STUDY OF PLATOON BEHAVIOR TO MEASURE LEVELS OF SERVICE ON AN MULTI-LANE EXPRESSWAY*

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1. Introduction

Levels of service were defined to explain quality of service of highway facilities as six levels from A to F since HCM 1965. Levels of service are the important parameter for traffic engineers, road planners including road users. Therefore, levels of service should be consistent and understandable for all of them. In near future, levels of service will play more important role in many parts of Intelligent Transport System (ITS) such as in traffic assignment problems.

At present, levels of service criteria are based on three macroscopic parameters, density, speed, and volume[1]. However there are inconsistences between these three parameters in various traffic conditions especially in high-grade sections and high percentage of heavy vehicles. Furthermore, densities in which measured in pcu/km/lane cannot be measured directly from the field but it need conversion from vehicle to pcu by multiply with PCE value. In the real world, PCE value is not constant, they vary depend on percentage of heavy vehicles and type of terrain. PCE value always decreases when percentage of heavy vehicles increases and increases when highway changes from flat terrain to mountainous terrain. Practically single PCE value usually be applied for any percentage of heavy vehicles. Moreover, present levels of service criteria represent service quality based on engineers' decision but cannot represent to the actual service quality according to driver perception. Therefore alternative parameters, which can show restriction level of vehicles should be proposed and investigate validity of the parameters. Platoon parameters, which represent constraint conditions for road users, were studied and proposed as new levels of service criteria for multi-lane expressway.

Due to the reason as mentioned above and the lack of study in platoon characteristic for multi-lane expressway, the objectives of this study are to present platoon characteristics for multi-lane expressway and to investigate possibility to apply platoon parameters as levels of service criteria. This paper examines platoon behaviors in various traffic volume based on lane-by-lane basis and whole cross-section basis. Furthermore effects of grade to platoon parameters were investigated for consistency of platoon parameters.

2. Background

(1) Platoon

There are very less number of studies related to platoon on multi-lane highway. However many researches for platoon on two-lane rural highway have been conducted. 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. Platoon vehicles can be separated from free-travel vehicles by a certain critical headway. Due to the lack of study in platoon characteristic for multi-lane expressway, a platoon criterion was applied from various researches of platoon in two-lane highway. Headway range from 2-8 seconds and speed difference were applied differently from many researchers for two-lane highway[2-5]. Major of them applied headway 2-5 seconds in their researches.

Several platoon or bunching models for two-lane highway have been postulated and a typical model consists of a distribution of platoon size and distribution of headway between platoons. The widely accepted models are Geometric distribution, Borel-Tanner distribution, and Two-parameters Miller distribution.

(2) Levels of service

According to Highway Capacity Manual 1965, levels of service (LOS) were classified into six levels from A to F , that is from, free flow condition to forced flow condition. Each level was defined in a range of volume-to-capacity ratio (v/c) and operating speed. However operating speed is relatively constant for wide-range of rates of flow and not consistent with v/c in many conditions. Therefore, density was introduced as the major parameter used to define levels of service for basic freeway segments instead of volume-to-capacity ratio since Highway Capacity Manual 1985 and 1994.

However parameters in present criteria are not consistent between each other for various highway sections. They need different tables for different design speed and speed limit of highway sections as shown in Table 3-1 of HCM 1994. According to driver behavior, drivers constantly seek to increase his speed by change to another lane when he cannot drive at desired speed. Drivers that have to drive in platoon and adjust their speed according to the leader will percept some driving constraint or lower service quality of highway. Therefore platoon parameters, which are used as level of service criteria for two-lane highway, could be examined to apply for multi-lane highway. Platoon criteria were expected to increase consistency of LOS measurement for various geometric design and traffic conditions.

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* Keywords: Highway capacity, Levels of service, Platoon

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3. Data Collection

In this study, times when vehicles pass on double loop type detectors were recorded automatically in millisecond from 18 locations of Tomei expressway, Japan. Data were collected for 24-hour period from two-lane sections and three-lane sections, 6 locations for inbound traffic and 12 locations for outbound traffic. Geometry of highway sections varied from slope –2.9% to 3.0% with radius varies from 700 m. to straight sections. There are 7 up grade sections, 7 flat sections and 4 down grade sections. Most of locations have design speed at 100 and 120 kph with speed limit at 100 kph. Time-mean-speed, traffic volume, vehicle length, headway, and distance gap can be calculated directly from the raw data. Types of vehicles were defined by vehicle length. Vehicles, which are longer than 5.5 m. were classified as heavy vehicles.

Unfortunately, data from traffic at forced flow condition cannot be found from these sets of data. Data at high volume traffic can be found from only several locations. Therefore this study will focus on platoon characteristic at free-flow condition and near-capacity flow condition only.

4. Platoon Characteristic

Platoon characteristics on multi-lane highway are quite different from two-lane highway due to many reasons such as the opportunity for overtaking or lane changing and effect from opposite lane. Platoon characteristics on multi-lane highway can be explained by platoon rate and average platoon size. Platoon rate is number of platoons in a certain distance or a certain time period such as platoon per kilometers or platoon per hour. Due to the difficulty of data collection for platoon per kilometer, number of platoons per hour was used in this study. Platoon rate only is not clear to describe LOS for all volume range because two traffic conditions can cause the same platoon rate. Thus platoon size was introduced to explain traffic conditions. Platoon size is the average number of vehicles in platoon including the platoon leader. Free-travel vehicles are counted as platoon size of one. For more clearly explanation of driving conditions, relationship between percentage of followers and traffic volume were examined.

One of major difficulties in empirical studies of platoon is the method to classified platoon vehicle from free vehicle. A single critical headway was applied for all type of vehicles. In this research, the vehicles, which travel with headway less than 3 second were classified as platoon vehicles. From previous empirical study on platoon criteria by author shows that effect from leader to followers increase rapidly at headway less than 2-3 seconds. The highway section at kilo post number 28.75 inbound direction on Tomei expressway, which has wide range of traffic volume and low interruption from ramp, was selected as an example location. This location represents typical geometric design of Tomei expressway, which moderate curvature between 1000-5000 m., design speed at 120 kph and low percent grade. Traffic compositions are 65% HV and 35% PC on shoulder lane, 40% HV and 60% PC on middle lane and 10% HV and 90% PC on median lane. Platoon characteristics were investigated based on lane-by-lane basis to understand behavior in each lane and interaction between them. The analyses on cross-section basis were done because they are more practical and easier to understand for road users. The cross-section and lane-by-lane results are shown in figure 1-6.

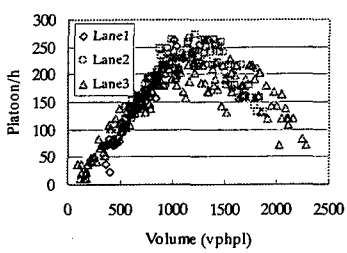

Fig.1 Platoon rate for each lane

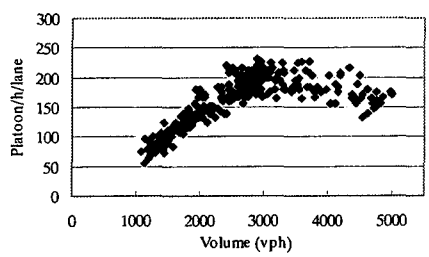

Fig.2 Platoon rate for cross section

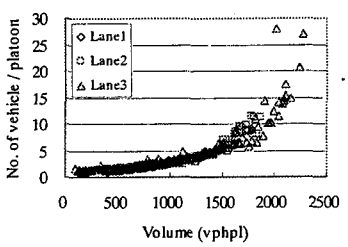

Fig.3 Average platoon size for each lane

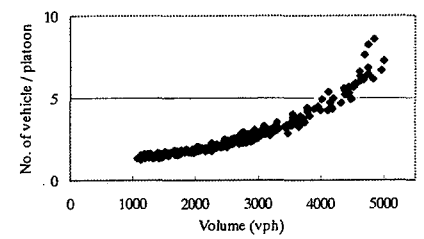

Fig.4 Average platoon size for cross section

Figure 1,2 demonstrate that platoon rate will increase linearly when volume increases up to around 1000 vphpl. Then it increases at slower rate and change to decrease slowly when volume passes 1200-1300 vphpl. Platoon rate decreases rapidly at volume close to capacity. In shoulder lane, turning point of platoon rate curve did not occur due to low volume in this lane. The critical volume that cause maximum platoon rate in middle lane and median lane are 1200 vphpl and 1300 vphpl

consecutively. The maximum platoon rate in second lane is higher and decreases earlier than median lane for every location because difference of traffic composition between lane and passenger cars have more tendencies to use median lane with low headway at high volume. Cross section result also shows the similar trend of platoon rate that increase as volume increase until reach 3000-3500 vph then decrease until reach capacity.

Figure 3,4 shows that average platoon size varies depend on volume as an exponential function. Average platoon sizes are less than 3 vehicles per platoon at volume less than 1000 vphpl and increase sharply to reach 10 vehicles per platoon at 1800 vphpl in middle lane and 2000 vphpl in median lane. Platoon size in median lane increases slower than middle lane at high volume but maximum platoon size is far more than other lanes. Cross section result indicates the similar exponential shape with maximum platoon size at 9 veh/platoon. Thus heavy vehicles need longer safe headway than passenger cars so some heavy vehicles never drive in headway less than 3 seconds. For that reason very high platoon size does not occur in cross section because of low platoon size in shoulder lane with high percentage of heavy vehicles.

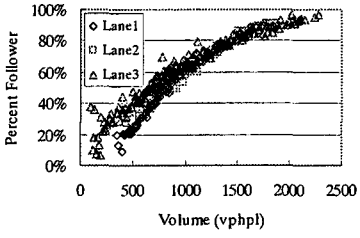

Fig. 5 Percent of Follower for each lane

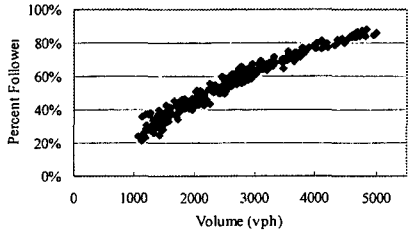

Fig. 6 Percent of follower for cross section

Figure 5,6 illustrate percent of following vehicles with total number of vehicles in traffic stream. Percentage of follower increases with decreasing rate as total volume increases. All three lanes have the similar characteristic that percent of follower at low volume are quite scatter and become more concrete when volume increases. Percent of follower vary within range ±10% at volume less than 1000 vphpl and reduce to range ±5% at volume from 1000 vphpl - 2000 vphpl then almost equal to 100% at volume more than 2000 vphpl. It is obviously show that percent of follower in shoulder lane is lower than other lanes at low volume. As the same with other parameters, percent follower in cross section is quite lower than that of lane by lane because of the effects from heavy vehicles in shoulder lane.

From those three parameters, behavior of vehicles can be explained that most of vehicles travel as single free vehicle at low volume. While traffic volume increase, vehicles tend to group as several small platoons and number of platoons increase as volume increases. At high volume, small platoons combine into larger platoon and then all vehicles are force in travel in one large platoon at traffic reach the capacity.

5. Platoon Parameters for Levels of Service

The ultimate goal of this study is to propose alternative LOS measuring parameters, which represent the actual service quality of highway based on driver perception. The levels of service must be defined in term that meaningful for drivers, who experience them and also meaningful for engineers who use them. Moreover definition of levels of service must be consistent with each other and consistent with various types of subsections on highway.

Due to speed and density at same traffic volume are different when gradient of highway sections change. Density at a certain traffic volume tends to increases when highway geometry changes from flat terrain to mountainous terrain according to the reduction of speed. Therefore platoon parameters were examined to consider the effects of gradient at various traffic volumes to verify that platoon parameters are suitable for measuring of levels of service. The test results from 18 sections of Tomei expressway are shown in figure 5-7. Highway sections are divided into three types based on gradient at detector location. Down represents for gradient between –3.00% to –1.01% sections. Flat represents for gradient between –1.00% to 1.00% sections. Up represents for gradient between 1.01% to 3.00% sections.

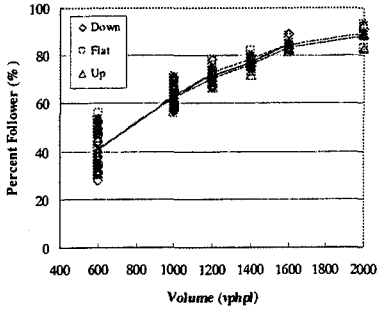

Fig.7 Percent follower at different grade

From figure 7 show that there are almost no effect of gradient to percent of follower in low rate of flow and only little effect at higher rate of flow. Percent of follower still increase linearly at low volume and increase with decreasing rate when volume increases. When consider carefully, we can see that percents follower at flat terrain are slightly higher than down slope and up slope sections. This can be explained that drivers tend to drive with more headway on slope sections due to safety reasons. The scatterness of data occurs at low volume because behavior of shoulder lane is different from other lanes as mentioned in figure 5.

From figure 8 also shows that effect of grade to average platoon rate has the similar result with percent of follower. This indicates that grade is almost no effect to platoon rate especially at low volume. At high volume, up grade sections easier chance to cause platoons due to speed reduction of heavy vehicles. The data scatter within ± 15-20 % around their mean equivalently among each lane. The slightly different of average value in the

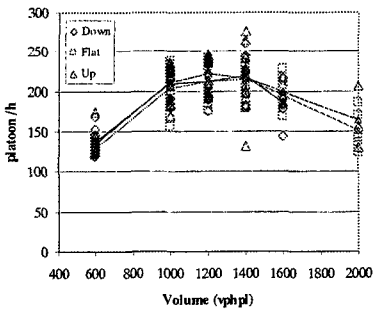

Fig.8 Platoon rate at different grade

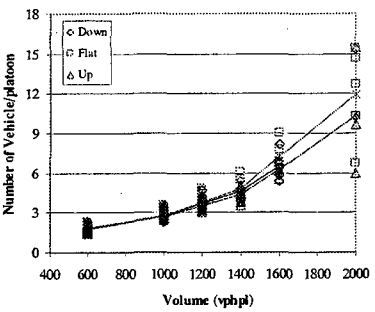

Fig.9 Platoon size at different grade

figure can be the effect of other factor such as percentage of heavy vehicles, effect of geometry of upstream section or may be the randomness of data themselves.

In the figure it can be seen that there are some different of platoon rate between flat section and upgrade section at high traffic volume. However the high traffic volume occurs not often at each location, so numbers of data are for high volume also low. Therefore the different of platoon rate can come from the variation of data only. Furthermore due to the lack of data at high volume at down grade section, so it is difficult to conclude that there are the effects of grade to platoon rate at high volume.

It can be stated from figure 9 that the average platoon size also gives the same result as the previous two parameters. Grade has almost effect to average platoon size for all volume. At high traffic volume average platoon size of flat sections are little higher than other sections. This result is corresponding to result of percent follower that can be explained with the same reasons.

The results of three parameters are confirmed that grade of the site has little effect to platoon parameters for all traffic volume. Even though results are not clear at high traffic volume due to the lack of data. These can imply that platoon parameters are consistent for every type of terrain. Furthermore platoon parameters are also consistent between each other in various conditions.

6. Conclusion

General characteristics of platoon on multi-lane highway are examined in this paper. The relationship between platoon rates, platoon size and percent of follower in various traffic volumes were presented. In this research found that platoon rate has parabolic relation with volume at peak number of platoon occur when volume reach 1200-1300 vphpl. Platoon size increases as an exponential function from 2-3 vehicles at volume less than 1000 vphpl to almost 20 vehicles at over 2000 vphpl. On the other hand percent of follower increases with decreasing rate as volume increases. This behavior is similar for all three lanes and cross section. Moreover effects of grade to platoon parameters were examined to test the consistent of parameters on various terrains. Gradient almost have no effects to all three parameters especially at low traffic volume. There is very little effect at high volume traffic. Even though heavy vehicle are likely to drive with smaller gap on upgrade sections but their speed also reduce. As this reason, vehicles tend to travel with slightly higher headway at upgrade section and downgrade section compare to flat section. Platoon parameters such as percent of follower and platoon size also reflect the constraint level of driving condition very clearly. Therefore platoon parameters could be the appropriate alternative parameters to measure levels of service for the multi-lane highway especially in the viewpoint of road users.

7. Further Research

Until now research, which related to platoon on multi-lane highway is very limited. A lot of researches related to this topic should be done in the future. Macroscopic characteristics of platoon were investigated for free-flow region and transition region in this study. However platoon characteristics in forced flow region are necessary to be examined. In many previous studies including this study, a single platoon criterion was applied for both passenger cars and heavy vehicles. While the behavior of passenger cars and heavy vehicles are quit different. The difference of traffic compositions in each lane caused different platoon characteristic among lanes. Most of heavy vehicles travel with lower speed and higher headway than passenger cars. Therefore higher critical headway should be applied separately for heavy vehicles. Furthermore microscopic behavior will be studied to develop a platoon model for multi-lane highway in the future.

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