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MODELING OF THE GAP ACCEPTANCE BEHAVIOR AT A MERGING SECTION OF URBAN FREEWAY

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Abstract: Gap acceptance is one of the most 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.
In this paper, we developed a gap acceptance model based on the discrete choice theory. This model is intended to combine these elements along with an experimental and quantitative analysis of drivers' behavior in actual merging situations.
For reflecting drivers' behavior, the gap acceptance model is designed. To develop this model, real data are used to set up explanatory variables and to estimate the model. The factors determining Gap Acceptance include lead gap, lag gap, front gap, heavy vehicle and remained distance. Congestion greatly affects gap acceptance in that it depends on gap acceptance to determine whether there is traffic conditions are congestion or not. When congestion conditions occur different behavior such as nosing occurs and provides different results.

Key Words: Gap acceptance, Merging section, Urban freeway, Remain distance, Probit model

1. INTRODUCTION

1.1 Background And Purpose

It is complex process to model the sequence of decision-making procedures of a driver's lane-changing because this procedure is not visible and can only see the final gap acceptance step. Therefore, by establishing a gap acceptance model with which one can simulate gap acceptance behaviors well can help explain a driver's decision-making procedures for changing lanes. To this end, we developed a gap acceptance model specifically to be applied to the urban freeway.

Most of the past studies on gap acceptance were focused on analyzing delay and capacity analysis in an uncontrolled intersection. Gap acceptance, which is an important submodel of the lane changing model, and is an essential microscopic traffic characteristics in the traffic control system and traffic management departments. So gap acceptance is more and more important. Recently traffic simulation and ITS(Intelligent Transport System) have been used for modeling lane change, but a mathematical model to show "gap acceptance" behavior is yet to be developed.

Existing studies on gap acceptance has short falls because they do not reflect behaviors nor were they validated through experiments or probability gap distributions. Therefore, in this paper, we proposed a gap acceptance model based on reality which describes the behaviors of driver on the road. The purpose of this study is to describe in detail the gap acceptance observed in a merging process and to present a gap acceptance model which can explain decision-making procedure during a lane-changing. We present herein a microscopic decision model that explains driver gap acceptance behavior when a driver is deciding whether to change lanes at a merging section of the road.

Merging has negative effects on capacity and traffic flow on the main lanes. In an urban freeway merging section, merging greatly influences the traffic movement. Therefore, in this paper, we will focus on the gap acceptance at urban freeway merging sections for our observation and analysis.

1.2 Scope And Subject

Drivers must consider various factors such as travel destination, driver behavior and traffic flow when deciding to change lanes. Lane changing in a traffic micro-simulation can be classified into two categories: mandatory and discretionary.

Mandatory lane changing occurs in the situations like the current lane is blocked; the current lane will merge to another lane; drivers must shift their lanes to another in order to arrive at destinations.

Discretionary lane changing occurs in the situations like the driver wishes to pass another vehicle that is moving to slowly or a heavy vehicle, a driver wishes to yield its way to another merging vehicle.

Normally, people do not change lanes unless it feels the need to do so. In order to reach their final destinations, drivers will need to 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 change lanes immediately.

Merging means the entering of a vehicle from a ramp into the main lane. This is a representative case of mandatory lane changing. Merging occurs frequently at ramps, it is easy to observe merging situations. As merging greatly affects the main lanes' volume and traffic flows, the gap acceptance phenomenon that occurs at merging sections is made as a research topic. And it is possible to present precise lane changing via gap acceptance.

1.3 Composition Of Study

This remainder of this paper is organized as follows. Chapter 2 will examine the results of the existing studies conducted on gap acceptance and related methodologies, and then analyze the issue. In Chapter 3, we described the gap acceptance behavior based on theoretical review and model concept, and then provide a theoretical model equation. Chapter 4 describes the model used in this study, some experimental data containing many useful instances of gap acceptance. This data was used to compare and validate the proposed gap acceptance models. In Chapter 5, we present our conclusions and discussion on gap acceptance behavior and model results, and finally present future prospects and areas for further work.

2. LITERATURE REVIEW

2.1 Concept Of Gap Acceptance

A driver entering into or going across a traffic stream must evaluate the space between a potentially conflicting vehicle and itself and decide whether to cross or enter or not.

"Gap" means 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 can help describe how a driver judges whether to accept or not.

The general assumption is that drivers consider only the adjacent gap that is headway between a lead vehicle and a lag vehicle over the object lane to which it wishes to change to. In the case of a merge into 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 the 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 takes to enter (accept gap) between the traffic streams on the object lane (headway). "Reject gap" is the time interval that subject vehicle fails to enter a main lane due to the main lane's vehicle obstacle flow. "Maximum reject gap" is the largest reject gap in the middle of the reject gaps of the individual vehicles.

The accept gap is the time interval for a subject vehicle in the current lane to enter the traffic stream on the main lane without main lane's vehicle obstacle flow. Therefore, it is possible to measure an individual vehicle's accepting gap and rejecting gap of a vehicle can be measured realistically, but it is possible to measure its critical gap. The 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, and so it is more focused on capacity analysis than on gap acceptance itself. To estimate deterministic critical gap, there are three representative methods.

The first method is used when vehicles on the ramp accept a gap. We can determine the critical gap through the median or mean observed from the gaps.

The second method is used 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 a regression method introduced by Drew(1968) which uses merge angle and acceleration lane length. An experimental equation is solved to determine critical gap. HCM(highway capacity manual) provides ramp lane and adjacent lane volume estimation equations by classifications using the deterministic regression analysis method. This method has advantages in that the calculation method is simple through regression analysis and has great practical applications. However, it has a demerit in that it is macroscopic and has certain limitations in reflecting a driver's behavior, hence making 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 which has the range of the limitation. To overcome these limits, attempts have been made to derive critical gap using gap distribution. Gap distribution uses logit or probit probability models partly. The advantage of gap distribution model is that it is very detailed, but requires many variables and parameters to be considered, and moreover, it is very time-consuming and costly.

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 are the diversities not only between different drivers, but also with the same driver. That is, different drivers as well as 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 affects by the number of gaps judging which are not critical gaps.

Troutbeck (1992) asserted that critical gap distribution assumed the 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 the difference of 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. With this model, he concluded that the components affecting gap acceptance at intersections are delays caused by gap and first gap indicator.[1] However, sequences of reject gap are not considered for model formulation or parameter estimation until after the lane-changing is completed.

2.2 Previous Studies On Related Methodologies

Studies about gap acceptance and critical gap have determined that drivers accepting gap more than the critical gap. But gap acceptance is not a simple phenomenon as it involves a module

[1] Drivers tend to escape from merging first gap for safety

for decision-making process to decide whether to change lanes. In addition, it requires the driver's judgment which is a complex procedure itself.

Kita(1993) formulated a gap acceptance problem at the merging section of freeways. He used the binary logit model and explanatory variables (i.e., remaining distance of the acceleration lane, gap, and relative velocity).

Yang and Koutsopoulos (1995) presented a 'rule-based' lane-changing model applied to freeways. They provided changeable lanes and presented lane-changing scenarios and modeled cases where drivers faced a conflict objective. However, in this study, formal parameters were not estimated nor the model evaluated.

Traffic microscopic simulation is currently in the process of development for the purpose of evaluating the Intelligent Transportation System (ITS), and consequently, to improve the Driver Simulator. Modeling driver behaviors is the core component in traffic microsimulation and has been a popular area of study in the field of engineering and psychology. Lane-change models are other key models in traffic micro-simulation besides car-following models. They are more complicated than car following models and are common phenomena in real traffic. Almost all the traffic micro-simulation includes lane change behavior models but involve the use of various kinds of models.

In spite of its importance, there have only a few researches conducted that were focused on the lane-changing behavior. Most researchers have put emphasis on finding a way to model the gap acceptance model (Gipps, 1995). Gipps (1986) presented a model for the structure of lane-changing decisions. He modeled the decision-making sequence into 3 steps: "mandatory lane changing → discretionary lane changing → gap acceptance." This model simulates lane-changing behavior in a rational manner. But, this study simulated as that driver's behavior uniform, model parameters were not estimated by model's equation.

Koutsopoulos (1996) presented his approach of using discrete choices for modeling lane-changing behavior. This model is based on the gap acceptance model. Very few existing lane-changing models are based on real traffic data and are mostly tested through simulations because they do not generate incidents or interrupt traffic flow.

Modeling lane-changing behavior is more complex because it considers three elements: the need to change lanes, the possibility of changing lanes, and the trajectory for changing lanes. Each element is important and need to be considered in order to develop a realistic lane-changing model. Lane-changing model is complex itself. It must consider not only the vehicle in the front, but also the vehicles nearby. It must take into account the traffic flow condition. It is also more dangerous than normal conditions. There is also a high possibility of incidents occurring during lane-change vehicle. It is difficult to model the behavior of drivers during lane-change, and there are many issues have to be considered to construct a realistic and reliable lane-changing model.

Ahmed et al. (1996) proposed a mandatory lane-changing model and extended the work by developing a new model for heavily congested traffic flow. In heavy congestions, there are very little gaps of acceptable lengths. Hence, a forced merging model is proposed which can capture instances of merging through the creation of gap either by yielding by the lag vehicle in the target lane or by forcing the lag vehicle to slow down.

He presented a conceptual framework for the lane-changing model proposed herein. This 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[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, etc. Drivers are likely to respond to the MLC situations earlier if it involves crossing several lanes. A longer delay makes a driver more anxious, hence deterring him to respond to MLC situations. Finally, due to lower maneuverability and larger gap length requirement of heavy vehicles as compared to less-heavy vehicles, drivers are more likely to respond to the MLC conditions.

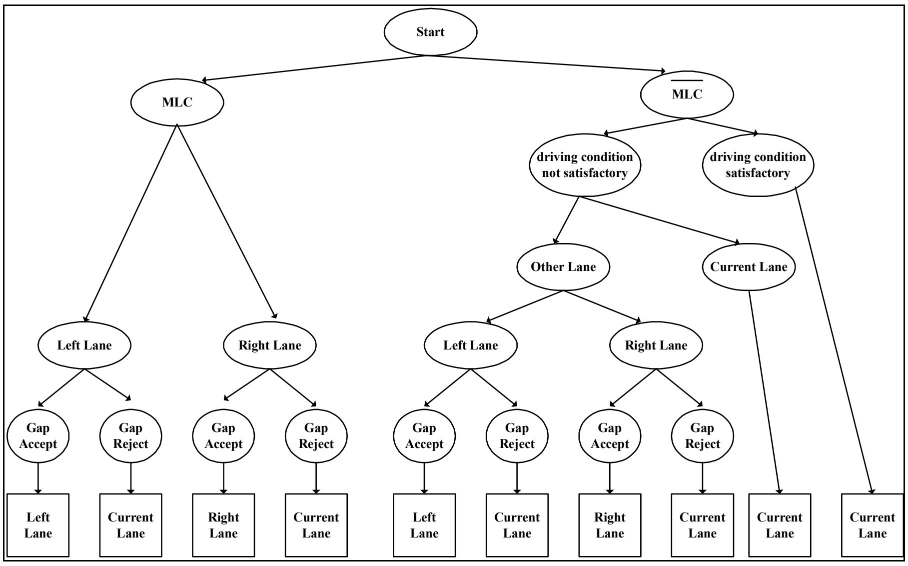

Figure 1. Structure of Lane Changing Model Structure

The MLC branch corresponds to the case where 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 there is an alternative lane that would be better choice than the current lane. The term satisfactory driving conditions imply that the driver is satisfied with the driving conditions of the current lane.

Important factors affecting the decision-making as to 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

2 mandatory lane changing

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, if a driver considers DLC even though a mandatory lane change is required and decides not to respond to the MLC conditions, it may be less desirable to change lanes in opposition to that required by the MLC.

If a driver decides not to perform a DLC either because the driving conditions are satisfactory, or, the current is the lane with the best driving conditions even though the driving conditions are not satisfactory. Which lane has good driving conditions the driver continues to drive on the current lane. Otherwise, the driver will select a lane from among the alternatives available and assess the adjacent gap in the lane. The lowest level of ovals in the decision tree as shown in Figure 1 corresponds to gap acceptance when the MLC conditions apply, and whether the subject vehicle is a heavy vehicle.

When a driver attempts a DLC, the factors that affect a drivers' gap acceptance behavior include the gap length, speed of the subject, speed of the vehicles ahead of and behind the subject in the lane, and the type of the subject vehicle (whether it is a heavy vehicle or not). For instance, a larger gap length is required if a driver is to attempt a merge at a high travel speed. A larger gap length is required for a heavy vehicle to safely compare to a vehicle due to its lower maneuverability and its length. In addition, the gap acceptance process under MLC conditions is also influenced by factors such as the remaining distance to the point at which lane change must be completed, delay (which captures the impatience factor that would make aggravates impatient drivers more aggressive), etc.

It should be noted that, delay can not be used as an explanatory variable except for very exceptional cases such a vehicle merging from an on-ramp. This is because the very inception of an MLC condition is usually unobserved.

Ahmed integrated MLC and DLC into a decision-making hierarchy, designed individual models, and derived parameters. These points were supported by its experimental results. There are very few significant explanatory variables. And the 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 (which considers whether the current lane conditions is satisfactory or not, target lane choice-, gap acceptance, etc.) is in progress simultaneously. Furthermore, the observations on the judgement is merely "gap accept or not". On the each hierarchy how to judge reject situation is difficult. Also, each hierarchy is not independent from each step. If a driver is less satisfied about the condition of the current lane, the probability of selecting another increases, and thus, the gap acceptance probability also increases. The selection of a target lane is strictly correlated condition that current gap accept or not.

It is impossible to apply Ahmed's model to explain the interaction of individual hierarchy establishments.

2.3 Methodology Of This Study

In this study, we developed a gap acceptance model of composed explanatory variables with which the behaviors of a driver during lane-change can be simulated. The factors affecting gap acceptance are different for MLC and DLC. In the case of DLC, the factors that affect gap acceptance are gap size, subject vehicle's velocity, on target lane lead vehicle and lag vehicle's velocity, and subject vehicle's type. In the case of MLC, the factors are similar to those of MLC, but also include remaining distance until lane changing finish and, delay. When a driver begins to change lanes, it is not measured normally. Therefore, unless for exceptional cases, it is difficult to use explanatory variables.

The gap acceptance model captures how drivers' assess whether to accept or reject a gap. It is generally assumed that drivers only consider the adjacent gap. An adjacent gap is defined as the gap in between the lead and lag vehicles in the target lane. In order to merge 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 the decision-making process of a driver on whether or not to change lanes, a model structure for lane-change. To change lanes, it is most important to check whether it is safe to proceed with the lane-change. Most lane-changing models are based on the gap acceptance model.

The model presented herein is theoretically based on the discrete choice model. The gap acceptance model is a part of the lane-changing decision making process, and thus we consider gap acceptance as the event. Event happens 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". We can also represent "accept" as "1", and "reject" as "0".

For a model of the decision-making process, we need to set up a judgment criteria. Generally, when a person decides whether to do something or not, if he or she is a rational human being, he or she will select the maximum utility. According to the utility maximization theory, if the utility of the accept is more than the utility of the reject, the driver will decide to accepts gap and choose to proceed with the lane-change. The reverse case is the same way.

To judge whether a driver accepts or not, we first composed a utility function which 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, the choice probability also increases.

Second, we can calculate choice probability by using either the 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. After the choice probability of the all factors are found, we can judge whether or not drivers accept the gap and change lanes according to their probability.

The flow chart of the gap acceptance model represents the driver's decision-making process and can be summarized as follows.

First, if the drivers decide to change lanes, they judge whether to merge or not by remaining distance. If the remaining distance does not meet the critical condition, drivers are forced to accept the current gap. But if the remaining 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 whether the current probability is higher than the boundary probability. If gap acceptance probability is more than the boundary, drivers attempt lane change. If not, each step feeds back and they wait in the current lane and repeat the same process until the gap is acceptable.

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 slightly under different traffic conditions.

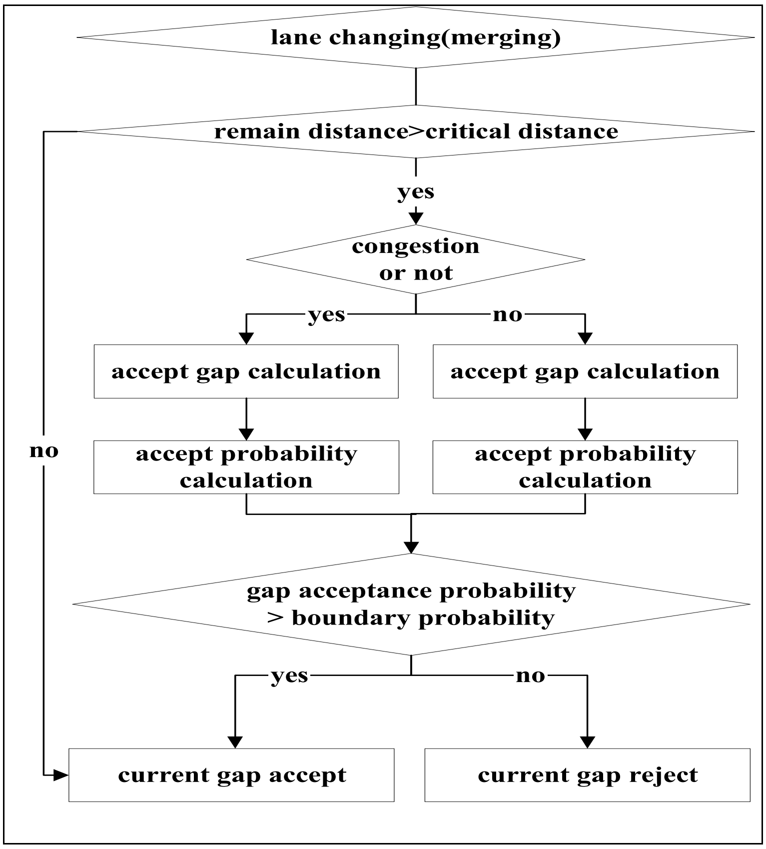

Figure 2. Model Formulation Flow Chart

The equation is shown as follows:

$$\begin{aligned} P_n(i) &= \Pr(\varepsilon_{jn} - \varepsilon_{in} \le V_{in} - V_{jn}) \\ &= \int_{\varepsilon=-\infty}^{V_{in}-V_{jn}} \frac{1}{\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\varepsilon}{\sigma}\right)^2 \right] d\varepsilon, \quad \sigma > 0 \\ &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{(V_{in}-V_{jn})/\sigma} \exp\left[-\frac{1}{2}u^2 \right] du = \Phi\left(\frac{V_{in}-V_{jn}}{\sigma} \right) \end{aligned} \tag{1}$$

where P: binary probit model
ϕ ( ) : generalized cumulative normal distribution

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

The equations are shown as follows:

$$P_a = \Phi\left(\frac{V_a - V_r}{\sigma} \right) \tag{2}$$

$$P_r = 1 - P_a \tag{3}$$

where P a: accept probability
P r: rejection probability
ϕ ( ) : generalized cumulative normal distribution

These values are obviously not only related to drivers but also to vehicle types. Since there is insufficient data about on this, the model will gather the data on its own and randomly validate it at its own discretion and differently for different vehicles.

3.2 Explanatory Variable Definition

In the gap acceptance model, we consider 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 wishes to change lanes, the critical lead gap and the lag gap must be acceptable to the driver. Otherwise, it is not safe for the driver to change lanes.

The front gap is the gap between the vehicles that will attempt to change lanes and the vehicle ahead it. In most situations, the lag gap and lead gap are acceptable for drivers, but they will not change lanes if 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 would beis possibility of the vehicle colliding with the front vehicle. Drivers normally decide whether the front gap whether safe or not based on their own experience.

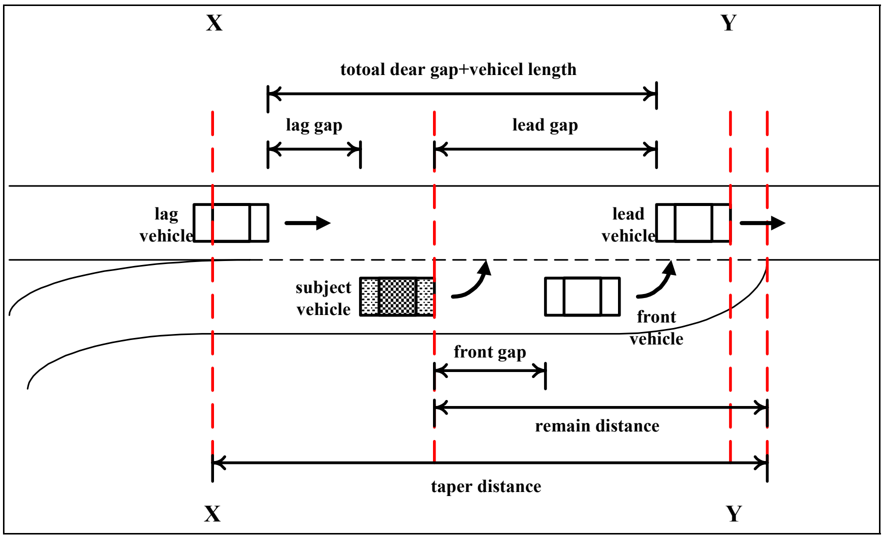

Figure 3. Explanatory Variable Concept

This so-called front gap is important in modeling gap acceptance. Especially, in DLC, drivers not only consider the traffic condition of adjacent lanes, but also that of the current lane. In addition, the vehicle that wish to change lanes vehicle mostly move at a faster speed than vehicles ahead in order to pass them vehicles and normally, a driver decides to pass vehicle in front of it when it is near enough to the front vehicle.

Let us considering the traffic condition of a freeway. Normally, on freeways, vehicle do not vehicle suddenly come to stops as is commonly observed in a dense urban traffic condition. Drivers will most likely behave aggressively and keep close to the front vehicle shorter when attempting to change lanes.

In this study, the front gap was obtained from experiments for different leading speeds. From this result, we found that most front gaps were shorter than the corresponding desired distance.

Actually, the front gap is not only related to the leading vehicle speed, but also to the speed difference between the leading vehicle and the vehicle wanting to change lanes. The front gap has the linear relationship of the speed difference. This is acceptable because the greater the speed difference is, the more safety distance the drivers should maintain.

The front gap can be considered as a minimum desired distance to the front vehicle. There is no set front gap distance for drivers to change lanes. The front gap only tells the distance that drivers would normally accept. Of course, drivers would most likely change lanes if the distance between a vehicle and that in front of it is farther than the front gap, and even if there is no vehicle in front of it vehicle. Therefore, this lane-changing model shall be said to only consider the front gap as the minimum lane changing distance. However, the way to choose a 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 in the way the lead gap and the lag gap are calculated. The most famous lane-changing model is the model introduced by Gipps's(1995). It has been widely used in micro-simulation like MITSIM. However, since the experiments could not be used to study the lead gap and the lag gap, the lead gap and the lag gap models were constructed based on the simulation results in that study. However, in this study, the actual observation results were used. The two gaps are required to make sure that during lane changing vehicles won't cause any accidents or have to brake suddenly.

The lead gap is the distance between subject vehicle and the lead vehicle to ensure that the subject vehicle that wishes to change lanes do not collide with the lead vehicle. Obviously, the gap is related to distance and velocity. Assuming that a driver will take only seconds to complete a lane-change, and both vehicles will maintain their current velocities, the minimum distance need to be known. After the vehicle has changed lanes, it changes its driving mode of following the front vehicle and the distance between the two vehicles naturally change to the desired distance. Therefore, in addition to maintaining a safe distance, an extra space should be secured do that drivers can comfortably change lanes.

The concept of lag gap is the same as the lead gap. The only difference is that the lane-changing vehicle does not want to, or it is not safe, for the lag vehicle to slow down

Drivers can not control the lag vehicle condition. Therefore, lag gap is an important factor that affects a driver's decision to change lanes. In merging, the remaining distance affects lane changing. As the remaining distance decreases, the gap acceptance probability increases, that means, the driver would most likely accept the smaller gap.

Vehicle velocity is an important factor that affects lane-change. If the vehicle is driven at high speed, it requires a larger gap. In addition to its own velocity, the relative velocities between other vehicles are also very important factors. There are differences in the velocity, distance and gaps between the subject vehicle and adjacent vehicles.

In conclusion, the explanatory variables include 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 realize the gap acceptance concept, we developed the gap acceptance model. For this, real data were used to set up variables and the model was estimated. Therefore, we gathered real data about gap acceptance.

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

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

Using the gathered event data, we input vehicle location coordinates on the image. By doing so, we could obtain information about a given vehicle's location, length, velocity and difference of the distance between vehicles.

With this information we also determined the explanatory variables and estimated model parameters. The results of the model estimation describe which factors are more significant and more important in lane-changing and gap acceptance. The parameter estimates present the degree of the influence on the gap acceptance.

The development process of the gap acceptance model is illustrated in the flow chart in Figure 4, and can be summarized as follows.

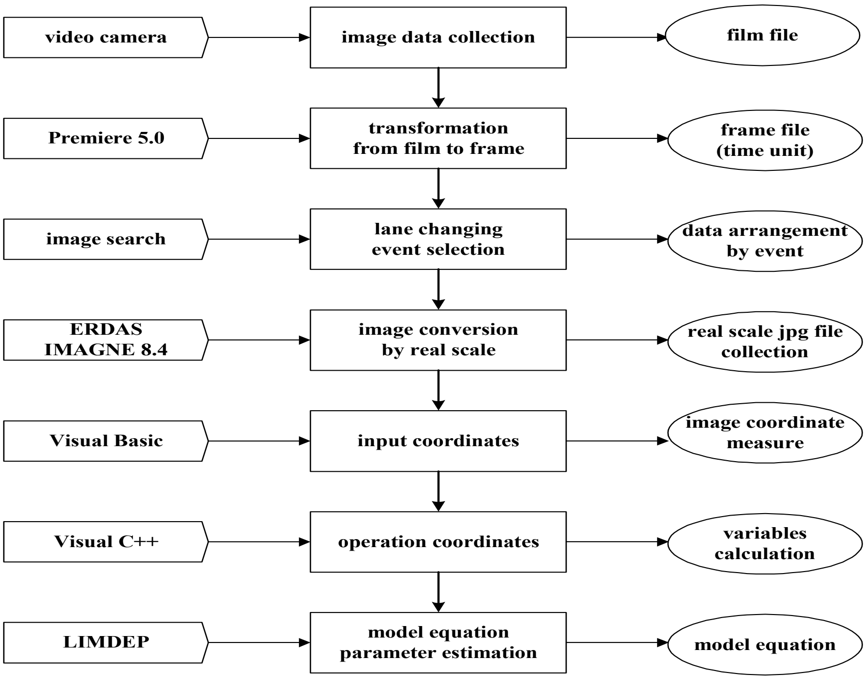

Figure 4. Gap Acceptance Model Development Flow Chart

The subject area is the merging section of the urban freeway (south part of the Young Dong Bridge on the Olympic road). Field data collection was performed on weekdays and photographs were taken from 6 am. to 10:30 am during which time congestion situation and non-congestion situation were captured.

Field data collection was performed by taking photographs via a video camera. We transferred these events from film to frame. From frame data files, we could study and quantify the lane-changing events. Using the gathered event data, we could obtain information about a given vehicle's location, length, velocity and difference of the distance between vehicles. We used the image detector and program for reducing image detector error, because lane-changing is a discrete event.

With the information for each vehicle, we could abstract the explanatory variables. The probit model which describes the real world more than other discrete models was used in this study. We used the maximum likelihood method for parameter estimation has the highest reliability among the existing studies. We used LIMDEP 7.0 as parameter calibration.

The explanatory variables include 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 statistical analysis, unreasonable explanatory variables are removed sequentially. Model estimation is based on the suitability test, parameter's p-value, sequential test, ρ value, and professional judgment.

Using the sequential test, the 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, remaining distance, subject heavy vehicle dummy, and object heavy vehicle dummy.

Table 1. Gap Acceptance Model

Variable	Expected Sign	Parameter Estimation Result	Standard Error	T Value
1. Constant	+	5.5667	1.0480	5.312
2. Lead Gap	+	0.0030	0.0038	0.793
3. Lag Gap	+	0.0129	0.0054	2.390
4. Front Gap	+/-	-0.0064	0.0027	-2.373
5. Remain Distance	-	-0.0629	0.0093	-6.748
6.Subject Heavy Vehicle	-	-0.1731	0.1476	-1.173
7.Object Heavy Vehicle	-	-0.6098	0.2142	-2.847
# Observed Data		835		
$L(0)$		-578.0441		
$L(\beta)$		-454.9731		
$-2[L(0)-L(\beta)]$		246.1420		
ρ^2		0.2129		
$\overline{\rho^2}$		0.2008		

The model means each variable affects gap acceptance. Driver consider lag gap to be more important than lead gap. As lag gap is the gap between its own vehicle and a rear vehicle, the subject driver does not have any control over the lag gap.

In case of the merge, the remaining distance is the most important factor for determining gap acceptance. If the remaining distance is smaller, the driver will most likely accept the smaller gap.
The Heavy vehicle dummy is another factor for determining gap acceptance. If heavy vehicle is on the roads, a driver will mostly likely decide not to merge. In case of the object heavy vehicle, gap acceptance probability is smaller than subject heavy vehicle dummy.

Model estimation results were found to agree well with the intuition results. We found that the statistic analysis model results were reasonable.

Congestion greatly affects gap acceptance. When the driver experiences delay in congestion condition, he will accept the smaller gap. When there is traffic congestion, we will observe behaviors, such as nosing. Noising is commonly observed merging section on urban freeways.

The result of the comparison of the gap size per the traffic condition shows that if there is traffic congestion, drivers tend to accept the smaller gap. This is because the driver wants to avoid delays. This means that in traffic congestions, the gap acceptance probability is higher than in a non-congestion condition. The change of the gap size of gap acceptance is larger than the reject gap size.

Table 2. Comparison of the Gap Size per Traffic Condition

Lag gap (m)	Reject	Accept
Non-congestion	20.41	32.70
Congestion	19.19	28.71

5. CONCLUSION AND FUTURE 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 various conditions (this include the conditions of drivers, vehicle condition and traffic conditions) and to learn their respective effects. With the newly proposed model, we will be able to analyze the effect of each element on gap acceptance.

The gap acceptance model was designed primarily to reflect a drivers' behavior. After composing and estimating the model, we found that of the space gap is a more important variable than the time gap. Because drivers run at their own speed, they tend to be more restrained by space than time. That is, drivers generally consider distance as a more important factor for determining the safety of a certain lane change.

The factors determining gap acceptance include the lead gap, lag gap, front gap, heavy vehicle and the remaining distance.

Congestion greatly affects gap acceptance. Whether conditions are congested or not depends on gap acceptance. When there is traffic congestion, we are more likely to observe behaviors such as nosing, occurs and provides different results.

5.2 Future Prospect

Gap acceptance is an important concept in the modeling of lane-change. In future works, more real data should be gathered, and more research should be conducted on gap acceptance characteristics under different congestion conditions. For this, we need to integrate the gap acceptance model, and also we need to consider the nosing phenomenon.

The application of the gap acceptance model can contribute greatly in many fields. For example, in the ITS (intelligent transport system), gap acceptance and lane-change are the main elements. This model can be applied to operate a microscopic traffic simulation, and to operate the traffic management system. Using the precise model to simulate gap acceptance, will enhance safety and efficiency for the transportation system.

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