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STUDY OF PLATOON CHARACTERISTICS ON A MULTI-LANE EXPRESSWAY*

高速道路多車線区間における車群特性に関する研究

By SURASAK Taweesilp**, Izumi OKURA***, and Fumihiko NAKAMURA****

1 Introduction

The multi-lane expressway or freeway are playing more important role for intercity transportation. In Japan, many intercity expressways were constructed to link between major cities in various parts of country. Basic traffic flow characteristics on the expressway such as speed-flow-density relationship have been studied in the past. However, behaviors of driving and driving constraint such as platoon characteristics on the multi-lane expressway have not yet been analyzed.

Platoon or bunching is the common driving condition on the highway. Platoon can be occurred for the whole range of traffic volume since low traffic volume until very high volume and most of the vehicles have to experience platoon driving. Even though many researchers have conducted various studies on platoon characteristics for two-way two-lane highway but the understanding on platoon characteristic for multi-lane highway is very limited. There are some different traffic behaviors between these two-way two-lane highway and multi-lane highway. At the same volume, vehicles on two-way two-lane highway have higher chance to follow slower vehicle. Because they lack of overtaking opportunities from many reasons such as from the opposite traffic and geometric of highway. On the other hand, only traffic conditions on the same direction have effects for vehicles on multi-lane highway. Moreover, lane utilization also effects traffic composition in each lane. All types of vehicles including passenger cars and heavy vehicles have to share the same lane on two-way two-lane highway but on multi-lane highway, most of heavy vehicles tend to use shoulder lane and passenger cars tend to use median lane. Therefore platoon characteristics on multi-lane highway should be studied separately.

Various points of view on platoon behaviors were investigated in this study. New criteria to classify vehicles into platoon leader and platoon followers were reconsidered to suit for multi-lane highway. The characteristics of platoon at different traffic volume were studied and explained by three platoon parameters, platoon rate, platoon size and percent of followers. The study was conducted on both lane-by-lane basis and cross-section basis. In later part, the comparisons of platoon distribution with the existing platoon models were presented. In near future, platoon characteristics will be applied to measure levels of service on the multi-lane expressway.

2 Platoon on Two-way two-lane highway

2.1 Platoon Definition

Platoon was defined as a group of vehicles driving together, which the followers have to adjust their speed, spacing and acceleration according to the vehicle immediately in front of them. Considering traffic behavior, it is assumed that, up to certain limits and without endangering his/her safety, a driver behaves as though driver is constantly seeking to increase his/her speed up to their desired speed. Therefore, when unable to change lanes, a driver will maintain what he considers to be a safe distance or headway between his vehicle and the vehicle ahead, and he will attempt to maintain this distance and not allow it to get significantly larger. Hence vehicles in traffic stream can be classified into two types, platoon leaders (free vehicles) and platoon followers (following vehicles).

Platoon leader can be defined as any driver maintaining a gap ahead, and hence driving at either his temporary or maximum desired speed. Platoon follower is otherwise.

2.2 Platoon Criteria

A platoon criterion is the criteria to classify vehicles traveling along the highway into either free vehicles or following vehicles. Following the platoon definition, platoon criteria can be determined from several parameters such as time headway, distance headway, and/or relative speed. The most accepted parameter on two-way two-lane highway is time headway, which usually is called critical headway.

Lay[3] summarized the critical headway defined by various authors and suggested three distinct states based on constraint conditions as:

Headway	< 2.5 sec.	Traffic is "following"
Headway	2.5sec to9.0 sec.	Traffic is either "following" or "free"
Headway	> 9.0 sec.	Traffic is "free"

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** M. Eng, Doctoral student, Dept. of Civil Eng., Faculty of Eng., Yokohama National University,
(79-5 Tokiwadai, Hodogaya-ku, Yokohama, Japan, TEL 045-339-4039, FAX 045-339-4039)
*** Member of JSCE, D. Eng., Professor, Dept. of Civil Eng., Faculty of Eng., Yokohama National University,
(79-5 Tokiwadai, Hodogaya-ku, Yokohama, Japan, TEL 045-339-4032, FAX 045-331-1707)
**** Member of JSCE, D. Eng., Associate Professor, Dept. of Civil Eng., Faculty of Eng., Yokohama National University,
(79-5 Tokiwadai, Hodogaya-ku, Yokohama, Japan, TEL 045-339-4033, FAX 045-339-1707)

Table 1 Summary of Platoon Criteria for two-way two-lane highway

Researcher	Study	Criteria	Remark
T. Dijker[4]	Car following under congested conditions	3.5 s. for PC and 5.0 s. for HV	To minimize non-follower as follower
Keller[5]	Effect of speed limit on platoon of vehicles	5.0 sec + 10% relative speed	Suggest that 2 sec would more realistically separate the vehicles hindered from passing
M. Pursula and A. Enburg[6]	Characteristic and LOS in Finland	5 sec. (following HCM) 3.5 sec (following Dijker)	
M.V. Aerde and S. Yagar[7]	Capacity, speed and platoon vehicle equivalent	Human observer method (Trained staff)	
A.J. Miller[8]	A queuing model for two-lane highway	6 sec. ± 10 km/h or 8 sec. –5/+10 km/h	To make sure for free vehicles are really free
A. Daou[9]	Headway of a vehicle in platoon	1.37 + 33.91/u u = speed	Based on safe driving distance (Safe reaction time + Buffer distance)
D.L. Guell and M.R. Virkler[10]	Capacity of Two-lane highway	Suggest to change from 5sec to 3.5-4 sec	For more useful for LOS and more consistent
HCM [1,2]	Chapter 8: Two-lane highway	5 sec	To measure delay for LOS determining
CR. Bennett and R.C.M. Dunn[11]	Critical headway in New Zealand	3.0-4.5 sec.	For free flow speed prediction

The platoon criteria for two-way two-lane highway from previous researches are summarized in table 1. Most of criteria were set based on critical headway varies from 3.0-5.0 second. Some of researchers used quite longer critical headway together with relative speed.

C.R Bennett and R.C.M. Dunn[11] studied and compared various techniques to determine critical headway. They concluded that the mean relative speeds, the mean relative speed ratio and the exponential headway model are the most suitable techniques for determining the critical headway as follows:

(1) Mean Relative Speeds Method

Relative speed are defined as the difference between successive vehicles:

$$RSP_i = S_i - S_{i-1}$$

Where: RSP_i is the relative speed between vehicles i and i-1 in km/h

S_i is the speed of vehicles i in km/h

A relative speed analysis is a common method of determining the critical headway. It can consist of evaluating the mean and/or standard deviations of the absolute relative speeds at different headways. As headways increase, the relative speeds increase until they reach a fairly stable level. The headway where the relative speeds stabilized is regarded as the critical headway.

(2) Mean Relative Speed Ratio Method

The relative speed ratio (RSR) is defined below.

$$RSR = abs\left[1 - \frac{S_i}{S_{i-1}}\right]$$

This method has the advantage in that it normalizes the data, thereby reducing the inherent variability in speeds and their standard deviations. The relative speed ratio analysis was undertaken in a similar manner to relative speeds. There was usually a great deal of scatter in the data but there was always a general trend whereby the relative speed ratio increased with increasing headway.

(3) Exponential Headway model method

The headway distribution theory assumes that the headways of free flowing traffic are random and can be modeled by negative exponential headway distribution. It therefore follows that the point at which the headway distribution ceases to be negative exponential is the point at which traffic ceases to be free-flowing. This point is the critical headway. When the headways are following the negative exponential distribution, the plots of headway versus ln (prob (h>T)) follow a straight line. Thus, the headway where the plots are no longer linear is the critical headway.

2.3 Platoon Distribution Model

Several platoon or bunching models for two-way two-lane highway have been postulated in the past. The typical model consists of a distribution of platoon size at each mean platoon size and distribution of headway between platoons. The widely accepted mathematical models are shown below.

Geometric distribution [12,13]

$$p_r = (1-\alpha)\alpha^{r-1} \qquad r = 1,2,3,.....$$

$$E_r = \frac{1}{1-\alpha}$$

Borel-Tanner distribution [12,13,14]

$$p_r = \frac{(r\alpha e^{-\alpha})^{r-1} * e^{-\alpha}}{r!} \qquad r = 1,2,3,.....$$

$$E_r = \frac{1}{1-\alpha}$$

Miller distribution (one-parameter) [12,13]

$$p_r = \frac{(m+1)(m+1)!(r-1)!}{(m+r+1)!} \qquad r = 1,2,3,.....$$

$$E = \frac{m+1}{m}$$

Two-parameters Miller distribution [12,13]

$$p_r = \frac{(m+1)(m+s+1)!(s+r-1)!}{s!(m+s+r+1)!} \qquad r = 1,2,3,.....$$

$$E = \frac{m+s+1}{m}$$

Where: P_r is the probability of a platoon size r and E_r is the expected platoon size
m and s are parameters in Miller distribution

Taylor M.A.P. et. al.[12] and D Galin[13] compared platoon models with data from different locations. They concluded the similar conclusion that Borel-Tanner distribution provide a good fit for two-way two-lane highway data for all range but geometric distribution and one-parameter Miller distribution fail at medium and high value of mean platoon size. All distributions except geometric distribution tend to over-estimate percent platoon size one for large mean platoon size.

3 Data Collection

Tomei Expressway was selected as study locations. The 24-hour data were collected from automatic double loop type detectors on 18 locations distribute from 2-kilo post to 155-kilo post, 6 locations for inbound traffic and 12 locations for outbound traffic. Fifteen locations are three-lane sections and three locations are two-lane sections. Highway geometry of each section varied from downgrade –2.9% to upgrade 3.0% with radius of curvature varies from 700 m. to straight sections. Sections that have slope more than 1% downgrade are classified as downgrade sections, and sections that have slope more than 1% upgrade are classified as upgrade sections, and sections that have slope between -1% to 1 % grades are classified as flat grade or level sections. There are 7 upgrade sections, 7 level sections and 4 downgrade sections. Most of locations have design speed of 100 kph and 120 kph with speed limit of 100 kph.

Time that front wheels and rear wheels of vehicles pass the first detector were recorded as T1 and T2, and time that vehicles pass second detector were recorded as T3 and T4 consecutively. Time-mean-speed, traffic volume, vehicle length, headway, and distance gap can be calculated directly from the raw data. Vehicles were classified into two types, passenger cars and heavy vehicles by vehicle's length. Vehicles that are longer than 5.5 m. were classified as heavy vehicles and other vehicles were passenger car.

Unfortunately, data during forced flow condition is rarely found from these sets of data. Data at high volume traffic can be found from only several locations within short period. Therefore this study focuses on platoon characteristic and service quality at free-flow condition and near capacity flow condition only.

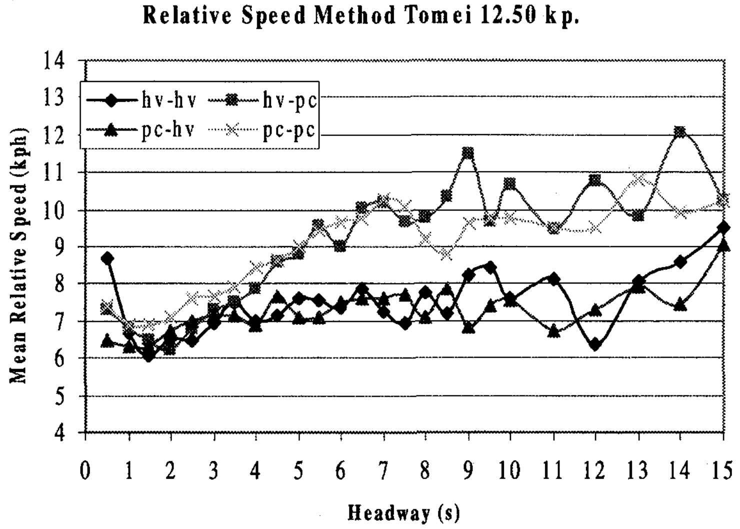
4 Platoon Criteria

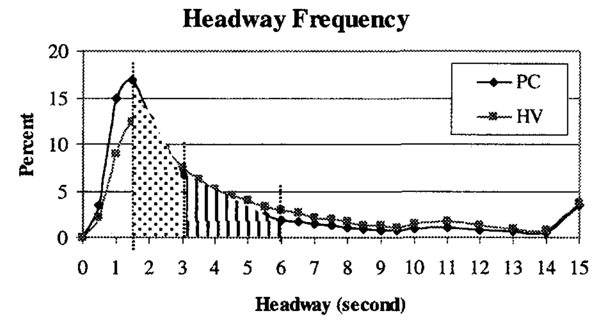
Vehicles in traffic stream can be classified into two types, following vehicles (platoon vehicles) and non-following vehicles (free vehicles). The criteria to classify vehicles into following vehicles or non-following vehicles have very crucial effect to the results of platoon analysis. Time headway is a common parameter to separate free vehicles from platoon vehicles. The headway that can distinguish driving conditions on multi-lane expressway was determined. Following the study of C.R Bennett, mean relative speeds method and Exponential headway model were selected to determine critical headway in this study.

4.1 Mean Relative Speeds Method

In mean relative speed method, leading-following pattern were classified into 4 types according to type of leader – follower as PC-PC, PC-HV, HV-PC, and HV-HV, where PC and HV mean passenger car and heavy vehicle respectively. The mean headway and the absolute value of relative speeds were calculated at every 0.5-second headway intervals for 0.5-10 seconds and every 1-second for headway more than 10 seconds from all 18 locations. Plots of relative speeds against headway were prepared and evaluated for the critical headway.

Figure 1 is an example of analyzed results for Tomei expressway at 12.50-kilo post outbound direction. At headway around 1.5 to 2.0 second, relative speeds of all cases reach the minimum point. This headway should represent the fully restricted condition and all vehicles have to adjust their speed according to vehicle in front of them. At headway around 3.5-4.0 second the relative speeds of heavy vehicle followers' cases become differ from passenger car followers' cases and start to almost constant. For passenger car, relative speed approach to constant value when headway is higher than 6 second. From this point, mean relative speeds are increase from 6 kph to around 10 kph. It can imply that most of passenger cars become independent from the preceding vehicles or become free vehicles. It can also conclude that only type of follower has influence for relative speed but type of leader almost has no effect.





Type	Mean Headway	S.D.
Passenger Car	4.043	6.048
Heavy Vehicle	4.770	4.984
Total	4.238	5.790

Figure 1: Relative Speeds Method

Partially constraint conditions occurred during headway between 1.5-6 second. Vehicles in this range are mixed from both free vehicles and following vehicles. Some of vehicles drive with out constraint but some of them still have to follow other vehicles. The critical headway should be in this range. As shown in figure 1, three-second headway was selected as critical headway for passenger car to balance the error of counting free vehicles as following vehicles with counting following vehicles as free vehicles. Due to different performance and different vehicle size between PC and HV, the safe distance for HV should be longer than PC. An average headway of heavy vehicles is higher than passenger car around one second for every locations. Therefore one more second should be added to critical for heavy vehicles to compensate this effect.

4.2 Exponential Model Method

Traffic data were classified into 4 groups by volume per hour per lane as 0-500, 500-1000, 1000-1500, and more than 1500 vphpl. The data were manipulated and the probability of headway greater than headway of T second was calculated (prob (h>T)). The nature logarithm of these values were calculated ln (prob (h>T)) and average in every 0.5-second range.

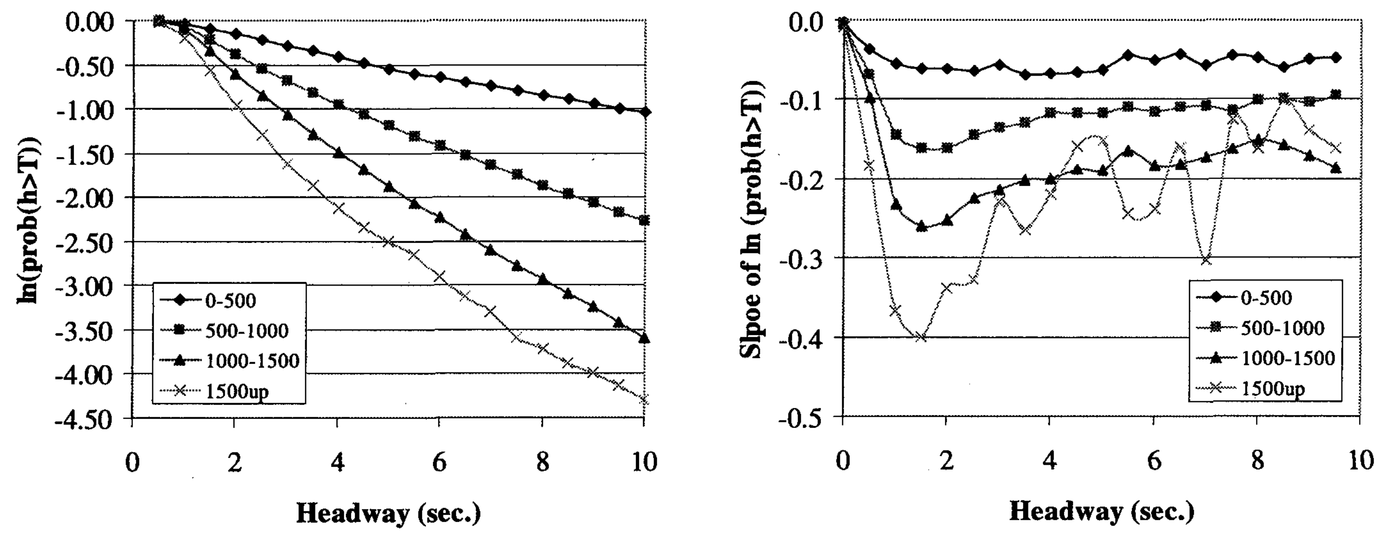


Figure 2: Exponential Headway Method

Figure 2 presents the example of critical headway by exponential model from the same location with relative speeds method. The right figure shows slope of ln (prob (h>T)) that provides clear image to determine critical headway. At low volume, headway distribution is close to exponential distribution at all range. At high volume, data quite fluctuate due to the low number of data at high headway but it still shows the similar trend with other groups. The critical headway can be determined apparently from medium volume at 500-1000 and 1000-1500 vphpl. When the slopes of ln (prob (h>T)) are almost constant, it means that the headway of vehicles is distribution as exponential distribution or vehicles are driving in free flow traffic. The headway, where slope of ln (prob (h>T)) becomes constant, can be judged as critical headway. Following figure 2, the critical headway may be estimated as 3.0-4.0 second at this location.

5 Platoon Characteristic

Platoon characteristics on multi-lane highway are quite different from two-way two-lane highway due to many reasons such as the opportunity for overtaking or lane changing and effect from opposite lane. The characteristics on multi-lane highway can be illustrated by number of platoon per unit time (platoon rate) and average number of vehicles in platoon (platoon size). Another parameter, percentage of following vehicles, is also useful to descript service quality of highway. Platoon rate was measured by number of platoons per hour. Platoon size is the average number of vehicles in a platoon. A single vehicle is counted as platoon size one. Percentage of following vehicle is the percent of following vehicles to total vehicles.

5.1 Cross-section Basis

In this study, each platoon parameters were calculated from every 5 minutes data. The platoon characteristics are investigated in both lane-by-lane basis and cross section basis. General characteristics of platoon can be observed by cross-section data. The example relationships of each platoon parameter on cross-section are plotted versus traffic volume as shown for six-lane section and four-lane section in the following figures.

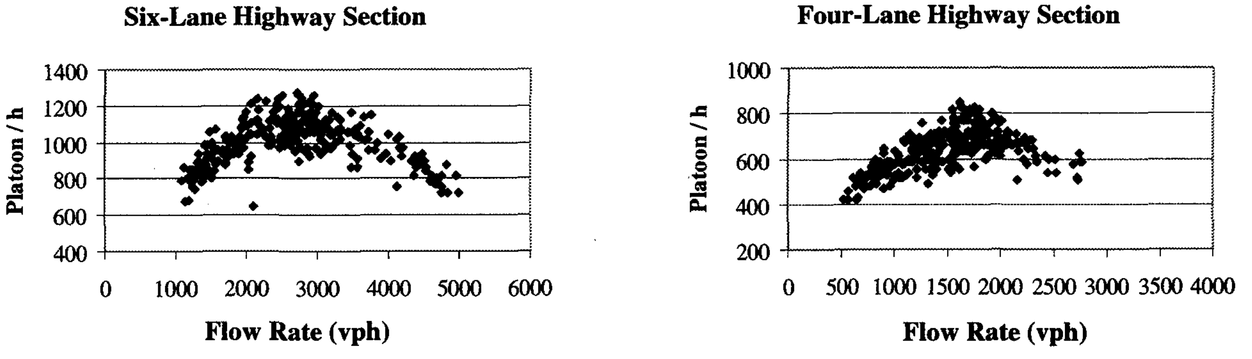


Figure 3: Platoon Rate and Traffic Volume

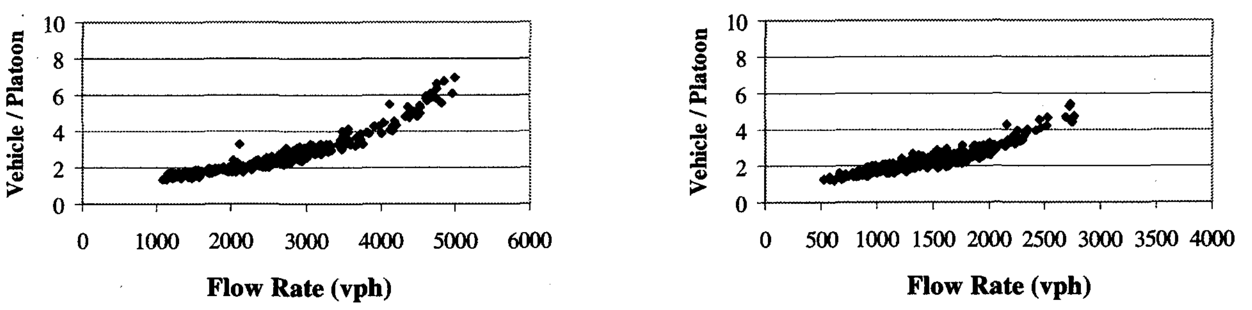


Figure 4: Average Platoon Size and Traffic Volume

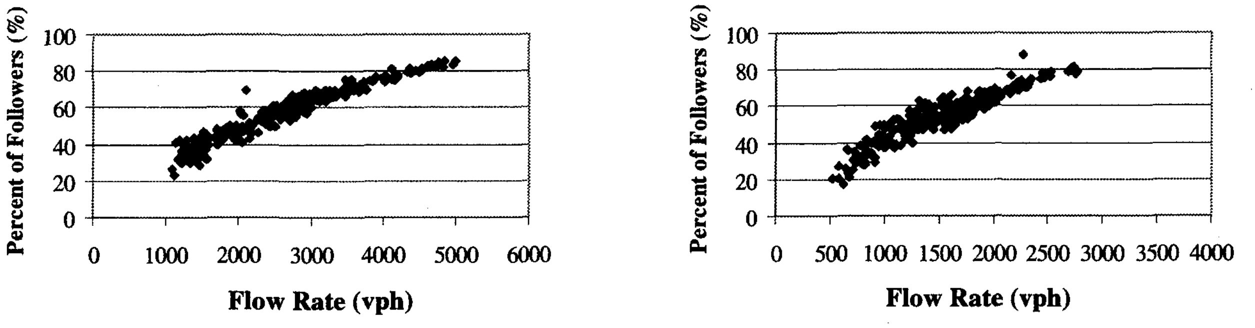


Figure 5: Percentage of Following Vehicles and Traffic Volume

Figure 3 illustrates that platoon driving can occur even when traffic volume is still low. Platoon rate increase when traffic volume increase until the certain number and then platoon rate will decrease. Platoon rate increases until volume reaches around 2400-2600 vehicle/hr on six-lane section and around 1800 vehicle/hr on four-lane section then become decreasing when volume increase. The relation of platoon rate with traffic volume can be fitted by inverse parabolic curve. The platoon rates scatter largely at medium volume, which platoon rate change from increasing to decreasing. The main reason is the effect from different percentage of heavy vehicles. Most of high volume data occur at low percentage of heavy vehicles but medium volume data can occur at wide range of percentage of heavy vehicles. At the same volume, most of high platoon rate groups should be result from low percentage of heavy vehicles data and most of low platoon rate groups should be results from high percentage of heavy vehicles data. The detail of effects from heavy vehicles will be presented in later part.

Figure 4 presents average platoon sizes versus traffic volume. Platoon size start from one and remain slightly higher than one at low volume traffic, this shows that most of vehicles are travel as free vehicle in this stage. The average size will increase slowly as volume increases then increase more rapidly after platoon rate decrease. The relationship between average platoon size and traffic volume is close to exponential function.

From platoon rate and average platoon size, they can explain the mechanism of platoon formation that most of vehicles will travel as free vehicle at low traffic volume. When volume increases, some vehicles cannot drive at their desired speed and have to follow another vehicle. Then small platoons will increase as volume increases. Until volume increases up to a certain number, small platoon groups are combined into larger platoon and number of platoon become constant. After that, most of vehicles will group together into several large platoons, number of platoons will decrease and platoon size will increase rapidly.

Figure 5 demonstrates that percent of following vehicle will increase as volume increases. Percent of followers will approach to 100 percent when traffic volume approach to capacity but it cannot reach 100 percent. Because some vehicles especially heavy vehicles in shoulder lane never allow their headway from leading vehicle less than critical headway due to their safety reason.

Since minimum safe distance between two vehicles were decided by two factors, reaction time and buffer distance. Reaction time plays more important role at high speed but on the other hand, buffer distance has higher effect at low speed or at forced flow region. Therefore headway between vehicles will increase when traffic reaches forced flow state. This study will concentrate only non-forced flow region, which time headway, plays more important role than distance headway.

5.2 Lane-by-Lane Basis

To study platoon characteristics on each lane, three platoon parameters were investigated on lane-by-lane basis. The platoons on each lane of highway have different characteristics. The important causes are traffic composition and lane utilization behavior on each lane. In this data set, average percentages of heavy vehicle are around 65% in shoulder lane, 40% in middle lane and 15% in median lane. The examples of platoon characteristics on six-lane section are shown separately in figure 6-8.

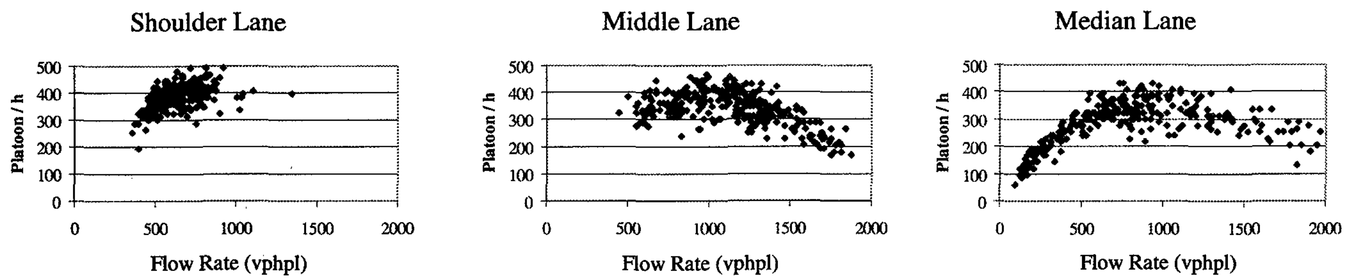


Figure 6: Platoon Rate

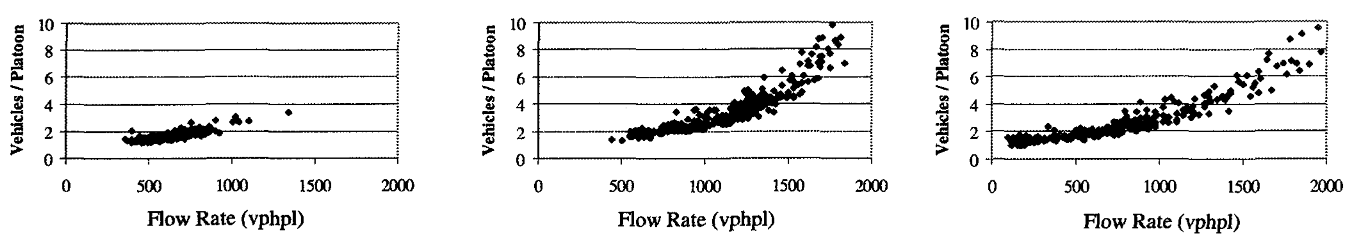


Figure 7: Average Platoon Size

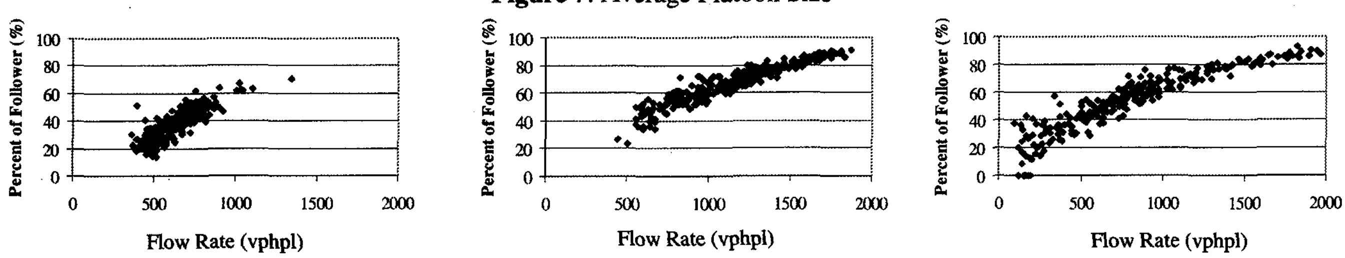


Figure 8: Percent of Followers

From figure 6-8 explain that the driving behaviors in shoulder lane is quite different from other lanes. Most of the heavy vehicles and slow vehicles tend to use this lane. Platoon rate reach the maximum point at 800 vphpl and traffic volume does not exceed 1000 vphpl in the general. Platoon size and percent of followers do not increase as much as other lanes because heavy vehicles usually drive with longer headway than passenger car and percent utilization of shoulder lane are low at high traffic volume. The behavior of middle lane and median lane are quite similar. There are wide volume range data on these lanes except there are no low volume data on middle lane because most of vehicles tend to use middle lane at low volume. Platoon rate reach the maximum at volume around 900-1000 vphpl on this location. The scatter of data should be caused from the different percentage of heavy vehicles that will be discussed later. Platoon size and percent of followers on middle lane increase slightly faster than median lane because of higher percentage of heavy vehicles. Percentage of followers on these lanes can increase to nearly 100 percent due to most of vehicles in these lanes are passenger cars.

5.3 Effects of Heavy vehicles

To study effects of heavy vehicles to platoon behavior, platoon characteristics at different percent of heavy vehicle are investigated. Due to the lack of wide range of percentage of heavy vehicles in any single location, data from consecutive locations on outbound direction were combined for this analysis. Percent of heavy vehicle were classified into three groups. Low percent of HV represents percent of HV less than 30%, medium percent of HV represents percent of HV from 30% to 60%, and high percent of HV represents percent of HV higher than 60%. Platoon rate and platoon size from every 5-minute and trend line of each group were plotted against traffic volume. The results are shown in figure 9.

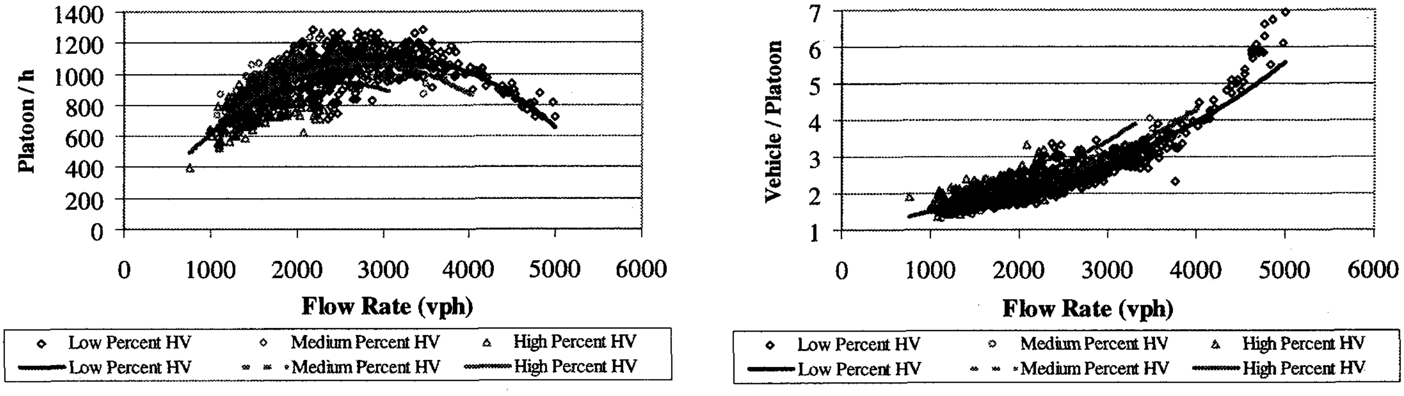


Figure 9: Effects of Heavy Vehicles to Platoon Behavior

Figure 9 illustrates that platoon rate at the same volume for low percentage heavy vehicle is higher than for high percentage heavy vehicle. Also platoon size increases faster at higher percentage of heavy vehicle. Most of high percentages of heavy vehicles are occurred at low volume and low percentages of heavy vehicles are occurred at high volume. The scatter of data at 2000-3000 vph can be explained that most of high platoon rate groups should be result from low percent HV data and most of low platoon rate groups should be results from high percent HV data. At high percentage of heavy vehicles, heavy vehicles have high tendency to drive together as platoons on shoulder lane but passenger cars tend to change to use middle lane and median lane. Therefore platoon rate at high percentage of heavy vehicles will reach the maximum point earlier than lower percentage.

Furthermore platoon parameters have been studied for measuring levels of service on multi-lane highway by the authors. These results show that, service quality can be percept differently by road users at the same volume. These properties of platoon parameters will be very useful to apply them to explain service quality of highway without converting vehicle unit to passenger car unit.

6 Comparison of Platoon Models for Multi-lane Highway

Several platoon models were proposed to predict platoon size distribution on two-way two-lane highway. Geometric distribution and Borel-Tanner distribution are the widely acceptable model that suitable for traffic on two-way two-lane highway. However platoon behavior on multi-lane highway is not exactly the same with two-way two-lane highway. To explain the platoon size distribution on multi-lane highway, geometric distribution and Borel-Tanner distribution were tested with multi-lane highway data.

Platoon distributions were determined for every 30-minute interval on each lane. Total data sets from 18 locations, which more than 2400 sets, were used in this study. Data sets were classified by lane and traffic volume. A comparison between platoon distribution models can be made by considering the behavior at each volume range. Data sets are divided into 7 groups by traffic volumes for every 300 vphpl. Mean platoon size at each volume range were calculated. Platoon size distributions were estimated by geometric distribution and Borel-Tanner distribution and then compared with real data. Platoon size distributions ware calculated from 1 to 20 vehicles and more than 20 vehicles. Chi-square test of fitness was applied at 80% and 95% significance level. The critical chi-square values at 95% and 80% significant for 20 degree of freedom are 10.851 and 14.587 respectively. The results of Chi-square test were presented in table 2.

From chi-square values, it can be said that geometric distribution provides more reasonable prediction than Borel-Tanner distribution for every volume range. Both distributions predict good results at low volume. Half of geometric distribution passes the test at 95 % confident level and almost all pass the test at 80% confident level. On the other hand, Borel-Tanner distribution does not pass the test even at 80% confident level for all medium and high volume range. In shoulder lane and middle lane, geometric distribution can predict good results on slightly deviation on median lane at very low and very high volume.

Table 2 Chi-square Test Results

Volume (vphpl)	Mean Platoon Size			Chi-Square value					
				Geometric			Borel-Tanner		
	Lane1	Lane2	Lane3	Lane1	Lane2	Lane3	Lane1	Lane2	Lane3
Less than300	-	1.55	1.38	-	2.20	24.38	-	3.18	1.36
300-600	1.58	1.91	1.85	0.34	11.91	9.22	6.20	10.22	8.75
600-900	2.17	2.49	2.59	1.38	4.64	9.90	18.77	23.34	23.51
900-1200	2.98	3.35	3.62	3.22	3.86	11.37	34.31	40.28	41.42
1200-1500	-	4.82	4.85	-	5.20	13.26	-	58.79	58.82
1500-1800	-	7.72	6.69	-	5.77	13.49	-	75.71	75.34
More than 1800	-	15.71	11.24	-	11.21	14.87	-	64.17	80.61

Represent data sets that pass Chi-square test at 95% significant level
Represent data sets that pass Chi-square test at 80% significant level
Represent data sets that do not pass Chi-square test at 80% significant level

For more details study, platoon size distributions of both distributions were plotted against real data at each volume range as shown in figure 10. At low volume both distributions provide results very similar to the data. The deviation of prediction can be observed at medium and high volume. Borel-Tanner distribution tends to over estimate for platoon size 1 or free vehicles and under-estimate for large size platoons. On the contrary, geometric distribution estimates slightly lower value for platoon size 1 and little higher value for the others. Since prediction of platoon size 1 is an important requirement for platoon model because it can be used to estimate percent for free flow vehicles and following vehicles. So Borel-Tanner distribution is unacceptable for multi-lane highway.

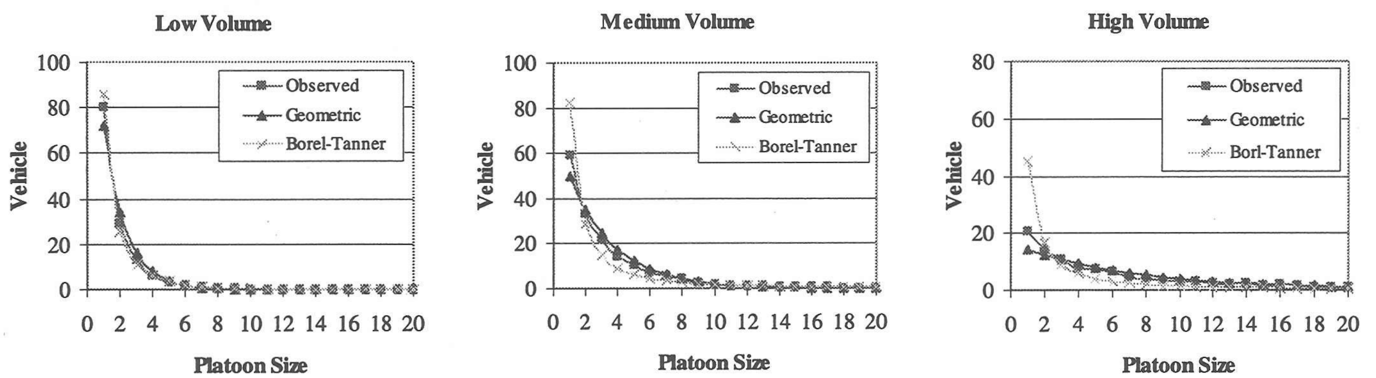


Figure 10: Comparison of Platoon Models

Borel-Tanner distribution predicts better result for two-way two-lane highway but geometric distribution provides better estimation for multi-lane highway. This result can be explained by the different characteristics between two-way two-lane highway and multi-lane highway. At low volume, platoon distributions on both types of highway are similar because there are low effects from overtaking opportunities. Conversely, overtaking opportunities become more influence for platoon distribution when volume increases. On two-way two-lane highway, large platoon groups can be formed due to the lack of overtaking opportunities but on the multi-lane highway, large platoon size will form only when the traffic volume on traveling direction increases. Therefore, mean platoon size on two-way two-lane highway can increase rapidly even many vehicles still travel as free vehicles but mean platoon size on multi-lane highway will increase when most of vehicles are in platoons. Borel-Tanner distribution has been widely accepted to represent platoon on two-way two-lane highway with limited overtaking opportunities. However it cannot provide a good fit for multi-lane highway that the overtaking opportunities are not so limit as on two-way two-lane highway.

7 Platoon Parameters and Levels of Service

This paper concentrates on platoon behaviors on various conditions on multi-lane expressway. However this knowledge will be applied to explain levels of service or service condition in the later part of research.

Present levels of service criteria which mainly are based on traffic density, have some drawbacks. Levels of service criteria were designed based on engineering point of view instead of the road users' point of view. They consider number of vehicles per a unit distance but they do not consider driving condition and pattern of traffic stream. Therefore, present levels of service criteria cannot represent the exact service quality perceived by road users. These criteria might be good enough for highway design engineers but they might not be meaningful in the sense of road users.

Platoon parameters that directly explain constraint conditions of vehicles in traffic stream, should be good parameters for levels of service criteria. In platoon study vehicles will be classified into leader or follower by their freedom of maneuver and then these results are used to calculate platoon parameters. Platoon rate can show general traffic conditions and driving pattern on traffic stream and it can also explain the freedom of lane changing maneuver. Percent of follower and average platoon size can indicate the chance that the drivers can drive freely on their desire speed (or drive without constraint). Therefore, with these platoon parameters, engineers can estimate the levels of service on the multi-lane expressway as the same quality of service which drivers perceive.

8 Conclusion

Due to the different characteristics between multi-lane highway and two-way two-lane highway, the platoon behaviors were analyzed. The platoon data were collected and investigated based on lane-by-lane basis and cross-section basis. A platoon criterion was reconsidered to suit for multi-lane highway based on driving constraint. The critical headway was determined by two approaches, mean relative speeds method and exponential headway model. Both methods give similar results for all locations. Critical headway is approximately 3-4 seconds. For platoon characteristics study, critical headway at 3 second and 4 second were selected for passenger car and heavy vehicle respectively.

Platoon characteristics were explained by three platoon parameters, platoon rate, platoon size, and percent of followers. Relationship of traffic volume with platoon rate and platoon size is inverse parabolic function and exponential function consecutively. Percentages of heavy vehicles also have effects on platoon. At the same volume, platoon rate will decrease and platoon size will increase when percentage of heavy vehicles increase.

Eventually, two famous platoon distribution models for two-way two-lane highway were compared with platoon distribution on multi-lane highway. Geometric distribution provided acceptable results for all volume range but Borel-Tanner distribution fail to estimate good result at medium and high volume. Borel-Tanner distribution tends to over estimate for platoon size 1 or free vehicles and under estimate for large size platoon. Even though, geometric distribution can estimate acceptable results but it still give slightly under-estimate value at high volume. Therefore the platoon distribution model for multi-lane highway should be developed in the future.

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STUDY OF PLATOON CHARACTERISTICS ON A MULTI-LANE EXPRESSWAY*

By SURASAK Taweesilp**, Izumi OKURA*** and Fumihiko NAKAMURA****

Platoon characteristics on multi-lane expressway were investigated based on lane-by-lane basis and cross-section basis by using data from 18 locations of Tomei expressway. Platoon criteria were determined to suit for driving behavior on multi-lane expressway by relative speeds method and exponential headway model. Critical headway at 3 second and 4 second were applied for passenger cars and heavy vehicles respectively. Three platoon parameters, platoon rate, average platoon size, and percent of followers, were used to explain platoon behavior on various traffic volume. Effects of heavy vehicles were examined. Finally several platoon distribution models for two-lane highway were compared with platoon size distribution data and chi-square test was applied to check the fitness of distribution. From this study, geometric distribution seems to be an acceptable model for all volume range.

高速道路多車線区間における車群特性に関する研究*

スラサク　タウィシルプ**、大蔵　泉***、中村　文彦****

本研究は、高速道路の多車線区間における車群形成特性について、東名高速道路の 18 地点の車両感知既データに基づいて車線別及び断面での分析を行ったものである。車群を特定する適切な状態量として相対速度と車頭時間を採用した。車群特定のための臨界車頭時間時間としては大型車・4 秒、小型車 3 秒を提案した。また、車群に関する状態量として車群流率、平均車群構成台数、追従車比率をとりあげて分析し、交通量との関係を明らかにした。大型車の影響についても明らかにした。さらに、2 車線区間については従来幾つかの車群台数分布モデルが提案されているが、これらのモデルについて比較分析した結果、多車線区間に関してはすべての交通量領域において幾何分布の適合性のよいことを明らかにした。