1 # How Merging Vehicles Choose and Approach Their Desired Merge

2 # Position in Congested Merge Area

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1 **ABSTRACT**

2 The lane change process is a tactical process. However, the transitions among important tactical
3 nodes are largely ignored in the existing microscopic lane change models. Prior to the lane
4 change maneuver, the merging vehicles need to reach the feasible lane change location (the
5 desired merge position), which is right after the target gap selection. This study explores how the
6 merging vehicle choose and approach the desired merge position in a congested merge area,
7 which may trigger the understanding of the complex lane change behavior and help microscopic
8 traffic flow modeling.

9   This paper reports a fundamental work by classifying the merging vehicles into "targeting
10 original gap" type and "targeting forward gap" type. The statistical analysis results indicate that
11 these two types of merging vehicles have different selection behavior of desired merge location.
12 The gap distance between putative leader (PL) and putative follower (PF), the vehicle type of PL
13 and speed difference between merging vehicle and vehicles surrounding it have influence on the
14 desired merge location selection of merging vehicles.

15   To investigate how the merging vehicles approach their desired merge position, the speed
16 synchronization and the acceleration behavior of merging vehicles are analyzed in the
17 approaching process. The results illustrate the acceleration behavior of the "taking forward gap"
18 type merging vehicles should be staged modeled depending on their location. Findings from this
19 study could shed light on the interpretation of complex lane changing.

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1. INTRODUCTION

The lane change behavior of vehicles is one of the fundamental parts of microscopic traffic flow simulation model. Several models have been developed specifically to model the gap-acceptance or acceleration behavior of merging vehicles in the lane change situation *(1-3)*. The importance to integrate driver's lane-changing decisions with their driving operation has been emphasized by recent research *(4-6)*. However, there are only a limited number of studies in the literature dealing with modeling the continuous lane change process in detail.

Existing lane change models emphasized on driver's decision-making aspects during the task, and largely neglected the lane change action itself and modeled it as an instantaneous event. These models usually arbitrarily compare the merging vehicle's plan and the available gap to make the lane change decision of merging vehicle in every time step. However, lane change is a tactical process with some transitions. For example, when a merging vehicle decides to reject current adjacent gap and approach acceptable gap forward or backward, the transition of the merging travel from current gap to next possible acceptable gap is usually ignored in existed lane change models. Another important transition process is that, after get into the selected merge gap, the merging vehicle adjusts its locations related to surrounding vehicles for preparation before the lane change maneuver. This point where the merging vehicles start the lane change maneuver is called the desired merge point for a specific merging process. Such ignorance during lane change behavior modeling would lead to a considerable amount of errors in simulation outputs.

Actually, a lot of lane change acceleration-decelerations models have been proposed specifically to capture the driving behavior of vehicles during the merging process. The car following theory is usually employed to generate the travel trajectory of merging. The potential problem of this method is that it just handles the response of merging vehicle to the stimuli coming from the surrounding vehicles and ignores the lane change tactics of merging vehicles. Hidas (2005) and Choudhury (2009) both modeled the lane change tactics in their proposed lane change models *(7, 8)*. The merging vehicle first arrives at its desired merge point, and then starts the lane change maneuver. The process of approaching desired merge point does not comply with conventional car-following rules, and it should be governed by the tactic of the merging vehicles. Hidas did not calibrate his model with real field data, and Choudhury did deploy rigorous statistical estimation for her model with detailed trajectory data. The limited existed empirical lane change driving behavior analysis motivates us to investigate the tactics of merging vehicle for selecting their desired merge position and the process to approach it.

In this study, we target on the desired merge position approaching behavior of the on-ramp merging vehicles which have clear motivations to conduct lane changes once they arrive at the auxiliary lane. This paper is followed with the literature review of lane-changing models and desired merge position analysis. The third section is the description of the data processing and definitions ever used across the paper. The fourth section explores the merging vehicles' desired merge position selection behavior. In section five, the process of the merging vehicle approaching their desired merge position is analyzed. The conclusion and future work are addressed in section six.

2. LITERATURE REVIEW

2.1 Driving Behavior of Merging Vehicle

Field trajectory data of the merging vehicle *(9-11)* reveal two types of merging behaviors at an entrance ramp. Some vehicles merge into the first gap available on the target lane; while the others overtake vehicles or are overtaken by vehicles on the target lane before successfully lane changes. Merging vehicles in the latter type spend more time in the merging preparation process and significantly extend the lane-changing duration. Some researchers have conducted the analysis of driver behavior *(9, 10, 12)* and vehicle interactions during the lane-changing duration *(2, 7, 13)* based on field vehicle trajectories in merge sections. Furthermore, the relaxation phenomenon after the lane change (vehicles are willing to accept very short spacing as they enter the freeway, but "relax" to more comfortable values shortly thereafter.) has also been investigated in details (14-16).

Wang et al. analyzed the merging behavior in the motorway merging section and built a model for the acceleration of merging vehicles with respect to the target gap and the states of the other vehicles on the auxiliary lane *(11)*. They concluded that alert drivers had high chance of successfully merging into their first choice of gaps. However, their study did not investigate the driver behavior of the merging vehicles after missing the first choice of gaps. Daamen (2010) conducted an empirical analysis of merging behavior based on a 35-min dataset of vehicle maneuvers in a merge section of freeway *(9)*. They found different merging location distributions for congested and free-flow condition, and slightly smaller gaps are accepted at the end of the auxiliary lane compared to the beginning part of the auxiliary lane. They also proved the existence of the relaxation after the merge execution. They argued that every merging vehicle is able to find a suitable gap without being overtaken by multiple vehicles on the main road and without a full stop at the end of the auxiliary road.Yeo et al. (2009) built a freeway microscopic traffic flow algorithm based on the NGSIM (Next Generation SIMulation) data analysis *(12)*. In their experiment, the merging vehicle, prior to the lane change, follows their most close leader vehicle driving on the current or target lane. During and after the lane-changing execution, the merging vehicle follows its leader on target lane. Safety constraints are introduced to the proposed car-following process to avoid collisions during the simulation.

The above-mentioned research has provided explanatory approaches of describing the lane-changing behavior. However, these researches are rather fragmented since most of them only focus on the successful lane-changing execution of merging vehicles and neglecting their failure trials in the merging process. On the other hand, the tactics of merging vehicles in the lane change process are not discussed in the empirical analysis.

2.2 Merging Tactics Modeling

In the merging area, there are two interactive traffic streams: merging vehicles and mainline driving-through vehicles. Different theoretical frameworks have been developed to formulate the merging process on freeway *(4, 7, 17-22)*.

One common merge behavior modeling method is setting the interactions into the stimuli–response psychophysical concept and modifying the conventional car-following models to suit the lane change background. Sarvi (2007, 2011) built a freeway ramp merging micro-simulation model, in which the acceleration-deceleration of merging vehicles and their PF (putative follower) are linearly related with the stimuli from surrounding vehicles *(21, 22)*. For example, the acceleration-deceleration of PF is under the stimuli of the speed of merging vehicle, the speed of PL, distance between PF and merging vehicle and distance between PF and PL. The simulation models were calibrated with observed field lane change data. The limitation of this

method is that this method only handles the response of merging vehicle to the stimuli coming from the surrounding vehicles and ignores the lane change tactics of merging vehicles. Actually, the merging vehicles often have to modify their driving behavior and relative location with a strategy in order to merge into the target lane *(7)*.

There are two studies incorporating the desired merge position selection and approaching process in lane change models. Hidas pointed out it is important to model the speed adjustment of merging vehicle to get desired merge position in congested flow condition, and this may be necessary even at low flow levels *(7)*. In Hidas' model, the desired merge position of every merge process is an identical value depending on the required minimum gap distance between merging vehicle and its PL and PF. The calculation of the acceleration of merging vehicle to reach the desired merge point is under the assumption that the merging vehicle would get the same speed and same acceleration as either its PL or PF uniformly. However, no empirical analysis based on field data was presented to support such conclusions.

In Choudhury's lane change model, the merging vehicle applies target gap acceleration to better position themselves with respect to the target gap *(8)*. The desired merge position is linearly related with the gap distance between the merging vehicle's PL and PF. Based on the NGSIM data, the calibrated desired merge position models have no difference for the different gaps (adjacent gap, forward gap and backward gap) merging vehicles choose. The acceleration of the merging vehicle during approaching the desired merge position is separately modeled depending on whether the leading vehicle on current lane would constrain the movement of merging vehicle *(22)*. Based on our previous analysis, the speed difference among vehicles and the vehicle type of PL and PL have significant impact on the driving behavior of merging vehicle in congested weaving section, so it should be consider as important effect factor of desired merge position selection.

The requirements for a merging vehicle to fulfill a successful merge are getting a sufficient gap and holding an appropriate speed to get the desired merge position for anticipated merge maneuver. The speed synchronization behavior of merging vehicle has been identified in our previous paper, which demonstrates that the merging vehicle attempts to decrease the speed difference between mainline traffic and themselves during the lane change preparation. The small speed difference among them could help the merging vehicle to achieve successful merge. When the merging vehicles get onto the auxiliary lane, they do not usually trigger the lane change maneuvers immediately, because some of them need to adjust their distance between PL and PF to approach the desired merge position, or even reject current involved gap to look for other acceptable gap.

3.   DATA SET

This study uses vehicles trajectory data collected on a five-lane freeway section with an on-ramp from Ventura Boulevard and an off-ramp to Cahuenga Boulevard on U.S. Highway 101 (Hollywood Freeway), Log Angeles, California, USA (see Fig.1*a* for the geometric layout). It is a part of FHWA's Next Generation Simulation (NGSIM) program. The total length of the observation area is 2100 ft, and the vehicle trajectories are updated in every 0.1 second from 7:50 to 8:35 a.m. on June 15, 2005. In this study, we focus on the weaving section, whose length is 698ft. In the 45 minutes observation time, the weaving section is in transition (7:50-8:05 am) or congestion (8:05-8:35 am) *(23)*. The speeds of main line traffic vary from 0 to about 80 ft/s

1 (average value is around 37.39ft/s) during the 45 minutes; while the average speed of the on-
2 ramp merging vehicles when arriving on the auxiliary lane is around 45.09 ft/s.
3   398 merging vehicles were extracted from this data set when a total of 11,779 vehicles
4 were processed. Due to the higher speed of merging vehicle comparing to the main line traffic,
5 38.65 percent of these merging vehicle do not choose their first meet gap when they arrive at the
6 auxiliary lane, which is called original gap in this paper. 151 merging vehicles finally choose the
7 gap in front of the original gap as their finally accepted gap, while only 5 merging vehicles
8 finally choose the gap behind of the original gap as their accepted gap. The Fig.1b shows an
9 example of merging vehicles taking its original gap as its accepted gap. The Fig.1c shows one
10 example of the merging vehicle taking the gap in front of the original gap as the accepted gap. In
11 the merge process, the alternatives for the merging vehicles target gap choice set are original gap,
12 forward gap and backward gap shown in Fig.1d. In our sample set, merging vehicles choosing
13 the backward gap have limited sample size. So, this paper primarily analyzes the driving
14 behavior of merging vehicle which choose their original or forward gap as accepted merge gap.
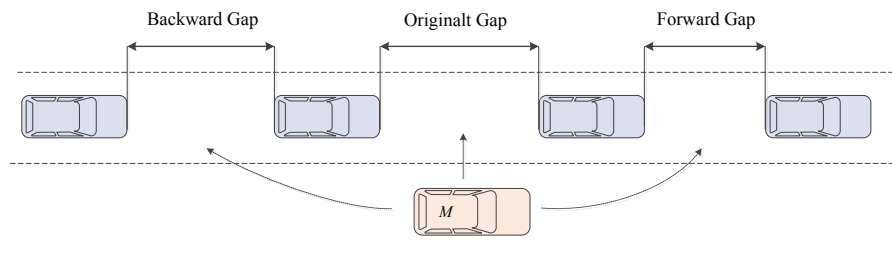
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16   (a) Data site-U.S.101

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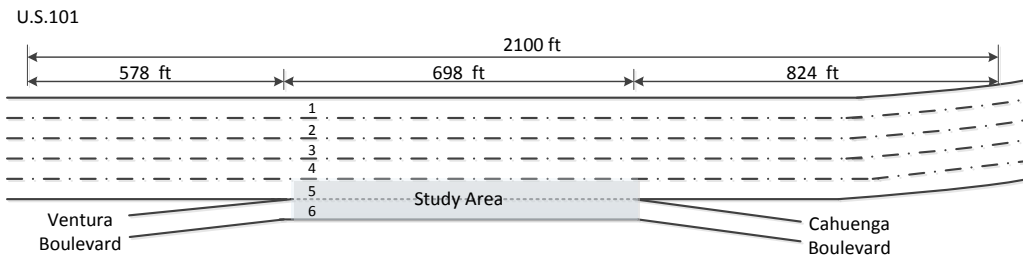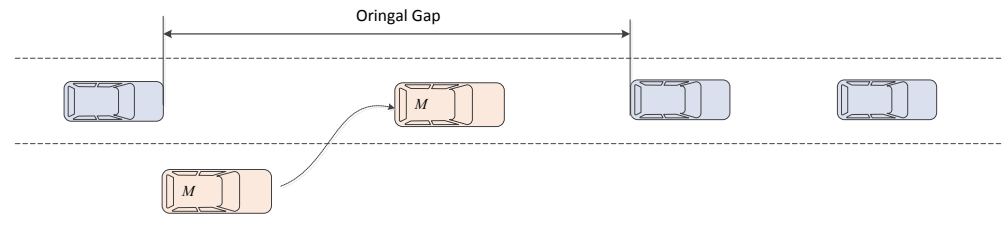
18   (b) Merging vehicle targets original gap

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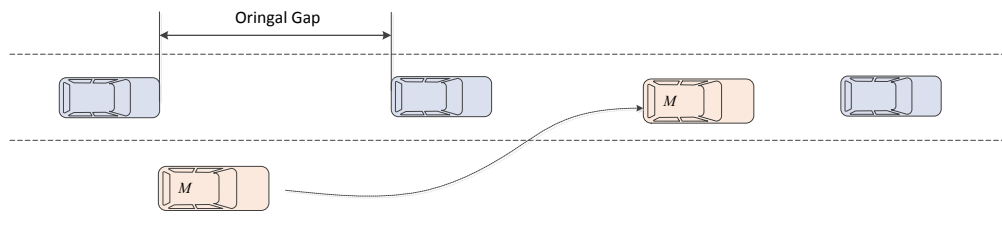
20   (c) Merging vehicle rejects original gap

21

22   (d) Target gap choice sets
23   FIGURE 1 Data Collection Site and the Related Vehicles.
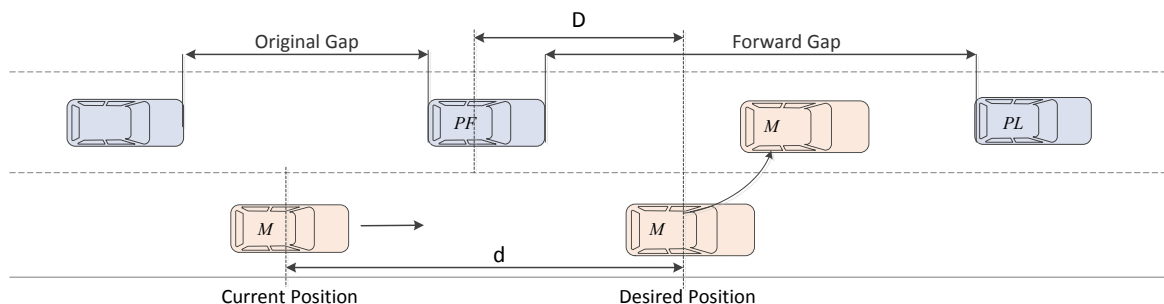
1 4. DESIRED MERGE POSITION

2 **4.1 Desired merge position**

3 During the gap selection, the merging vehicles choose original gap and forward gap as the final
4 target gap in the congested area. In this study, we do not distinguish the taking forward gap
5 merging vehicles which reject different number of gaps before lane change maneuver. The
6 trajectories of the merging vehicle are carefully analyzed and the abnormal lateral movement
7 sample is filtered out. We use the lateral movement information of vehicle trajectory to identify
8 its desired merge position. The desired merge position is defined as the location where the
9 merging vehicle initiates significant lateral movement for lane change maneuver as shown in
10 Fig.2.
11   In Fig.2, the relative relationship between current position and desired merge position are
12 drawn out. When the merging vehicle arrive its desired merge position, D presents the distance
13 between desired merge position and its PF. d presents the distance between current location of
14 merging vehicle and the desired merge position.
15
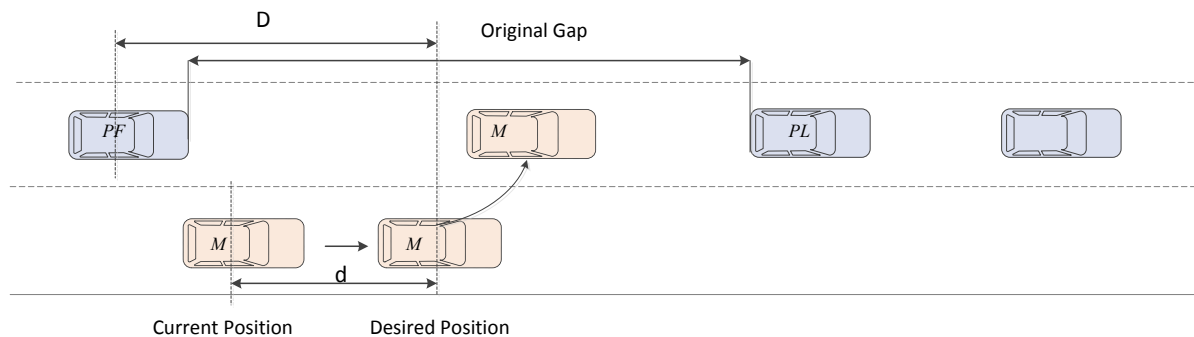
16
17   (a) Merging vehicle target original gap
18

19
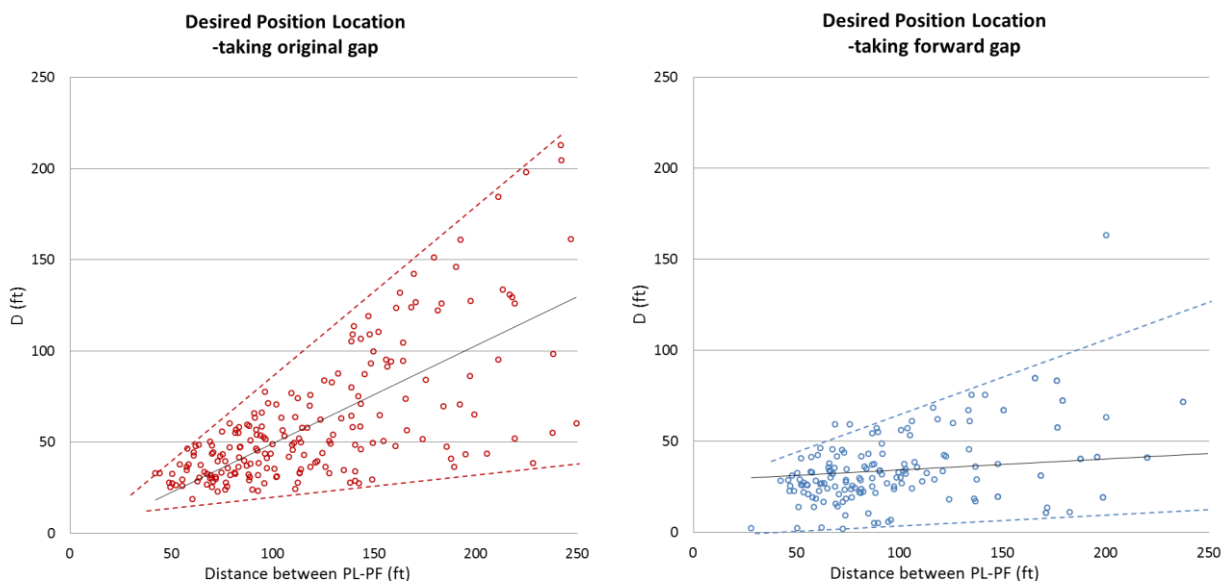20   (b) Merging vehicle target forward gap
21
22   FIGURE 2 Desired Merge Position for Different Target Gaps.

23 **4.2 Characteristics of desired merge position selection**

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25 Based on the analysis results of Choudhury, gap distance between PL and PF is the only
26 significant factor in her desired merge position selection model *(8)*. To investigate the different
27 desired merge position selection characteristics for different target gaps, Fig. 3 shows the effect

1 of the distance between PL and PF (ft) on the selection of desired merge position, where D value
2 (y axis) presents the distance between desired merge position and merging vehicle's PF.
3   In general, Fig. 3a and Fig.3b show the D values rise up with the increasing of the gap
4 distance between PL and PF for both type of target gap merging vehicles. This result is
5 reasonable and consistent with the findings of Choudhury. However, such increasing trend is
6 more obvious for targeting original gap condition than targeting forward gap. From these figures,
7 we could tell that, the merging vehicles targeting forward gap would like to execute the lane
8 change near their PFs. The blue dots in Fig.3b near the x axis illustrate the extremely cases that
9 some merging vehicles act lane change maneuver just after overtaking their PF. The possible
10 reason is that the merging vehicles having gap rejection experience are more eager to merge into
11 the target lane.
12

(a) Target original gap   (b) Target forward gap

FIGURE 3 Desired Merge Position and Distance between PL and PF

17   The speed synchronization phenomenon of merging vehicle has been observed in our
18 previous research, which affects the gap selection of merging vehicles *(22)*. From this point, we
19 assume the speed difference between vehicles has the possibility to affect the desired merge
20 position selection of merging vehicles. In Fig.4, the X axis represents difference between the
21 speed of merging vehicle and the average speed of its specific PL and PF. The Y axis is the
22 proportion of D value to the Gap distance between PL and PF, which ranges from 0 to 1. From
23 Fig.4, it could deduct that, when the merging vehicles have higher speed comparing to their PL
24 and PF, they would choose to operate the lane change maneuver near their PF. The downward
25 trend lines for both types targeting gap selection illustrate the larger positive speed difference
26 leads the merging vehicle to choose to start to merge maneuver closer to its PF. This
27 phenomenon could be explained in a manner that the merging vehicle prefer to leave enough
28 space between PL and itself for deceleration. The analysis results prove our assumption that the
29 speed difference between vehicles has effects on the desired gap selection.
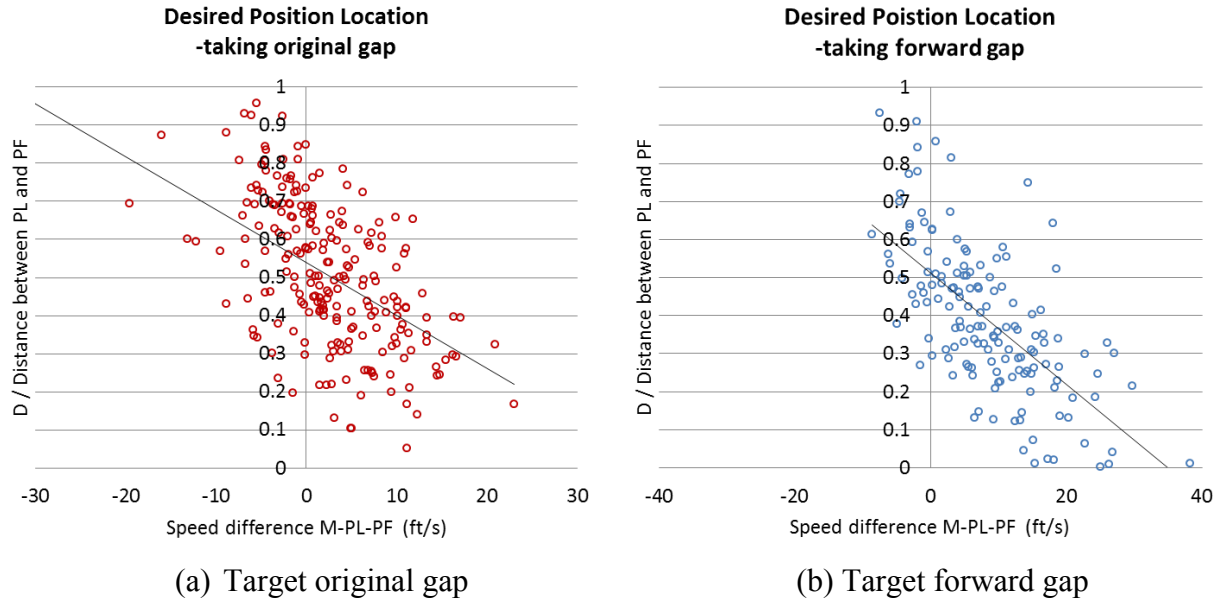
(a) Target original gap (b) Target forward gap

FIGURE 4 Desired Merge Position and Speed Difference

4.3 Regression model for desired merge position selection

The desired merge position selection of merging vehicle may rely on various factors, such as the driving behavior and skills, traffic conditions, and the relations of the merging vehicles with the other surrounding vehicles. The models for desired merge position for targeting original and forward gaps are developed to identify key effects.

A multi-liner regression model is built here with following specifications:

$$D_n^i = \alpha + \gamma \Delta X_n^{PL\text{-}PF} + \vec{\beta} V_n(PL, PF, M) + \theta_1 T_n(PL) + \theta_2 T_n(PF) \tag{1}$$

where

$D_n^i = D_n^{original}$ or $D_n^{forward}$. $D_n^{original}$ refers to the distance from the desired merge position of merging vehicle n to its PF, when merging vehicle targets on its original gap.

$D_n^{forward}$ stands for the distance from the desired merge position of merging vehicle n to the its PF, when merging vehicle targets on its forward gap.

ΔX_n^{PL-PF} = The distance between PL and PF of merging vehicle n,

$V_n(PL, PF, M)$ = explanatory variables related to speed and speed difference between vehicles, including the merging vehicle n, its PL and PF;

$T_n(PL), T_n(PF)$ = the vehicle type of PL and PF, which are dummy variables. The alternatives for vehicle type set are: driving-through vehicle, merged vehicle and exiting vehicle in the weaving section, and

$\alpha, \gamma, \vec{\beta}, \theta_1, \theta_2$ = coefficients for explanatory variables.

After correlation tests between variables, the estimation results of the desired merge position selection models are presented in Table 1. Critical factors and their empirical implications can be summarized as following.

1   TABLE 1 Estimation Results of the Desired Merge Position (D) Models (ft)

Variable	Targeting original gap model (242 samples)		Targeting forward gap model (151 samples)	
	Parameter Value	t-Statistic	Parameter Value	t-Statistic
Constant	1.796	0.382	23.576	9.334
Distance between PL and PF (ft)	0.540	18.918	0.146	5.948
Speed difference between M and PL (V_m-V_{PL}, ft/s)	-1.934	-5.855	-1.608	-5.581
PL is merged vehicle (dummy variable)	-12.795	-2.131	-	-
PL is exiting vehicle (dummy variable)	-	-	-17.441	-2.141
R	0.802		0.649	
R^2	0.643		0.422	

2

3   •   Distance between PL and PF(ft): The positive parameters in both models reveal that the
4   larger gap distance between PL and PF can increase the distance from the desired merge
5   position to PF. The calibration results are in accordance with our empirical analysis.
6   •   Speed difference between vehicles (ft/s): The negative value of the V_m-V_{PL} variables in
7   both models illustrates that when the merging vehicle holds higher speed than its PL, the
8   merging vehicle tends to act the merge maneuver near its PF to avoid collision. Other
9   speed related variables are not significant in these two models, and the possible reason is
10   the high correlation between the speed related variables.
11   •   Vehicle type: The PL is merged vehicle or existing vehicle leads the merging vehicles to
12   choose to keep longer distance from them for safety issue, because these two types of PL
13   have different route plans comparing to the driving-through vehicles(great majority in
14   target lane).
15   •   The overall results: the desired merge position for targeting original gap merging vehicle
16   gets better modeling results with higher correlation coefficient R and R square. This is
17   reasonable because the merge situation is more complicated for the targeting forward gap
18   merging vehicles, which are usually under more congested condition and have gap
19   rejection experience.
20   Based on our analysis, the desired merge position selection behavior for "targeting
21 original gap" and "targeting forward gap" have significant difference, and they should be
22 separately modeled in the lane change modeling. After analysis the desired merge position
23 selection of merging vehicles, we will investigate how the merging vehicle approaches their
24 desired one in next section.

5. APPORACHING DESIRED MERGE POSITION

5.1 Speed Synchronization during Approaching Desired Merge Position

The speed synchronization of merging vehicle is the process during which merging vehicles reduce their speed differences with their PL and PF vehicles. The speed synchronization process of the merging vehicle contains considerable information about the lane change tactics about how to approach their desired merge position. Fig.5 shows the speed difference change along with time for "targeting original gap" and "targeting forward gap" merging vehicles, respectively.

The graphs in Fig. 5 were plotted with following data process. First, the segments of the trajectory of every merging vehicle were extracted out. For the "targeting original gap" merging vehicles, the analysis segments are since they get on the auxiliary lane to they arrive at their desired merging position. For the "targeting forward gap" merging vehicles, the analysis segments are since they are in their last rejected gap to get their final desired merging positions. Second, the duration of the analysis segments were rescaled to 20 intervals with equal length. Third, 50 merging vehicles for each type were randomly selected for speed difference changes plotting. The time duration for "targeting original gap" merging vehicles is 4.00 ± 2.55s, and for "targeting forward gap" merge vehicles is 8.78 ± 3.94s for.

From Fig. 5(a) and 5(c), it could notice that the speed difference between the "Targeting original gap" merging vehicles and their PL/PF slightly changes during approaching desired merge position, and the reduction of speed difference is insignificant. For "Targeting forward gap" merging vehicles showed in Fig.5 (b) and 5(d), the speed difference between merging vehicles and their PL/PF has an increasing trend after they decide to reject their adjacent gap, and then the speed difference significantly drops in the last half part of approaching desired merging position process. Compared to the "Targeting original gap" merging vehicles, all the "Targeting forward gap" merging vehicles maintain a higher relative speed to the main line traffic, and they operate speed synchronization obviously when they are closing their desired merge position.
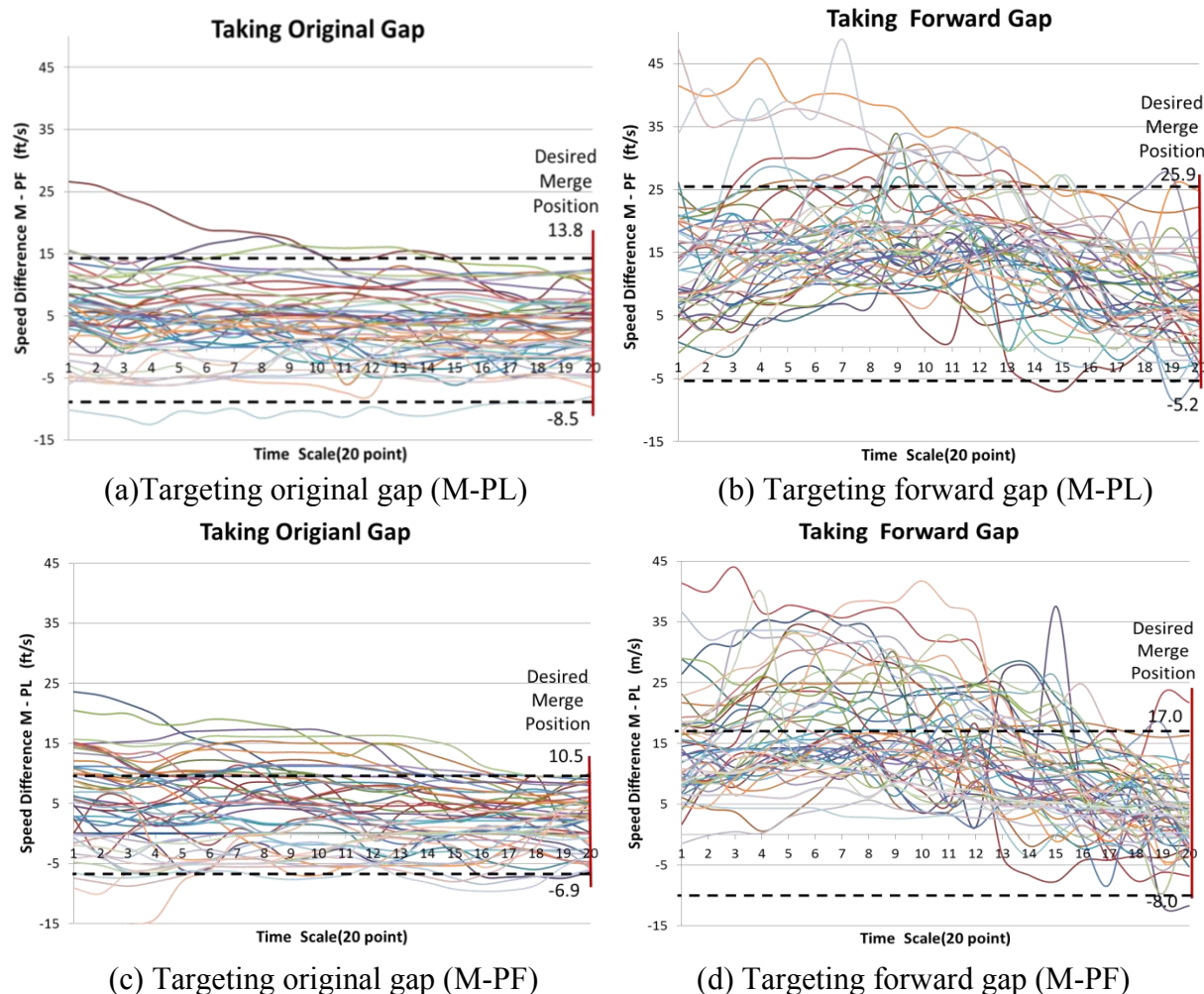
Taking Original Gap

(a)Targeting original gap (M-PL)

Taking Forward Gap

(b) Targeting forward gap (M-PL)

Taking Origianl Gap

(c) Targeting original gap (M-PF)

Taking Forward Gap

(d) Targeting forward gap (M-PF)

FIGURE 5 Speed Synchronization during "Approaching Desired Merge Position"

5.2 Acceleration of Merging Vehicles

With the evidence of the existence of synchronization in approaching desired merging position process, the acceleration in longitudinal direction and the movement in lateral direction of merging vehicles are further investigated in this section.

In Fig. 6, the average acceleration and absolute acceleration of different types of merging vehicles are displayed. For the "targeting original gap" merge vehicles, the average acceleration line (the red line) illustrates them slightly decelerate (around -1.0 ft/s^2) in order to approach their desired merge position, and the average absolute acceleration value decreases from 4.5 ft/s^2 to 2.0 ft/s^2 during the approaching process. For the "targeting forward gap" merging vehicles shown in Fig.6b, the time axis (X axis) is adjusted in order to make the middle of the time axis (point 11) to be overlaped with the time point where the merging vehicles overtake the PF of their accepted gap. The average acceleration line (the red line) presents that the "targeting forward gap" merging vehicles accelerat to overtake their rejected gap, and immediately decelerate after they arrive at their target gap. The absolute acceleration of "targeting forward gap" merging vehicles shows (the blue line) the absolute acceleration for overtaking is around

2.0 ft/s^2, and the absolute acceleration for "the approaching desired merge position" is around5.0 ft/s^2.

The above analysis results imply that, the acceleration behavior of "taking forward gap" merging vehicle have significant difference before and after overtaking action the PF of their accepted gap, so the acceleration modeling of them should be staged.
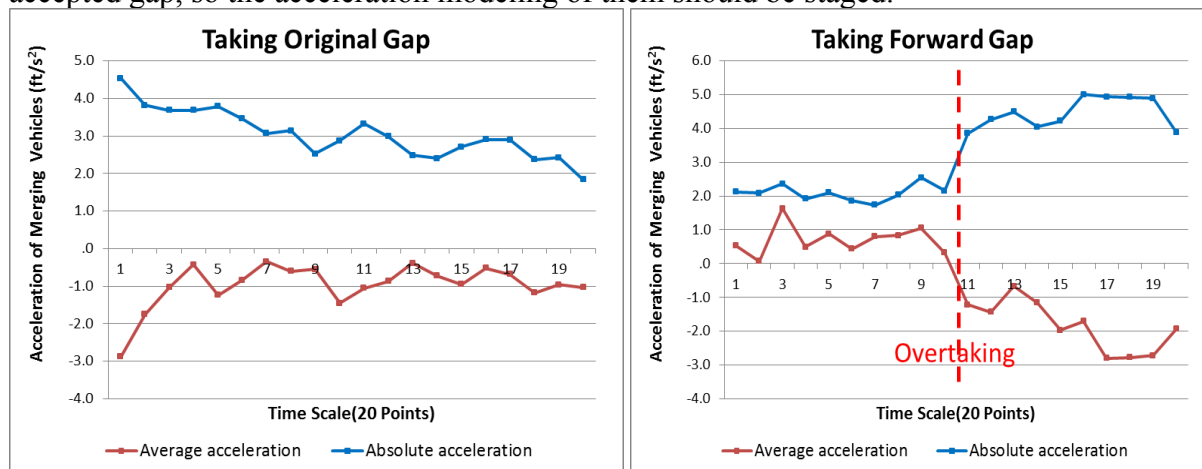
(a)Targeting original gap　　　　　　　　　　(b) Targeting forward gap

FIGURE 6 Acceleration of Merging Vehicles to Approach Desired Merge Position

5.3 Merge Maneuver after Approaching Desired Merge Position

Right after the merging vehicles arrive at their desired merge positions, they operate the lane change maneuver to merge in their target lane. To explore whether some difference exists in the merge maneuver of different type merging vehicles, Fig. 7 shows the distribution of time consumed in lane change maneuvers of "targeting original gap" and "targeting forward gap" merging vehicles. The consumed time is accounted since the merging vehicles arrives at the desired merge position to the geometric central point of the merging vehicle cross the lane line shared by the auxiliary lane and the target lane.

From Fig.7, it is notable that 67.5 percent of the "targeting forward gaps" merging vehicles merge into their target lane in 2 seconds after they reach the desired merge position, while more than 50 percent of the "targeting original gap" merging vehicles use more than 2 seconds. This distinct merging characteristic of these two types of merging vehicles highlights the effect of choosing different gap on the driving behavior of merging vehicles.

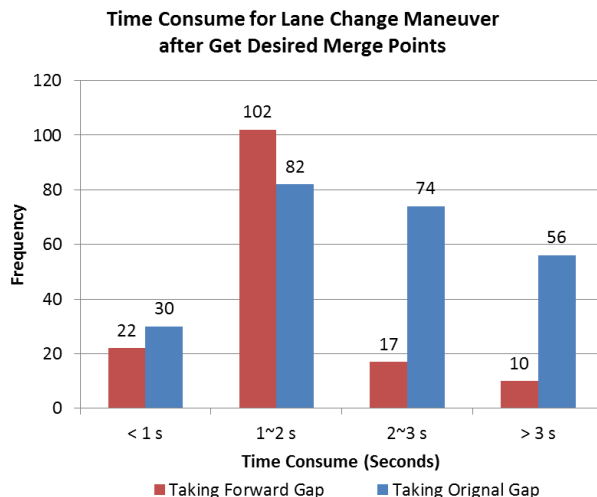**Time Consume for Lane Change Maneuver
after Get Desired Merge Points**

FIGURE 7 Time Consume for Lane Change Maneuver

6. CONCLUSION AND FUTURE WORK

In this study, to reveal the fundamental driving behavior of merging vehicles, we investigate how the merging vehicles select and approach their desired merge position at a weaving section by using the US101 NGSIM data. The desired merge position in this study is defined as the location where the merging vehicles start to operate the lane change maneuver with significant lateral movement. Valid vehicle trajectories of 398 merging vehicles are obtained in this congested merging area. The merging vehicles are classified into two types based on their accepted gap selection: "Targeting Original gap" and "Targeting forward gap". The original gap is the gap the merging vehicles meet when they arrive at the auxiliary lane. The forward gap is the gap in front of the original gap.

Based on the obtained trajectories, statistical analysis and regression models are conducted to explore the characteristics and the key factors in desired merge position selection. Our findings are consistent with the existed study that the selection of the desired merge position is related with the gap distance between the merging vehicles' putative leader (PL) and putative follower (PF). But we also found the "Targeting Original gap" and "Targeting forward gap" merging vehicles have different desired merge location selection behavior. The desired merge location selection models for both type of merging vehicles were built to further exam the other key effect factors. The results shows that the speed difference between merging vehicle and it PL and the vehicle types of PL have influence on the desired merge location selection of merging vehicles.

To investigate how the different gap targeting merging vehicles approach their desired merge position, speed synchronization behavior and acceleration of the merging vehicles are analyzed in the approaching process. We find that the speed difference between the "targeting original gap" merging vehicle and its PL/PF slightly changes during "the approaching desired merge position process". While the speed difference between "targeting forward gap" merging vehicle and its PL/PF has an increasing trend after they decide to reject the current adjacent gap, and then the speed difference significantly drops after the merging vehicles arrive at their target gap. The corresponding acceleration analysis results imply that, the acceleration behavior of the

"taking forward gap" merging vehicle has significant difference before (acceleration) and after (deceleration) the overtaking the PF of its accepted gap. Thus the acceleration of the "taking forward gap" merging vehicles should be modeled staged in lane change model.

The analysis results of the time consumed for lane change maneuvers of merging vehicles indicate that the "targeting forward gaps" merging vehicles cost less time to merge in to the target lane compared to the "targeting original gaps" merging vehicles, which manifests the effect of choosing different gap on the driving behavior of merging vehicles.

All the above findings can help understand the fundamental characteristics of the complex lane change process. By considering a lane change as a transition process rather than an instantaneous event, the study can provide insights for more accurate modeling lane-changing behavior. Further study is to model the acceleration-deceleration behavior of merging vehicles during merging process with their merging tactics. Another work needed to do in the future is to incorporate the interactions between vehicles into merging process analysis and modeling.

REFERENCE

[1] Kazi, A.I., *Modeling Drivers'Acclleration and Lane Changing Behavior*. 1991, Massachusetts Institute of Technology.

[2] Kim, T., D. J. Lovell, and Y. Park. Empirical Analysis of Underlying Mechanisms and Variability in Car-Following Behavior. In Transportation Research Record: Journal of the Transportation Research Board, No. 1999, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 170–179.

[3] Liu, H., W. Xin, Z. Adam and J. Ban. A Game Theoretical Approach for Modelling Merging and Yielding Behaviour at Freeway on-Ramp Sections. *17th International Symposium on Transportation and Traffic Theory*, London, UK, 2007,

[4] Toledo, T. Integrated Driving Behavior Models. PhD dissertation. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, 2002.

[5] Gunay, B. Car Following with Lateral Discomfort. Transportation Research Part B, Vol. 41, No. 7, 2007, pp. 722–735.

[6] Jin, S., D.-H. Wang and X.-R. Yang. Non-Lane-Based Car-Following Model with Visual Angle Information. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2249, No. -1, 2011, pp. 7-14.

[7] Hidas, P. Modelling Vehicle Interactions in Microscopic Simulation of Merging and Weaving. Transportation Research Part C: Emerging Technologies, Vol. 13, No. 1, 2005, pp. 37-62.

[8] Choudhury, C., V. Ramanujam and M. Ben-Akiva. Modeling Acceleration Decisions for Freeway Merges. Transportation Research Record: Journal of the Transportation Research Board, 2009, No. 2124, pp. 45-57.

[9] Daamen, W., M. Loot, and S.P. Hoogendoorn. Empirical Analysis of Merging Behavior at Freeway On-Ramp. In *Transportation Research Record: Journal of Transportation Research Board, No. 2188*, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 108–118.

[10] Ahemd, k.I. *Modeling Drivers' Acceleration and Lane Changing Behavior*. Massachusetts Institute of Technology, 1991.

[11] Wang, J., R. Liu., and F. Montgomery., A Simulation Model for Motorway Merging

Behavior, in *16th International Symposium on Transportation and Traffic Theory (H. S. Mahmassani, ed.)*. 2005, Elsevier: New York.

[12] Yeo, H., A. Skabardonis., J. Halkias., and J. Colyar. Vassili Alexiadis Oversaturated Freeway Flow Algorithm for Use in Next Generation Simulation. In *Transportation Research Record: Journal of Transportation Research Board, No. 2088*, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 68-79.

[13] Kim, J.T., J. Kim, and M. Chang, Lane-changing gap acceptance model for freeway merging in simulation. *Canadian Journal of Civil Engineering*, Vol. 35, No.3, 2008, pp. 301-311.

[14] Laval, J.A. and L. Leclercq. Microscopic modeling of the relaxation phenomenon using a macroscopic lane-changing model. *Transportation Research Part B-Methodological*, Vol. 42, No.6, 2008, pp. 511-522.

[15] Cohen, S.L. Application of relaxation procedure for lane changing in microscopic simulation models. In *Transportation Research Record: Journal of Transportation Research Board, No. 1883*, Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 50-58.

[16] Leclercq, L., N. Chiabaut., J. A. Laval., and C. Buisson. Relaxation phenomenon after lane changing - Experimental validation with NGSIM data set. In *Transportation Research Record: Journal of Transportation Research Board, No. 1999*, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 79-85.

[17] Sun, D. and A. Kondyli. Modeling Vehicle Interactions During Lane-Changing Behavior on Arterial Streets. Computer-Aided Civil and Infrastructure Engineering, Vol. 25, No. 8, 2010, pp. 557-571.

[18] Schakel, W.J., V.L. Knoop, and B.v. Arem, LMRS: An Integrated Lane Change Model with Relaxation and Synchronization, in TRB 2012 Annual Meeting. 2012: Washionton. D. C.

[19] Kou, C.-C. and R. Machemehl. Modeling Driver Behavior During Merge Maneuvers. Book, Published by Southwest Region University Transportation Center, Center for Transportation Research, University of Texas, 1997.

[20] Sarvi, M. and M. Kuwahara. Microsimulation of Freeway Ramp Merging Processes under Congested Traffic Conditions. Intelligent Transportation Systems, IEEE Transactions, Vol. 8, No. 3, 2007, pp. 470-479.

[21] Sarvi, M., O. Ejtemai and A. Zavabeti. Modelling Freeway Weaving Manoeuvre. *Australasian Transport Research Forum (ATRF)*, 34th, 2011, Adelaide, South Australia, Australia, 2011.

[22] Wan, X., J. Jin, L. Zheng, Y. Cheng and B. Ran. Empirical Analysis of Speed Synchronization of Merge Vehicle from Entrance Ramp. *Transportation Research Record: Journal of the Transportation Research Board*, Washington, D.C., 2013. (under press)