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[Special Topic]

MEASURING LEVEL OF SERVICES ON MULTI-LANE EXPRESSWAYS BY PLATOON PARAMETERS

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Platoon characteristics were introduced to measure service quality on multi-lane highway. The data used were collected from18 locations on Tomei expressway. Due to the lack of study on platoon behavior on multi-lane highway, new platoon criteria and platoon behavior were investigated. Critical Headway was determined by relative speed method and exponential model. Platoon characteristics were explained by platoon rate, platoon size and percent of followers. New levels of service criteria, which based on road users points of view was proposed based on platoon parameters.

Key Words: *highway capacity, level of service, platoon, expressway, user's perception*

1. INTRODUCTION

The quality-of-service on highway is the important topic for highway capacity analysis. Many criteria and techniques were developed to measure quality-of-service on highway in purpose of both operating and design. Levels of service concept were developed to explain quality-of-service of highway facilities since HCM 1965[1]. At present, levels of service become the standard parameter for traffic engineers, road planners who apply this standard for highway design and operation including road users who directly experienced the service quality of highway. Therefore, levels of service should be consistent and easy to understand 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 and road pricing scheme. Present levels of service criteria are mainly based on engineering purpose. Even though, these criteria are meaningful for engineers but it quite difficult for road users to understand. Therefore, the levels of service that describe service conditions of highway based on road users perception should be developed.

Platoon parameters were introduced as new state variables to measure levels of service on multi-lane expressway. Platoon criteria were recalibrated to suit for multi-lane highway characteristic. Platoon rate, average platoon size and percent of platoon following vehicles were studied and tested for their consistency on various types of highway geometry. Finally, levels of service criteria based on road users point of view was proposed

(1) Discussion on current levels of service criteria

Present levels of service criteria are based on three major macroscopic parameters, traffic density (pcu/km), travel speed (km/h), and traffic volume (pcu/h). However there are inconsistencies among these three parameters in various traffic conditions especially on steep-grade sections and during high percentage of heavy vehicles.

Different tables are required for different design speed and speed limit of highway sections as shown

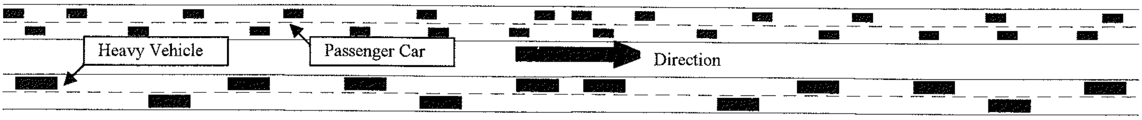

Fig.1 Highway with the same density but different traffic composition

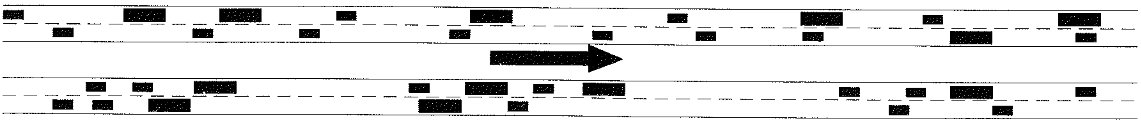

Fig.2 Highway with the same density but different driving pattern

in Table 3-1 of HCM 1994 [3]. Furthermore, densities in which measured in pcu/km/lane, cannot be measured directly from the field and it need conversion from vehicle unit to passenger car unit by multiplying with passenger car equivalent (PCE) values.

These PCE values are commonly calibrated based on capacity equivalent for capacity analysis. In the real world, PCE values are not constant and they vary depending on percentage of heavy vehicles, driving speed, and type of terrain. PCE value decreases when percentage of heavy vehicles increases and increases when highway changes from flat terrain to mountainous terrain. Practically single PCE value is usually applied for any percentage of heavy vehicles. **Fig.1** illustrates two highway sections with the same density but have different service quality in the road users' points of view. The upper section shows a highway with 24 passenger cars and lower section shows a highway with 12 heavy vehicles (assume PCE = 2). When there are a large number of heavy vehicles, they tend to drive in a group of platoon at the similar desired speed. So heavy vehicle drivers will feel more comfortable than passenger car drivers.

The driving pattern also has effect to quality-of-service in sense of drivers. Drivers who driving in well distributed traffic stream must feel more comfortable than driving behind slow vehicles or driving in a platoon. **Fig.2** presents two situations with the same group of vehicles but different driving pattern. The upper section shows that vehicles are driving in uniform distribution along the section and the lower section presents the vehicles driving in platoon. This figure shows that drivers who drive in platoon will suffer from traffic constraint more than drivers who drive in uniform traffic.

The above two cases are the examples of many highway sections that have the same density but have different service quality. Moreover, present levels of service criteria describe service quality mainly based on engineers' decision but cannot represent the actual service quality according to driver perception successfully. Different boundaries were set for various design speed highways. That is very difficult for users to understand the difference of highways, which they are driving on. Therefore alternative parameters, which can describe restriction levels of vehicle maneuver should be proposed and investigated the validity of them.

Following the driving behavior on multi-lane highway, drivers constantly seek to increase his speed by changing to another lane when he cannot drive at their desired speed. Drivers that have to drive in platoon and adjust their speed according to the leader will percept some driving constraint or low service quality of highway. Platoon conditions, which represent constraint conditions for road users should be a good parameter to indicate service quality of highway sections. Therefore platoon parameters, which are used as level of service criteria for two-lane highway, could be examined to be applying for multi-lane highway. Platoon criteria were expected to increase consistency of LOS measurement for various geometric design and traffic conditions.

(2) History of levels of service

Highway Research Board introduced a highway capacity concept in HCM 1950 to explain service conditions of highway. The manual was based on two capacity levels, possible capacity and practical capacity. Possible capacity represented the maximum hourly volume under prevailing highway and traffic condition. Practical capacity is the maximum traffic volume that could be accommodated (under prevailing highway and traffic conditions) while an acceptable quality of service is provided.

The concept of service volume was remaining in Highway Capacity Manual 1965[1]. Levels of service (LOS) were classified into six levels from A to F that represent free flow condition to forced flow condition. Many factors were considered in evaluating levels of service as travel speed and travel time, traffic interruption, freedom to maneuver, safety, driving comfort and convenient, and economy.

Among these factors, travel speed and service volume to capacity ratio were selected from committee as first and second major factors to identify levels of service. The maximum volume that can be carried at any selected levels of service is referred to as the service volume for that level. Each level was defined in a range of volume-to-capacity ratio (v/c) and operating speed. However it was difficult for individual road users to realize each level of traffic volume. Furthermore, operating speed is relatively constant for wide-range of rates of flow and not consistent with v/c in many conditions.

Therefore, traffic 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[2] and 1994[3] . However travel speed and traffic volume still be criteria of levels of service until now. The concept of passenger car unit (PCU) was added into new levels of service criteria to overcome the effects of heavy vehicles. Vehicle unit will be transferred into passenger car unit by passenger equivalent numbers (PCE), which are different for each type of vehicles and geometry of highway. Levels of service A to F are maintained as in HCM1965.

According to Highway Capacity Manual (HCM 1994), levels of service A to F briefly represent various service conditions on highway as below.

LOS A describes primarily free-flow operations. Average operating speeds at the free-flow speed generally prevail. Vehicles are almost completely unimpeded in their ability to maneuver within traffic stream.

LOS B also represents reasonably free flow, and speeds at the free-flow speed are generally maintained. The ability to maneuver within traffic stream is only slightly restricted.

LOS C provides for flow with speeds still at or near free-flow speed. Freedom of maneuver within traffic stream is noticeably restricted.

LOS D is the level at which speeds begin to decline slightly with increasing flows. Freedom of maneuver within traffic stream is more noticeably limited.

LOS E describes operation at capacity. Vehicles are spaced at approximately six car lengths, leaving little room to maneuver within traffic stream

Maneuverability within the traffic stream is extremely limited.

LOS F describes breakdown in vehicular flow.

In the latest version of HCM (HCM 2000), the same concept has been applied, though the thresholds of density to evaluate LOS have been changed.

2. BACKGROUND ON PLATOON

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 he is constantly seeking to increase his 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 car 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 leader and platoon follower. Platoon leader is any driver maintaining a gap ahead, and hence driving at either his temporary or maximum desired speed. Platoon follower is otherwise.

The studies related to platoon on multi-lane highway are very limited. Most of researches on platoon have been conducted on two-lane rural highway[4)-11)]. However platoon behaviors on multi-lane highway are different from two-lane highway in various parts and some results from two-lane highway cannot be applied to multi-lane highway.

Platooning vehicles are commonly separated from free-travel vehicles by a certain critical headway. Due to the lack of study in platoon characteristics for multi-lane expressway, a platoon criterion from various researches of platoon in two-lane highway was investigated. Major platoon criterions are summarized and shown in **Table 1**. Headway range from 2-8 seconds and speed difference were applied differently from many researchers for different purposes. Short headway interval were used to minimized number of non-following vehicles counted as following vehicles, and long headway interval are vise versa.

3. DATA COLLECTION

Tomei Expressway, which connects from Tokyo to Nagoya, was selected as study locations. The 24-hour data were collected from automatic double loop type detectors on 18 locations 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 –2.9% grade to 3.0% grade with radius of curvature varies

Table 1 Summary of Platoon Criteria

Researcher	Study	Criteria	Remark
T. Dijker [6]	Car following under congested conditions	3.5 s. for PC and 5.0 s. for HV	To minimize non-follower as follower
Keller [7]	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 [8]	Characteristic and LOS in Finland	5 sec. (following HCM) 3.5 sec (following Dijker)	
A.J. Miller [9]	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
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
CR. Bennett and R.C.M. Dunn [11]	Critical headway in New Zealand	3.0-4.5 sec.	For free flow speed prediction

from 700 m. to straight line 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 and 120 kph with speed limit of 100 kph.

Time that front bumper and rear bumper 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. 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, which 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.

In the following chapters, the authors selected one location which is appropriate in the context in each analysis. As the unit of the data is 5 minute and it was acquired through one day, the number of sample for the calculation or plotting is 288 (=(60/5)*24).

4. PLATOON CRITERIA

Vehicles in traffic stream can be classified into two types, following vehicles (platooning vehicles) and non-following vehicles (free vehicles). The non-following vehicles represent vehicles that can travel without constraint. They can drive at their desired speed and have enough space to maneuver within traffic stream. On the other hand, following vehicles represent vehicles that have to adjust their speed according to the vehicle in front of them and have to drive in constraint condition. The criteria to classify vehicles into following vehicles or non-following vehicles are very important in this study. Time headway is a common parameter to separate free vehicles from platoon vehicles on two-lane highway. The headway that was selected as criteria usually is called as critical headway. Mean relative speed method and exponential model are the most suitable techniques for determining the critical headway[6].

Concept of mean relative speed method is, when vehicles are following, their speed will be similar to those of the preceding vehicle and relative speed will be very low. Free vehicle speeds are independent of the preceding vehicle. So their speeds may range anywhere from very low to substantial.

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 a passenger car and a heavy vehicle individually. The mean headway of the absolute value of relative speeds were calculated at 0.5 second headway intervals for all 18 locations. Plots were prepared and evaluated for the critical headway.

Fig.3 is an example of result 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 seconds the relative speeds of HV followers' cases become different from PC followers' cases and start to almost constant. For passenger car, relative speed approach to constant value when headway is higher than 6 second. At this point, all passenger cars have full ability to drive at their desired speed. According to the result from this method, it can imply that type of follower has influence for relative speed but type of leader almost no effect.

Partially constraint conditions occurred during headway between 1.5-6 second. The proper critical headway should be in this range. For passenger car, three-second headway was selected as critical headway to balance the error of counting non-following vehicles as following vehicles with counting following vehicles as non-following 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.

In Exponential headway model method[11], following the concept of the headway distribution theory that assumes the headways of free flow traffic or headways between each platoon group tend to distribute as random and can be modeled by a negative exponential headway distribution. So we can say that headway distribution of platoon leaders should follow the exponential distribution. Therefore the point at which the headway distribution ceases to be negative exponential can be estimated as the point at which traffic ceases to be free-flowing. This point can be called the critical headway

According to **Fig.4**, at low volume(≤1000 vphpl), most of vehicles drive in non-following condition, so the plots of this group become straight line. For medium volume (1000-1500 vphpl), the plots start with curve and then become a straight line at headway more than 3 or 4 seconds. On the other hand, it is hardly to find the straight line from the plots for high volume (≥ 1500 vphpl).

As mentioned in the previous sections, platoon criteria in case of multi-lane highway where interaction between the lanes must be considered was not analyzed so far. Therefore the acquired result is quite important for further platoon analysis. Based on these results, 3 seconds for passenger car and 4 seconds for heavy vehicle have been set and were used for the next chapter on platoon characteristics.

5. PLATOON CHARACTERISTICS

Platoon characteristics on multi-lane highway are quite different from two-lane highway due to some reasons such as the opportunity for overtaking or lane changing and effect from opposite lane. Moreover platoon criteria have high effect to them. The authors already discussed the difference between multi-lane case and two-lane case[12]. The following analysis is based on this investigation.

The characteristics on multi-lane highway can be illustrated by platoon rate and platoon size. Another parameter, percentage of following vehicles, is also useful to describe service quality of highway. Platoon rate is measured by number of platoon per hour. Platoon size is the average number of vehicles in a platoon. Free vehicle is counted as platoon size one.

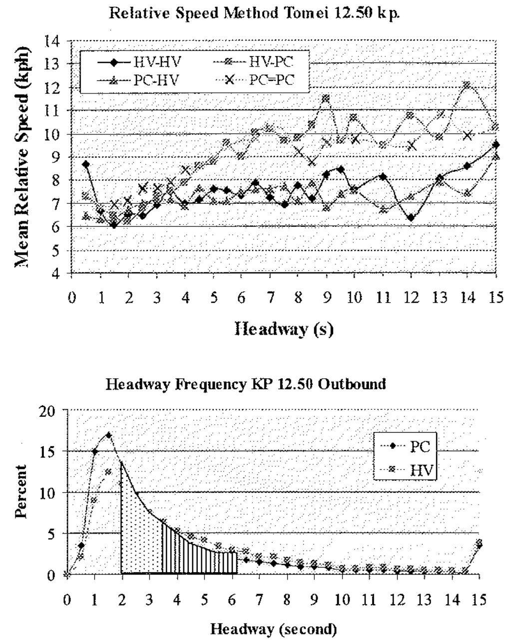

Fig.3 Relative Speed and Time Headway

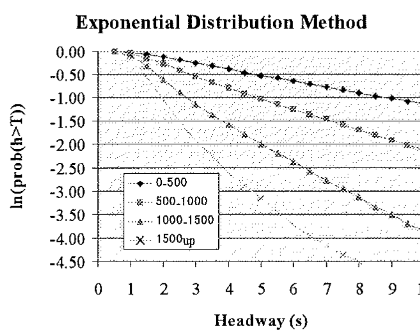

Fig.4 Exponential Headway Model

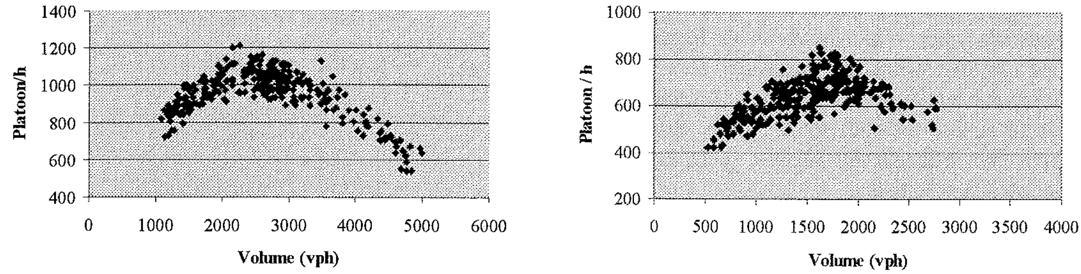

Fig.5: Platoon Rate(Platoon/h) and Traffic Volume (6 lane case (left) and 4 lane case(right))

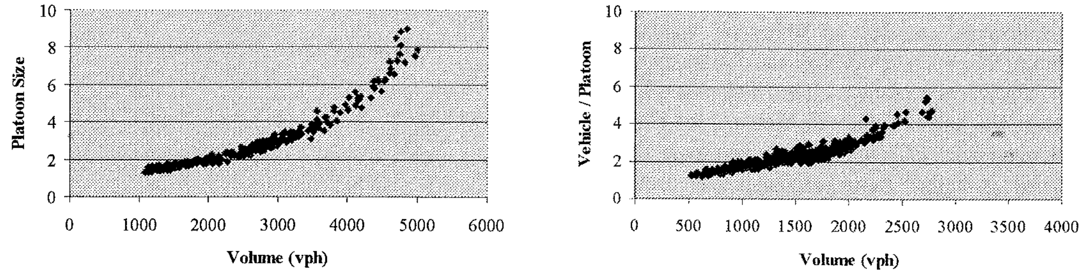

Fig.6: Average Platoon Size and Traffic Volume (6 lane case (left) and 4 lane case(right))

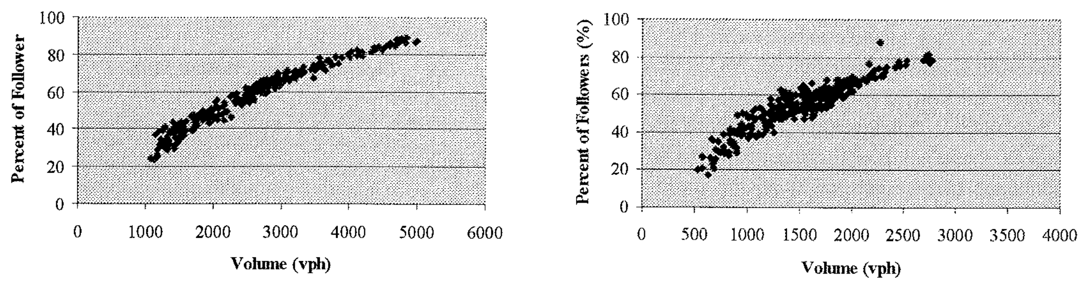

Fig.7: Percentage of Following Vehicles and Traffic Volume(6 lane case (left) and 4 lane case(right))

Percentage of following vehicle is the percent of following vehicle to total vehicles. Platoon parameters were calculated from data in every 5 minutes. The typical relationships between each platoon parameter and traffic volume are illustrated versus traffic volume as shown for six-lane section and four-lane section in the following figures.

Fig.5 illustrates that platoon will occur even though directional total traffic volume is still low. Platoon rate increases when traffic volume increases 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 becomes decreasing when volume increases. Platoon rate at each traffic volume has a little change when percent of heavy vehicle changes but shape of curve remains the same. The relation of platoon rate with traffic volume is inverse parabolic curve with zero intercept.

The scatter of data at the peak of curve can be explained by two reasons. The first reason is the difference of percent of heavy vehicles at same traffic volume. This causes dissimilar traffic conditions at the same traffic volume. Another reason is most of vehicle at this volume range have headway close to platoon criteria. Therefore platoon rate at this range can vary widely at the similar traffic volume.

Fig.6 presents average platoon sizes versus traffic volume. Platoon size is calculated by the number of vehicles divided by the number of platoon as shown in the vertical axis in the right graph. The average size will increase as exponential function when volume increases. Platoon size is close to or slightly higher than unity at low volume traffic, that means most of vehicles travel as free vehicle. It will increase rapidly when number of vehicles increase up to a certain level.

From platoon rate and average platoon size, they can explain behavior of vehicles in traffic stream that 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 form and increase as volume increases. Until volume increases up to a certain number, vehicles have less ability to maneuver. Then small sized platoons will be combined into larger platoon and number of platoon become constant. After that, number of platoons will decrease and platoon size will increase rapidly.

Fig.7 shows that percent of following vehicle will increase as volume increases. It will increase as decreasing rate. Percent of follower will approach to 100 percent when traffic volume close to capacity but it will not reach 100 percent. Because some heavy vehicles especially in shoulder lane never allow their headway from leading vehicle less than 4 second mainly due to their safety reason. Furthermore time headway between vehicles usually increase when traffic reaches forced flow state. Since minimum safe distance between two vehicles will be 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. However quality-of-service at forced flow region is obviously evaluated by travel speed. Therefore this study will concentrate on only non-forced flow region which time headway plays more important role than distance headway.

The similar results were obtained from all other locations. The models to predict each platoon parameter were also developed based on these relationship by authors[12].

6. LEVELS OF SERVICE BASED ON PLATOON PARAMETERS

Present levels of service criteria which mainly are based on density, have some drawback as mentioned earlier. They consider number of vehicles per a unit distance but they do not consider pattern of traffic stream at all. These criteria might be good enough for engineers but they might not represent correct service quality of highway in sense of road users.

Platoon parameters which directly explain

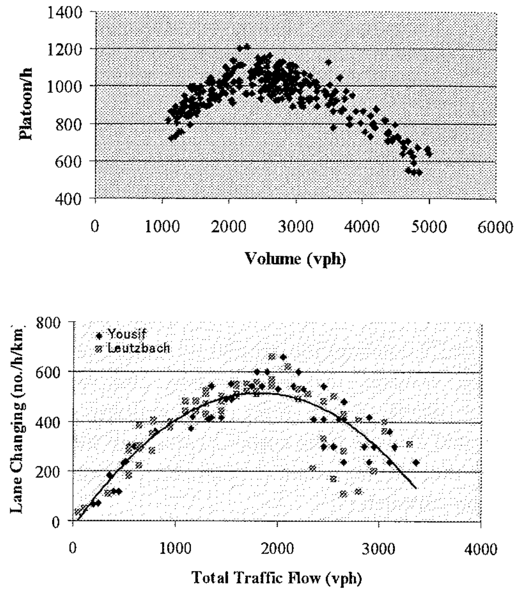

Fig.8 Platoon Rate and Lane changing Rate[13]

constraint conditions of vehicles in traffic stream, should be good parameters for levels of service criteria. Platoon rate can show general traffic conditions of traffic stream. Besides it can explain the freedom of lane changing maneuver also. When we compare platoon rate and rate of lane changing, it can be found that there is some similarity between platoon rate and lane changing rate. This relation can confirm that platoon parameter can reflect service quality in the term driving comfort, convenience and freedom of maneuver.

Fig.8 illustrates that platoon rate on multi-lane highway has strong relation with the opportunity for lane changing maneuver[13]. The upper figure which was the same as the left graph in **Fig.5** is compared with the lower figure which was drawn from the data by two-previous researches done in two different countries. The data source in this comparison is different as the authors could not get the lane changing data from our data source. Even though, the comparison from general characteristics points of view is worth to discuss. When drivers have no constraint for lane changing maneuver, both number of lane changings and platoons will increase as linear proportion of volume. Average platoon size still remains low with range between one and two vehicles. With further increasing of traffic volume, the opportunity of lane changing will decrease and then more vehicles have to follow other vehicles and consequently platoon size become larger.

According to HCM, many factors were considered in evaluating levels of service as travel speed, travel

Table 2 Proposed Level of Service Criteria

Level of Service (HCM)	Proposed LOS Criteria For Road User	Average Platoon size	Chance of free vehicle
Level A	Free-Flow	1.0-1.5 vehicles	70%-100%
Level B		1.5-2.0 vehicles	50%-70%
Level C	Partial-Constraint Flow	2.0-3.0 vehicles	33%-50%
Level D		3.0-4.0 vehicles	25%-33%
Level E	Constraint-Flow	4.0-7.0 vehicles	Less than 25%
Level F	Congested-Flow	More than 7 vehicles	N/A

time, traffic interruption, freedom to maneuver, safety, driving comfort and convenience, and economy. Travel speed, travel time and economy can be evaluated directly from speed. Freedom of maneuver, safety and driving comfort could be evaluated from platoon parameters.

As mentioned above, platoon rate could be a simple parameter to describe driving conditions according to driver perception because it reflects the freedom of maneuver directly. Following the description of each LOS from HCM 1994, LOS was redefined based on driving conditions. Tentative LOS criteria can be constructed for an example. Start with classified each LOS from platoon rate and then estimate average platoon size at the corresponding traffic condition. The LOS from A to F can be approximately divided according to platoon conditions as shown in **Fig.9** and **Table 2**.

LOS A is represented by ranges that the relationship between platoon rate and traffic volume is nearly straight line. It starts from no traffic volume until around 1200 vph or V/C = 0.2. This can imply that all of vehicles are free vehicles. Each platoon is a representation of each vehicle. This range is hardly found when we consider total volume on section of highway but it can be found especially on median lane at low volume.

LOS B is the range that platoon rate still increases as volume increase but not in linear relation. At this range, the platoon rate increases following parabolic curve and platoon size still small. Most of platoon counts compose of platoon size one (free vehicles) and platoons that arise from the combination of single vehicles. More than 50% of vehicles can drive as free vehicles at this stage.

During traffic volume increasing, average platoon size gradually increases although platoon rate become constant at volume around 2000-2700 vph or V/C around 0.35-0.45. It means that freedom of maneuver within traffic stream is noticeably restricted. This range can be classified as LOS C according to HCM definition.

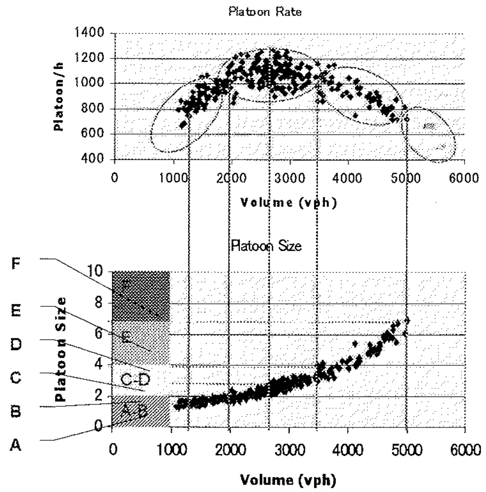

Fig.9 Platoon and LOS

LOS D is divided as the section that platoon rate start to decrease when volume increases. At this level, small sized platoons gradually group as larger size platoons and freedom of maneuver becomes more limited.

Under the conditions that platoon size increases rapidly even if small change in volume increase occurs and also platoon rate drops sharply, most of vehicles lose their freedom of maneuver and have to adjust their speed and distance according to vehicle in front of them. This condition commonly is defined as LOS E or capacity level. At capacity level, traffic stream is very sensitive to the incident. Even a single incident can disturb all traffic streams, and then queue or congestion may occur.

In LOS F, traffic stage changes from stable flow to unstable flow. Even though traffic density increases, traffic volume will drop significantly. Time headway is not a major concern for drivers anymore but distance headway becomes more important for traffic safety. Traffic parameters are difficult to be predicted at this stage due to the limitation of observed data.

After that, average platoon size that corresponding to each level can be determined. Then LOS can be defined based on average platoon size. This parameter was selected as a criterion because relationship between this and traffic volume is one-to-one function and low scatter.

Finally, levels of service criteria based on platoon parameters were developed. Service levels were not only divided in to previous 6 levels following HCM but also proposed 4 levels for road users as shown in ellipse-shape of the upper figure of **Fig. 9**. Because in the real world, drivers are hardly to identify levels of service in too detail. From several researches related to levels of service, they presented that those road users hardly to percept all 6 service levels as mentioned in the manual. Most of road users cannot identify the difference between each level of service especially between good service and very good service. Therefore number of levels of service for road users could be reduced. Four service levels based on platoon mechanism were proposed. These four levels can be compared with HCM six levels by approximately combined level A with level B, combined level C with level D, level E and level F. The results can be concluded that the first level is the traffic condition at platoon rate increase. The second level is the traffic condition during the transition of platoon rate from increasing to decreasing. The third level is the traffic condition at platoon rate decreases until reach the capacity and the forth level is the traffic condition after capacity level or after traffic stream breaks down. These four levels can be simply named as Free-flow condition, Partial-constraint flow condition, Constraint flow condition, and Congested-flow condition. Nevertheless six-level service conditions must be estimated first for maintaining correct communication between engineers and road users. The LOS criteria based on platoon parameters are proposed in **Table 2**.

Based on the discussion on LOS mentioned above, in order to evaluate the effect of heavy vehicles referring to LOS, the combined data from three

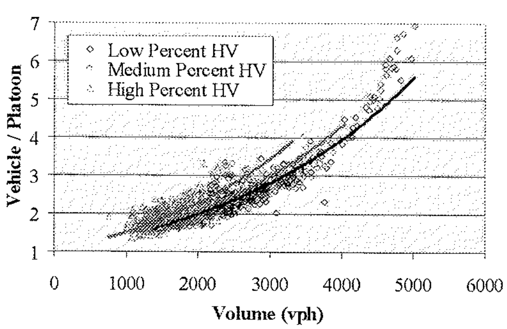

Fig.10 Platoon size at Different Percent HV

consecutive locations of inbound direction were

applied because of the lack of wide range percent of heavy vehicle in a single location. Traffic composition was classified into three types, low percent of HV for 0%-30% HV, medium percent of HV for 30%-60% HV, and high percent HV for more than 60 % HV. Average platoon sizes from each group are presented in **Fig.10**. The calculation was done only the 6-lane case due to the limitation of the data. From the figure, it shows that average platoon size increases faster at higher percent of heavy vehicle. Therefore the effects of heavy vehicle have already been considered in this method. Moreover percent of followers can be estimated from average platoon size by the following equation.

$$\% \text{ of Followers} = (1\text{-}1/\text{platoon size}) \text{x} 100\% \quad (1)$$

7. CONCLUSION

In this study, the platoon characteristics on multi-lane highway were studied and applied to measure service quality on highway including recalibration of platoon criteria, (critical headway of 3.0 sec for passenger car and 4.0 sec for heavy vehicle), followed by the analysis of platoon rate, average platoon size and percent of followers. Based on the results, new LOS criteria were proposed based on platoon characteristics Further studies are expected especially on LOS classification. The proposal shown here might be checked by other data sources in further researches.

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