A STUDY OF GAP ACCEPTANCE
AT A MERGING SECTION OF URBAN FREEWAY

Sun Yon Hwang
PH.D. Course
Transport Planning & Traffic Eng.
School of civil, urban and geosystem engineering
Seoul National University
Sinlim-Dong, Kwanak-Gu, Seoul, 151-742, Korea
Tel: +82-2-880-7377
Fax: +82-2-889-0032
E-mail: hsuny95@snu.ac.kr

Chang Ho Park
Professor
School of civil, urban and geosystem engineering
Seoul National University
Sinlim-Dong, Kwanak-Gu, Seoul, 151-742, Korea
Tel: +82-2-880-7378
Fax: +82-2-889-0032
E-mail: parkch@gong.snu.ac.kr

Kyung Soo CHON
Professor
School of civil, urban and geosystem engineering
Seoul National University
Sinlim-Dong, Kwanak-Gu, Seoul, 151-742, Korea
Tel: +82-2-880-7376
Fax: +82-2-889-0032
E-mail: chonks@snu.ac.kr

Abstract: Gap acceptance is one of the important components in microscopic traffic characteristic. Recently it has been used to study simulation models and the ITS(Intelligent Transport System). We need the mathematical modeling of Gap Acceptance behavior.

Existing researches used experimental methods and probability distribution. But there are many factors such as driver conditions, vehicle conditions and traffic conditions. This study develops gap acceptance model based on the discrete choice theory. Therefore, the purpose of this paper is to combine these elements, along with an experimental, quantitative analysis of driver behavior in actual merging situations.

For reflecting driver behavior, the gap acceptance model is designed. To build up the model, real data are used to set up explanatory variables and estimate the model. After the model composition and estimation, we found that of the space gap and the time gap, the space gap is more significant. The factors determining Gap Acceptance are as follows: the lead gap, lag gap, front gap, heavy vehicle and remain distance. Congestion greatly affects gap acceptance. Whether conditions are congested or not depends on gap acceptance. When congestion conditions occur, different behavior, such as nosing, occurs and provides different results.

Key Words: Gap Acceptance, Merging Section, Urban Freeway, Lead Gap, Lag Gap, Front Gap, Critical Gap, Remain Distance, Probit Model

1. INTRODUCTION

1.1 Background And Purpose

It is complex to model the sequence of a driver’s lane-changing decision-making procedure because the decision-making procedure is not visible. We can only observe the final gap acceptance step. Therefore, establishing a gap acceptance model that simulates gap acceptance behaviors well would explain a driver’s lane-changing decision-making procedures. To do this, I will develop a gap acceptance model especially applied to the urban freeway.

Most of the past studies about gap acceptance were delay and capacity analyses in an uncontrolled intersection. But gap acceptance is an important submodel of the lane change model, and is the necessary microscopic traffic characteristics in the traffic control system and traffic management departments. So gap acceptance is more and more important. Recently traffic simulation, ITS(intelligent transport system) has been used for modeling lane changing. But we need a mathematical model to show “gap acceptance” behavior.

Existing studies of gap acceptance fall short because they do not reflect behavior using experimental methods or probability gap distributions. Thus I will develop a gap acceptance model based on reality which can describe driver’s behaviors. Therefore, the purposes of this study are to describe precisely the gap acceptance observed in the merging process and to provide a gap acceptance model that explains the lane-changing decision-making procedure. I will present a microscopic decision model for driver gap acceptance behavior when a driver makes a decision to change lanes at a merging section.

Merging negatively influences the main lanes’ capacity and traffic flow. In an urban freeway merging section, merging influences traffic movement greatly. Therefore I will focus on the gap acceptance at urban freeway merging sections for observation and analysis.

1.2 Scope And Subject

Drivers make decisions to do lane changing based on a complicated mix of factors such as travel destination, driver behavior and traffic flow. Lane changing in a traffic micro-simulation can be classified into two categories: mandatory and discretionary.

Mandatory lane changing happens in the following situations: the current lane is blocked; the current lane is merging to another lane; the destination requires to change to another lane. Discretionary lane changing happens in the following situations: passing a low speed or heavy vehicle, yielding to another merging vehicle.

People won’t do lane changing without any reason in normal situations. To reach their final destination, drivers will do mandatory lane changing when the current lane is not available. To adjust vehicle speed, drivers will do discretionary lane changing. Note that even under a mandatory lane changing situation, the driver does not need to do lane changing immediately.

Merging means that a vehicle enters from the ramp to the main lane stream. This is a specific case of mandatory lane changing. At the ramp merging occurs frequently, so it is easy to observe merging situations. Because merging heavily affects the main lanes’ volume and traffic flows, the gap acceptance phenomenon that occurs at merging sections is made a research topic. And it is possible to present precise lane changing through gap acceptance.
1.3 Composition Of Study

This paper consists of 5 chapters. Each of the chapters’ contents are as follows: The second chapter provides a review of the existing study’s results on gap acceptance and methodology, and analyzes the issue. The third chapter describes gap acceptance behavior based on theoretical review and model concept, and provides a theoretical model equation. Chapter 4 describes the model used, experimental data containing many useful instances of gap acceptance and is used to compare and validate the gap acceptance models. Chapter 5 concludes with a discussion on gap acceptance behavior and model results and provides prospects and areas for further work.

2. LITERATURE REVIEW

2.1 The Concept Of The Gap Acceptance

A driver entering or crossing a traffic stream must evaluate the space between a potentially conflicting vehicle and himself or herself and make a decision whether to cross or enter or not.

“Gap” refers to the time and space that a subject vehicle needs to merge adequately safely between two vehicles. Gap acceptance is the minimum gap required to finish lane changing safely. Therefore a gap acceptance model would describe the judgement of the driver about whether to accept or not.

The general assumption was that drivers consider only the adjacent gap that is headway between a lead vehicle and a lag vehicle over the object lane. In the case of merging to an adjacent lane, if the driver can accept both lead headway and lag headway, the gap is accepted and the lane-change is accomplished.

In a gap acceptance model, the critical gap is an important parameter and is defined as follows: “Critical gap” is the minimum time interval that a vehicle in the current lane can enter (accept gap) between the traffic streams on the object lane (headway). “Reject gap” is the time interval that subject vehicle can not enter a main lane due to the main lane's vehicle obstacle flow. In the middle of the reject gaps of the individual vehicles, the largest reject gap is defined as the “maximum reject gap”.

The accept gap is the time interval that a subject vehicle in the current lane can enter the main lane’s stream without main lane’s vehicle obstacle flow. Therefore an individual vehicle’s accept gap and reject gap can be measured realistically, but its critical gap can not. Critical gap can be estimated, however, as more than the maximum reject gap and equal to or less than the minimum accept gap.

2.1.1 Deterministic Gap Acceptance

The gap acceptance model is based mainly on capacity analysis. So it is more focused on capacity analysis than on gap acceptance itself. To estimate deterministic critical gap three methods are used representatively.

The first method is when vehicles on the ramp accept gap. We can determine the critical gap through median or mean observed from the gaps.
The second method to determine critical gap is to determine the intersection of the accumulated curve representing the accept gap and the accumulated curve representing the reject gap.

The third method is the regression method provided by Drew (1968) using merge angle and acceleration lane length. We can solve an experimental equation and determine critical gap. HCM (highway capacity manual) provides ramp lane and adjacent lane volume estimation equations by classifications using the deterministic regression analysis method. The advantages of this method are simple calculation by regression analysis and great practical applications. But it is macroscopic, and has limits to reflecting driver behavior. So it is difficult to accurately simulate the real world.

### 2.1.2 Stochastic Gap Acceptance

Up to now the critical gap derived a unique value based on limits. To overcome limits, research has derived critical gap using gap distribution. Gap distribution uses logit or probit probability models partly. The gap distribution model has the advantage that it is detailed, but it needs many variables and parameters, and spends much time and cost.

Daganzo (1981) used the ‘probit model’ to reflect the heterogeneity of drivers’ behavior and to estimate parameters of normal distribution of the intersection critical gap. He found that there is diversity not only between different drivers, but also with the same driver. That is, different drivers or the same driver behave differently to the same gap size.

Mahmassani and Sheffi (1981) used the ‘probit model’ to estimate the mean and variance of critical gap at an uncontrolled intersection. They explained that the model is affected by the number of gaps judged that it are not critical gaps.

Troutbeck (1992) argued that critical gap distribution assumes log-normal distribution. According to his model, the best critical gap estimation method is the “maximum likelihood” method. The results show that the maximum likelihood method has the smallest value in difference population mean and sample mean and deviation to mean measure. That is, the maximum likelihood method has the highest reliance of the critical gap estimation methods.

Cassidy et al (1995) used the binary logit model to calculate the mean of the single-valued critical gap function to evaluate capacity and delay experientially. This model concluded that the components that affect gap acceptance at intersections are delays due to gap and first gap indicator. But until lane changing is finished, sequences of reject gap are not considered for model formulation or parameter estimation.

### 2.2 Methodology Of Existing Studies

Studies about gap acceptance and critical gap have determined that drivers accepted gap more than the critical gap. But gap acceptance is not a simple phenomenon; it is a module of the lane-changing decision-making process. Gap acceptance requires the driver’s judgement.

Kita (1993) formulated the gap acceptance problem at the merging section of freeways. He

---

1 Driver tend to escape from merging first gap for safety.
used the binary logit model and explanatory variables (remain distance of the acceleration lane, gap, relative velocity).

Yang and Koutsopoulos (1995) presented a ‘rule-based’ lane-changing model applied to freeways. They provided changeable lanes and scenarios about lane-changing and modeled events where drivers faced a conflict objective. But this study did not estimate formal parameters or evaluate the model.

Traffic microscopic simulation is currently under development to evaluate the Intelligent Transportation System (ITS) and improve the Driver Simulator. Modeling driver behaviors is the core component in traffic microsimulation and has been a popular area in engineering and psychology. Lane-change models are other key models in traffic microsimulation besides car-following models. They are more complicated than car following models and are common phenomena in real traffic. Almost all the traffic microsimulation includes lane change behavior models but has different kinds of models.

In spite of its importance, not a lot of research has focused on lane changing behavior. Most researchers put emphasis on how to model the gap acceptance model (Gipps, 1995). Gipps (1986) presented a model for the structure of lane-changing decisions. He modeled the sequence as 3 steps: “mandatory lane changing → discretionary lane changing → gap acceptance.” It seems to simulate lane changing behavior rationally. But this study simulated driver’s behavior uniform, model parameters were not estimated by model’s equation.

Koutsopoulos (1996) presented his approach for modeling lane-changing behavior using discrete choice. This model is based on the gap acceptance model. Few existing lane changing models are based on the real traffic data. They are mostly tested by simulation and accepted since they do not generate incidents or interrupt traffic.

Modeling lane-changing behavior is more complex since it actually includes three parts: the need for lane-changing, the possibility for lane changing, and the trajectory for lane-changing. Each part is important for getting a realistic lane-changing model. Furthermore, the lane changing model is complex itself. It needs to consider not only the vehicle in the front, but also the vehicles nearby, and even the traffic flow information. It is also more dangerous. The possibility to cause incidents is great when the car changing lanes. Modeling driver behavior in lane-changing becomes difficult and a lot of issues have to be considered to construct a realistic and reliable lane-changing model.

Ahmed et al. (1996) proposed mandatory lane changing model and extends the work by developing a new model for heavily congested traffic. Under heavily congested traffic, gaps of acceptable lengths are hard to find. Hence, a forced merging model is proposed which captures merging by gap creation either through courtesy yielding of the lag vehicle in the target lane or through the subject forcing the lag vehicle to slow down.

He presented the conceptual framework of the proposed lane changing model. The model uses the likelihood function formulation.

The lane changing model structure is shown in Figure 1. Except for the completion of the execution of the lane change, the whole decision process is latent in nature. The latent and observable parts of the process are represented by ovals and rectangles respectively.
The MLC\textsuperscript{2} branch in the top level corresponds to the case when a driver decides to respond to the MLC condition. Explanatory variables that affect such decision include the remaining distance to the point at which lane change must be completed, the number of lanes to cross to reach a lane connected to the next link, delay. Drivers are likely to respond to the MLC situations earlier if it involves crossing several lanes. A longer delay makes a driver more anxious and increases the likelihood of responding to MLC situations. And finally, due to lower maneuverability and larger gap length requirement of heavy vehicles as compared to non-heavy vehicles, they have a higher likelihood of responding to the MLC conditions.

The MLC branch corresponds to the case where either a driver does not respond to an MLC condition, or that MLC conditions do not apply. A driver then decides whether to perform a discretionary lane change (DLC). This comprises of two decisions: whether the driving conditions are satisfactory, and if not satisfactory, whether any other lane is better than the current lane. The term satisfactory driving conditions implies that the driver is satisfied with the driving conditions of the current lane.

Important factors affecting the decision whether the driving conditions are satisfactory include the speed of the driver compared to its desired speed, presence of heavy vehicles in front and behind the subject, if an adjacent on ramp merges with the current lane, whether the subject is tailgated etc. If the driving conditions are not satisfactory, the driver compares the driving conditions of the current lane with those of the adjacent lanes. Important factors affecting this decision include the difference between the speed of traffic in different lanes and the driver's desired speed, the density of traffic in different lanes, the relative speed with respect to the lag vehicle in the target lane, the presence of heavy vehicles in different lanes ahead of the subject etc. In addition, when a driver considers DLC although a mandatory lane change is required but the driver is not responding to the MLC conditions, changing lanes opposite to the direction as required by the MLC conditions may be less desirable.

\textsuperscript{2} mandatory lane changing
If a driver decides not to perform a discretionary lane change (i.e., either the driving conditions are satisfactory, or, although the driving conditions are not satisfactory, the current is the lane with the best driving conditions) the driver continues in the current lane. Otherwise, the driver selects a lane from the available alternatives and assesses the adjacent gap in the target lane. The lowest level of ovals in the decision tree shown in Figure 1 corresponds to gap acceptance when the MLC conditions apply, and whether the subject vehicle is a heavy vehicle. When trying to perform a DLC, factors that affect drivers' gap acceptance behavior include the gap length, speed of the subject, speed of the vehicles ahead of and behind the subject in the target lane, and the type of the subject vehicle (heavy vehicle or not). For instance, a larger gap is required for merging at a higher travel speed. A heavy vehicle would require a larger gap length compared to a car due to lower maneuverability and the length of the heavy vehicle. In addition to the above factors, the gap acceptance process under the MLC conditions is influenced by factors such as remaining distance to the point at which lane change must be completed, delay (which captures the impatience factor that would make drivers more aggressive) etc.

Note that, delay cannot be used as an explanatory variable except for very specialized situations, for example, merging from an on-ramp. This is because the very inception of an MLC condition is usually unobserved.

Ahmed integrated MLC and DLC into decision making hierarchy, designed individual models, derived parameters. These points are evaluated with good results. Significant explanatory variables are few, rational decision making structure completed lane changing process by composing unique hierarchy that linked current lane satisfactory or not, target lane choice and gap acceptance. But a real driver’s behavior (current lane satisfactory or not, target lane choice, gap acceptance) is in progress simultaneously. Furthermore what we can judge from observation data is only “gap accept or not”. On the each hierarchy how to judge reject situation is difficult. Also each hierarchy is not independent. If current lane satisfaction level deceases, target lane selection probability increases, thus, gap acceptance probability also increases. Target lane selection is strictly correlated condition that current gap accept or not.

That is, it is impossible for Ahmed’s model to explain the interaction of individual hierarchy establishments.

### 2.3 Methodology Of This Study

This study has constructed a gap acceptance model of composed explanatory variables which simulate drivers’ lane changing behaviors. The factors affecting gap acceptance are different in the cases of MLC and DLC. In the case of DLC, factors are gap size, subject vehicle’s velocity, on target lane lead vehicle and lag vehicle’s velocity, subject vehicle’s type. In the case of MLC, factors are the above factors plus remaining distance until lane changing finish, delay. When lane changing begins is not measured mostly. So except of the special case, it is difficult to use explanatory variables.

The gap acceptance model captures drivers’ assessments of gaps as acceptable or unacceptable. Drivers are assumed to consider only the adjacent gap. An adjacent gap is defined as the gap in between the lead and lag vehicles in the target lane. For merging into an adjacent lane, a gap is acceptable only when both lead and lag gaps are acceptable.

Drivers are assumed to have minimum acceptable lead and lag gap lengths which are termed...
as the lead and lag critical gaps respectively. These critical gaps vary not only among different individuals, but also for a given individual under different traffic conditions.

3. MODELING

3.1 Model Concept

To reflect driver’s lane-changing decision-making process, we need to build a model structure of lane-changing. To do the lane changing, the most important thing is to check whether it is safe to do it or not. Most of lane-changing models are based on the gap acceptance model.

The model for this study is theoretically based on the discrete choice model. The gap acceptance model is a part of the lane-changing decision making process. So we consider gap acceptance as the event. Event comes to the end the choice problem. That is, what drivers consider the lane changing is event, driver to do the lane changing or not is driver’s choice.

If the driver changes lanes, we can represent it as “accept”. If the driver does not change lanes, we can represent it as “reject”. Also we represent “accept” as “1”, and “reject” as “0”.

For a model of the decision-making process, we need to set up the criteria of judgement. Generally when a person decides what to do, if he or she is a rational human being, he or she selects the maximum utility. According to utility maximization theory, if the utility of the accept is more than the utility of the reject, the driver chooses lane-changing and accepts gap. The reverse case is the same way.

To judge whether a driver accepts or not, we first compose the utility function. Utility function is based on the driver’s own characteristics. In lane-changing, the size of the utility corresponds to choice probability, that is, gap acceptance probability. As utility increases, choice probability is higher.

Second, we can calculate choice probability by logit model or probit model. For the result called accept or reject, the result is the dependent variable. Factors affecting the results are the independent variables. We find choice probability of the all factors, and, according to their probability, we can judge whether or not drivers accept the gap and change lanes.

This flow chart of the gap acceptance model represents the driver's decision-making process. First, the drivers decide to change lanes. They judge whether to merge or not by remain distance. If the remain distance does not meet the critical condition, drivers are forced to accept the current gap. But if the remain distance meets the critical condition, drivers consider the congestion condition. In the second step, the gap is calculated according to congestion.

The gap acceptance probability is calculated. In the third step, drivers judge that current probability is more than the boundary probability. If gap acceptance probability is more than the boundary, drivers attempt to do lane changing. If not, each step feeds back and they will wait in the current lane and repeat the process until the gap can be accepted.

In the model, gap acceptance is constructed as a probability function of factors (gap, velocity, remain distance, velocity difference, delay). The coefficient and parameters vary a little at different traffic conditions.
The equation is shown as follows:

\[
P_a(\delta) = Pr\left(\varepsilon - \varepsilon_{\mu} \leq V_{\mu} - V_{\mu}\right) = \int_{-\infty}^{V_{\mu} - V_{\mu}} \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{1}{2} \left(\frac{\xi}{\sigma}\right)^2\right] d\xi, \sigma > 0
\]

\[
= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{(V_{\mu} - V_{\mu})/\sigma} \exp\left[-\frac{1}{2} \left(\frac{u}{\sigma}\right)^2\right] du = \Phi\left(\frac{V_{\mu} - V_{\mu}}{\sigma}\right)
\]

where \( P \): binary probit model
\( \phi (\cdot) \): generalized cumulative normal distribution

According to drivers’ accept choice, we can calculate acceptance probability and rejection probability.

The equations are shown as follows:

\[
P_a = \Phi\left(\frac{V_{ga} - V_{gr}}{\delta}\right)
\]

\[
P_r = 1 - P_a
\]

where \( P_a \): accept probability
\( P_r \): rejection probability
\( \phi (\cdot) \): generalized cumulative normal distribution
These values are obviously not only related to drivers but also to vehicle types. Since not enough data about this is available, the model will gather the data and randomly validate it in certain ranges for different cars.

3.2 Explanatory Variable Definition

In the gap acceptance model, we assume the relationship of four vehicles: the subject vehicle, the front vehicle, the lead vehicle and the lag vehicle. Among the vehicles, there are gaps and differences of velocity.

First, there are four gaps: the total gap, the front gap, the lag gap and the lead gap. When a driver wants to do lane changing, the critical lead gap and the lag gap are required to be acceptable for the driver. Otherwise, it is not safe for the driver to do the lane changing.

The front gap is the gap between the vehicle doing lane changing to the vehicle ahead it. In most of situations, the lag gap and lead gap are acceptable for drivers, but they won’t do the lane changing when the front gap is too far or too short. In the Car-following model, there is a desired distance for each individual driver. Of course, the front gap is much shorter than the desired distance for following. However, the front gap can not be too short or there is possibility to collide with the front car. Drivers will justify the front gap whether safe or not by their own experience.

But, the front gap is important in modeling gap acceptance. Especially in discretionary lane changing, drivers not only notice the traffic of side lanes, but also the traffic of the current lane. The car doing lane changing is mostly faster than cars ahead when it wants to pass the front cars. Normally, it only does lane changing when it is near the front car.

Considering a freeway traffic situation, the front car won’t brake suddenly as in a dense urban traffic situation. Drivers will behave aggressively and keep the distance to the front car shorter while doing lane changing. The front gap was obtained from experiments for different
leading speeds. It was found that most front gaps are shorter than the corresponding desired distance.

Actually, the front gap is not only related to the leading vehicle speed, but also related to the speed difference between the leading car and the car doing the lane changing. The front gap is kind of linear to the speed difference. It is reasonable because the bigger the speed difference is, the longer safe distance drivers need to keep.

The front gap can be considered as a minimum desired distance to the front car. It is not necessary for drivers to do lane changing at the exact front gap distance. The front gap only tells the normal distance drivers would accept. Of course, drivers would do lane changing when the distance is farther than the front gap, and even when there is no front car. Therefore, this lane-changing model only considers the front gap as the minimum lane changing distance.

But how to choose suitable front gap for different situations is a higher-level control problem. The lead gap and the lag gap are key elements in lane changing models. The differences between most lane changing models are how to calculate the lead gap and the lag gap. The most famous lane changing model may be Gipps’s(1995), and it has been used in a lot of micro-simulation like MITSIM. Since the experiments could not be used to study the lead gap and the lag gap, the lead gap and the lag gap models are constructed based on the simulation results. But actual observation results will be used to do this study. The two gaps are required to make sure that during lane changing cars won’t cause any accidents or have to brake suddenly.

The lead gap is to prevent the car doing lane-changing from colliding with the lead vehicle. Obviously, the gap is related to distance and velocity. Assuming a driver will take seconds to finish lane-changing, and both vehicles maintain their current velocities, the minimum distance is needed. After the car finishes its lane changing, it will change its driving mode to follow the front car. Then the distance will eventually change to the desired following distance. So besides the safe distance, an extra space is needed to be comfortable for drivers to change modes.

The idea for the lag gap is the same. The difference is that the lane changing car does not want to, or is not safe, to make the lag car brake.

Drivers do not control the lag vehicle situation. So lag gap is an important factor that affects lane changing. In merging, the remain distance affects lane changing. Remain distance decreases, and the driver tends to merge to the smaller gap. That is, the gap acceptance probability increases.

Vehicle velocity is the important factor that affects lane-changing. If the vehicle drives at a high speed, it needs to merge the larger gap. Not only its own velocity, but also the relative velocity between vehicles are very important factors. Between the subject vehicle and adjacent vehicles, there are differences of the velocity, distance and gaps.

In conclusion, the explanatory variables are as follows: total gap, front gap, lead gap, lag gap, each vehicle’s velocity, relative velocity between vehicles, remain distance, and delay.
4. DEVELOPMENT OF MODEL

To embody the gap acceptance model concept, we need to develop the model. To build up the model, real data are used to set up variables and estimate the model. Therefore, we need to gather real data about gap acceptance.

First, we decided the area of the investigation. The subject area should have a clear vantage point from which to photograph actual gap acceptance behavior.

Field data collection is performed by taking photographs via a video camera. From the continuous film data, we can abstract the lane-changing events to discrete conditions. We transfer these events from film to frame. From 0.5 second time unit frame data files, we can study and quantify the lane-changing events.

Using the event data gathered, we input vehicle location coordinates on the image. Through the location coordinates, we gain information about a given vehicle’s location, length, velocity and difference of the distance between vehicles.

With this information we can also determine the explanatory variables and estimate model parameters. The results of the model estimation will describe which factors are more significant and more important in lane-changing and gap acceptance. The parameter estimates provide influence of the gap acceptance.

The whole process of the development of the gap acceptance model is provided in the following flow chart.

Figure 4. Gap Acceptance Model Development Flow Chart
The whole process of the development of the gap acceptance model is provided in details.

The subject area is merging section of the urban freeway (south part of the Young Dong Bridge on the Olympic road). Field data collection is performed on weekdays. We took a photograph from 6 am. to 10:30 am. This period contains congestion situation and non-congestion situation.

Field data collection is performed by taking photographs via a video camera. We transfer these events from film to frame. From frame data files, we can study and quantify the lane-changing events. Using the event data gathered, we gain information about a given vehicle’s location, length, velocity and difference of the distance between vehicles. We use instead of the image detector and program for reducing image detector error. Because lane-changing is the discrete event.

Using the each vehicles’ information, we abstract the explanatory variables. We use probit model that describe real world more than other discrete model. Parameter estimation is used maximum likelihood method that has the highest reliance of the existing studies. Parameter calibration is used LIMDEP 7.0.

The explanatory variables are shown as follows:
total gap, lead gap, lag gap, front gap, remain distance, subject heavy vehicle dummy, object heavy vehicle dummy, velocity difference between subject vehicle and lead vehicle, velocity difference between subject vehicle and lag vehicle.

First, all explanatory variables are used in the model parameter estimation. Through sequence of the statistic analysis, we remove unreasonable explanatory variables. Model estimation is based on the suitability test, parameter’s p-value, sequential test, p value, and professional judgement.

Using the sequential test, final gap acceptance model is selected. The selected model is shown as follows:

Gap acceptance model contains 7 variables. Lead gap, lag gap, front gap, remain distance, subject heavy vehicle dummy, object heavy vehicle dummy.

The model means each variable affects gap acceptance. Driver consider factor lag gap than lead gap importantly. Because lag gap is between own vehicle and back vehicle, subject driver can not control the lag gap.

Especially, in case of the merge, remain distance is most important factor determined gap acceptance. If the remain distance is smaller, driver tend to accept smaller gap.

Heavy vehicle dummy is the factor determined gap acceptance. If heavy vehicle is, driver avoid to merge. In case of the object heavy vehicle, gap acceptance probability is smaller than subject heavy vehicle dummy.

Model estimation results are agreed with the intuition results. According to the statistic analysis model results are reasonable.
Table 1. Gap Acceptance Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Expected sign</th>
<th>Parameter estimation result</th>
<th>Standard error</th>
<th>T value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Constant</td>
<td>+</td>
<td>5.5667</td>
<td>1.0480</td>
<td>5.312</td>
</tr>
<tr>
<td>2. Lead Gap</td>
<td>+</td>
<td>0.0030</td>
<td>0.0038</td>
<td>0.793</td>
</tr>
<tr>
<td>3. Lag Gap</td>
<td>+</td>
<td>0.0129</td>
<td>0.0054</td>
<td>2.390</td>
</tr>
<tr>
<td>4. Front Gap</td>
<td>+/-</td>
<td>-0.0064</td>
<td>0.0027</td>
<td>-2.373</td>
</tr>
<tr>
<td>5. Remain distance</td>
<td>-</td>
<td>-0.0629</td>
<td>0.0093</td>
<td>-6.748</td>
</tr>
<tr>
<td>6. Subject Heavy vehicle</td>
<td>-</td>
<td>-0.1731</td>
<td>0.1476</td>
<td>-1.173</td>
</tr>
<tr>
<td>7. Object heavy vehicle</td>
<td>-</td>
<td>-0.6098</td>
<td>0.2142</td>
<td>-2.847</td>
</tr>
</tbody>
</table>

# Observed data 835

\[
L(0) = -578.0441 \\
L(\beta) = -454.9731 \\
-2[L(0) - L(\beta)] = 246.1420 \\
\rho^2 = 0.2129 \\
\rho^2 = 0.2008
\]

5. CONCLUSION AND PROSPECT

5.1 Conclusion

It is important to analyze gap acceptance behavior at merging sections of the urban freeway in order to grasp traffic behavior under multiple conditions (driver condition, vehicle condition and traffic conditions,) and to learn their individual effects. This model will be able to analyze the effect of each element on gap acceptance.

For reflecting driver behavior, the gap acceptance model is designed. After the model composition and estimation, we found that of the space gap and the time gap, the space gap is more significant. Because drivers run at their own speed, they recognize space more than time. That is, drivers think that distance is the more important factor to lane changing safety.

The factors determining Gap Acceptance are as follows: the lead gap, lag gap, front gap, heavy vehicle and remain distance.

Congestion greatly affects gap acceptance. Whether conditions are congested or not depends on gap acceptance. When congestion conditions occur, different behavior, such as nosing, occurs and provides different results.

5.2 Prospect

Gap acceptance is important to the model of lane-changing. And our own model is important. For further study, more real data, and more research about gap acceptance characteristics under different congestion conditions are needed. To explain this situation, we need to integrate the gap acceptance model. Also we need to consider the nosing phenomenon.

Various fields can benefit from application of the gap acceptance model. In the
ITS (intelligent transport system), gap acceptance and lane changing are the main elements. To operate a microscopic traffic simulation, certainly we need a gap acceptance model. To operate the traffic management system, we also need a model. Using the precise model to simulate gap acceptance, we will provide safety and efficiency for the transportation system.

REFERENCES


