8 Target section on Vo Van Ngan Street

Figure 9 Target section on Le Van Viet Street

Figure 10 Line for counting vehicles

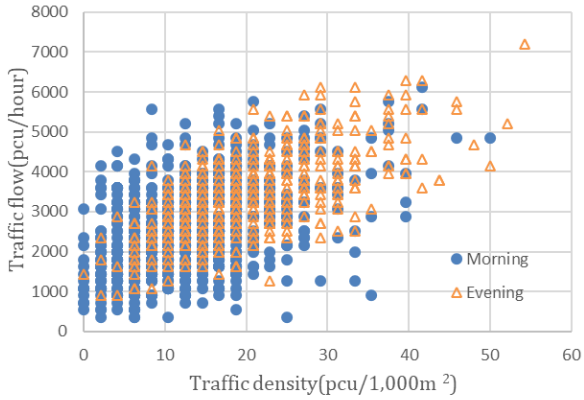

Figure 11 Q-K diagram for Vo Van Ngan Street upward direction (pcu = passenger car unit)

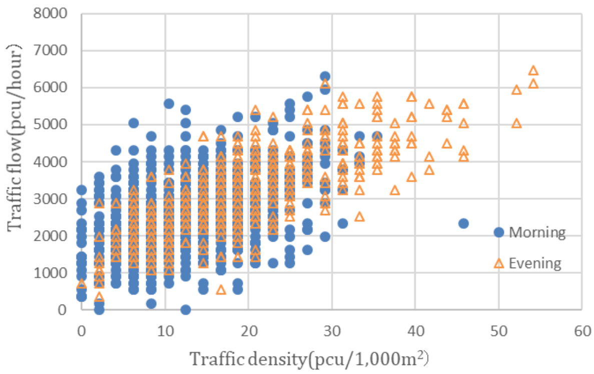

Figure 12 Q-K diagram for Vo Van Ngan Street, downward direction

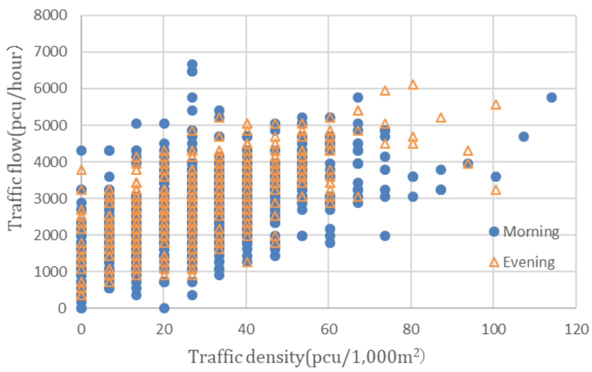

Figure 13 Q-K diagram for Le Van Vien Street, upward direction

counting the number of motorcycles and passenger cars in the passing target section. The mixing ratio was calculated from the numbers of motorcycles and passenger cars at the same time the traffic density was determined. Because the sizes of the vehicles are different, we divided motor vehicles into passenger cars and large cars.

5. Q-K diagram at survey section

To understand traffic conditions in each target section, a fundamental Q-K diagram was drawn using the traffic flow rate and traffic density from aggregated basic data. These diagrams showed that traffic congestion was not observed in the target sections during the observation time (Figure 11, Figure 12, Figure 13). However, maximum traffic density on Le Van Viet Street is higher than that on Vo Van Ngan Street. From the figures, it can be understood that the evening is congested because the traffic flow rata and the traffic density are higher in the evening than in the morning in either section.

Internet Journal of Society for Social Management Systems Vol.12 Issue 2 sms19-8641
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6. Analysis of inter-vehicle space, speed, and mixture ratio

This section explains the method used to analyze the inter-vehicle space, average speed, and mixture ratio. Because we found heavy traffic volume on Le Van Viet Street, we analyzed it using these data. The analysis method correlates the three factors of traffic flow rate, space between vehicles, and speed with a scatter diagram. To do this, we set up sample conditions and used these conditions to collect data on mixing ratio, speed, and inter-vehicle space.

6.1 Data extraction

The analyzed data were set as shown in Table 1. and shown below. The scenes are ordered from high density to low density. Figure 13 shows the data extraction method as an example situation. From the video data, five scene of images of passenger cars and motorcycles within the target section was extracted. Extraction of image data was performed by the procedure suggested for each condition, and 45 sample data (5 images × 9 condition types) were collected for the analysis. An example of the sample is shown using condition i in Figure 14.

Table 1 Number of passenger car and motorcycle on extracted data by each scenc

Condition	Passenger cars	Motorcycles
a	1	4
b	1	6
c	0	10-12
d	1	1
e	0	2
f	0	4
g	0	6
h	0	8
i	1	5

Figure 13 Image of extracted data of condition i

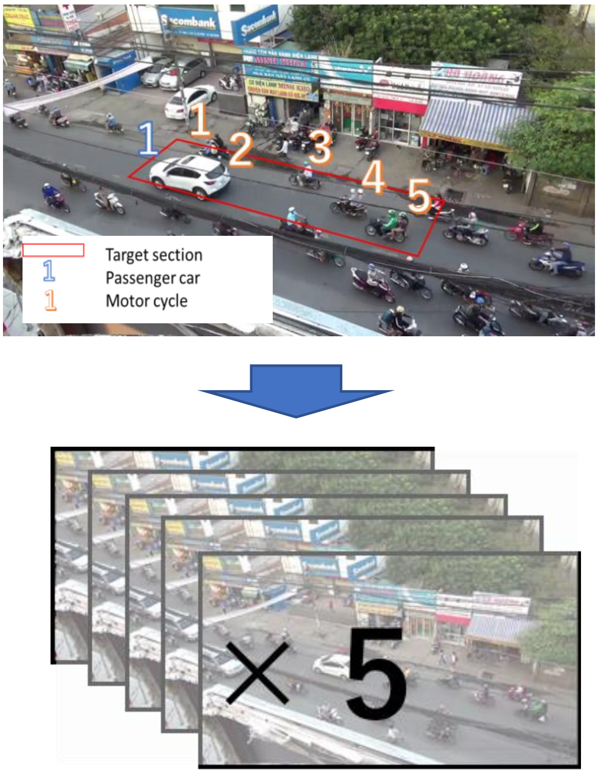

Figure 14 Image of data extraction of five situations on condition i.

6.2 Methodology for extracting inter-vehicle space, speed, and mixture ratio

This section describes how the data you needed for analysis were obtained.

6.2.1 Inter-vehicle space data

To measure the space between vehicles, Delaunay diagrams were created from the extracted image data. The inter-vehicle space data were obtained from the Delaunay diagram.

ISSN: 2432-552X

6.2.1.1 Delaunay diagram creation method

From the sample obtained from the defined section, images were extracted and defined for each sample that were acquired by the coordinates of the four corners of the target section and the defined size of vehicles. The size of the vehicle was defined using the average sizes of small cars and passenger cars. The sizes of the defined vehicles are shown in Table 2 Next, projective transformation was performed according to the target section (width of 5 m and road length of 16 m). Figure 15 shows the example of target section for projective transformation. Projective transformation was performed to obtain the coordinates (Figure 16). The lower left coordinates of the vehicle were obtained from the projected image. A Delaunay diagram was created from the acquired vehicle and the lower left coordinates of the target area, and the gap was simplified based on the concept of Nair's method. Delaunay diagrams were created with the following procedure. First, the road width and section length were created. Next, the vehicle was positioned using its acquired coordinates. Finally, the section vertex and the vehicle were connected with a triangle. An example Delaunay diagram is shown in Figure 17.

6.2.1.2 Inter-vehicle space measurement

The inter-vehicle space data were obtained from the Delaunay diagrams. Each inter-vehicle space is defined as the length of one side of each triangle. All sides were measured and a cumulative graph was created and converted into data.

Table 2 Defined vehicle size (cm)

Dimension	Motorcycle	Passenger car	Large car
Vehicle width	72	170	249
Vehicle length	189	470	761

6.2.2 Speed measurement

The extracted inter-vehicle space data were used to measure, vehicle speed for each sample and condition. We defined a measurement start line and measurement end line to measure vehicle speed. These lines are defined in Fig. 18. Timing started when the tip of the target vehicle reached the measurement start line, and timing stopped when

Figure 15 Target section

Figure 16 Collection of coordinate data

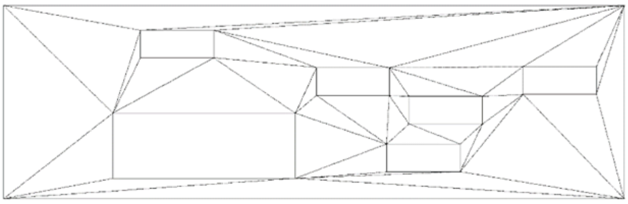

Figure 17 Obtained Delaunay diagram

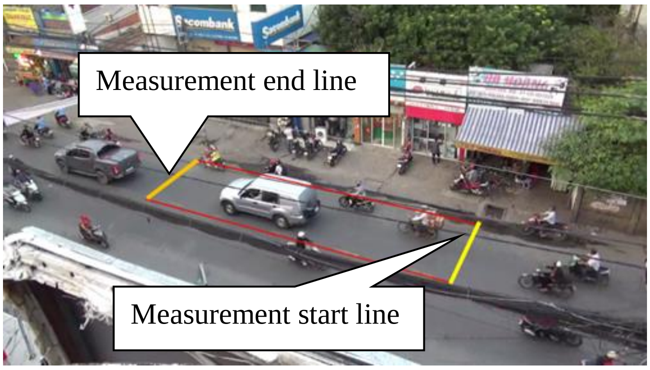

Figure 18 Measurement start line and measurement end line

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the tip of the target vehicle reached the measurement end line. The speed of the target vehicle was estimated from the distance and timing result. By estimating the speed of each vehicle, the space mean speed was estimated for each scene, as defined in Section 6.1.

6.2.3 Mixing ratio determination

The mixing ratio of motorcycle is caluculated based on the number of vhiecle which were exracted at Table 1. in Section 6.1.

6.3 Relathinship between Inter-vehicle space and speed

6.3.1 Inter-vehicle space

The length of the triangle sides in the Delaunay diagram shown on Figure 17 was defined as the size of the gap. In this analysis, the length of each side was measured and evaluated on a to i condition. Figure 19 shows the cumulative side length. From the figure, it can be understood that when the traffic density is low, the inter-vehicle space increases. On the other hand, the inter-vehicle space decreases if the density is high. Therefore size of inter-vheicle space possible to describe mixed traffic condition under the extracted condition which is free flow traffic condition.

6.3.2 Speed measurement

Table 3 shows the speed per vehicle for each condition described in the previous chapter. And

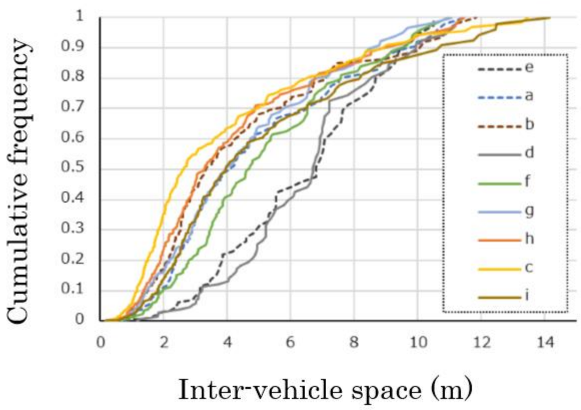

Fig. 19 Cumulative graph of inter-vehicle space

Table 4 shows the average speed of all vehicles in each condition. The counting results exclude errors, such as when the road before and after the scene is empty or when there is a traffic jam. From this result, we can see that the average speed of the section decreased when the traffic density was high, and the average speed of the section was high when the density was low.

6.4 Analysis of speed and inter-vehicle space

The cumulative graph created in Section 6.3 was divided by 5% to produce a graph that compared average speed and average inter-vehicle space. By

Table 3 Average speed for each Delaunay chart of each extracted condition a to i [km/h]

Condition	Image 1	Image 2	Image 3	Image 4	Image 5
a	21.31		20.37	21.58	
b		19.66	21.00	17.61	
c	16.52	15.26	16.89	17.13	15.35
d	26.35	25.85	29.60	30.78	30.64
e	25.90	25.62	33.43	27.64	25.71
f	20.66	28.17	28.00	27.79	21.53
g	21.05	19.80	20.10	17.42	22.81
h	23.05	20.92	16.91	18.78	17.71
i	20.65	19.31	19.29	23.11	22.71

Table 4 Average speed for each condition [km/h]

Condition	Average speed
a	21.32
b	19.42
c	16.23
d	27.66
e	28.64
f	25.23
g	20.94
h	19.47
i	21.01

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comparing the correlation coefficient of the size of the inter-vehicle space every 5%, an appropriate percentage for speed prediction can be found.

6.4.1 Inter-vehicle space and speed relationship between 5% and 100% of cumulative graph

Using the cumulative graph created in the previous section, the relationship between the inter-vehicle space and speed was created in the graph for every 5% increment. Figure 20 shows the relationship between the 5% to 100% inter-vehicle space and average speed. After that, an approximate straight line was drawn on the created graph to calculate the correlation coefficients, which are shown in Table 5. The Table, shows that there is a strong positive correlation from 5 to 85%. However, the correlation from 90% to 100% is weakly positive and did not reflect the inter-vehicle space. From this, it can be concluded that the speed is reduced when many small vehicles and vehicles are densely packed.

6.4.2 Comparison of average inter-vehicle space and average speed

A scatter plot was created to compare the average inter-vehicle space and average velocity calculated in Section 6.4.1. Figure 21 shows the relationship between average inter-vehicle space and speed. The resulting correlation coefficient of 0.86 indicates a strong correlation. In other words, it is demonstrated that speed can be predicted by creating a Delaunay diagram regardless of the mixing ratio. If the average size of the inter-vehicle space is large, the traffic density is relatively low. As a result, the traffic speed will be high The 5% to 10% graphs in Fig. 20 can only be evaluated in narrow inter-vehicle spaces. Therefore, the average speed is predictable for the target section depending on the average inter-vehicle space.

7. Speed prediction method

Analysis was performed using 46 samples. The

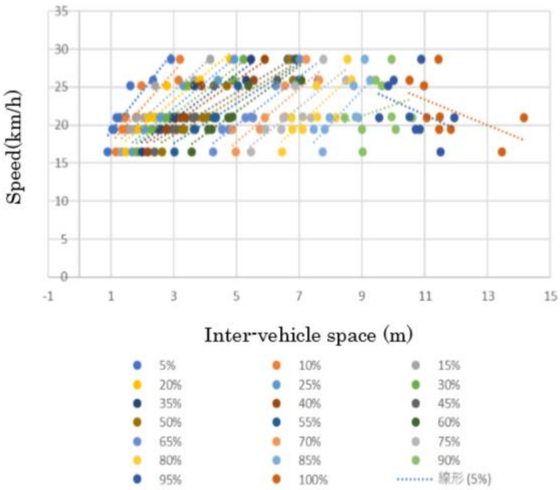

Figure 20 Relationship between 5 to 100% inter-vehicle space and speed

Table 5 5% to 100% inter-vehicle space and speed correlation

%	Correlation coefficient
5	0.94
10	0.91
15	0.94
20	0.95
25	0.97
30	0.96
35	0.95
40	0.95
50	0.94
55	0.95
60	0.95
65	0.94
70	0.86
75	0.82
80	0.83
85	0.79
90	0.25
95	0.38
100	0.54

analysis results of Section 6 showed the relationship between the size of the inter-vehicle space and speed

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from 5% to 100％ of the cumulative space graph.

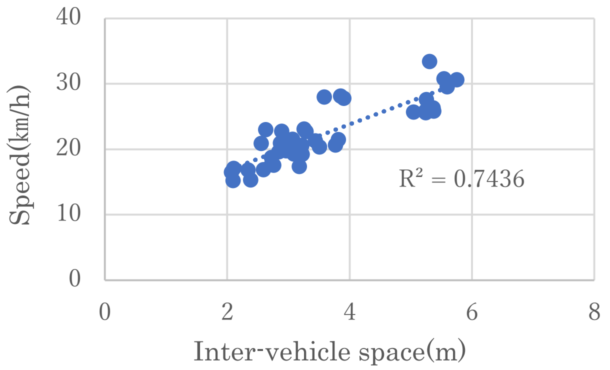

Figure 21 Relathionship between inter-vehicle space and speed

Therefore, the approximate expression was calculated by adopting the evaluation of the relationship, that is, the average value of the inter-vehicle space size and speed. The result of this approximate expression is shown in the following equation:

$$Y = 3.533x + 9.6797 \qquad (1)$$

where Y is the space mean speed and x is the inter-vehicle space each sample. A high correlation coefficient revealed a strong correlation between speed and space between vehicles. It also shows that this formula is effective for speed prediction based on the inter-vehicle space and mixing ratio. Furthermore, the analysis results showed the possibility of predicting the speed using only the space between vehicles regardless of the mix of vehicle sizes, if the traffic is free flow condition although it is mixed traffic condition.

8. Conclusion

The traffic condition of a target road section can be grasped by analyzing the traffic flow and traffic density. Thus, it can be clarified whether the traffic condition of the target section is free flow. This study created an approximate expression using the average vehicle spacing value calculated from Delaunay diagrams to predict the speed in a target road. This verified the purpose of this research, that is, to determine the traffic situation from the spacing between vehicles. In this study, although the correlation coefficient of the approximate expression was high, the target section was short, 16 m. Thus, further verification is needed to confirm that this approach is applicable even to long sections. In addition, this observation showed only free flow. There is also a need to verify this approach for traffic jams. In other words, this study alone is not enough, because it has to be applicable to any situation to evaluate the entire road network. The currently established method, which is suitable for roads subdivided into lanes, can not be applied in Southeast Asia, where mixed traffic flow without lanes is seen. Therefore, it is necessary to conduct micro analysis based on the characteristics of mixed traffic flow, as described in this study, and to construct a model for evaluating the entire road network.

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