INVESTIGATING DRIVERS' REPONSES TO ADVISORY MESSAGES IN A CONNECTED VEHICLE ENVIRONMENT

A dissertation presented to
The faculty of the School of Engineering and Applied Science
University of Virginia

In Partial Fulfillment
Of the requirements for the Degree
Doctor of Philosophy (Civil and Environmental Engineering)

By

Md Tanveer Hayat

December 2015

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APPROVAL SHEET

The dissertation

is submitted in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

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Abstract

Freeway congestion is one of the most severe problems of the transportation system. Congestion has resulted in the loss of billions of dollars in terms of delays and fuel consumption, among others. Among the many contributing factors, merging conflicts in freeway ramp areas have been identified as one of the major causes of congestion. Though different ramp management strategies have been implemented over the years, each of these strategies has been partially successful due to their limited real-time traffic data collection and information dissemination capabilities.

To address the limitations of current ramp management strategies, the Connected Vehicle (CV) initiative takes advantage of advances in wireless communication, sensors, in-vehicle computer and GPS technologies, in addition to providing a unique opportunity to collect and exchange real time individual vehicular data. The Freeway Merge Assistance System (FMAS) is a connected-vehicle enabled prototype traffic management approach to ensure smoother merging by early identification and dynamic notification of merging opportunities through advisory messages. This is one of the first prototype applications that fully utilizes the capabilities provided by connected vehicle technology to enable a more cooperative driving environment between vehicles and the infrastructure. However, the effectiveness of this application entirely depends on actual drivers' response behavior to these new generation of in-vehicle personalized advisories. Numerous studies have investigated drivers' responses to safety alerts, automated braking and situational awareness alerts. As the objectives and benefits of safety systems are fundamentally different from mobility applications, drivers may demonstrated varied response behavior between these two systems. Therefore, proper understanding of drivers' response behavior under CV-based mobility application is a must. This provided the fundamental motivation for this dissertation to evaluate the freeway merge management system from the perspective of driver behavior.

To understand the variability of drivers' responses under diverse traffic conditions, in this research, a field experiments with 68 naïve test subjects was conducted with instrumented vehicles in a controlled environment. To simulate diverse traffic conditions for the participants, a set of nine scenarios were developed with three different gap sizes (small, medium and large) for each of the three FMAS algorithms (Variable Speed Limit, Lane Changing Advisory and Merging Control Algorithm). The three gaps sizes represented three different traffic conditions- free-flow, medium congestion, high congestion. The collected compliance data indicated that drivers feel more comfortable following the advisories when large and medium gaps are available, which represent low and medium traffic conditions respectively. Though the small gap size scenarios resulted in the lowest compliance rates, this is still meaningful in that "some" drivers are still willing to follow the advisory even in a high volume traffic condition. No significant difference was found between the compliance rates of male and female drivers. However, older driver group demonstrated lower advisory compliance rate (63%) than the younger driver group (84%).

The data on perception-reaction times show that perception-reaction time increases as the available gap size decreases. An estimated 0.64 sec difference in average perception-reaction time was observed from a large gap case (3.77 sec) and small gap case (4.41 sec). This increase in

perception-reaction time can be attributed to drivers becoming more cautious in making decision under relatively congested situation. Therefore, in the system design the variability of perception-reaction time for diverse traffic conditions should be considered. Similar to compliance rate data, no significant difference was found in perception-reaction time between male and female drivers. On the other hand, older drivers were found having significantly higher perception-reaction times with a significant difference of 1.57 sec when compared with the youngest group of drivers. This relatively slow perception-reaction can be attributed to age-induced cognition and motor skill loss. However, actual lane changing time does not change much regardless of the traffic condition, gender and age; this indicates once a driver initiates a lane change, the required time to complete lane change is independent of the traffic condition.

Another significant finding from the field testing was that drivers demonstrated better responses in terms of both compliance and perception-reaction times with a direct advisory messages, which gives clear and specific instruction. On the other hand, an indirect advisory message, which indirectly stimulate a driving action were found to be relatively less effective and efficient. The compliance data from field test show that direct advisories such as Merging control algorithm (84.8%) and Lane Changing advisory (84.3%) have higher compliance rates than the Variable Speed limit (63%) which provided indirect instructions to the participants. Perception reaction time was reduced by 1.30 sec (from 4.76 sec of variable speed limit to 3.46 sec of merging control) by providing most direct advisories. It is therefore recommended that developing and implementing an application that provides more direct advisory messages is desirable.

In conclusion, the actual drivers' response data collected and presented in this research is one of the very first studies that directly investigates driver behavior in a cooperative CV mobility application. Given the significance of proper understanding of drivers' behavior in developing, evaluating, and deploying connected vehicle mobility applications, continuous effort should be made to gather actual drivers' behavior data which provides valuable insight in drivers' decision making process under connected-vehicle environment.

Introduction

1.Background

Freeway traffic congestion is a significant problem within the transportation system. Congestion is not only a major factor of economic loss in terms of delays and fuel costs, it also adversely impacts the environment. A growing number of travelers and freight movement already pose significant challenges to the current transportation system, and these numbers are projected to grow substantially, further aggravating the traffic congestion problem. Various strategies such as ramp metering, variable speed limit, etc. have been implemented to improve freeway merging operation. However, each of these strategies have disadvantages [1] as well as limited capabilities in reducing freeway merge conflicts because of the real-time data collection and dissemination limitations of current traffic surveillance system [2].

The Connected Vehicle (CV) initiative addresses the above limitations by establishing wireless communication between vehicles and also between vehicles and infrastructure. Vehicles will be able to transmit individual vehicular data such as speed, location, acceleration, vehicle type, vehicle length, vehicle ID, etc. to nearby vehicles and infrastructure [3]. Another enormous advantage of the CV technology is the ability to send customized messages\advisories to targeted vehicles. With these new capabilities, more proactive and cooperative strategies can be developed and deployed to address various transportation problems.

2. Freeway Merge Assistance System

With the new capabilities offered by the Connected Vehicle technology, it may be possible to develop new approaches to address freeway merge conflicts. The University of Virginia Center for Transportation Studies (UVA CTS) has developed the CV technology enabled Freeway Merge Assistance System to promote safer and more efficient merging operation by minimizing conflicts between the mainline vehicles and on-ramp vehicles. Four algorithms developed under this system are: variable speed limit, lane changing advisory, gap responsive metering and merging control. The overall goal of this system is to either identify existing gaps in the freeway mainline lane or to create gaps in the merging lane for the on-ramp vehicles. Initial results showed that the algorithms can significantly improve the overall network performance. In addition, a simulation modeling results in an integrated CV test bed indicated that the performance of the underlying communication network will greatly impact the performance of the individual algorithms [4], [5].

The above mentioned four algorithms under the merge assistance system provide personalized advisories to both freeway mainline and merging vehicle drivers. Based on the advisory given, it was assumed that the drivers will take the necessary courses of action to create gaps, change lanes or control the speed of their vehicles. The benefits anticipated from the merge management system in reducing merging conflicts and bottlenecks in merge areas entirely depend on the compliance of drivers. It was assumed during the development and simulation evaluation phase that all drivers comply with all the relayed personalized advisories. However, in real-world scenarios 100% driver compliance may not be possible due to various reasons. Therefore, before deploying any new traffic management strategy it is necessary to conduct a comprehensive evaluation by using both the simulation approach and a field study. One of the key components of CV mobility applications is the personalized advisory for drivers, the success of these dynamic mobility applications depend on driver compliance. Therefore, it is necessary to investigate and fully understand driver behavior to personalized advisories for different traffic conditions in a Connected Vehicle environment.

3. Previous Work

Previous studies on dynamic traffic advisory to drivers/commuters mainly have focused on relaying route choice advisory information through ATIS, Radio and Internet. These studies investigated how pre-trip and en-route advisory information impacts the route choice decision making process of drivers. The factors that might influence drivers' decisions in these studies included the traffic congestion levels on the different routes, accident events on a preferred route and the estimated travel-time information of these different route choices[6]. These studies either relied on surveys or vehicle simulator to understand drivers' responses to this dynamic advisory information [7]. Researchers used the data gathered to develop probabilistic models of route diversion based on the participant socio-demographic characteristics, network spatial knowledge, message content, trip activity, message medium, traffic condition, incident presence and other factors[8]. This eventually helps understand how drivers' route choice decision can be influenced to enhance network performance under different traffic conditions and incident scenarios [9]. Most of these studies either depended on historical traffic events or hypothetical situations to get participants response to the advisory messages.

Recently, researchers have also investigated driver response to both stand-alone and CV-based in-vehicle safety system [11][12]. Most of these studies focus on the fact of driver perception-reaction to the safety alerts provided by these systems. The message content of the alerts, delivery time and audio level are also considered as primary factors for investigation in these studies. The effectiveness of these systems is also often judged on the level of driver distraction and how these systems can reduce the risk of collision and severity at different vehicle dynamics. Though these systems focuses on specific driver actions like braking, lane changing maneuvers, etc., the focus is again is on either on the human factor aspect and/or finding the optimal parameters settings for these systems to function properly/optimally to minimize risk to humans and vehicles. Some CV-based field study are also investigating the potentiality of situational awareness alerts in reducing risk of crashes [13].

4. Research Needs

However, the fundamental difference between a safety application and a mobility application lies in the objective of these two systems. The primary objective of an in-vehicle safety system, mainly CV based active safety system is to prevent accidents, reduce the severity of a collision, and/or alert drivers of an imminent danger. Whereas, the aim of a CV mobility application is to ensure better driving conditions and assist and/or advise drivers with information that will lead them to more efficient and better driving condition, that is improving individual mobility and overall system efficiency. Therefore, the advisory or alerts provided by a safety system has far greater utility to a driver, since it manifests an immediate and immense benefit for the drivers and passengers[14]. On the other hand, advisories relayed from mobility applications are more assistive in nature and do not require as much mandatory attention from the driver as alerts from safety system do. The factors that influence drivers' response to safety advisory may be different from the factors that influence compliance to mobility advisory.

In addition, with the advent of dynamic mobility applications there is another need to assess and understand driver response to advisory generated from these mobility applications under the Connected Vehicle environment. The goal of the Dynamic Mobility Application (DMA) program of US DOT is to develop applications that can exploit multi-source data from both connected mobile and fixed entities [15]. Different mobility applications will disseminate various types of advisory messages to the system users; drivers will comprise a significant portion of the receivers of these advisories. The effectiveness of this mobility applications will depend on successfully communicate with the drivers in a timely and effectively way so that the drivers understand the advisories as the system managers intend them to. If the message is successfully conveyed and the drivers react as advised, the intended benefits by deploying these applications will be achieved. System managers and mobility application developers need a broader and deeper understanding of driver response behavior to these mobility advisories so that they can design and implement a system that effectively utilizes real-time multi-source data to maximize system performance by incorporating the knowledge of user behavior.

As mentioned earlier, though extensive research has been done on developing in-vehicle safety systems and understanding driver response behavior to alerts/advisories provided under this system, there has been no studies found by the author investigating drivers' response behavior under dynamic mobility applications. Some mobility applications such as Queue Warning System under the INFO bundle, though warns driver of potential downstream queue, its overall goal is to minimize congestion in the bottleneck and allow drivers to make early route change [16]. Similarly the Speed Harmonization strategy seeks to dynamically adjust and coordinate speed to maximize throughput and delay the flow breakdown. Unlike safety systems these applications do not provide mandatory advisory message rather they provide real-time driving recommendation to improve individual mobility[17]. Mobility advisories are assistive in nature to improve mobility where safety comes as a secondary benefit.

Therefore it is of high importance to conduct human factors study in Connected Vehicle to understand driver behavior under different driver assistive CV applications. As mentioned earlier, response behavior under mobility advisory may be different from response behavior under safety advisory, the experimental design of the study should consider that factors under these two different environments may be different or may not completely overlap. Driver compliance to mobility advisory may be dependent individual behavioral factors such as age, gender, driving experience, the locality of the driver. In addition, situational factors such as dynamic traffic condition will likely to have significant influence on driver response behavior to mobility advisories. Unlike safety system, system engineers and transportation system managers have to put more emphasis on driver compliance under mobility applications, as positive compliance may result in anticipate benefits of this system. This will eventually help them develop and deploy reliable mobility applications that can potentially improve individual mobility and overall system performance. Understanding the effects of these factors will help formulate strategies to disseminate advisories to achieve maximum compliance. Since future automation technology will provide the opportunity to address individual driver preference or enable customized driver application, it may be possible to accommodate driver characteristics heterogeneity in this application development process. For example by understanding the perception-reaction time of different age and gender group applications can optimize internal processes of advisory dissemination. In addition, it is very important to understand that under different dynamic traffic condition how drivers react and what would be the implication of those reactions in achieving anticipated benefits of mobility applications.

5. Goals and Objectives

This research takes the initiative to investigate and analyze driver behavior from the perspective of real-time advisory compliance and response times. To collect driver response data, a field test was conducted with various traffic scenarios for the three different algorithms. Understanding driver behavior to personalized advisories will help enhance CV-based mobility applications before field deployment. This new knowledge will also allow transportation system managers to utilize information as a traffic management tool and to adopt strategies and policies for effective implementation of CV-enabled dynamic mobility applications, such as the freeway merge assistance system.

The main objectives of this research are as follows:

1. To conduct a field test to collect revealed and stated preference data on driver compliance to the advisories provided.
2. To collect data on drivers' response times to advisory messages under diverse traffic conditions.
3. To analyze data to investigate the driver compliance behavior to personalized advisories; and
4. To investigate the drivers' response times to a new generation of mobility advisory messages.

This will eventually help us investigate further how actual driver compliance affects the benefits anticipated from the merge management system in a Connected Vehicle environment. Various prior research studies investigated how information at broader levels impacts travel behavior and thus network performance. However, there is a gap in the current knowledge about how individual drivers will react to advisories specifically targeting them. Variability in driver compliance can significantly affect the outcomes of these mobility applications. As mentioned earlier the earlier work on the freeway merge management system did not consider any component of driver behavioral factor and situational factor influencing individual compliance, whereas compliance can be attributed to individual driver characteristics to dynamic traffic conditions.

6. Research Contributions

Based on the stated objectives, this research makes a number of contributions to the CV-based cooperative strategy domain in transportation engineering:

a) Small scale feasibility demonstration of CV-based freeway merge assistance system,

b) Better understanding of drivers' responses to personalized advisory message,

c) Improved understanding of drivers' advisory compliance under different traffic conditions,

d) Understanding of advisory response variability between male and female drivers

e) Understanding of variability in advisory response among different age groups

f) Understanding of the impact of direct and indirect advisory messages on driver compliance and response times.

To present and discuss the findings of this research the rest of the dissertation is arranged in journal paper format. Each of the paper discusses the various aspects of the driver response behavior.

The first paper presents in detail the design of the field test, description of the simplified system architecture, scenario development, participant sampling, scenario description and test procedure steps. It also presents the some preliminary compliance data and survey data. This paper was published in the proceedings of the 2014 IEEE Intelligent Vehicles Symposium.

The second paper discusses the compliance behavior of drivers under diverse traffic condition. In this paper, the variability of compliance behavior was presented in terms of both gap sizes and strategies. This paper was accepted for presentation in 2015 Transportation Research Board annual meeting.

The third paper focuses on the response times of drivers to the various personalized advisory messages under different traffic scenarios. Detailed analysis of variability in perception-reaction time and lane changing times in terms of both gap sizes and strategies are presented in this paper. This paper accepted for presentation at the 2016 Transportation Research Board annual meeting and currently being reviewed for publication in the Transportation Research Record.

The fourth paper investigates the variations in both compliance and response times in terms of gender and age groups among the field test participants. Male and female drivers do not have significant differences in driving skills though have differences in demonstration risky behavior and hazard level perception. And with age both cognitive and motor skills decrease which may cause difference in responses among different age group. This working paper will be submitted to the Journal of Transportation Engineering.

Connected vehicle enabled freeway merge assistance system- field test: Preliminary results of driver compliance to advisory

Md Tanveer Hayat, Hyungjun Park, and Brian L. Smith

Abstract— **The Connected Vehicle enabled Freeway Merge Assistance system is developed by the University of Virginia Center for Transportation Studies, with the aim of reducing conflicts between merging vehicles in freeway ramp area. Initial simulation evaluation results showed that the merge assistance system has significant potential to increase capacity of freeway merge areas and reduce accidents by minimizing the number of conflicts between vehicles. As a next step of evaluation, a field test is conducted at a Connected Vehicle test bed to investigate drivers' response to the personalized advisories relayed by this system. This paper provides an overview of the field test methodology, system architecture, stated preference survey and presents preliminary results for this prototype freeway merge assistance system developed for the Connected Vehicle Environment. The revealed and stated preference data gathered will be used to develop an advisory response model that will incorporate drivers' response variability in the simulation evaluation framework of the freeway merge assistance system.**

I. INTRODUCTION

Freeway congestion is one of the major problems of the transportation system. Congestion has resulted in the loss of billions of dollars in terms of both delay and fuel cost. Among the many reasons, merging conflicts in freeway ramp areas have been identified as one of the major causes of congestion [1]. Though different ramp management strategies have been implemented over the years, each of these strategies is somewhat limited in benefits and also in some cases induces negative impacts on the network [2].

However, the Connected Vehicle initiative takes advantage of advances in wireless communication, sensors, in-vehicle computer and GPS technologies, and provides a unique opportunity to facilitate development and deployment of advanced proactive traffic management strategies. With the aim of improving the efficiency and safety of freeway merges, UVA CTS has developed the freeway merge assistance system for the Connected Vehicle environment. This prototype system is developed to take advantage of the Connected Vehicle technology to address the limitations of current merge management practice. Four algorithms were developed under this system: variables speed limit, lane changing advisory, gap-responsive metering and merging control. Simulation evaluation results demonstrated significant potential of the algorithms in improving freeway merging operation [3].

At the initial algorithm development phase, it was assumed that the vehicle drivers will comply with all the personalized advisories relayed to them by these different algorithms. However in reality, advisory compliance will greatly depend on a variety of factors ranging from situational factors like traffic conditions to behavioral factors like age, gender, etc. To understand the variability in driver compliance, one approach is to conduct field experiments with naïve test subjects by exposing them to different advisories provided by the freeway merge assistance system. Besides the field experiment, survey on hypothetical scenarios will also provide necessary information about drivers' decision making process to this novel system. An important part of the proposed work is to develop an Advisory response model from the data gathered through field experimentation on naïve drivers.

The proposed advisory response model will be incorporated into the integrated freeway merge assistance system to evaluate how individual driver compliance affects the performance of the algorithms.

A. Freeway Merge Assistance System

Following are three important fundamental components central to objectives of the system:

a. Dynamic Lane Control: The dynamic lane control logic is identifies available capacity in lanes and encourage drivers travelling on the lane adjacent to the merging lane to change lane to create bigger and frequent gaps in the merging area. This dynamic lane control logic was implemented by two algorithms:

(i) Lane-level Variable Speed Limit: Considering the existing mainline traffic condition, this algorithm dynamically determines and implements lower speed limit on the right most lane to encourage drivers to move to the left lane and thus creating gaps for merging vehicles on the right lane. [3].

(ii) Lane Changing Advisory: This algorithm aims at dynamically selecting vehicles on right lane to send lane changing advisory for early lane change to create bigger gaps for merging vehicle on the right lane [4].

b. Gap-responsive Metering: This algorithm utilizes CV enabled vehicle trajectory data to identify gaps in the mainline lane and implement dynamic gap-based ramp metering strategy for on-ramp merging traffic. However, in this study this algorithm is not considered for the field test phase.

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c. Merge Control: The merging control algorithm employs V2V and V2I communication to control longitudinal movements or advice speed changes for specific mainline and ramp vehicles, to ensure smooth merging in smallest gap sizes by reducing merging conflicts.

The algorithms were developed and evaluated in an integrated Connected Vehicle simulation environment. In this simulation test bed VISSIM is used as the microscopic traffic simulator and NCTUns is adopted as the communication simulator; this allows following the WAVE/DSRC standards and simulation of SAE J2735 message sets [5].

II. DESIGN OF FIELD TEST

A. Testing Facility-Connected Vehicle Test Bed

The field test is conducted on a Connected Vehicle test bed Smart Road located in Blacksburg, Virginia. This facility has a 2-lane road instrumented with DSRC based wireless infrastructures to support experimental procedures in testing and developing Connected Vehicle based research. This facility also provides a small fleet of vehicles equipped with DSRC-based on-board equipment, which allows implementing V2V and V2I communications. The vehicles also have on-board display which is capable of providing both audio and visual advisory.

B. Segment and Lane Configuration

To test the proposed freeway merge assistance algorithms in the Smart Road facility, it will be necessary to modify the existing lane configuration. Since the geometric design of the facility does not it will not be possible to have actual on-ramp sections and merging lane sections, the two-lane segment can be converted temporarily for the testing purpose. Only two lanes will be necessary for testing different scenarios. One lane will serve as a right lane and another lane as a left lane of a freeway segment. Temporary lane markers and traffic cones will be used to create a mock freeway section of 2,000ft to give test-drivers the perception of a freeway merging area. Fig. 1 shows the GIS map with proposed lane configuration for the substitute freeway merging area in the Smart Road facility.

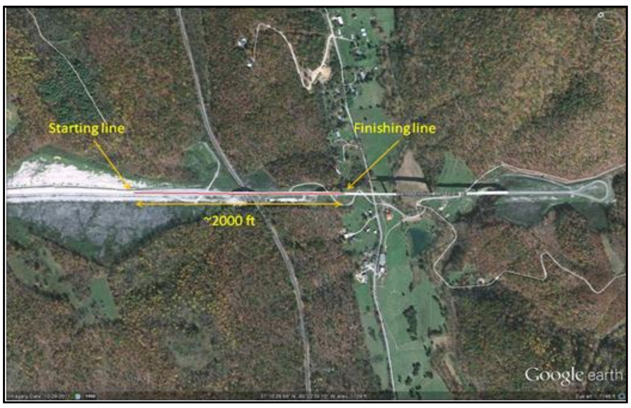


Fig. 1. Lane Configuration – Smart Road

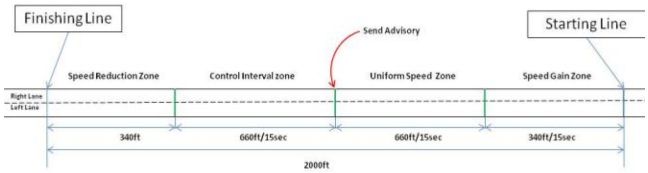


Fig. 2 Lane Configuration with activity zones.

The 2000ft segment will be divided into four zones as depicted in Figure 2, based on the general sequential driving activities as follows:

- Reaching target speed - Speed Gain Zone (Activity 1)
- Driving at uniform speed - Uniform Speed Zone(Activity-2)
- Sending/receiving/reacting to advisory - Control Interval Zone (Activity-3)
- Reducing speed - Speed Reduction Zone (Activity-4)

Vehicles will travel at a speed of 30mph for most of the scenarios; the speed gain zone will provide necessary length to attain that speed from stopping position. So it would take approximately 15 sec for a vehicle to reach that speed with a moderate acceleration rate of $3fps^2$. To allow vehicles to travel at uniform speed and get confirmation about their location, the uniform speed zone will be utilized. An advisory will then be sent to the participant vehicle and a 5 second time is selected as control interval for that advisory. For multiple advisory scenarios, this time can be extended to 10 seconds. The last section is for vehicles to safely reduce speed and prepare for stopping after crossing the finishing line. The proposed section length and time allocation is an approximation of what ideally the research team expects to happen in the field, but this can be further modified after a few trial runs in the actual testing location. After finalizing the length of each section, the zones can be implemented in the actual testing section by using traffic cones on the side of the road.

III. SIMPLIFIED SYSTEM ARCHITECTURE FOR FIELD TESTING

Since it was not possible to have a fully operational System architecture that supports the proposed Merge Assistance System within the project time frame, the research team designed simplified system architecture was designed to conduct the field test. Fig. 3 illustrates the proposed simplified system architecture, in which a Test Control Application is directly connected to an OBE in the participant vehicle through Ethernet. Through the Test Control Application the experimenter can manually send advisory to the on-board display of all test vehicles. In this simplified architecture RSEs, the application server with three merge assistance applications, and the central database system will not be included. Rather, testing will be conducted using only a Test Control Application and OBEs of test vehicles.

Following are the sequential steps that will be followed in the proposed simplified system architecture:

1. The Test Control Application is started by the Test Administrator, who is riding in the participant vehicle. Then the test administrator will select one of the three applications and the specific scenario to be tested.

2. The OBE application will start sending BSMs to other OBEs. The data acquisition system in the vehicles will keep record of all the BSMs sent and received.

3. When the test administrator selects to send an advisory specific to the selected scenario, the on-board display system will show that advisory in both visual and auditory format to the test subject vehicle.

4. In the test control application, Test administrator will record the response of test participant to the advisory displayed.

5. After recording the response the test administrator will send the end signal through the test control application to the OBEs. The OBEs will stop sending BSMs. In addition to that the test control application will also generate a test log report for each test run.

IV. Scenario Development

A. Factors Considered in Scenario Developments

The goal of this field test is to understand how individual drivers react to the merge assistance advisories at different traffic condition, mainly at different gaps sizes. One of the major factors for considering lane change is the available gaps in the target lane [6]. The Freeway Merge Assistance system provides advisories depending on the current traffic condition. Drivers may also have individual preference for following or complying with the advisories. Therefore, for developing the set of test scenarios, following are two major factors that were considered:

1) Advisory types provided by each of three algorithms
2) Available gap sizes on the left lane for lane change.

1) Advisory Types

Each of three algorithms that will be employed in the field testing provides different types of advisory messages. The goal of this test is to understand how individual drivers react to these different advisories.

a) *Variable Speed Limit (VSL):* As mentioned in the earlier section, this strategy employs a lower speed limit on the right lane vehicle to encourage drivers to move to left lane, resulting adequate gaps for merging vehicles. Fig. 4a illustrates an example VSL advisory that is relayed to the participants in the merge management field test.

b) *Lane Changing Advisory (LCA):* This advisory is simplistic in design as it directly advices driver to change lane. Fig. 4b illustrates the LCA advisory designed for the field test. The Lane changing advisory algorithm provides an advisory message that directly encourages a lane change.

c) *Merging Control Advisory (MCA):* This strategy includes sending two different advisories to the driver. First, it sends acceleration advisory with recommended speed (Fig. 4c). Given that the driver complies with first advisory and there is adequate gap for lane change, a lane changing advisory is sent to the driver (Fig. 4b).

2) Available Gap Sizes

By using the concept of time headways between vehicles in different traffic conditions, we prepared a set of gap sizes for the different scenarios. Ye and Zhang investigated the time-headway distribution for different traffic levels as presented in Table 3 [7]. Based on this data, it was observed that the mean time headways for high, moderate, and low traffic conditions are approximately 2sec, 3sec, and 4sec respectively.
According to Lobo et. al (2011) for two lane rural highways, the "free gap" varies between 5 and 6sec [8]. Also, the proposed ideal safe gap equation proposed by Yang et. al estimated the safe gap for merging vehicle travelling at 40 mph to be 1.31 sec [9].

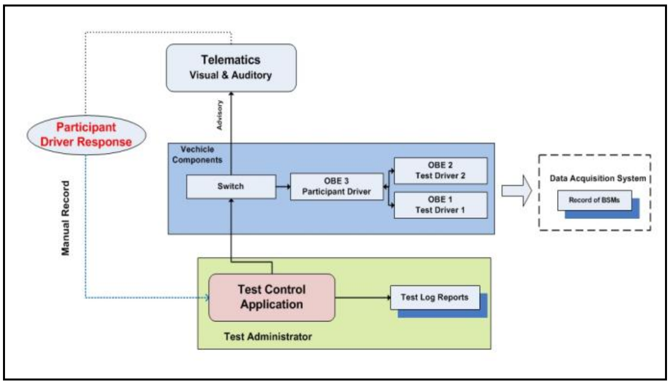
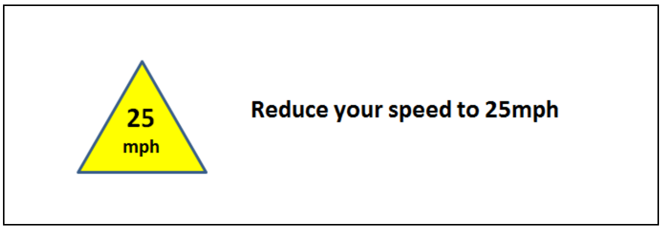
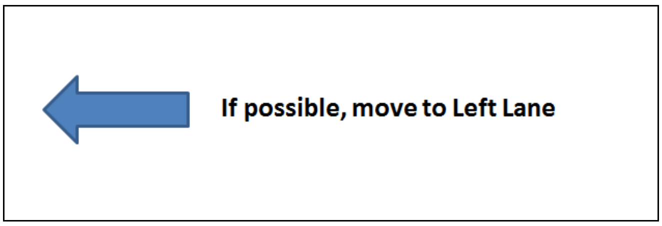


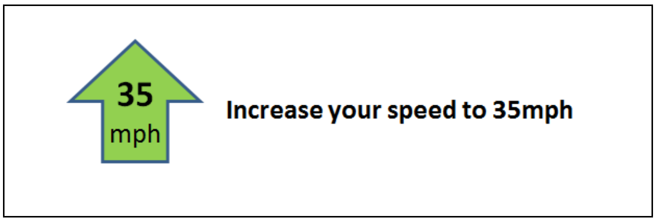
Fig. 3. Simplified System Architecture



(a)



(b)



(c)

Fig. 4 Advisory (a) VSL (b) LCA (c) MCA

TABLE 3: SELECTED GAP SIZES

Headway Type	**Number of Observation**	**Mean**	**Std. Dev**	**CV**	**Lower 95% CL for Mean**	**Upper 95% CL for Mean**
Uncongested Low Traffic Flow Level (<800 uncongested)						
Car-Car	1411	8.38	9.05	1.08	7.91	8.86
Congested Low Traffic Flow Level (< 800 congested)						
Car-Car	1100	4.16	3.29	0.79	3.96	4.35
Moderate Traffic Flow Level ([800,1500])						
Car-Car	7004	2.85	2.44	0.86	2.79	2.91
High Traffic Flow Level (>1500)						
Car-Car	13146	1.95	1.52	0.78	1.92	1.98

Based on the findings from the literature mentioned above, we defined the different gap sizes for field testing in terms of time-headway and converted it into space headways. For vehicles traveling at 30 mph, the various proposed gap sizes are as follows:

TABLE 1: SELECTED GAP SIZES

Gap Type	Time-Headway (sec)	Space-Headway (ft)	Selected Gap Sizes for Testing (ft)
Small Gap	2.00	88	100
Medium Gap	3.00	132	150
Large Gap	4.00	176	200

B. *Scenario Overview*

Finally, based on the combination of the three gap sizes and advisory types, nine test scenarios are developed for the field test to understand drivers' response to real-time advisories in dynamic driving environment. The set of nine scenarios are presented in Table 5.

V. SAMPLING OF TEST PARTICIPANTS

The participants in field-test will be selected to represent the overall demographics of licensed drivers in US. Participants are recruited from surrounding area of Blacksburg, Virginia. Each participant undergoes an eligibility screening process before allowed to participate in the test. Personal information of each participant will be stored with strict confidentiality. As mentioned earlier one of the main objective of this project is to observe driver response to different advisories at different scenarios. The variable of interest is advisory compliance which is a dichotomous variable, since driver either can comply or not comply for a given advisory.

TABLE 2: SCENARIO OVERVIEW

Advisory Types / Gap Sizes	Variable Speed Limit *New Speed Limit 25mph*	Lane Changing Advisory *If possible, move to left lane*	Merging Control Algorithm *Increase speed to 35mph If possible, move to left lane*
Large Gap (200ft)	Scenario #1	Scenario #4	Scenario #7
Medium Gap (150ft)	Scenario #2	Scenario #5	Scenario #8
Small Gap (100ft)	Scenario #3	Scenario #6	Scenario #9

Hence for the scenarios to be tested we need to calculate the sample size so that with a reasonable level of confidence we can conclude about response type for the entire driver population. The population size of interest for this case is the entire driver population in US, which is infinite in size in terms of effects in the sample size calculation. For calculating the sample size for categorical data the equation (1) is widely applied [10]. An important component of this sample size formula is the estimation of variance on which the researchers don't have any direct control. Since there is no prior information about drivers' response to these types of advisories, in this kind of situation, Krejcie and Morgan (1970) suggested using a conservative assumption that population proportion is 50% [11]. In our case this population proportion represents the percentage of population that complies with the given advisory. The product of the two proportions gives an estimate of variance in the population.

Sample Size, $$n = \frac{Z_c^2 pq}{d^2} \qquad (1)$$

Where,
n = sample size
p = population proportion, q = 1-p
pq = estimate of variance
z = z-score for the selected confidence interval
d = Margin of error

With equation (1) the sample size was estimated as 68 with a confidence interval of 90% and margin of error 10%. This sample size indicates that for each of the scenario 68 responses is necessary to have statistically significant conclusion about the whole population with a confidence level of 90% and margin of error 10%. Therefore, 68 participants will be recruited and each of the participants will take part in all the test scenarios for the three algorithms.

VI. SCENARIO DESCRIPTION AND TEST PROCEDURE STEPS

To conduct the field test, a detailed field test procedure and test protocol has been developed by the research team. The order of the scenarios is randomized to eliminate any bias in

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the data gathered and minimize the learning effects of the participants. Before the beginning of each scenario the three test vehicles are positioned on numbered spot designated specifically for each of them. Fig. 5 shows the field setup configuration that illustrates the location of the three vehicles for each scenario. The lead vehicle on the left lane is placed on the designated position with location marker #1 for all scenarios. The lag vehicle on the left lane is placed on three different positions depending on the scenario to be tested.

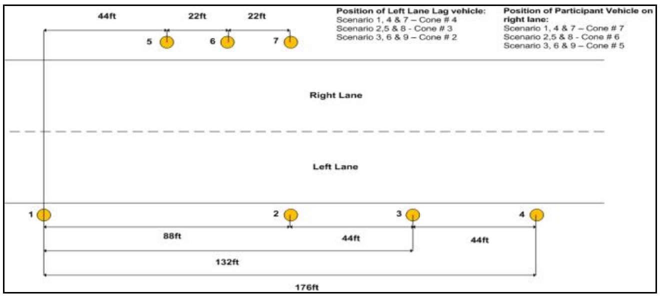


Fig 5. Field setup configuration

For example, for scenarios with large gap the lag vehicle is placed before the cone with location marker 4, for scenarios with medium gap before cone with location marker 3 and for scenarios with small gap with location marker 2. On the right lane, the participant vehicle is placed on the cone with location marker #5, #6 & #7 for small, medium and large gap size scenarios respectively.

Typical procedural steps:

- Depending on the scenarios to be tested all the three vehicles are position at designated locations.
- Experimenter on the participant vehicle instructs all the drivers to start driving at the same time. Instruction is sent to all drivers through radio communication.
- The participant is instructed to reach uniform speed of 30mph and maintain that speed until any advisory is displayed in the on-board display.
- After the vehicle reaches a uniform speed, the experimenter sends an advisory to the on-board display.
- Upon receiving the advisory, the participant can either comply with the advisory or he/she can keep on driving on right lane.
- The experimenter records the response of the participant driver and sends further instruction to all the drivers for the next scenario.

VII. STATED PREFERENCE DATA

Besides collecting revealed preference data from the field test, a stated preference questionnaire survey was conducted. After the field test, the stated preference questionnaire was provided to the participants to give their response to the different hypothetical situations. First part of the questionnaire collects socio-demographic information and the second part has some questions about hypothetical scenarios. The stated preference survey provides valuable information to the researchers about what hypothetical situational factors will influence drivers' advisory compliance behavior regarding advisory compliance[12], [13].

VIII. PRELIMINARY RESULTS

The study has already collected data from 25 naïve participants. Participants were recruited through advertisement on classified websites like craigslist and local newspaper from the surrounding area of Blacksburg, Christiansburg, Roanoke and Charlottesville, Virginia. Participants went through an eligibility screening over the phone. If participants are eligible, the participants are scheduled to participate for the field test at a specific time on the Smart Road facility. Upon arriving at the facility, the participants go through necessary paperwork and training before the field test. In the training phase, each participant is oriented with the test vehicle, on-board display and a detailed instruction is given about their responsibility and course of actions for different advisories during the field test. In this section preliminary compliance results are provided, that this study has gathered so far.

A. *Revealed Preference Data-Field Test*

1) Variable Speed Limit: For the VSL scenarios, the compliance is highest for the scenarios with mid-size gaps (68%) followed by scenarios with large gaps (60%). This rate of compliance is consistent with the intuitive expectation that drivers are willing to change lane when gaps are comparatively bigger [Fig. 6(a)].

2) Lane Changing Advisory: For lane changing advisory, all the participants accepted the gaps or changed lane for scenario with largest gap. For scenario with mid-size gap only one participant driver did not comply with LCA advisory. About 32% of the drivers (8 drivers) did not feel comfortable complying with the lane changing advisory in the scenarios with the smallest gap [Fig. 6(b)].

3) Merging Control Algorithm: For the MCA scenarios, compliance result indicates that participant drivers were most comfortable in following the two advisories for the scenarios with largest gap, followed by scenarios with mid gap. 28% of the participant drivers were not able to accept gaps for the small gap scenario [Fig. 6(c)].

4) Compliance across strategies: If compliance is compared, across the strategies irrespective of the gap sizes for the scenarios, it can be observed that LCA has the highest compliance followed by MCA. However, VSL has the highest non-compliance rate of 44%. The reason for high non-compliance for VSL is that participant drivers were confused after getting the reduced speed limit advisory provided under this strategy. The goal of the reduced speed limit advisory is to encourage drivers to move to the left lane with higher speed limit, however participant drivers interpreted the advisory simply as reduced speed limit advisory, even though they were given specific instructions about their possible choices after receiving this advisory [Fig. 6(d)].

5) Compliance across different gap sizes: Compliance across the scenarios for the three different gaps size is consistent with the initial expectation of the researchers. Participants show exactly similar gap acceptance behavior for scenarios with large and mid-size gaps. On the other hand, 40% of the drivers did not accept gaps or complied with advisory for scenarios with smallest gap size [Fig. 6(e)].

B. *Stated Preference Data-Questionnaire Survey*

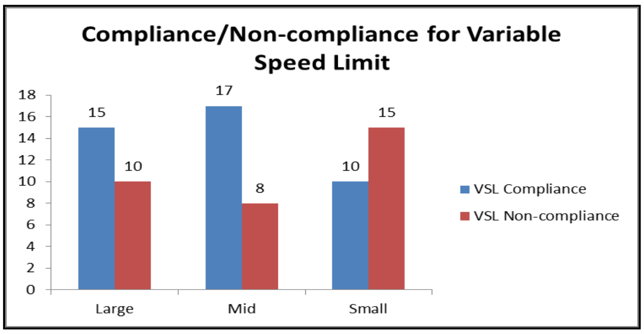
This section presents the preliminary results from the questionnaire survey where participants responded to a 4-point Likert scale survey to statements depicting several hypothetical situations.

1) Advisory Compliance under different traffic condition: In the survey, participants were asked about how they would respond to the different advisories for different traffic condition. Stated responses from the participants indicate that the participants are most likely to comply at medium traffic condition scenario, followed by free-flow condition. Participants stated that they are least likely to comply with advisories at condition with heavy traffic congestions. This indicates that at heavy traffic condition, drivers will not rely on advised control by the merge assistance system [Fig. 7(a)].

2) Advisory Compliance with network familiarity: About 70% of the participants stated that they would comply with the relayed advisories if they are travelling on an unfamiliar network. This indicates travelling on road with little or no familiarity will not have any effect on complying with advisory [Fig. 7(b)].

3) Advisory Compliance leading to travelling on a higher speed lane: Participants were asked in one question, whether they would comply with an advisory if compliance would lead them travelling on lane with comparatively higher speed [Fig. 7(c)]. All the participants showed willingness to move to a lane with higher speed with 32% participants strongly agreed with the statement.

4) Advisory compliance under sense of conflict: All the participants showed consent to comply with an advisory if they can sense that complying with the advisory will help avoiding a conflicting situation. 15 participants out of the 25 participants strongly agreed with statement and rest of the 10 participants agreed with participants [Fig. 7(d)].



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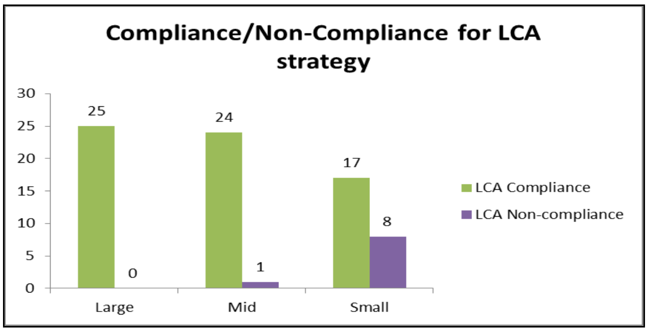

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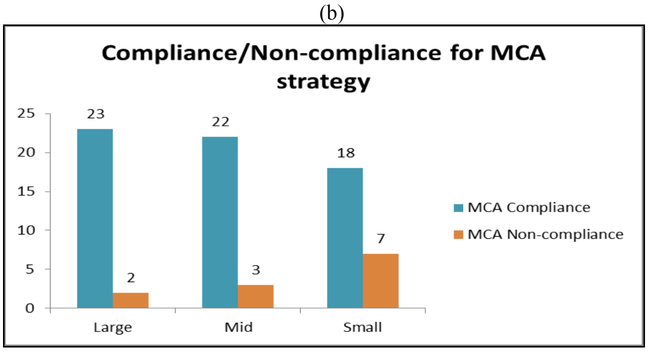

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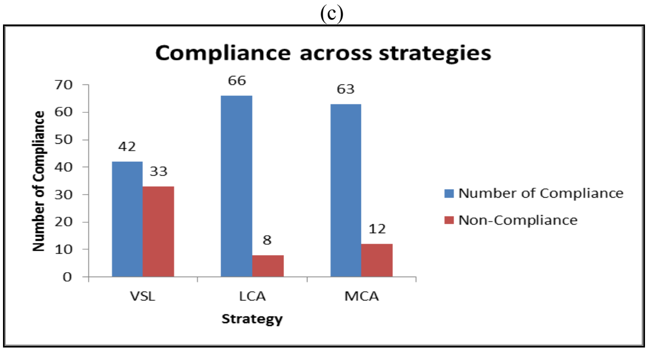

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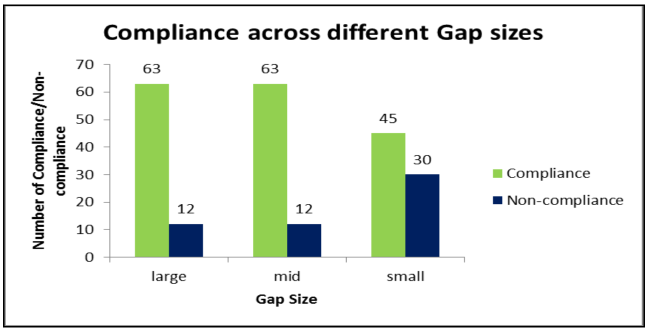


(e)

Fig. 6. Revealed Preference Data (a) VSL (b) LCA (c) MCA (d) across strategies, (e) across gap sizes

5) Advisory Compliance under presence of a front vehicle: In the field test, there was no vehicle in front of the participant vehicle on the right lane. In an ideal Connected Vehicle environment, the prototype freeway merge assistance system will have location information of all the vehicles of the network and the advisories will be relayed to vehicles considering the dynamic position of all these vehicles. The presence of a vehicle in front of the target vehicle in the same lane may influence the compliance behavior of the target vehicle driver. Stated preference data indicates supports this assumption with 76% of participants indicated that the presence of a lead vehicle will influence their compliance behavior [Fig. 7(e)].

6) Advisory Compliance under presence of merging vehicle: Similar to the previous hypothetical statement, participants were presented with a hypothetical statement with appropriate figure to respond to a scenario that they would comply with advisory if they can see that a vehicle in the merging area. 96% of the participants agreed to the statement with only one participant disagreed with the statement [Fig. 7(f)].

IX. Future Steps

One of the main objectives of this study is to develop and estimate an advisory response model using: (a) revealed preference data gathered from the field test which demonstrates actual driver behavior and (b) stated preference data from the survey questionnaire to understand drivers' preference for unknown conditions.

For modeling of choice behavior, it is important to consider the taste heterogeneity that result due to response differences to alternative attributes and also differences in individual preference. Extensive literature review indicates, the mixed logit form is the appropriate approach to model the advisory response behavior by incorporating the correlation between repeated choices [14],[15].

For the model development and estimation, a unified mixed logit framework will be adopted [16], [17] that will allow joint analysis of revealed and stated preference data by accommodating heterogeneity across individual, scale difference in the two data sets and correlation of choice sets. The utility function for the model can have the following form:

$$U_{nit} = b_n^{'} x_{nit} + \eta_{nit} + \varepsilon_{nit} \qquad (2)$$

Where,

U_{nit} = utility of alternative i to individual n on choice occasion t;

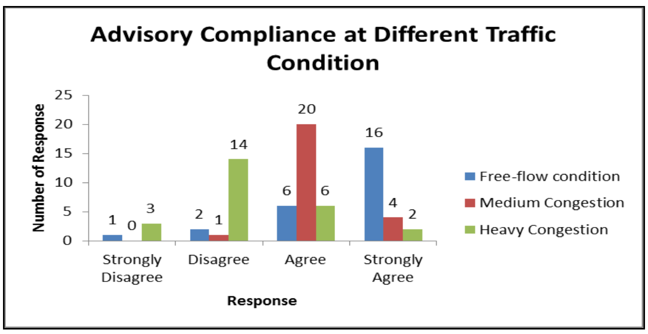
x_{nit} = vector of observed variabels

$b_n^{'}$ = vector of fixed coefficients

η_{nit} = error term capturing heteroscedasticity and correlation

μ= vector of random terms with zero mean

ε_{nit} = independently and identically distributed value



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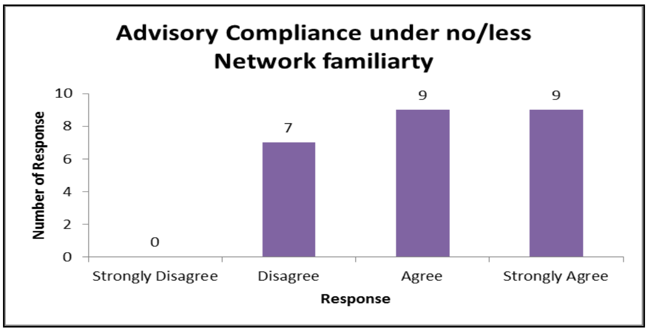

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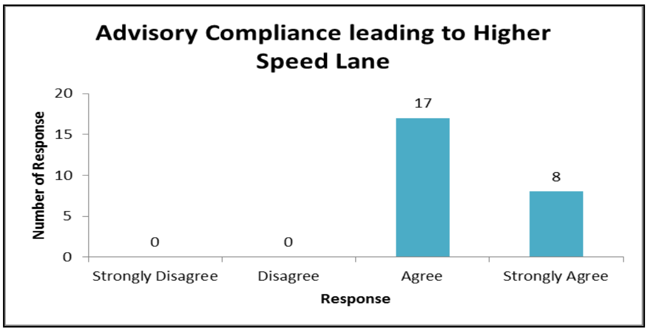

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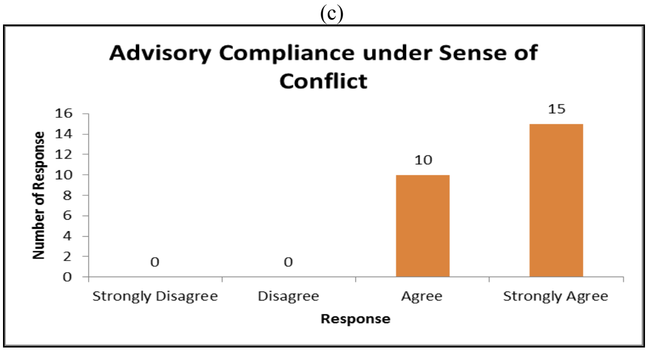

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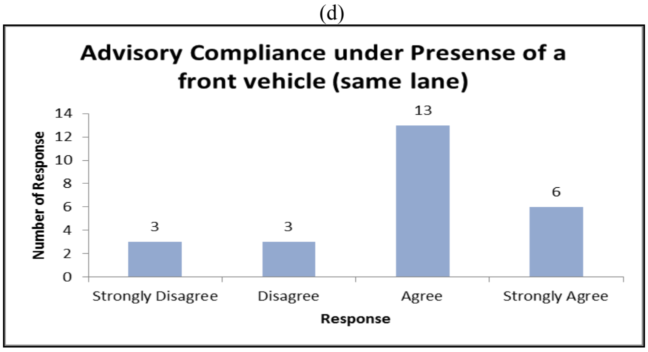

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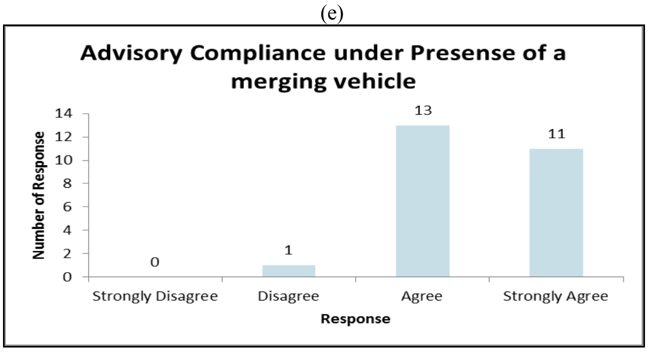

(f)

Fig. 7. Stated Preference Data (a) Traffic Condition (b) Network familiarity (c) moving to higher speed lane (d) Sense of conflict (e) presence of a front vehicle (f) presence of a merging vehicle

The equation (1) can be presented as a simplified standard logit form where, $\eta_{nit} = \delta_{nit} z_{nit}$, with δ_{nit} is a vector of random terms with zero means , contributing to the individual taste variation. Assuming, $x_{nit} = z_{nit}$ are the same vector of observed variables that contribute to systematic and random portion of the utility, the utility can be expressed as:

$U_{nit} = \beta_{nit} x_{nit} + \varepsilon_{nit}$, where $\beta_{nit} = b_n + \delta_{nit}$

varies randomly across individuals.

The conditional probability that individual n choosing alternative i at the choice occasion t can be presented as the multinomial logit form:

$$P_{nit}(\beta_{nit}) = \frac{e^{\beta_{nit} x_{nit}}}{\sum_i e^{\beta_{nit} x_{nit}}}$$

The unconditional probability can be written as:

$$P_{nit} = \int P_{nit}(\beta_{nit}) f(\beta_{nit} \mid \theta) d\beta_{nit} \qquad (3)$$

Where, θ are the parameters that describe the density of β , log-likelihood functions will be developed to estimate the parameters of equation (3).

Finally, the developed advisory response model will be included in the simulation evaluation framework to evaluate the freeway merge assistance system considering driver response variability to customized advisories.

X. Conclusion

This paper provided an overview of the field test methodology of a prototype Freeway Merge Assistance system design for the Connected Vehicle environment. The goal of this test is to investigate drivers' response to advisories provided by the merge assistance system. A detailed discussion of the experimental design and field test procedure is presented. In addition, preliminary compliance result gathered so far from the field test is also presented. A unified mixed Logit framework is proposed for the advisory response model development and estimation to combine the revealed preference data and stated preference data. The developed model will be integrated in the simulation evaluation framework to incorporate driver response variability in the Freeway Merge Assistance system.

Acknowledgment

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References

[1] J. L. Evans, L. Elefteriadou, and N. Gautam, "Probability of breakdown at freeway merges using Markov chains," *Transp. Res. Part B Methodol.*, vol. 35, no. 3, pp. 237–254, Mar. 2001.

[2] "Ramp Management and Control Handbook | Chapter 5 Ramp Management Strategies - FHWA Operations." [Online]. Available: http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/5_1.htm. [Accessed: 31-Mar-201.

[3] University of Virginia Center for Transportation Studies, "Freeway Merge Assistance." [Online]. Available: http://www.fhwa.dot.gov/publications/publicroads/13novdec2013/01.cfm. [Accessed: 31-Jan-2014].

[4] H. Park, C. S. Bhamidipati, and B. Smith, "Development and Evaluation of an Enhanced IntelliDriveSM Enabled Lane Changing Advisory Algorithm to Address Freeway Merge Conflict," in *Proceeding of 90th Transportation Research Board Annual Meeting*.

[5] H. Park, A. Miloslavov, J. Lee, M. Veeraraghavan, B. Park, and B. L. Smith, "Integrated Traffic / Communications Simulation Evaluation Environment for IntelliDrive SM Applications Using SAE J2735 Dedicated Short Range Communications Message Sets," *Transp. Res. Rec. J. Transp. Res. Board*, no. November 2010, pp. 1–19, 2011.

[6] K. I. Ahmed, M. Ben-Akiva, H. N. Koutsopoulos, and R. G. Mishalani, "Models of freeway lane changing and gap acceptance behavior," in *Proceedings of the 13th international symposium on the theory of traffic flow and transportation*, 1996, pp. 501–515.

[7] F. Ye and Y. Zhang, "Vehicle Type-Specific Headway Analysis Using Freeway Traffic Data," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2124, no. -1, pp. 222–230, Dec. 2009.

[8] A. Lobo, M. Jacques, C. Rodrigues, and A. Couto, "Free-Gap Evaluation for Two-Lane Rural Highways," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2223, no. -1, pp. 9–17, Dec. 2011.

[9] C. Yang, S. Mattingly, J. Williams, and H. Kim, "Development of Managed-Lane Access Guidelines Based on Gap Acceptance Theory," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2257, no. -1, pp. 95–102, Dec. 2011.

[10] J. E. Bartlett, J. W. Kotrlik, and C. C. Higgins, "Organizational Research : Determining Appropriate Sample Size in Survey Research," vol. 19, no. 1, pp. 43–50, 2001.

[11] R. V Krejcie and D. W. Morgan, "Determining Sample Size for Research Activities," *Educ. Psychol. Meas.*, vol. 38, pp. 607–610, 1970.

[12] H. N. Koutsopoulos, A. Polydoropoulou, and M. Ben-Akiva, "Travel simulators for data collection on driver behavior in the presence of information," *Transp. Res. Part C Emerg. Technol.*, vol. 3, no. 3, pp. 143–159, Jun. 1995.

[13] M. a. Abdel-Aty, R. Kitamura, and P. P. Jovanis, "Using stated preference data for studying the effect of advanced traffic information on drivers' route choice," *Transp. Res. Part C Emerg. Technol.*, vol. 5, no. 1, pp. 39–50, Feb. 1997.

[14] D. Revelt and K. Train, "Mixed Logit with Repeated Choices: Households' Choices of Appliance Efficiency Level," *Rev. Econ. Stat. 80.4*, pp. :647–657, 1998.

[15] B. Han, S. Algers, and L. Engelson, "Accommodating Drivers ' Taste Variation and Repeated Choice Correlation in Route Choice Modeling by Using the Mixed Logit Model," *80th Annu. Meet. Transp. Res. Board*, 2001.

[16] C. R. Bhat and S. Castelar, "A unified mixed logit framework for modeling revealed and stated preferences: formulation and application to congestion pricing analysis in the San Francisco Bay area," *Transp. Res. Part B Methodol.*, vol. 36, no. 7, pp. 593–616, Aug. 2002.

[17] D. a. Hensher, "Empirical approaches to combining revealed and stated preference data: Some recent developments with reference to urban mode choice," *Res. Transp. Econ.*, vol. 23, no. 1, pp. 23–29, Jan. 2008.

INVESTIGATING DRIVERS' REPONSE TO MERGE MANAGEMENT ADVISORY MESSAGES IN A CONNECTED VEHICLE ENVIRONMENT

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ABSTRACT

With the emerging Connected Vehicles technologies that enable the transmission of high resolution vehicular data and advisory messages through wireless communications between vehicles and infrastructure, more opportunities to develop proactive approaches to address freeway merge conflict are becoming available. The Freeway Merge Assistance System takes advantages of this opportunity by providing personalized advisories to individual drivers to request small modifications to their vehicular control in order to support smoother system-level merging. One thing to note here is that the benefits anticipated from these strategies will completely depend on the advisory compliance of the drivers, which may be influenced by a variety of factors such as traffic conditions and the types of advisories provided.

The purpose of this research is to investigate actual drivers' responses to this new generation of personalized in-vehicle advisory messages provided by the freeway merge assistance system. For this, a field test was conducted with naïve human subjects to collect driver behavior data to different types of advisory messages under different traffic scenarios in a controlled environment. The data gathered from the field test indicates that a compliance rate is higher when a large or medium size gap is available for a lane change while the lowest compliance rate was observed for a small gap size scenario. In addition, it was found out that more drivers follow a direct advisory message that directly advises a lane change, rather than an indirect message which indirectly stimulates a lane change through speed control.

Keywords: Connected Vehicle, Freeway Merge, Advisory Response, Field-test, Revealed Preference

INTRODUCTION

Freeway traffic congestion is a significant problem within the transportation system. Congestion is one of the major factors of national economic loss in terms of delays and fuel costs. Among the many causes, merging conflicts[1] contribute heavily to freeway congestion by creating bottlenecks within freeway ramp areas [2]. Various strategies such as ramp metering, variable speed limit, are somewhat limited in improving freeway merging operation because of the limited capabilities of current traffic monitoring system [3].

However, to address the limitations of current strategies advanced capabilities of Connected Vehicle (CV) initiative such as V2V and V2I wireless communication and high-resolution individual vehicular data (speed, location, acceleration, vehicle type, vehicle length, etc.) can be used to develop and deploy more advanced and proactive traffic management approaches. Another unique advantage of the CV technology is the ability to send customized advisories to targeted vehicles to take appropriate actions to improve individual safety and mobility.

With the aim of improving the efficiency and safety of freeway merging operation, the UVA Center for Transportation Studies has developed the Freeway Merge Assistance System (FMAS) for the Connected Vehicle Environment. Four algorithms developed under this system are: variable speed limit, lane changing advisory, gap responsive metering and merging control algorithm [4]. The overall goal of this system is to either identify existing gaps in the freeway mainline lane or to create gaps in the merging lane for the on-ramp vehicles. Initial simulation evaluation showed that the algorithms can significantly improve merging operation and the overall network performance.

All the above mentioned four algorithms provide personalized advisories to both freeway mainline and merging vehicle drivers. The advisories are provided to the drivers to take the necessary courses of action to create gaps, change lanes or control the speed of their vehicles. The benefits anticipated from the merge management system in reducing merging conflicts and bottlenecks in merge areas entirely depend on the advisory compliance of drivers. It was assumed during the development and evaluation phase that all drivers comply with all the relayed personalized advisories. However, in real-world scenarios 100% driver compliance may not be possible due to various reasons. Advisory compliance will depend on individual advisory type, driver characteristics and dynamic traffic conditions. And variability in driver compliance can significantly affect the outcomes of these mobility applications. As the anticipated benefits from all these control strategies depend on drivers taking actions based on the advisory messages, there is a need to investigate drivers' responses to these advisories and the consequent impact on the performance of these strategies.

Previous studies on driver behavior or driver response to dynamic information have mainly focused on the impacts of pre-trip or en-route information on driver route choice and the consequent aggregated impact of those choices on the study network. The tools of disseminating this information are mainly through Variable Message Signs (VMS), Advanced Traveler Information Systems (ATIS) or radio [5], [6], [7]. Recent studies have investigated how drivers react to alerts provided by in-vehicle collision warning system, driver distraction warning, and lane departure warning, which falls under the category of safety system [8], [9], [10]. However, with the introduction of Connected Vehicle technology equipped-vehicles, there will also be a market for various CV-enabled mobility applications for individual drivers.

However, the primary objective of an in-vehicle CV safety system is to prevent accidents, reduce the severity of a collision, and/or alert drivers of an imminent danger. On the other hand, the aim of a CV mobility application is to ensure better and efficient driving conditions by assisting drivers with dynamic advisory information. Therefore, the advisory or alerts provided by a safety system has far greater utility to a driver, since it manifests an immediate and immense benefit[11]. On the other hand, mobility application advisories are more assistive in nature and do not require as much mandatory attention from the driver as alerts from safety system do. The factors that influence drivers' response to safety advisory may be different from the factors that influence compliance to mobility advisory.

The benefits of improving system efficiency and individual mobility by a CV mobility application like the Freeway Merge Assistance system greatly depend on the aggregated compliance of the drivers. Hence, prior to field deployment, it is necessary to investigate how individual drivers react to these advisories and how their responses will affect the performance of these applications in a CV environment. This research takes the initiative to investigate and analyze driver behavior from the perspective of real-time advisory compliance. For comprehensive evaluation of a strategy, both the simulation approach and a field study can be adopted. Field tests involving naïve test subjects are one of the preferred approaches to collect behavioral data, since it provides a more accurate representation of the real road driving environment, and the data gathered is more reliable than data from driving simulators [12].

Therefore, the major objectives of this research work were: 1) to design a field test to investigate driver compliance behavior in a Connected Vehicle Test bed and 2) to understand how drivers react to the advisories under different traffic conditions. For those purpose, a field test was conducted to collect driver compliance data in a Connected Vehicle test bed, where multiple traffic scenarios was created to test participants under the different strategies. This will eventually help further investigate how actual driver compliance affects the benefits anticipated from the merge management system in a Connected Vehicle environment.

Following section of this paper presents detailed discussion of the experimental design, description of the field test. Finally, the paper concludes with the results and analysis of the data collected from the field test.

EXPERIMENTAL DESIGN

There is a gap in current knowledge about drivers' response behavior to these different control strategy advisories within a CV-enabled environment and we could not find any study that has focused specifically on this issue. Therefore, it is necessary to conduct a comprehensive evaluation of these strategies to addresses these problems. The field-test in this study was conducted in the Smart Road facility located in Blacksburg, Virginia. This facility has a 2-lane road instrumented with DSRC-based Road-Side Equipment (RSE) and a small fleet of vehicles equipped with DSRC-based on-board equipment (OBE). However, limitation of resources did not allow a full-fledged experiment replicating real-world traffic scenarios. With these limitations, a simplified architecture was developed to conduct the field-test, which involved OBEs, in-vehicle on-board display and a test application. The test application was developed to allow the experimenter to randomly select test scenario and send advisory to the participant vehicle.

For all the algorithms under the merge management system, gap size is the main factor behind lane change decision making process. An extensive literature review has also indicated lane change and merging operation depends on the available gap size along with other variables such as relative speed of lead and lag vehicle, and the remaining distance of merge area [13]. Since it was not feasible to consider all the factors for scenario development due to complexity and limited resources, only gap size was considered for scenario development. The algorithms that were evaluated in the field-test were: (i) Variable Speed Limit (ii) Lane Changing Advisory and (iii) Merging Control Algorithm.

For the scenario development, the mean time headway for high, medium and low traffic conditions found by Ye and Zhang[14] were adopted to define the small, medium, and large gap size respectively and were converted to space headway. For vehicles traveling at 30 mph the different proposed gap sizes in terms of time-headway and space-headway are as presented in Table 1(a). Based on the three levels of gap size and three application types, a set of nine testing scenarios were developed (Table-1b).

TABLE 1(a): Time and Space Headway for different gap size

Gap Type	Time-Headway (sec)	Space-Headway (ft.)
Small Gap	2.00	88
Medium Gap	3.00	132
Large Gap	4.00	176

TABLE 1(b) Scenario Overview

Gap Sizes	Advisory Types		
	Variable Speed Limit	Lane Changing Advisory	Merging Control
Large Gap (176ft)	Scenario #1	Scenario #4	Scenario #7
Medium Gap (132ft)	Scenario #2	Scenario #5	Scenario #8
Small Gap (88ft)	Scenario #3	Scenario #6	Scenario #9

Sampling of Test Participants

The sample population was selected represent the overall demographics of licensed US. driver population so that with a reasonable level of confidence the response nature of entire driver population can be concluded. As we did not have any direct control in variance estimation and there was no prior information about drivers' response to these new type of advisories; a conservative assumption of 50% about the compliance proportion was made, as suggested by Krejcie and Morgan[15] . The sample size was estimated to be 68 with a confidence interval of 90% and margin of error 10% [16].

Participants were recruited through advertisement on classified websites like Craigslist and local newspaper from Blacksburg and surrounding area in Virginia. Final sample population constituted participants from all age groups with 36 male and 32 female participants. Eligible participants were scheduled for the field test at a specific time on the Smart Road facility. Upon arriving at the facility, the participants went through necessary paperwork and training before the field test. In the training phase, each participant was oriented with the test vehicle, on-board display and a detailed instruction was given about their responsibility and course of actions during the field test.

FIELD TESTING

Lane Configuration

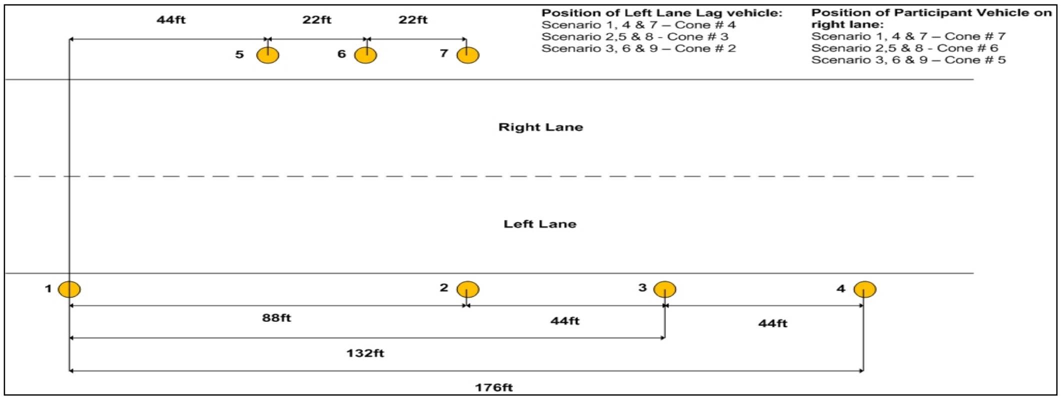
The current geometric configuration of the Smart Road does not allow replicating a freeway merge area with an on-ramp section and merging lane. As a result, the existing lane-configuration was modified to conduct the field test with merge assistance strategies. Before the beginning of each scenario the three test vehicles were positioned on numbered spot designated specifically for each of them [Figure 1(a)]. Left lane vehicles were driven by confederate drivers and participants drove the right lane vehicle with the experimenter in the front passenger seat. For all scenarios, the left lane lead vehicle was placed on the position with location marker #1. The lag vehicle on the left lane was placed on three different positions depending on the scenario to be tested. For large, medium and small gap scenarios the lag vehicle was placed on position with location marker #4, #3 & #2 respectively. On the right lane, the participant vehicle was placed with location marker #5, #6 & #7 for small, medium and large gap size scenarios respectively.

Smart Road Segmentation

Based on the lane configuration of the Smart Road, one lane served as a right lane and another lane as a left lane of a freeway segment. In addition, it was identified that there would be four specific activities during a scenario run. Based on the general sequential driving activities, figure 1(b) illustrates the activity based test track segmentation of the 2000ft section:

1. Reaching target speed - Speed Gain Zone (Activity-1)
2. Driving at uniform speed - Uniform Speed Zone (Activity-2)
3. Sending/receiving/reacting to advisory - Control Interval Zone (Activity-3)
4. Reducing speed - Speed Reduction Zone (Activity-4)

The speed gain zone provided necessary length to attain the test speed of 30mph with a moderate acceleration from the starting position. To allow vehicles to travel at uniform speed and get confirmation about their location, the uniform speed zone was utilized. The control interval zone was used to send the advisory and record the participant’s response within this zone. The last section, speed reduction zone, was used for vehicles to safely reduce speed and get prepared to stop.



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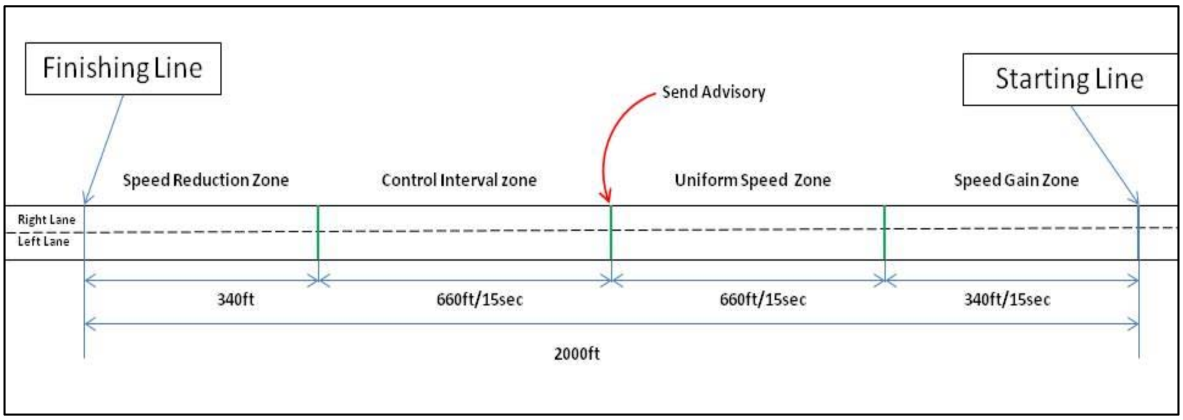


(b)

FIGURE 1 Smart Road Configuration: (a) Lane Configuration, (b) Activity based test track segmentation

Scenario Descriptions

To conduct the field test, a detailed field test procedure, test protocol and test script was developed by the research team. The order of the scenarios was randomized to eliminate any bias in the data gathered and minimize the learning effects of the participants. Each of the participants took part in all the nine test scenarios.

Following were the typical procedural steps followed for each scenario run:

- Before the beginning of a particular test scenario, all the three research vehicles were positioned at designated locations for that specific scenario.
- Experimenter on the participant vehicle sent instruction over the radio to all drivers to start driving at the same time and reach the speed of 30 mph.
- Participant driver was instructed to maintain the speed of 30mph and keep driving on the right lane, until any advisory was displayed in the on-board display.
- After all the vehicles drove at the advised speed, the experimenter used the test application to send an advisory to the on-board display.
- Upon receiving the advisory, the participant either complied with the advisory or kept driving on right lane, if they did not feel comfortable following the advisory.

- The participant driver's reaction to the advisory was recorded by the experimenter.
- At the end of the designated test section, all drivers are instructed to slow down and further instruction is sent for the next scenario.

Following are the brief descriptions of each strategy in the field:

Variable Speed Limit

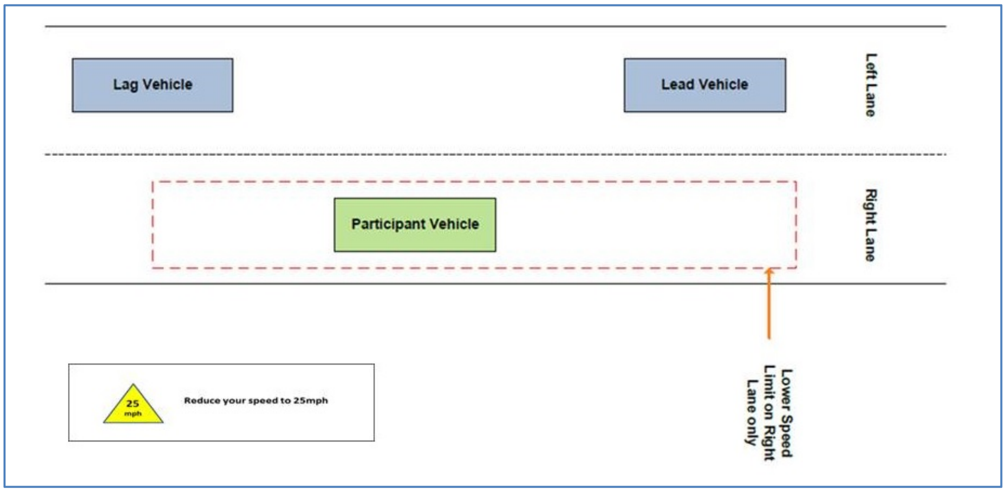
In the VSL scenarios, when all the drivers on both lanes reached the uniform speed of 30 mph, the lower speed limit advisory of 25mph was sent by the experimenter. The goal of this strategy is to motivate drivers to move to the faster left lane and create gaps for merging vehicle. During the training phase the participants were instructed to not decrease speed in responding to the advisory rather they should try to change lane and take gaps between the two vehicles on left lane. In case, drivers did not feel comfortable moving to the left lane, they were instructed to keep driving on the right lane. Figure 2(a) illustrates a schematic diagram of this strategy with the VSL advisory shown in the inset on the left bottom corner.

Lane Changing Algorithm

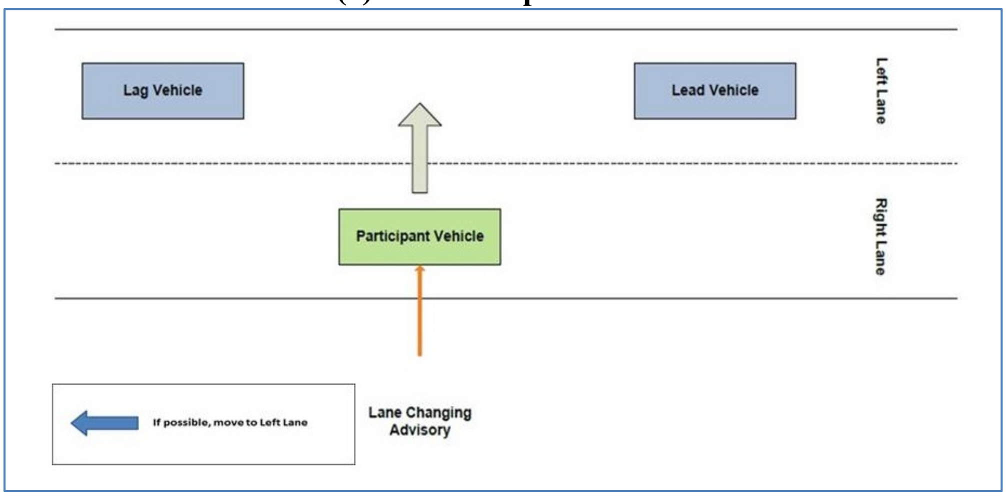
For the LCA scenarios, the participant drivers were simply sent a lane change advisory, after all the vehicles reached the speed of 30mph. During the training, the participant drivers were instructed to change lane and take the available gap on the left lane between the two vehicles, only when they feel comfortable to do so. The gap between the two left lane vehicles was changed from scenario to scenario. Figure 2(b) presents a schematic diagram for this strategy with the LCA advisory shown in the inset on the left bottom corner.

Merging Control Algorithm

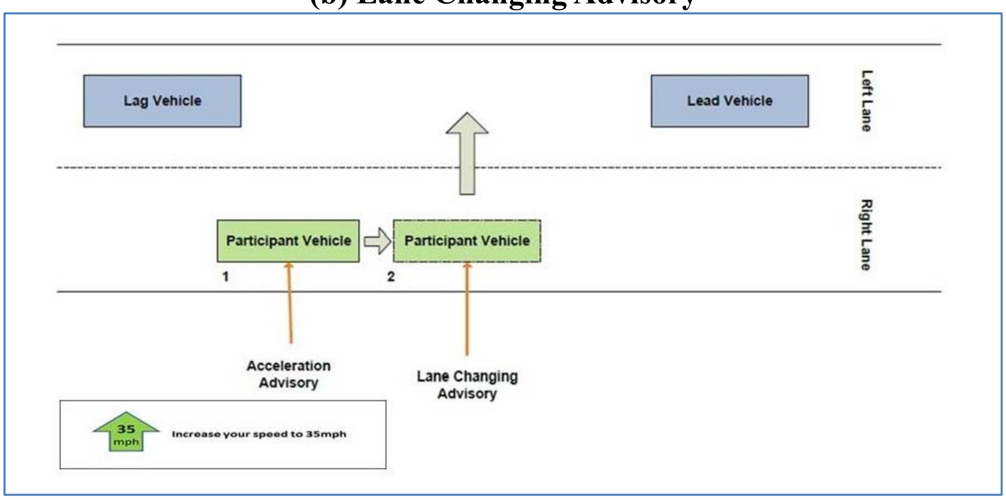
In the MCA scenarios, the participants received two sequential advisories. The goal of this strategy to help drivers smoothly merge, when adequate gap is not available, by first advising speed changes and then sending lane changing advisory. For example, as shown in figure 2(c), the participant vehicle (green vehicle) on right lane at position 1 does not have enough lag-gap to change lane. In this situation, the merging control algorithm sends acceleration advisory [inset figure 2(c)] to the participant driver. After the participant driver moves to position 2 by accelerating and have adequate gap to change lane, MCA sends the lane changing advisory. If the driver feels comfortable, he/she complies and takes the gap on the left lane between the two vehicles.



(a) Variable Speed Limit



(b) Lane Changing Advisory



(c) Merge Control

FIGURE 2 Scenario Descriptions

RESULTS AND ANALYSIS

The following section discusses the results from the data gathered in the Smart Road from the 68 participants. All of the 68 participants participated in all the nine scenarios. Collected data were analyzed for each advisory type to understand how different gap sizes, strategies influenced drivers' compliance.

1) Variable Speed Limit: For the VSL scenarios, the compliance rates are similar for the scenarios with large gap sizes (72%) and mid-size gaps (72%). Compliance rate for small gap size scenarios is the lowest with more than 55% of the time drivers opted not to follow the advisory (Figure 3). This difference of compliance rates between small gap scenarios and both large and mid-gap size scenarios is statistically significant [χ^2 (1, N=68) = 9.78, $p < 0.10$]. This supports the assumption that drivers are willing to change lane when gaps are comparatively larger and more skeptical about changing lanes where headways between vehicles are small. Earlier simulation evaluation of the VSL strategy indicated that this strategy has potential to improve overall average network performance in condition of high volume and high density traffic on both left and right mainline lanes. Though the compliance rate for small gap scenarios are smallest, 45% compliance rate indicates that in some cases driver will be influenced by lower speed limit to move to left lane thus creating gap for merging vehicle.

2) Lane Changing Advisory: For the LCA strategy, all the participants except one accepted the gaps for scenarios with the largest gap with a compliance rate of 97%. For scenarios with mid-size gap the compliance rate is more than 90 % with only six participants out of 68 did not comply with LCA advisory (figure 3). About 36% of the drivers (25 drivers) did not feel comfortable complying with the lane changing advisory in the scenarios with the smallest gap, which is statistically different[χ^2(1, N=68) = 13.53, $p < 0.10$] with the compliance rate of medium gap scenarios. The gap acceptance behavior for LCA scenarios is similar to that observed for VSL scenarios and supports the notion of drivers' preference of larger and medium gap sizes. In simulation evaluation, the LCA strategy provided biggest network-wide benefits for biggest gap followed by medium gap and the smallest gap strategy resulted in marginal benefits. In addition, sensitivity analysis of compliance rate in simulation indicated that at least 90% compliance rate is desirable to achieve significant benefits from this strategy. Higher compliance rates for large and medium gap scenarios in the field test, support the simulation result that the LCA strategy will provide biggest benefit in low and medium traffic conditions.

3) Merging Control Algorithm: For the MCA scenarios, compliance result indicates that participants were most comfortable in following the advisories for both large gap and mid-size gap scenarios, with non-compliance rate of about 5% in both cases. However, more than 35% of the participant drivers did not comply under small gap scenarios (Figure 3), which is significantly different from the response behavior under large [χ^2(1, N=68) = 16.23, $p < 0.10$] and medium [χ^2(1, N=68) = 18.48, $p < 0.10$] gap scenarios. Though the MCA strategy is a combination of two advisories, drivers did not show greater level of difficulty of complying with the advisories. Simulation evaluation of the MCA strategy showed that significant benefits in terms of network performance can be achieved both at mainline lanes and merging lanes with high compliance rate of 70% or higher. Compliance results from the field test indicates that the biggest benefits from the MCA strategy may be achieved under low and medium traffic conditions than under heavy traffic condition. However, a 65% compliance rate under small gap scenarios in the field test indicates that even in highly congested situation drivers are willing to follow speed change advisory to create gaps and then follow lane changing advisory when adequate gaps are available.

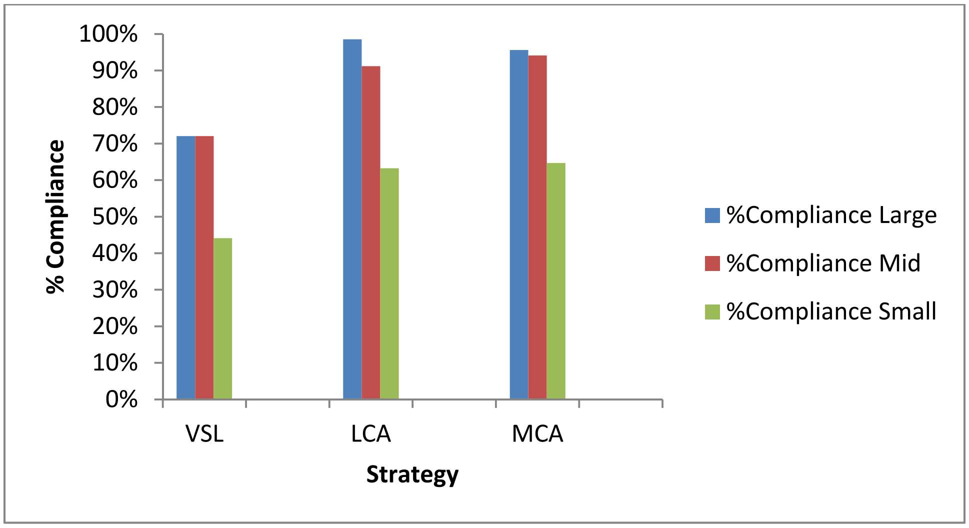
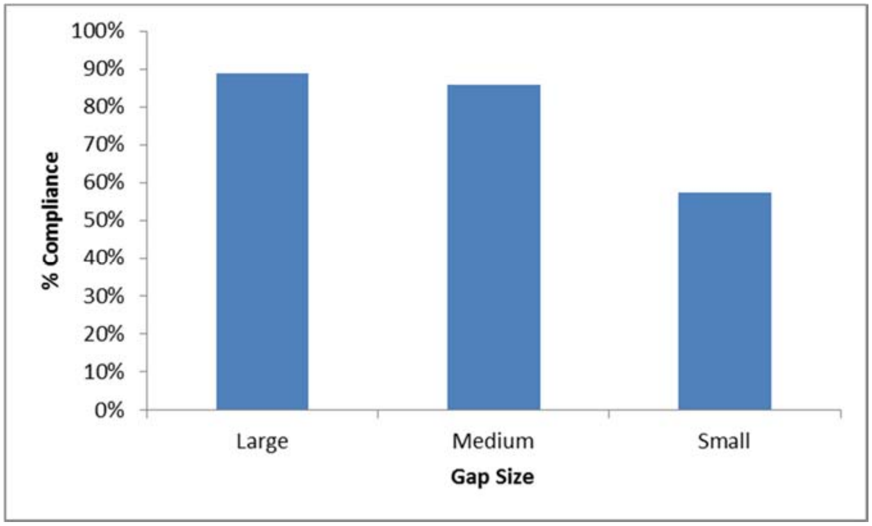


FIGURE 3: Compliance under VSL, LCA and MCA

4) Compliance across gap sizes: Compliance rates across the scenarios for the three different gaps sizes are similar for both large and medium gap size scenarios. For large gap scenarios, the compliance rate is highest (88%) followed by compliance rate mid-gap size scenarios (85%). And there are no significant [χ^2 (1, N=204) = 0.551, $p > 0.10$] difference between compliance rates for large gap and medium gap scenarios. On the other hand, about 42% of the drivers did not complied with advisory under small gap scenarios; which has significant difference with the compliance rates of large gap [χ^2(1, N=204) = 49.4, $p < 0.10$] and medium gap [χ^2(1, N=204) = 39.13, $p < 0.10$] [Figure 4(a)]. This suggests that drivers will be most comfortable following the advisories in both low and medium traffic congestions. As traffic condition worsens, drivers will be relying more on individual perception, judgment and decision making process rather depending on driver assistive systems. However, compliance under small gap scenario also suggests that some drivers will trust FMAS and will comply with the advisories by taking the advised course of actions. This indicates that this system has the potential to improve merging operation even in high volume traffic condition where the gaps are small and possibility of vehicular conflict is very high.

5) Compliance across strategies: For compliance across the strategies irrespective of the gap sizes, both LCA (84.3%) and MCA (84.8%) has almost similar compliance rate, with no significant difference. However, VSL has the highest non-compliance rate of 37%, significantly different from the non-compliance rate for LCA [χ^2 (1, N=204) = 23.28, $p < 0.10$] and MCA [χ^2 (1, N=204) = 24.52, $p < 0.10$] [Figure 4(b)]. The higher non-compliance rate for VSL strategy can be attributed to misunderstanding the objective of this advisory. The goal of this advisory is to implement a lower speed limit on the right lane and encourage drivers to make earlier discretionary lane changes i.e. to move to the left lane with higher speed limit; however some participants interpreted the advisory simply as reduced speed limit advisory, even though they were given specific instructions in the pre-field test training session, about what would be the expected choice for this advisory. This suggests that it is necessary investigate in a deeper level how drivers understand and then react to a particular type of advisory, and how advisories can be linguistically designed and delivered so that the desired outcomes can be achieved. This also indicates the necessity of driver education and training about advancement in transportation technologies.



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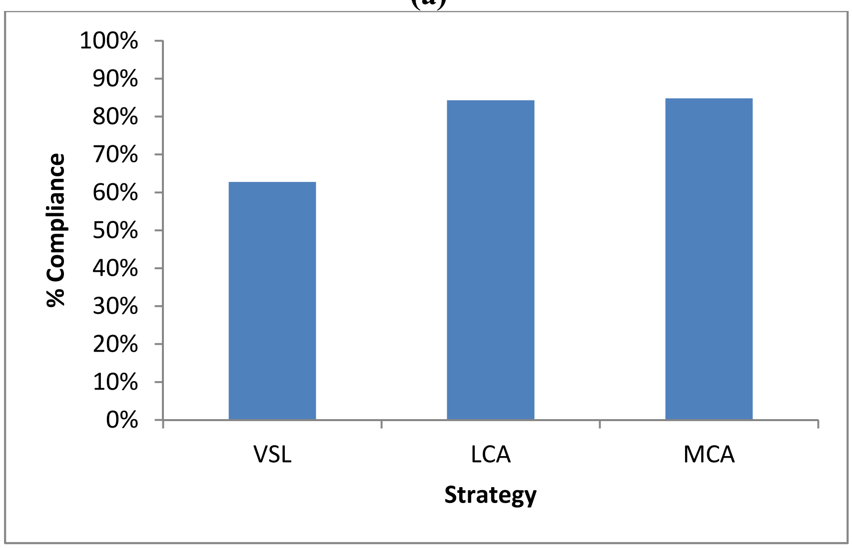


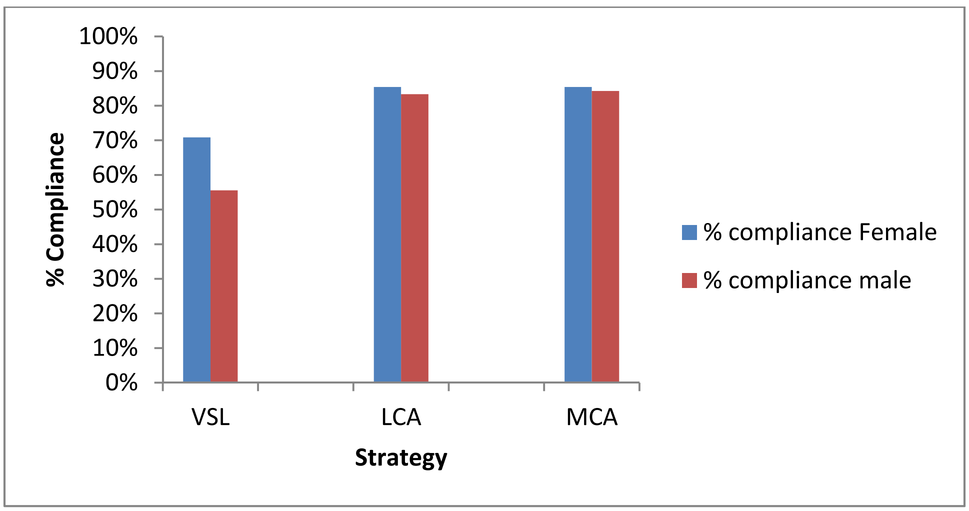
(b)

FIGURE 4: (a) Compliance across gap sizes, (b) Compliance across strategies

6) Compliance for different gender groups:

a) Compliance across strategies: For compliance across strategies for different gender groups, similar compliance rate is observable for both LCA and MCA strategies with no significant difference between female and male participants [Figure 5(a)]. For LCA scenarios female participants had a compliance rate of 85% and male participants had a compliance rate of about 83%, with no significant[$\chi^2(1, N{=}108{,}96) = 0.0465$, $p > 0.10$] difference in compliance. For MCA scenarios, there was no significant [χ^2 (1, N=108, 96) = 0.0012, $p > 0.10$] difference in compliance rate, with male participants complied 84% and for female participant complied 85%. However, for the VSL strategies female participants show a higher compliance rate of 70% compared to 55% compliance rate from male participants, with significant difference [$\chi^2(1, N{=}96{,}108) = 3.4036$, $p < 0.10$].

b) Compliance across gaps sizes: For compliance across the three gap sizes for different gender, similar compliance rate is observable for large gap size for both female and male participants with compliance rate of about 89% and 87 % respectively, with no significant difference [χ^2(1, N=96,108) = 0.0206, $p > 0.10$]. For medium gap size scenarios, there is significant [χ^2 (1, N=96,108) = 2.7749, $p < 0.10$] difference in compliance rate, with female participants exhibiting higher compliance rate of 90% followed by male compliance rate of 81% [Figure 5(b)]. Comparing with large and medium gap size scenario, small gap size scenarios have lower compliance rate with 61% for female participants followed by 53% for male participants, however this difference not significant [χ^2(1, N=96,108) = .9526, $p > 0.10$]. It is obvious from the data that for all the three gap sizes female participants has the lowest non-compliance rate. If compliance rate is aggregately considered irrespective of gap sizes, the difference in compliance rate between female (80.5%) and male (74.3%) participants is statistically significant[χ^2(1, N=288,324) = 2.9673, $p < 0.10$].



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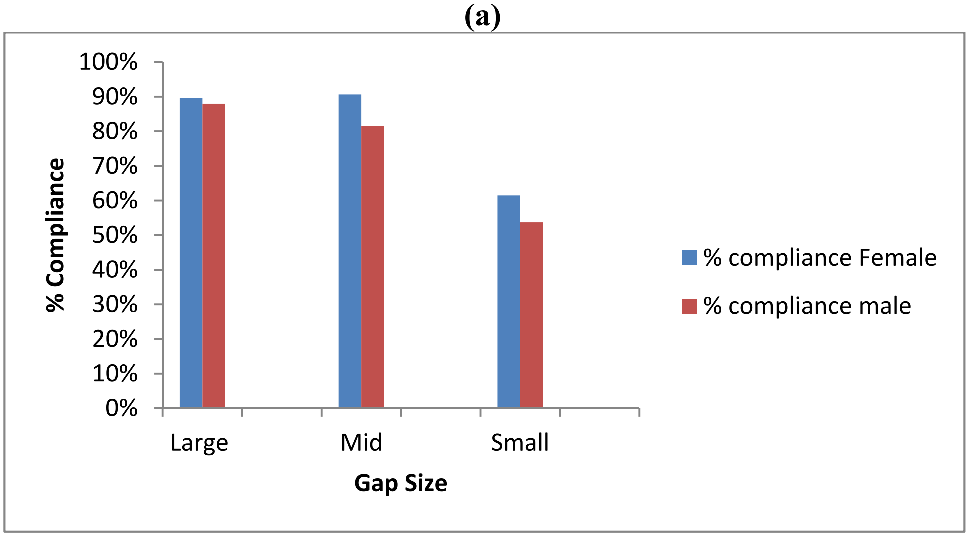

(b)

FIGURE 5: Compliance for different genders: (a) across strategies, (b) across gap sizes

Discussion

Gap Size preferences/Compliance under different traffic conditions: Based on the data gathered from the field test, it is evident that highest compliance rates are achieved for large and medium gap size scenarios with no significant difference in compliance rates between these two gap sizes. This indicates that during high and medium traffic conditions when headways between vehicles are relatively large enough so that drivers can comfortably change lane, drivers will be willing to follow the advisories more than that at traffic conditions when gaps between vehicles are comparatively smaller. Though small gap scenarios have resulted in the lowest compliance rates, it implies that some drivers were comfortable changing lanes in conditions when available gaps were relatively smaller. The gap acceptance behavior demonstrated by the participants in the field test is similar to what is usually observed in real-world traffic conditions. From the perspective of deployment of Merge Management strategies, the observed compliance behavior indicates highest benefits will be achieved during low and medium traffic flow conditions, as drivers are most likely to follow the advisories during these conditions. And even in highly congested situation, when available gaps are small and there is limited freedom to change lane, some participant drivers will comply with the advisories and will take the advised actions.

Effectiveness of strategies: From the field-test data, we can see that highest compliance rates were achieved for both LCA and MCA strategy. By design, the Lane Changing advisory provides very simple and straightforward instruction for the drivers to understand and act accordingly. This strategy can be easily deployed as one of the first Merge Management strategies with minimum resources towards driver education and training. Similar conclusions can be made about the MCA's effectiveness in improving merging operation. The merging control advisories simply guide the driver to smoothly merge by appropriate speed changes and changing lanes. Participant drivers demonstrated same compliance rate for the MCA as they did for the LCA, even though the former is a two-advisory strategy. However, in the case of VSL, we observe significantly low compliance rate comparing with the compliance rates for LCA and MCA. This low compliance rate is due to the fact that the VSL advisory provides a lower speed limit advisory but the goal is to motivate drivers to move to the left lane to create gaps for the merging vehicle. Another approach to deliver this message may to advise drivers about alternate choice(s) in responding to this message. In the case of VSL advisory, the advisory can be delivered as *"Reduce your speed to 25 mph or Move to faster left lane"*. Therefore, an important lesson from this study is that it is important to design advisory messages in a way that drivers can readily understand and the desired outcomes are easily achieved.

This study provides not only provides deep insight to drivers' response behavior to merge advisories, it also provides necessary data for further evaluation of the FMAS. The compliance rate for each of the strategy can be used to evaluate the benefits in the simulation framework and enhance the algorithms to optimize their performance in improving freeway merge operations. In the field test, as scenarios with small gap size resulted in lowest compliance rate, it can also be evaluated in simulation how frequently advisories can be sent so that meaningful benefits can be achieved during highly congested congestion.

CONCLUSIONS

With the Connected Vehicles technology, more sophisticated and advanced traffic management strategies can be developed and deployed to address limitations of current approaches. The Freeway Merge Assistance System is one of the example strategies that take advantages of this technology in improving freeway merging operations. It should be however noted that, in developing and evaluating any mobility applications, proper understanding of drivers' behavior is a must to ensure the applicability and efficiency of the mobility applications in the real world.

In this paper, we investigate how drivers actually react to the advisories sent by the Freeway Merge Assistance System by conducting a field test of different gap size scenarios with naïve participants. Based on the data gathered from the field test, it is evident that drivers feel more comfortable following the advisories when large and medium gaps are available, which represent low and medium traffic conditions respectively. Though the small gap size scenarios resulted in the lowest compliance rates, this is still meaningful in that "some" drivers are still willing to follow the advisory even in a high volume traffic condition. Another significant finding from the field testing was that drivers tend to better comply with a direct advisory message, which directly advises the drivers to make a lane change. On the other hand, an indirect advisory message, which attempts to indirectly stimulate a lane change through speed control, turned out to be less effective.

In conclusion, the actual drivers' response data collected and presented in this paper is one of the first sets of data that allows for better understanding of the realistic driver compliance rate. Given the significance of proper understanding of drivers' behavior in developing, evaluating, and deploying connected vehicle mobility applications, continuous effort should be made to gather actual drivers' behavior data which provides valuable insight in drivers' decision making process.

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REFERENCES

[1] H. Yi and T. E. Mulinazzi, "Urban Freeway On-Ramps: Invasive Influences on Main-Line Operations," *Transp. Res. Rec.*, vol. 2023, no. -1, pp. 112–119, Dec. 2007.
[2] J. L. Evans, L. Elefteriadou, and N. Gautam, "Probability of breakdown at freeway merges using Markov chains," *Transp. Res. Part B Methodol.*, vol. 35, no. 3, pp. 237–254, Mar. 2001.
[3] H. Park, C. S. Bhamidipati, and B. Smith, "Development and Evaluation of an Enhanced IntelliDriveSM Enabled Lane Changing Advisory Algorithm to Address Freeway Merge Conflict," in *Proceeding of 90th Transportation Research Board Annual Meeting*.
[4] University of Virginia Center for Transportation Studies, "Freeway Merge Assistance." .
[5] M. a. Abdel-Aty, R. Kitamura, and P. P. Jovanis, "Using stated preference data for studying the effect of advanced traffic information on drivers' route choice," *Transp. Res. Part C*

Emerg. Technol., vol. 5, no. 1, pp. 39–50, Feb. 1997.

[6] S. Madanat and N. K. Jain, “Modeling Driver ’s Route Choice Behavior Under the Influence of Advanced Traveler Information,” 1997.

[7] S. Peeta and J. Ramos, “Driver response to variable message signs-based traffic information,” *IEE Proceedings-Intelligent Transp. Syst.*, vol. 153, no. 1, 2006.

[8] J. D. Lee, D. V McGehee, T. L. Brown, and M. L. Reyes, “Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator.,” *Hum. Factors*, vol. 44, no. 2, pp. 314–34, Jan. 2002.

[9] M. Rimini-doering, T. Altmueller, U. Ladstaetter, and M. Rossmeier, “Effects of lane departure warning on drowsy drivers’ performance and state in a simulator,” in *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design.*, 2005.

[10] E. E. Wiese and J. D. Lee, “Auditory alerts for in-vehicle information systems: the effects of temporal conflict and sound parameters on driver attitudes and performance.,” *Ergonomics*, vol. 47, no. 9, pp. 965–86, Jul. 2004.

[11] K. A. Harder, J. Bloomfield, and B. J. Chihak, “The Effectiveness of Auditory Side- and Forward - Collision Warnings in Winter Driving Conditions,” *No. 156. Draft Tech. Rep. Submitt. under Mn/DOT Agreem. No. 74708—Work Order.*, 2003.

[12] T. Sato, M. Akamatsu, T. Shibata, S. Matsumoto, N. Hatakeyama, and K. Hayama, “Predicting Driver Behavior Using Field Experiment Data and Driving Simulator Experiment Data: Assessing Impact of Elimination of Stop Regulation at Railway Crossings,” *Int. J. Veh. Technol.*, vol. 2013, pp. 1–9, 2013.

[13] K. I. Ahmed, M. Ben-Akiva, H. N. Koutsopoulos, and R. G. Mishalani, “Models of freeway lane changing and gap acceptance behavior,” in *Proceedings of the 13th international symposium on the theory of traffic flow and transportation*, 1996, pp. 501–515.

[14] F. Ye and Y. Zhang, “Vehicle Type-Specific Headway Analysis Using Freeway Traffic Data,” *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2124, no. -1, pp. 222–230, Dec. 2009.

[15] R. V Krejcie and D. W. Morgan, “Determining Sample Size for Research Activities,” *Educ. Psychol. Meas.*, vol. 38, pp. 607–610, 1970.

[16] J. E. Bartlett, J. W. Kotrlik, and C. C. Higgins, “Organizational Research : Determining Appropriate Sample Size in Survey Research,” vol. 19, no. 1, pp. 43–50, 2001.

INVESTIGATING DRIVERS' RESPONSE TIME TO FREEWAY MERGE MANAGEMENT ADVISORY MESSAGES IN A CONNECTED VEHICLE ENVIRONMENT

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ABSTRACT

Vehicular conflict is one of the major causes of congestion in freeway merge areas. With the emerging connected vehicle environment, more proactive strategies can be developed and implemented to improve merging operations to achieve enhanced safety and mobility. The freeway merge assistance system is a connected vehicle-enabled advanced prototype traffic management approach to ensure smoother merging by early identification and dynamic notification of merging opportunities through advisory messages. However, given that the effectiveness of this mobility application depends entirely on drivers' response to advisory messages, proper understanding of drivers' behavior responding to a new generation of dynamic advisory messages is a necessity.

In this paper, a detailed analysis of drivers' response time (consisting of perception reaction time and actual lane change time) to advisory messages from the freeway merge assistance system was conducted based on the actual data collected in a field test with 68 naive participants. The analysis results showed the following. Firstly, the perception reaction time increases as an available gap size decreases. An estimated 0.64 sec difference was observed between a large gap case (3.77 sec) and a small gap case (4.41 sec), implying that simply assuming a uniform perception reaction time regardless of various traffic conditions may lead to an unintended consequence. Secondly, the perception reaction time decreases as advisory becomes more direct and proactive. Pairwise comparison indicates a 1.30 second decrease in perception reaction time between the most direct (3.46 sec of merging control) and indirect (4.76 sec of variable speed limit) advisories. It is therefore recommended that an application that provides more direct advisory messages is desirable. Lastly, and interestingly, it was found that the actual lane changing time does not change much regardless of advisory types and available gap sizes. In conclusion, the implications of all these results are of significance and thus need to be considered in design and implementation of connected vehicle-enabled mobility applications.

INTRODUCTION

Vehicular conflict within ramp merging areas is one of the main causes of bottlenecks and congestion in freeways[1]. Although traditional approaches such as ramp metering have been used to overcome this issue, it has been only partially successful mainly due to their limited real-time traffic data collection and information dissemination capabilities [2].

Recent advancements in communications technologies have led to the development of a connected vehicle (CV) environment which enables vehicle-to-vehicle (V2V) as well as vehicle-to-infrastructure (V2I) communications. This real-time connectivity will allow the implementation of more proactive traffic management strategies designed to respond dynamically to diverse traffic situations [3], [4], [5]. One example of these new applications is a connected vehicle-enabled freeway merge assistance system that provides various advisory messages in an attempt to encourage early lane changes to secure a bigger gap within freeway merging areas [6].

While this new generation of connected vehicle-enabled mobility applications holds significant potential, it should be also noted that the effectiveness of these applications entirely depends on actual drivers' response behavior. Numerous studies have investigated drivers' responses to in-vehicle <u>safety</u> systems alerts/advisories [7], [8], [9]. However, the motivation and incentive to follow safety alerts/advisory may be different from that of <u>mobility</u> application alerts/advisories. Safety systems provide immediate and immense safety benefits whereas the goal of mobility applications is to assist drivers to improve their mobility and driving experience. Some CV-based field experimentation have already shown the potential of situational awareness alerts in reducing risk of crashes and in improving driving experiences [10]. In addition, from system design perspective it is also necessary to deliver the messages optimally for proper driver comprehension. A study conducted by Finnegan and Green [11] suggested that exit messages should be present at least 6.6 seconds before the exit lane. As drivers, each individual has their own preferences of driving speed, headway and acceptable gap size [12], [13]. These individual preferences will lead to variability in response times. In addition, different situational factors such as dynamic traffic conditions also dictate drivers' response times. As such, proper understanding of drivers' response behavior to CV-based mobility application is a must.

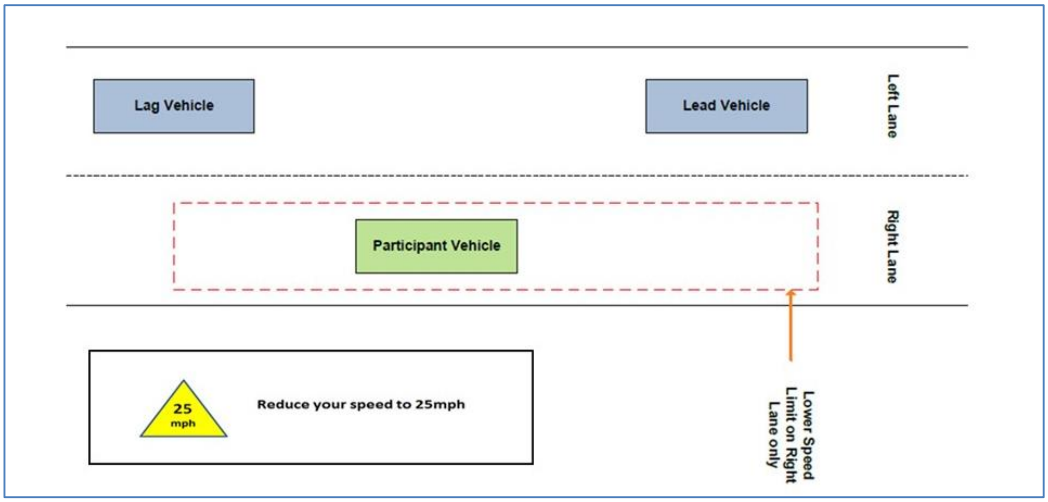
The goal of this research is to investigate the drivers' response times to a new generation of real-time advisory messages under diverse traffic conditions. To collect drivers' response time data, a field test was conducted with 68 naïve participants in a connected vehicle testbed in Blacksburg, VA. Video files from this field testing were analyzed to estimate actual response times. Followed by the introduction, a brief description of a freeway merge assistance system is provided. This paper will then present the experimental design of a field testing conducted to collect real-world data. Finally, the results from analysis of drivers' response times are presented.

FREEWAY MERGE ASSISTANCE SYSTEM

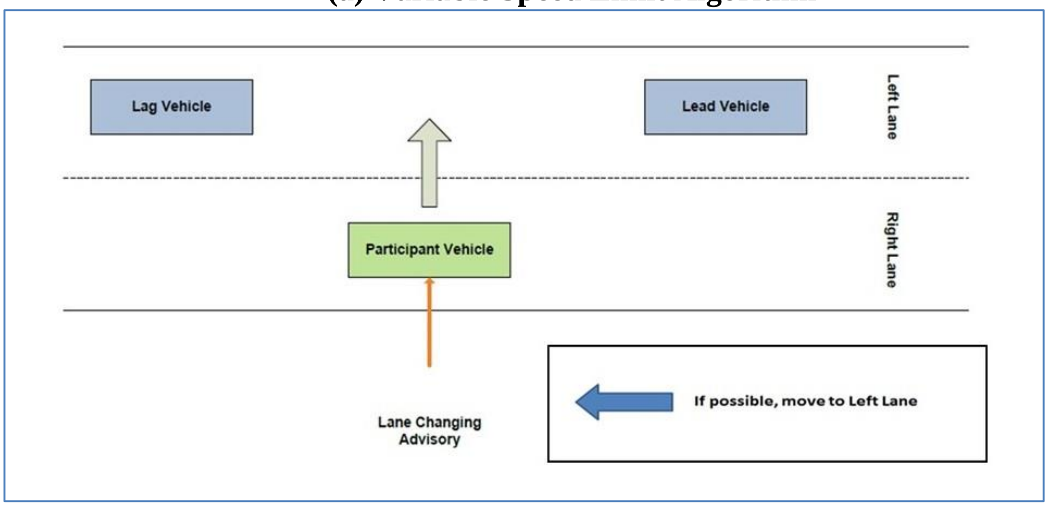
The freeway merge assistance system is a prototype driver assistance system designed to take advantage of the connected vehicle environment. This system utilizes V2V and V2I wireless communications, and provides dynamic advisory messages to reduce conflicts between vehicles in merging areas. Three distinct algorithms represent different strategies that utilize high resolution dynamic traffic data to identify gaps in mainline lanes for safe and smoother merging operation. A brief description of the algorithms is presented below:

- Variable Speed Limit (VSL): Based on the existing traffic density, this algorithm implements a lower speed limit on the rightmost lane of a freeway mainline to "indirectly" encourage drivers in that lane to move into the left lane for better merging situations within merging areas [14]. This algorithm is the least active one out of three as it does not directly advise driver to change lane. Rather in this strategy drivers are encouraged to move to left lane and thus creating gaps for the merging vehicle in the right lane. Figure 1 (a) illustrates the schematic representation of variable speed scenario and the inset shows the advisory used in the field test for this study. Participants were instructed before the field test to change lane after receiving the "Reduce your speed to 25 mph", only if they were comfortable with the available gap in the left lane.
- Lane Changing Advisory (LCA): Based on the estimated gap availability in the left lane, this algorithm sends a lane changing advisory to the target vehicle in the right mainline lane to stimulate an early lane change, thus creating larger gaps for merging vehicles and reducing vehicular conflicts in the merging area [15]. Figure 1 (b) is a schematic diagram of the Lane Changing Scenario and the inset shows the advisory messages used in the field test. In field test, participants received the "If possible, move to left lane" for different gap size scenarios and they were instructed only to change lane if they were comfortable.
- Merging Control Algorithm (MCA): The algorithm is more proactive in nature than two other algorithms. In order to assist smooth merging, it focuses on controlling the longitudinal movements of vehicles by advising speed changes for both mainline and ramp vehicles [16]. This strategy provides a recommended speed advisory as well as a lane changing advisory, which makes this algorithm the most proactive and direct one. Figure 1 (c) is a schematic illustration of the Merging control algorithm and the inset shows the acceleration advisory used in the field test scenarios. For MCA scenarios in the field test, participants first received the acceleration advisory "Increase your speed to 35 mph". And after they accelerated and place their vehicle in a suitable position to change lane, they received the lane changing advisory. If they were comfortable with the gap on the left lane, they changed lanes otherwise they ignored the LCA and kept driving on the right lane.

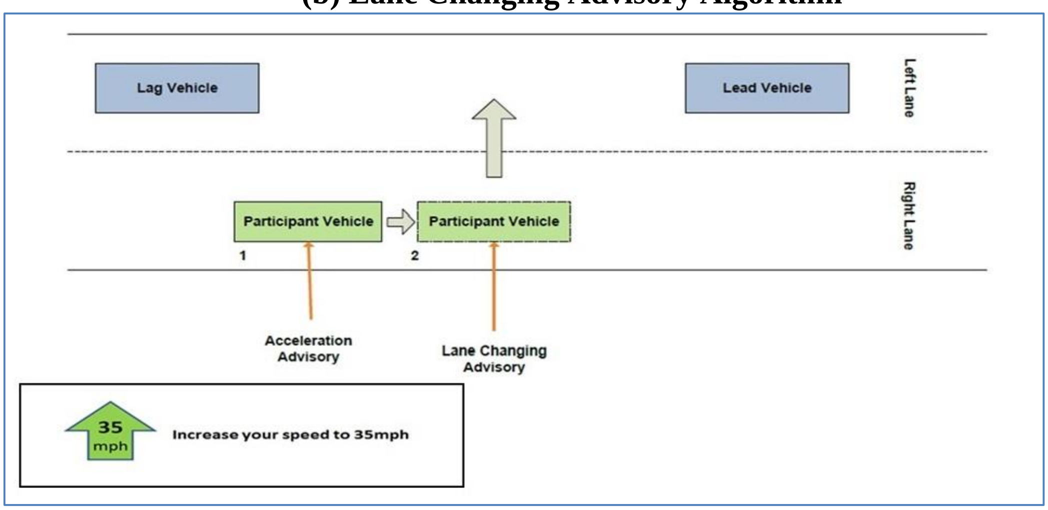
Simulation evaluation of the freeway merge assistance system showed that these algorithms can significantly improve merging in diverse traffic conditions.



(a) Variable Speed Limit Algorithm



(b) Lane Changing Advisory Algorithm



(c) Merge Control Algorithm

Figure 1: Freeway Merge Assistance System – Three Algorithms

EXPERIMENTAL DESIGN

Design of Field-Test

In this study, a field test was conducted to collect driver response time data using the Smart Road facility located in Blacksburg, Virginia. This Smart Road test bed facility is a 2-mile 2-lane road equipped with Dedicated Short Range Communication (DSRC)-based Road Side Equipment and a small fleet of DSRC-equipped vehicles with a Data Acquisition System. Due to the limitations of both personnel and vehicle resources it was not possible to conduct experiments replicating all possible real-world traffic scenarios. Considering these limitations, the research team developed a set of scenarios that was designed to represent diverse traffic conditions in the test environment.

A well designed set of test scenarios should give drivers similar merging experience as they would experience in actual freeway ramp areas under different traffic conditions. A review of the literature indicates that for merging and lane changes, the main factor considered by the drivers is the size of the available gap in the target lane. In addition, for all three algorithms developed under the freeway merge assistance system, a gap size was the main factor that affects the decision-making process of changing lanes. In addition to the gap size, other variables such as the relative speed of lead and lag vehicles and the remaining distance in the merging area also influence merging operations [17], [18], [19]. However, since it is not feasible to consider all the factors for scenario development due to the complexity and limited resources, only the gap size and the advisory types were considered as factors for scenario development.

In order to emulate different traffic conditions in the field test scenarios, the mean time headway for high, medium and low traffic conditions identified by Ye and Zhang [20] were used to define the small, medium and large gap size, respectively. The mean time headways for the three different traffic conditions were converted to space headway for a speed of 30 mph. The different proposed gap sizes in terms of time-headway and space-headway are presented in Table 1 (a). Based on the three levels of gap size (front bumper to front bumper) and three advisory types, a set of nine scenarios were developed for the field tests. The proposed scenarios are presented below in Table 1 (b):

Table 1 (a): Time and Space Headway for Different Gap Sizes

Gap Sizes	Time-Headway (sec)	Space-Headway (ft.)
Large Gap	4.00	176
Medium Gap	3.00	132
Small Gap	2.00	88

Table 1 (b): Scenario Overview

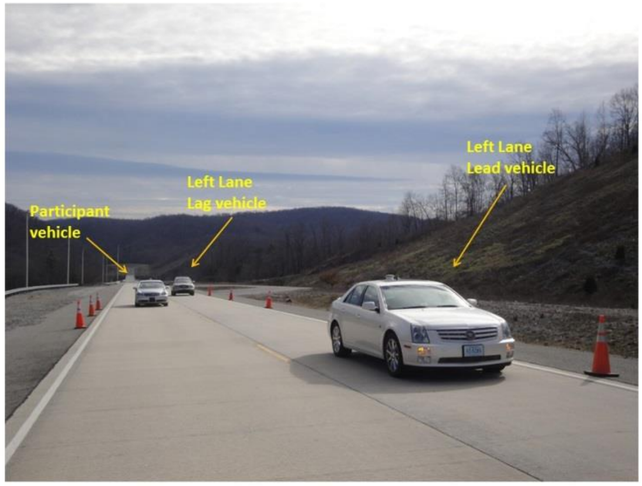
Gap Sizes	Advisory Types		
	Variable Speed Limit	Lane Changing Advisory	Merging Control Algorithm
Large Gap (176ft)	Scenario #1	Scenario #4	Scenario #7
Medium Gap (132ft)	Scenario #2	Scenario #5	Scenario #8
Small Gap (88ft)	Scenario #3	Scenario #6	Scenario #9

Naive Test Participants

The field test included 68 participants between the ages of 18 and 79 with 36 male and 32 female participants. They were recruited from the Blacksburg, Virginia and the surrounding area, requiring participants to have a minimum driving experience of 2 years. Interested participants responded to an advertisement on Craigslist or the local newspaper, after which they went through a phone-screening process for eligibility. The phone-screening was conducted to ensure that participants met the necessary traffic record and medical history threshold to participate in the test. Eligible participants were scheduled for field test at the Smart Road facility. At the test facility, participants went through initial paperwork and a pre-test training. During the training phase, experimenter explained the objectives of the research, introduced the in-vehicle technology. Most importantly the participants were instructed to demonstrate exact driving behavior as they would do in a real world traffic scenario. Experimenter asked the participants to change lanes in response to the advisories only when they feel comfortable with the available gap between the left lane vehicles. Unlike the other two scenarios, in the VSL scenarios, participants were not instructed to change lanes directly. However, during the training session, they were instructed to change lanes upon receiving the "Reduce your speed to 25 mph", if they were comfortable with the available gap in the left lane. After the training, they participated in the field test on the test track. After all the field test scenarios were completed, participants were asked in a stated preference survey how they would react to the advisories under different hypothetical conditions.

Field Test

Existing lane configuration at the Smart Road facility did not have an on-ramp section and a merging lane to fully replicate a freeway merge area. The right lane was designated as the target lane where the participants drove the target vehicle accompanied by the experimenter in the front passenger seat. Research team members drove two left lane vehicles as confederate drivers. Depending on the test scenario, the three vehicles were positioned on numbered spots designated specifically for them (Figure 2 (a)) with traffic cones placed at different gaps. All vehicles started at the same time with radio instruction from the experimenter and the left lane vehicles maintained the initial gap between them throughout the scenario. Participant drivers received advisory in the on-board display both in auditory and visual format (Figure 2 (b)). The research team used a laptop connected to the on-board display unit to send the advisory. Scenarios were randomized to eliminate any systemic bias in the participants' responses. The advisories used in the field test are illustrated in inset for all the strategies in Figure 1.



(a) Smart Road Lane Configuration

(b) In-Vehicle Configuration

Figure 2: Smart Road experimental configuration

Definition of Response Time

In general, the response time is an indication of how quickly a driver reacts to a certain stimulation. In this paper, to better understand drivers' response to advisories, the total response time is decomposed into two subsets: a perception reaction time (PRT) and a lane changing time (LCT). First, a perception reaction time in this paper is defined as the time taken by an individual participant to perceive an advisory message, to make a decision, and to initiate a lane change action after an advisory is delivered. In other words, the perception reaction times were measured as the time duration between advisory delivery and initiation of lane changing maneuver by the driver. Video data was analyzed to extract the timestamps when a driver started to initiate a lane change, i.e. when the driver started to move the steering wheel to change lane. For example in

Figure 3, the driver received advisory at time t_1 and started lane changing at t_2. The time difference between when the advisory was delivered and the initiation of lane change is defined as the perception reaction time. Therefore,

$$Perception\ Reaction\ Time = t_2 - t_1$$

One the other hand, a lane changing time is defined as the time duration between the initiation of a lane change and its' completion. The difference between the timestamp of lane change initiation and timestamp of lane change completion provided the values for lane changing times.

$$Lane\ Changing\ time = t_3 - t_2$$

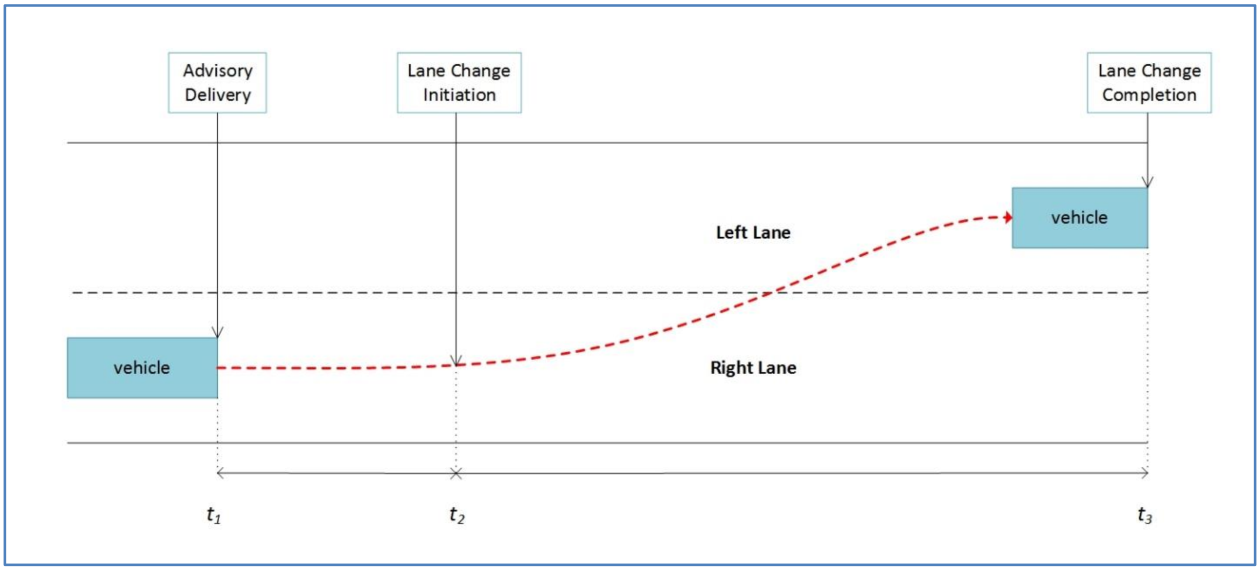


Figure 3: Response Time Definition

RESULTS AND ANALYSIS

The goal of this field test was to investigate the response behavior of naive participants to merge management advisories. During the testing, the researchers instructed the participants to comply when safely possible, that is ultimately to change lanes in response to the advisories in a manner that they would do in a real world situation. A summary of compliance rates for all the nine scenarios is presented in Table 2. One thing to note here is that not all participants followed all the advisories, which is expected in real world situations.

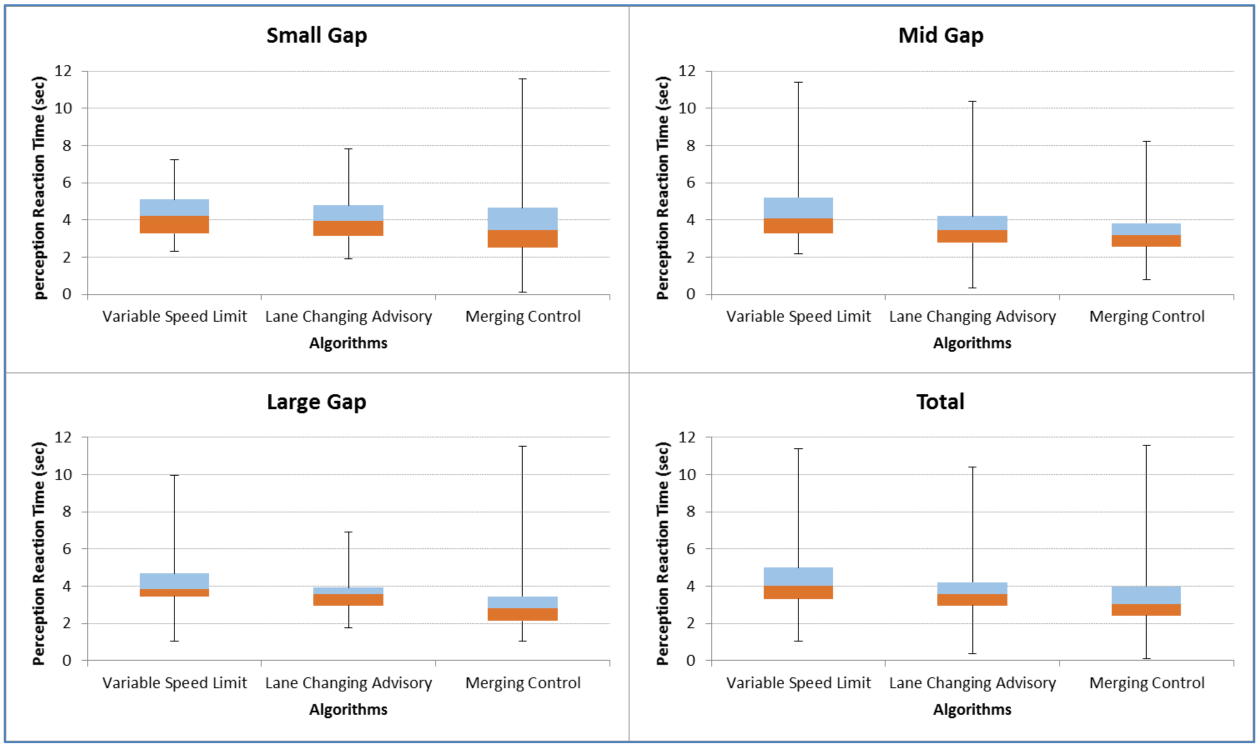
Table 2: Number of Participants Complying with Advisories (Out of 68 Participants)

Strategy	Gap Size		
	Large	Medium	Small
Variable Speed Limit	48	49	30
Lane Changing Advisory	67	60	44
Merging Control Algorithm	63	62	45

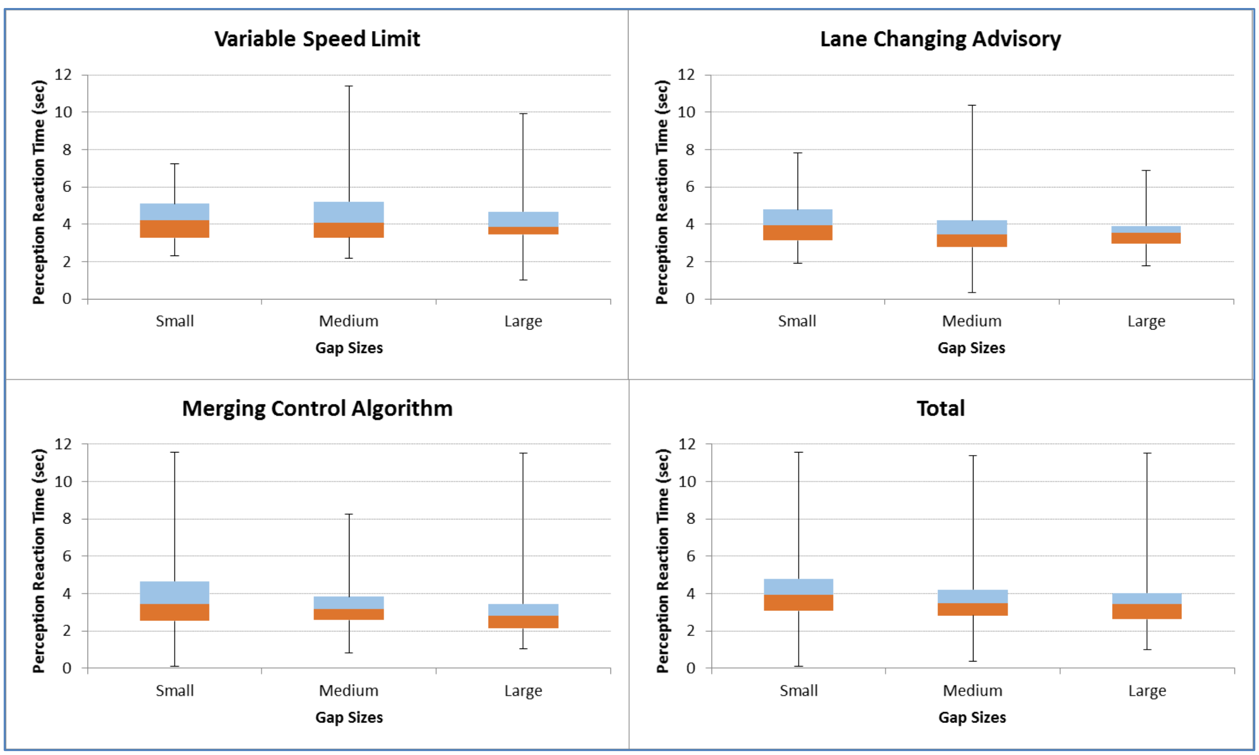
Two different data sets (i.e., perception reaction times and lane changing times) were separately analyzed by using a linear mixed effect model with Restricted Maximum Likelihood (REML) estimation approach in SPSS. As the response time dataset did not have all 68 data points for all nine scenarios (see Table 2), a linear mixed model was preferred over a repeated measures ANOVA [21]. And, in comparison with ML estimation, REML produces unbiased estimation of variance and covariance parameters [22]. In this section, detailed analysis results for perception reaction times and lane changing times are presented.

Perception Reaction Time Analysis

Figure 4 illustrates the boxplots of perception reaction times for each gap size and for each algorithm, respectively. From a visual inspection, it seems that the merging control algorithm requires a shorter perception reaction time, compared to the lane changing advisory and the variable speed algorithm cases. Also, longer perception reaction time is required by the drivers as the available gap size decreases. Note here that the total time in Figure 4 (and Figure 5 later) represents all the data points aggregated across the gap sizes or the algorithms.



(a) Perception Reaction Times for Each Gap Size Case



(b) Perception Reaction Times for Each Algorithm

Figure 4: Boxplots of Perception Reaction Times (sec)

A statistical analysis was conducted in order to examine whether the gap size and the strategy is a significant factor for perception reaction times. For this, we used both gap size (referred to as "GapSize" in the result tables) and strategy (referred to as "Strategy") as fixed factors in the linear mixed model. In addition, an interaction term "GapSize*Strategy" was included in the model as another fixed factor to examine the interactions between the gap size and the specific strategy. Furthermore, to characterize the idiosyncratic variation due to individual differences, we added subject as the random effect. Table 3 presents the fixed effect results from the linear mixed model analysis. Both fixed factors, GapSize and Strategy, were found statistically significant with the significance level of 0.003. On the other hand, there was no significant interaction between GapSize and Strategy with the significance level higher than 0.05.

Table 3: Fixed Effects of Linear Mixed Model for PRT

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	97.969	759.818	.000
GapSize	2	57.611	6.574	.003
Strategy	2	83.218	6.072	.003
GapSize * Strategy	4	69.223	1.626	.177

Based on these findings, further analyses were conducted in terms of GapSize and Strategy, separately.

Perception Reaction Time Analysis in terms of GapSize

As presented in Table 4 (a), it was found that the highest PRT was needed for a small gap case (M = 4.405, SD = 0.203), followed by a medium gap case (M = 3.958, SD = 0.154) and a large gap case (M = 3.770, SD = 0.156). Pairwise comparison (Table 4 (b)) further revealed that the small gap PRT is statistically different from the large gap PRT (p=0.001) and the medium gap PRT (p=0.012). However, no significant difference was observed between the large and medium gap cases (p=0.112). In addition, the p-value (0.002) obtained from the univariate test (Table 4 (c)) indicated the PRT means of all gap size cases are statistically different.

Table 4: Perception Reaction Time Analysis in terms of GapSize

(a) Estimates

Gap Size	Mean	Std. Error	df	95% Confidence Interval	
				Lower Bound	Upper Bound
LARGE	3.770	.156	101.744	3.461	4.079
MID	3.958	.154	94.588	3.652	4.264
SMALL	4.405	.203	97.108	4.001	4.809

(b) Pairwise Comparisons

(I) Gap Size	(J) Gap Size	Mean Difference (I-J)	Std. Error	df	Sig.	95% Confidence Interval for Difference	
						Lower Bound	Upper Bound
LARGE	MID	-.188	.116	60.760	.112	-.421	.045
	SMALL	-.635*	.176	63.440	.001	-.986	-.283
MID	LARGE	.188	.116	60.760	.112	-.045	.421
	SMALL	-.447*	.173	60.512	.012	-.794	-.100
SMALL	LARGE	.635*	.176	63.440	.001	.283	.986
	MID	.447*	.173	60.512	.012	.100	.794

(c) Univariate Tests

Numerator df	Denominator df	F	Sig.
2	72.233	6.574	.002

Based on the results presented above, it can be concluded that, for any application that attempts to impact drivers' behavior, the expected density of traffic, and thus the size of available gaps, should be considered explicitly when designing a strategy. The common trend found here was that the perception reaction time increases as the gap size decreases. The implication of this result is that drivers need more time to react when the size of available gaps was small. Simply assuming a uniform perception reaction time regardless of various traffic conditions may lead to an unintended consequence. The estimated 0.635 sec difference in average perception reaction times for a large gap case (3.770 sec) and a small gap case (4.405 sec) can make a difference in the performance of an application. In many cases, mobility applications will be intended to improve traffic conditions in heavily congested areas. These results indicate that advisory messages will not result in "desired" driver behavior in a uniformly predictable manner.

Perception Reaction Time Analysis in terms of Strategy

Next we conducted an analysis of perception reaction times in terms of three strategies (or algorithms). Table 5 (a) presents the estimates for each strategy obtained from the linear mixed model, with the highest mean estimate for VSL (M=4.758, SD=0.382), followed by the medium for LCA (M = 3.912, SD = 0.144) and the lowest for MCA (M = 3.462, SD = 0.149). Mean differences (Table 5 (b)) of all pairs of strategies were found to be statistically significant (p-value ranging between 0.002 and 0.041) and the univariate tests (Table 5 (c)) further verified that these means were not equal to each other (p = 0.003).

Table 5: Perception Reaction Time Analysis in terms of Strategy

(a) Estimates

Strategy	Mean	Std. Error	Df	95% Confidence Interval	
				Lower Bound	Upper Bound
LCA	3.912	.144	62.256	3.625	4.200
MCA	3.462	.149	70.794	3.164	3.760
VSL	4.758	.382	59.240	3.994	5.523

(b) Pairwise Comparison of strategies

(I) Strategy	(J) Strategy	Mean Difference (I-J)	Std. Error	df	Sig.	95% Confidence Interval for Difference	
						Lower Bound	Upper Bound
LCA	MCA	.450*	.204	110.082	.029	.047	.854
	VSL	-.846*	.406	74.052	.041	-1.655	-.036
MCA	LCA	-.450*	.204	110.082	.029	-.854	-.047
	VSL	-1.296*	.408	75.785	.002	-2.109	-.483
VSL	LCA	.846*	.406	74.052	.041	.036	1.655
	MCA	1.296*	.408	75.785	.002	.483	2.109

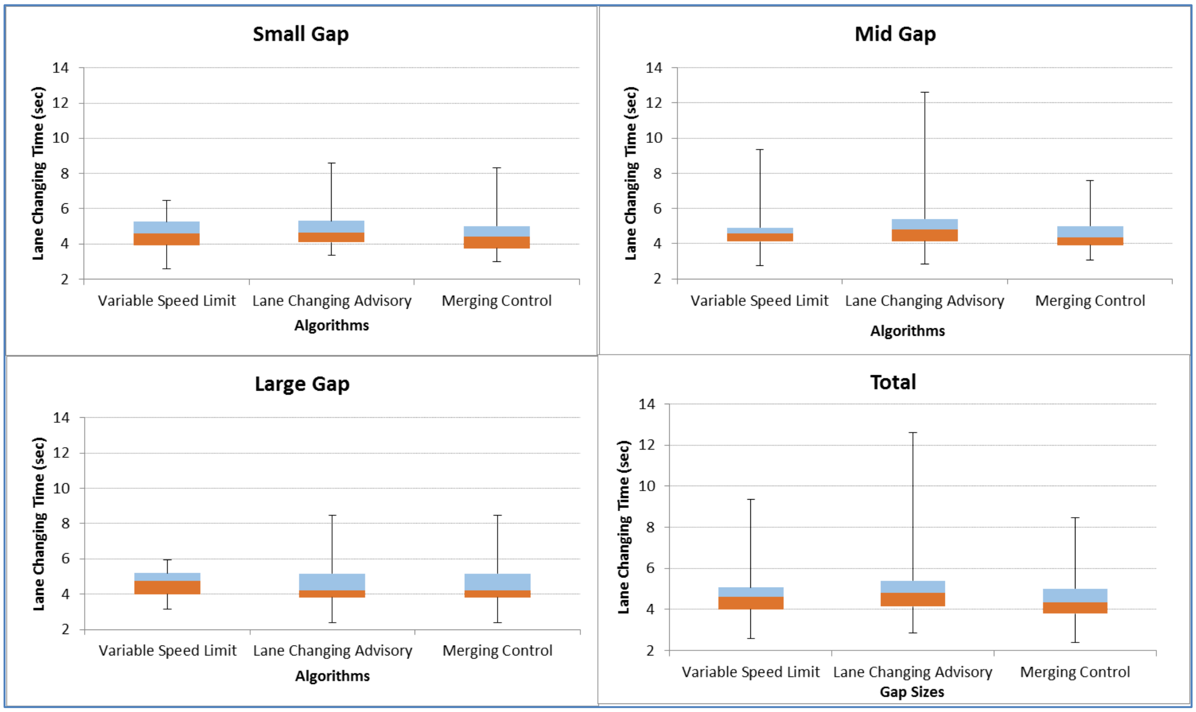
(c) Univariate Tests

Numerator df	Denominator df	F	Sig.
2	98.223	6.072	.003

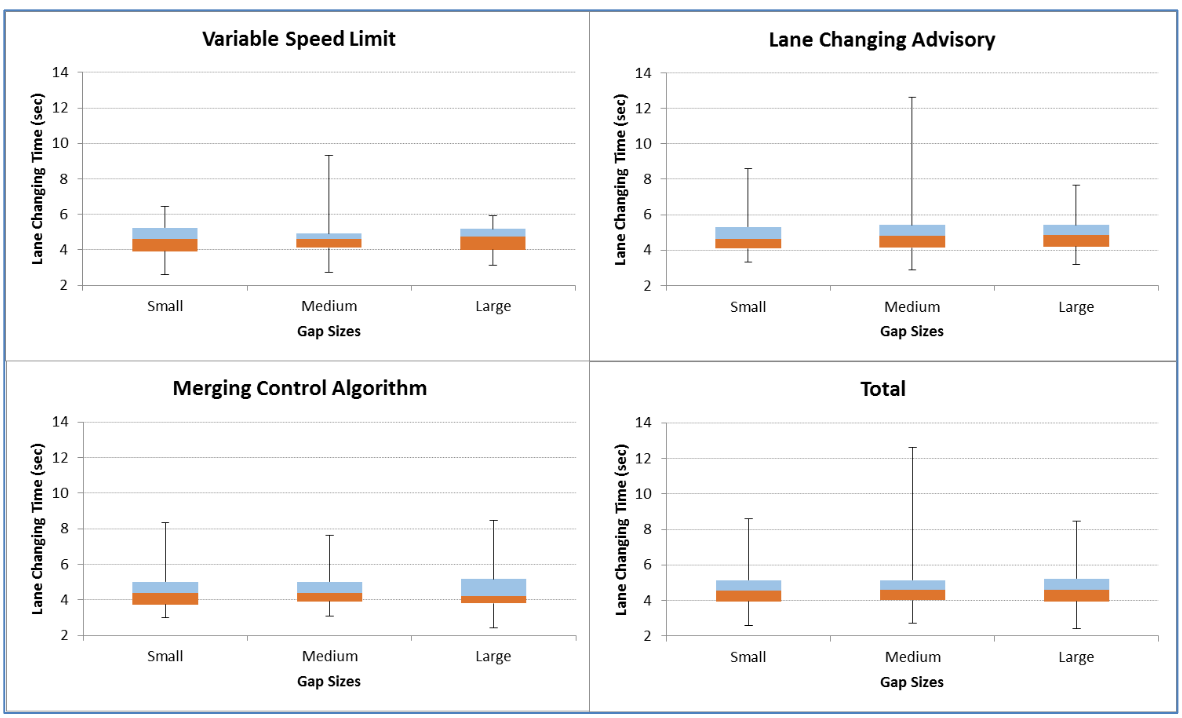
Based on the analysis results, it can be concluded that perception reaction time decreased as the advisory message becomes more direct and proactive. As previously mentioned, the merging control algorithm (MCA) provided the most direct and active advisory (i.e. recommended speed as well as lane change advisory), which can help drivers to digest the advisory more quickly and to make more prompt decisions. On the other hand, the variable speed limit algorithm was the most passive strategy, attempting to “indirectly” stimulate a lane change by lowering the speed limit of the right most lane of the freeway mainline. This implied that a driver may need more time to fully understand the situation and to decide on what to do. The lane changing advisory algorithm was located between these two algorithms in terms of directness, providing only a lane change advisory. In conclusion, it was found that, on average, a perception reaction time could be reduced by about 1.30 sec (from 4.76 sec of variable speed limit to 3.46 sec of merging control) by providing most direct advisories and it is therefore recommended that developing and implementing an application that provides more direct advisory messages is desirable.

Lane Changing Time Analysis

First of all, as presented in Figure 5 (a), the lane changing times did not change much regardless of the available gap sizes for each of three algorithms and for the total average case. In addition, for each of three gap size scenarios (small, medium, and large), the lane changing time observed from all three algorithms were similar – see Figure 5 (b).



(a) Lane Changing Times for Each Gap Size Case



(b) Lane Changing Times for Each Algorithm

Figure 5: Boxplots of Lane Changing Times (sec)

Similar to the PRT analysis, a linear mixed model configuration was adopted to statistically analyze lane changing times with GapSize, Strategy, and GapSize*Strategy as fixed factors. The fixed factor results indicated only Strategy as a significant factor for LCT (p = 0.024) as presented in Table 6.

Table 6: Fixed Effects of Linear Mixed Model for LCT

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	218.748	5993.160	.000
GapSize	2	45.028	.092	.912
Strategy	2	75.562	3.909	.024
GapSize * Strategy	4	70.105	.289	.884

Further analysis was conducted to examine the exact impact of the strategies in the resulting lane change times. Pairwise comparison of lane change times between strategies indicated that only the lane changing time of the LCA strategy (4.872 sec) is statistically different from the VSL (4.575 sec, p=0.032) and the MCA (4.525 sec, p= 0.010), as summarized in Table 7 (b). However, given the maximum difference is only up to 0.347 sec without any plausible interpretation, it would be reasonable to conclude that once a driver initiated a lane change (after receiving and understanding advisories, making an appropriate decision, and possibly already finding a gap for a lane change), the time required to complete a lane change did not vary much, regardless of the strategy or the available gap size.

Table 7: Lane Change Time Analysis in terms of Strategy

(a) Estimates

Strategy	Mean	Std. Error	Df	95% Confidence Interval	
				Lower Bound	Upper Bound
LCA	4.872	.102	66.207	4.669	5.075
MCA	4.525	.091	60.192	4.343	4.706
VSL	4.575	.098	59.671	4.379	4.771

(b) Pairwise Comparisons

(I) Strategy	(J) Strategy	Mean Difference (I-J)	Std. Error	df	Sig.	95% Confidence Interval for Difference	
						Lower Bound	Upper Bound
LCA	MCA	.347*	.131	66.672	.010	.086	.608
	VSL	.297*	.136	89.630	.032	.026	.567
MCA	LCA	-.347*	.131	66.672	.010	-.608	-.086
	VSL	-.051	.128	82.873	.695	-.306	.205
VSL	LCA	-.297*	.136	89.630	.032	-.567	-.026
	MCA	.051	.128	82.873	.695	-.205	.306

CONCLUSION

A fuller understanding of drivers' behavior responding to a new generation of dynamic mobility-focused advisory messages is a necessity to be able to develop, implement, and evaluate any mobility applications in a connected vehicle environment. Given this background, the research team at the University of Virginia Center for Transportation Studies conducted a field testing with 68 naive participants. Based on the drivers' behavior data collected from this field testing, analysis of drivers' response times to freeway merge management advisories was conducted and the results are presented below:

1. Perception reaction time increased as an available gap size decreased regardless of the algorithms implemented. The estimated 0.64 sec difference in average perception reaction times observed from a large gap case (3.77 sec) and a small gap case (4.41 sec) should not be neglected when designing a system or its' strategy. Simply assuming a uniform perception reaction time regardless of various traffic conditions may lead to an undesirable consequence.
2. Perception reaction time decreased as the advisory became more direct and active. Drivers responded more promptly to the merging control algorithm (most direct and active), followed by the lane changing algorithm (medium), and a variable speed limit algorithm (least direct and active). Perception reaction time was reduced by 1.30 sec (from 4.76 sec of variable speed limit to 3.46 sec of merging control) by providing most direct advisories. It is therefore recommended that developing and implementing an application that provides more direct advisory messages is desirable.
3. Actual lane changing times did not change much regardless of the types of advisories given and the size of gaps available for a lane change. Once a driver initiated a lane change, the time required to complete a lane change did not vary much. However, it should be noted that more stringent testing methodologies might provide a clearer difference. It is therefore recommended that further study is needed before making a conclusion.

All these results have significant implications in the design, implementation, and operation of connected vehicle-enabled applications. In addition, continuous efforts to better understand drivers' behavior under a connected vehicle environment should be made.

REFERENCES

[1] H. Yi and T. E. Mulinazzi, "Urban Freeway On-Ramps: Invasive Influences on Main-Line Operations," *Transp. Res. Rec.*, vol. 2023, no. -1, pp. 112–119, Dec. 2007.

[2] "Ramp Management and Control Handbook | Chapter 5 Ramp Management Strategies - FHWA Operations." [Online]. Available: http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/5_1.htm. [Accessed: 31-Mar-2013].

[3] "Multi-Modal Intelligent Traffic Signal System — Safer and More Efficient Intersections Through a Connected Vehicle Environment." [Online]. Available: http://econolitegroup.com/files/2514/2128/2875/IMSA-Sept_Oct_2014.pdf. [Accessed: 03-Feb-2015].

[4] J. P. O. Intelligent Transportation System, "Dynamic Mobility Application." [Online]. Available: http://www.its.dot.gov/dma/index.htm. [Accessed: 30-Jun-2015].

[5] S. Narla, "The Evolution of Connected Vehicle Technology: From Smart Drivers to Smart

Cars to.... Self-Driving Cars.," *ITE J.*, no. July, pp. 22–26, 2013.
[6] "Advanced Freeway Merge Assistance: Harnessing the Potential of Connected Vehicles, Exploratory Advanced Research Program (EARP) | Center for Transportation Studies." [Online]. Available: http://www.cts.virginia.edu/advanced-freeway-merge-assistance-harnessing-the-potential-of-connected-vehicles-exploratory-advanced-research-program-earp/. [Accessed: 01-Aug-2015].
[7] J. D. Lee, D. V McGehee, T. L. Brown, and M. L. Reyes, "Driver Distraction, Warning Algorithm Parameters, And Driver Response To Imminenet Rear-End Collisions in a High-Fidelity Driving Simulator."
[8] M. Rimini-doering, T. Altmueller, U. Ladstaetter, and M. Rossmeier, "Effects of lane departure warning on drowsy drivers' performance and state in a simulator," in *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design.*, 2005.
[9] E. E. Wiese and J. D. Lee, "Auditory alerts for in-vehicle information systems: the effects of temporal conflict and sound parameters on driver attitudes and performance.," *Ergonomics*, vol. 47, no. 9, pp. 965–86, Jul. 2004.
[10] C. Nowakowski, D. Vizzini, S. Gupta, and R. Sengupta, "Evaluation of Real-Time Freeway End-of-Queue Alerting System to Promote Driver Situational Awareness," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2324, pp. 37–43, Dec. 2012.
[11] P. Finnegan and P. Green, "TIME TO CHANGE LANES: A LITERATURE REVIEW."
[12] T. J. Ayres, L. Li, D. Schleuning, and D. Young, "Preferred time-headway of highway drivers," *ITSC 2001. 2001 IEEE Intell. Transp. Syst. Proc. (Cat. No.01TH8585)*, no. 1980, pp. 827–830, 2001.
[13] E. M. Grey, T. J. Triggs, and N. L. Haworth, "Driver Aggression: The Role of Personality, Social Characteristics, Risk and Motivation," *Stay. 58*, 1989.
[14] H. Park, "Investigating Lane-Level Variable Speed Limit Implementation in Freeway Operations," University of Virginia, 2011.
[15] H. Park and B. Smith, "Investigating Benefits of IntelliDrive in Freeway Operations: Lane Changing Advisory Case Study," *J. Transp. Eng.*, no. November 2009, 2012.
[16] S. Su, "Design Implementation and Evaluation of a Freeway Merging Control Algorithm utilizing Connected Vehicle Technologies," 2011.
[17] K. I. Ahmed, M. Ben-Akiva, H. N. Koutsopoulos, and R. G. Mishalani, "Models of freeway lane changing and gap acceptance behavior," in *Proceedings of the 13th international symposium on the theory of traffic flow and transportation*, 1996, pp. 501–515.
[18] C. Choudhury, M. Ben-Akiva, and T. Toledo, "Modeling cooperative lane changing and forced merging behavior," *86th Annu. Meet. …*, pp. 1–16, 2007.
[19] T. Toledo, "Modeling integrated lane-changing behavior," *… Rec. J. …*, 2003.
[20] F. Ye and Y. Zhang, "Vehicle Type-Specific Headway Analysis Using Freeway Traffic Data," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2124, no. -1, pp. 222–230, Dec. 2009.
[21] C. Krueger and L. Tian, "A comparison of the general linear mixed model and repeated measures ANOVA using a dataset with multiple missing data points.," *Biol. Res. Nurs.*, vol. 6, no. 2, pp. 151–7, Oct. 2004.
[22] B. T. West, K. B. Welch, and A. T. Galecki, *Linear Mixed Models: A Practical Guide Using Statistical Software, Second Edition*. CRC Press, 2014.

Investigation of Connected vehicle mobility advisory response behavior among drivers across gender and age groups: A case study with Freeway Merge Assistance System

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Abstract

Conflicts among vehicles in merge areas are one of the major causes of freeway congestion. Current traffic congestion mitigation strategies are more of responsive in nature and are of limited capabilities. With emerging connected vehicle technology, more predictive and cooperative strategies can be implemented to improve merging condition with enhanced safety and mobility. The freeway marge assistance system is a connected vehicle enabled advanced prototype traffic management approach that utilizes early identification and notification of merging opportunities to minimize vehicular conflicts and ensure smoother merging operation. The effectiveness of this system depends on the correct comprehension and compliance of drivers who received the dynamic notifications. With aging population and increasing number of teenage deaths due to motor vehicle accidents, it is of high importance to investigate the potentiality of connected vehicle based advisory system in improving freeway safety.

In this paper, we presented a detailed analysis of drivers' advisory response behavior in terms of gender and different age groups. A field test was conducted to collect responses to advisory messages delivered from the freeway merge assistance system with 68 participants representing a wide variety of US driver population demographics. The goal of this research was to investigate the response variation among gender and different age groups to this new generation of in-vehicle personalized advisories for different dynamic traffic conditions. Based on the analysis of field data, no significant difference were found in the both compliance rates and perception reaction times between gender groups. In terms of age, older drivers demonstrated lower compliance rate (63%) and average higher perception-reaction time when compared with younger drivers; which can be attributed to age-induced cognitive skills decline. In terms of actual lane changing times, there were no significant differences found either at the gender or age level analysis. The findings of this research provides important insight into response behavior variability across gender and age which needs to be considered in the development and implementation of connected vehicle enabled mobility applications.

Introduction

Freeway traffic congestion is a significant problem of the transportation system. Among the many reasons, merging conflicts, contributes heavily to freeway congestion by creating bottlenecks within the freeway ramp areas. Over the years, various such as ramp metering strategies, variable speed limit, etc. have been implemented to improve freeway merging operation. However, each of these strategies has their own disadvantages and has limited capabilities in reducing freeway merge conflicts because of the limitations of current traffic surveillance system [1].

The Connected Vehicle (CV) initiative addresses the above limitations by establishing wireless communication and dynamic notification between vehicles and also between vehicles and infrastructure. With the new capabilities offered by the Connected Vehicle technology, the University of Virginia Center for Transportation Studies (UVA CTS) has developed the CV technology enabled prototype freeway merge assistance system to ensure smoother merging operation by minimizing conflicts between the mainline vehicle and on-ramp vehicle using dynamic advisories to target vehicle drivers. This system proactively identifies merging opportunity and dynamically notifies drivers through advisory messages to enhance safety and mobility in freeway merge areas.

However, the anticipated benefits from CV-based mobility application such as merge assistance system entirely depend on the compliance of the drivers. Drivers need to correctly perceive, make decision and then react to these advisories to achieve the intended benefit in both mobility and safety. Previous studies have investigated how pre-trip and en-route advisory information influences drivers' route choice making decisions where messages were delivered through ATIS [2], [3](CITE). In more recent studies, researchers have looked into drivers' responses to CV-based in-vehicle safety alerts, automated braking systems, etc [4], [5]. In contrast to safety systems, mobility systems have different objectives such improving the driving condition, individual mobility and thus may yield different response behavior than that of safety systems.

Moreover as drivers, each individual has their own preferences of driving speed, headway and acceptable gap size [6], [7]. These individual preferences will lead to variability in compliance with advisories. In addition, different situational factors such as dynamic traffic conditions also dictate driver preferences. As mentioned earlier, the variability can be due to dynamic traffic conditions as well as individual characteristics, such as driving experience. For example, experienced drivers may be more comfortable following a lane-changing advisory although the available gaps between vehicles are small.

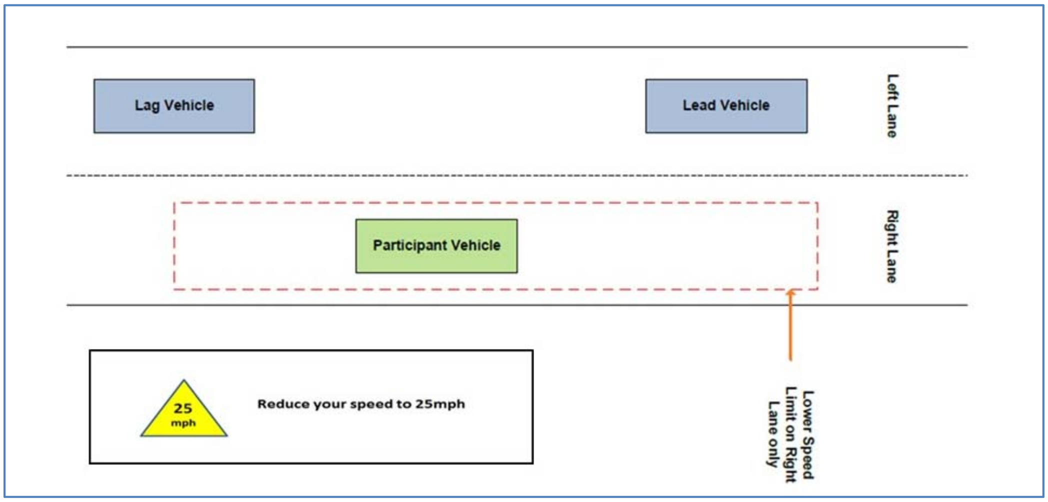
Many studies have already established that there significant difference between male and female drivers which are not easily explainable in terms of competence level and driving skill but more acute difference in specific behavior and psychological functioning [8]. In general, male drivers are significantly at more risk than female drivers in terms of higher crash rates and fatalities [9]. Research on the risk-taking behavior of different age groups indicates that young male drivers demonstrate more aggressive behavior than relatively older drivers [10] (CITE). The less sensitive hazard perception [11] together with risk taking attitude [12] have unfortunately led vehicular accident be at the top of the list of cause for untimely teenage deaths [13]. Moreover, with aging there are significant decline in human basic cognitive functions. Research on age-related impairments on cognitive abilities have found that older adults cannot allocate resources properly in divided attention and attention switching tasks, which can directly related with paying attention on the road while driving and looking at an in-vehicle display to dynamic message [14]. The age-related deficits also contributes to a general decline in information processing , which may contribute a longer time of perception and decision making for older drivers [15]. And with aging driver population (by 2025, 25% of US licensed drivers will be over 65 years old) [16], there is a need to explore how advanced transportation technology such as CV-based mobility application can be used to enhance the safety and mobility of the older driver population.

Therefore, this study investigates how drivers respond to the personalized advisories provided under diverse traffic condition and whether there are any significant response variability because of sex and age. A field test with naïve participants was conducted on a CV –enabled test track to collect data on compliance and response times for merge advisories under different traffic scenarios. In this paper, we present the results and analysis of compliance behavior and response times in terms of gender and age groups followed by a brief description of the Freeway Merge Assistance System and experimental design.

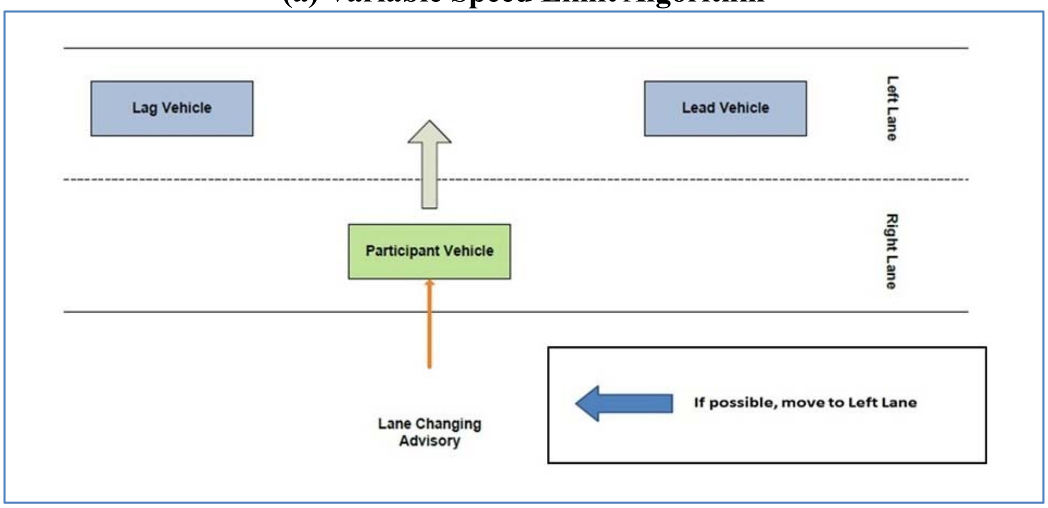
Freeway Merge Assistance System

This section presents a brief overview of the freeway merge assistance system developed by the UVA CTS. With the goal of improving the efficiency and safety of freeway merges, this system is developed to take advantage of the Connected Vehicle technology to address the limitations of current merge management practice. Following are three important fundamental components central to objectives of the system:

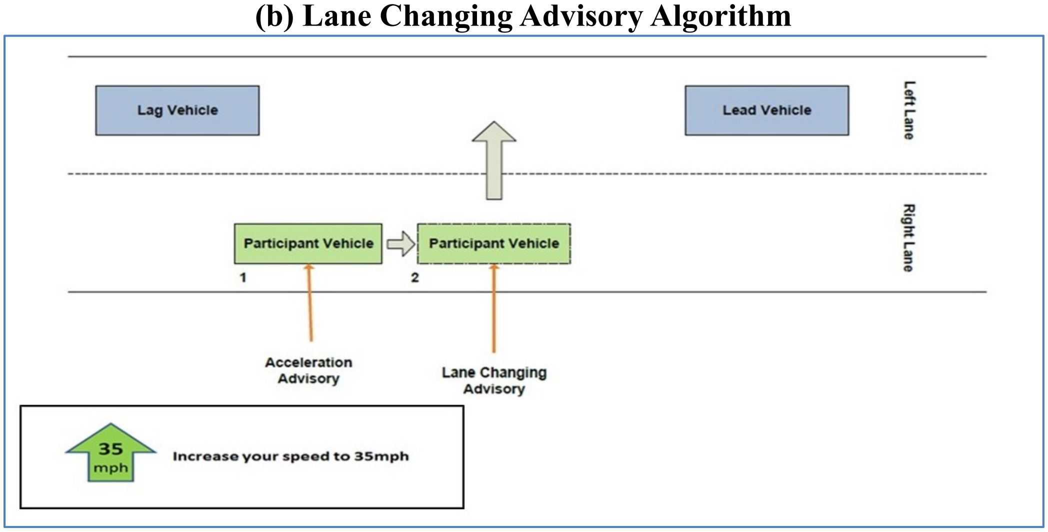
- Dynamic Lane Control: The purpose of this logic is to identify available capacity in the left lanes and encourage drivers travelling on the mainline lane adjacent to the merging lane to change lane to left and thus creating bigger and frequent gaps in the merging area. This dynamic lane control logic was implemented by two algorithms:
    - Lane-level Variable Speed Limit: Based on the mainline traffic density, this algorithm dynamically determines and implements lower speed limit on the right most lane to encourage drivers to move to the left lane for better driving condition and thus creating gaps on the right lane for merging vehicles [17]. Figure 1(a) illustrates a schematic representation of the variable speed limit scenario and the inset shows the advisory used in the field study.
    - Lane Changing Advisory: This algorithm dynamically targets vehicles travelling on right lane to send lane changing advisory for early lane change and thus creates bigger gaps for merging vehicle and reduces conflicts in the ramp merging area [18]. Figure 1(b) presents an illustration of the lane changing advisory scenarios and the inset shows the advisory used in this scenarios.
- Merge Control: This algorithm utilizes V2V and V2I communication to either control longitudinal movements or to advice speed changes for both mainline and ramp vehicles, to ensure smooth merging in smallest gap sizes by reducing merging conflicts and thus, increasing capacity by reducing minimum headways . Figure 1 (c) is an illustration of the merging control algorithm and the inset shows the acceleration advisory used in the field test.



(a) Variable Speed Limit Algorithm



(b) Lane Changing Advisory Algorithm



(c) Merge Control Algorithm

Figure 1: Freeway Merge Assistance System – Three Algorithms

The algorithms were developed and evaluated in an integrated Connected Vehicle simulation environment. Simulation evaluation results indicated significant potentiality of these algorithms in improving freeway merge operation.

Design of Experiment

The goal of the field-test is to understand drivers' response to advisories provided by the different algorithms under the freeway merge assistance system. Since there is a gap in the knowledge about how drivers' will react to the different control strategies under a Connected Vehicle enabled environment and also the success of this approaches depend on driver compliance, it is necessary to conduct a test that addresses this problems. The algorithms that are currently being evaluated are: (i) Variable Speed Limit (ii) Lane Changing Advisory and (iii) Merging Control Algorithm.

The field-test phase of this study will be conducted in the Smart Road, a Connected Vehicle test bed facility located in Blacksburg, Virginia. This University Transportation Center test bed provides an excellent opportunity and necessary resources for the proposed research work. This facility has a 2-lane road instrumented with DSRC-based RSEs along the 2 mile length section. In addition, this facility also has a small fleet of vehicles equipped with DSRC-based on-board equipment. Though the facility provides a Connected Vehicle enabled controlled environment for testing and conducting research; the length of the facility and limited number of equipped vehicles does not allow a full-fledged experimentation replicating real-world traffic scenarios. With this limitation, the research team has developed a testing plan with detailed description of the required system architecture, scenario development, test procedure steps, test personnel protocol.

As mentioned earlier, the main objectives of this field-test is to understand driver response behavior to advisories provided from the three merge assistance strategies in a small scale. For all the algorithms developed under the merge assistance system, gap size is the main factor behind the decision making process of lane change. Extensive literature review has also indicated lane change and merging operation depends on the available gap size along with other variables such as relative speed of lead and lag vehicle, remaining distance of merge area. Since it will not be feasible to consider all the factors for scenario development due to complexity and limited resource, only gap size and advisory types are considered as the factors for scenario development.

By using the concept of time headway between vehicles in different traffic condition the gap sizes for the different scenarios can be adjusted. For the scenario development, the mean time headway for high, medium and low traffic condition found by Ye and Zhang [19] were adopted to define the small, medium and large gap size respectively and were converted to space headway. For vehicles traveling at 30 mph the different proposed gap sizes in terms of time-headway and space-headway are as presented in (Table-1). Based on the three levels of gap size and application types, a set of testing scenarios are developed to get the driver compliance data. Scenarios will be completely randomized to overcome experimental bias. The proposed scenarios presented below in Table-1(b):

Table 1 (a): Time and Space Headway for Different Gap Sizes

Gap Sizes	Time-Headway (sec)	Space-Headway (ft.)
Large Gap	4.00	176
Medium Gap	3.00	132
Small Gap	2.00	88

Table 1 (b): Scenario Overview

Gap Sizes	Advisory Types		
	Variable Speed Limit	Lane Changing Advisory	Merging Control Algorithm
Large Gap (176ft)	Scenario #1	Scenario #4	Scenario #7
Medium Gap (132ft)	Scenario #2	Scenario #5	Scenario #8
Small Gap (88ft)	Scenario #3	Scenario #6	Scenario #9

Field Test

For the field 68 participants were recruited between the ages of 18 and 79(36 male and 32 female). All the participants went through initial screening to meet the required traffic and medical history threshold. Before the field test participants went through extensive in-vehicle training and dry run through the test tracks.

Due to the absence of an actual freeway merge section in the Smart Road facility, the right lane in the 2-lane facility was used as merging lane and the left lane was used as mainline lane. Test participants drove vehicles in the right lane with an experimenter in the front passenger seat. Research team members drove two vehicles on the left lane and the gaps between these two vehicles varied depending on the test scenario. In each scenario, all the vehicles started at the same time on experimenter's instruction and left lane drivers maintained the initial gap between them throughout the scenario. Participants received advisory in the on-board display in both visual and auditory format. Advisories were sent at random using a laptop with a test control application that gave the researcher the flexibility to send any advisory at any time. Scenarios were randomized to eliminate systematic bias in the response behavior.

Definition of Compliance

One of the main focus of this experiment to collect the compliance data for the three strategies at different gap sizes. It is important to note that the participants were instructed specifically to change lane in response to the advisory, only if they are comfortable with available gap size on the left lane. After the start of a test scenario, at some point the experimenter sent the advisory and if the participant changed lane within a reasonable period of time; it was considered as a compliance. The maximum total time for lane change was limited to 16 seconds after receiving an advisory.

Definition of Response Time

To understand drivers' responses, we decomposed the total response time into (a) perception-reaction time and (b) lane changing time. The Perception-reaction time (PRT) is defined as the time taken by a participant to perceive an advisory, make decision and initiate a lane change after an advisory is received. Video data was analyzed to extract timestamps of when the advisory was delivered and when the driver started to initiate a lane change. As illustrated in the Figure -3, an advisory was delivered at time t_1 and the participant started to initiate lane change at time t_2. Therefore,

$$Perception\ Reaction\ Time = t_2 - t_1$$

The lane change time was defined as the time taken to change lane, i.e. the time duration between the initiation of lane change and its completion. As illustrated in Figure -3, the driver starts to change lane at time t_2 and completes the change lane at time t_3. Therefore,

$$Lane\ Changing\ time\ =\ t_3 - t_2$$

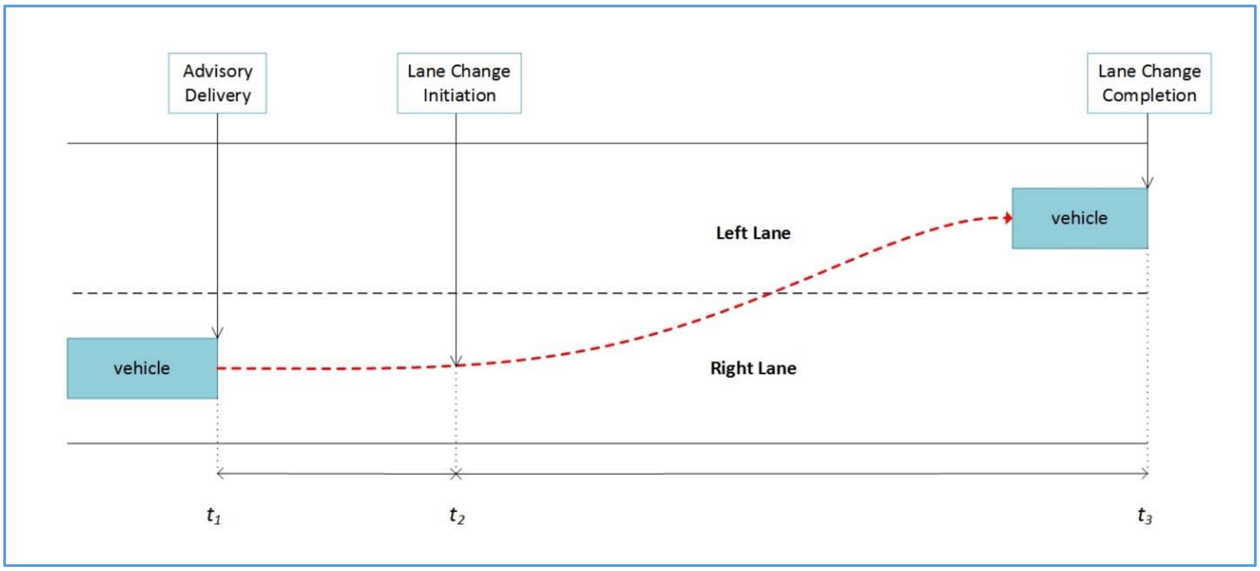


Figure 2: Response Time Definition

RESULTS AND ANALYSIS

In this section, we first present the results of compliance across the gender and different age groups. In the later section, the results and analysis on PRT and LCT data are presented.

Compliance for different gender groups

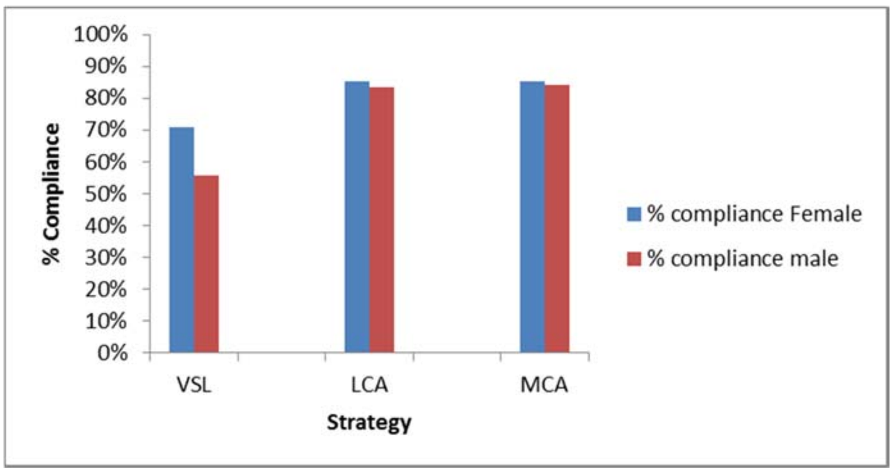
a) Compliance across strategies:

For compliance across strategies for different gender groups, as we observe similar compliance rate for both the LCA and MCA strategies, in which there is with no statistically significant difference between the compliance rates of female and male participants [Figure 3(a)]. In the LCA scenarios, female participants had a compliance rate of 85% and male participants had a compliance rate of about 83%, which is not significantly [$\chi 2(1, N=108,96) = 0.0465$, $p > 0.10$] different. For the MCA scenarios, there was no statistically significant [$\chi 2(1, N=108,96) = 0.0012$, $p > 0.10$] difference in the compliance rate; male participants complied at 84% and females at

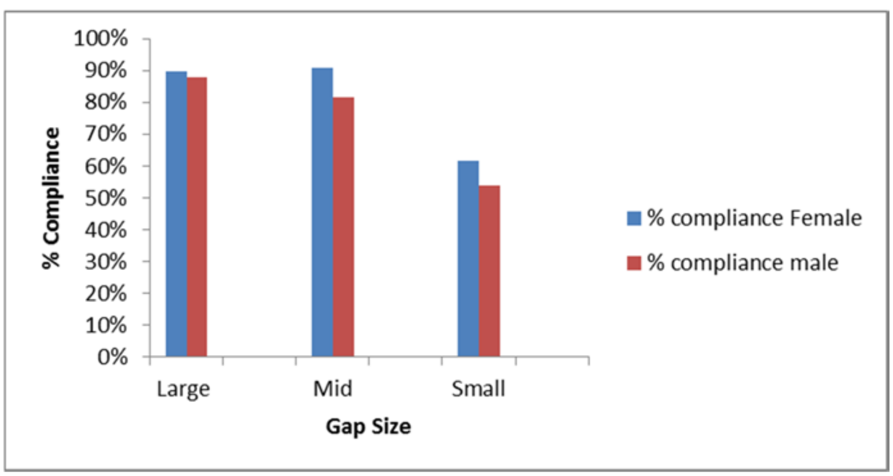
85%. However, for the VSL strategies, female participants showed a higher compliance rate of 70% compared to a 55% compliance rate from male participants, which is a statistically significant difference [$\chi 2(1, N=96,108) = 3.4036$, $p < 0.10$].

b) Compliance across gaps sizes:

For compliance across the three gap sizes in relation to gender, a similar compliance rate is observable in the case of the large gap size for both female and male participants with compliance rate of 89% and 87 % respectively, which is not significant [$\chi 2(1, N=96,108) = 0.0206$, $p > 0.10$]. For the medium gap size scenarios, there is significant [$\chi 2(1, N=96,108) = 2.7749$, $p < 0.10$] difference in the compliance rates. Female participants exhibit a higher compliance rate of 90% followed by male compliance rate of 81% [Figure 3(b)]. Compared to the large and medium gap size scenarios, the small gap size scenario have a lower compliance rate of 61% for female participants, followed by 53% for male participants, however, this difference not significant [$\chi 2(1, N=96,108) = .9526$, $p > 0.10$]. It is obvious from the data that for all three gap sizes, female participants have the lowest non-compliance rate. If the compliance rate is aggregately considered irrespective of gap sizes, the difference in the compliance rate between female (80.5%) and male (74.3%) participants is statistically significant [$\chi 2(1, N=288,324) = 2.9673$, $p < 0.10$].



(a) Compliance rate across strategies



(b) Compliance rate across gap Sizes

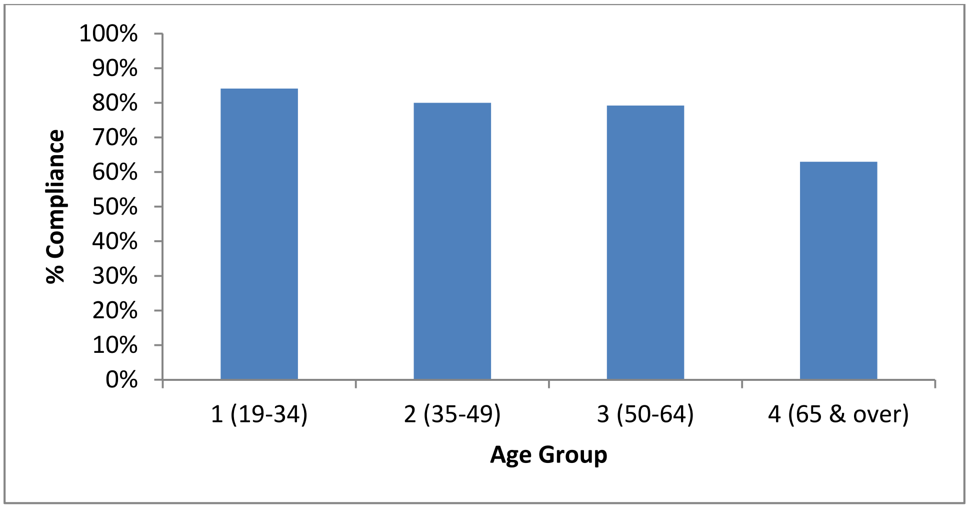
Figure 3: Compliance rate for Different Genders

Compliance for different age groups

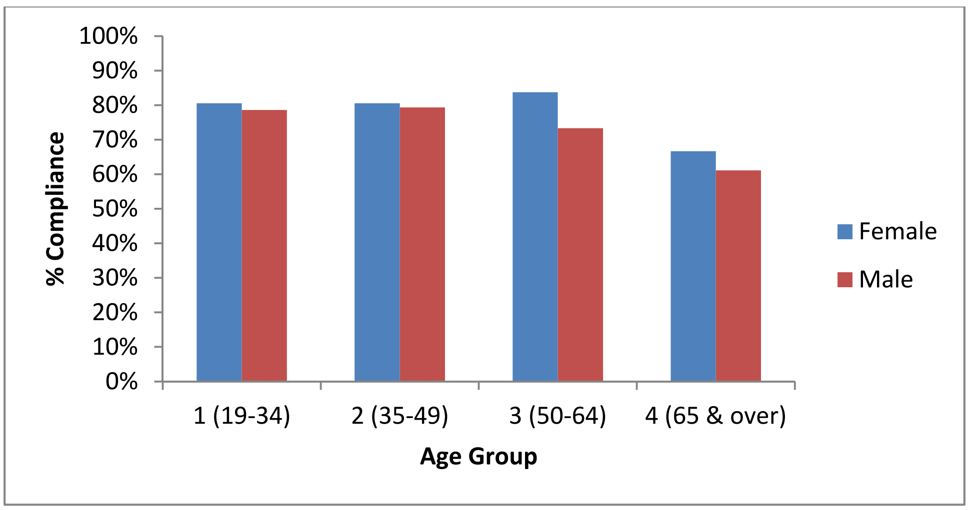
The participants in the field test were recruited from different age groups to represent the overall demographics of the current population of licensed US drivers. Recruited participants were divided into four age groups. Though initially it was planned to maintain the actual percentages of the US driver population for each group, due to difficulty in the recruitment of participants it was not possible to maintain that distribution.

If the compliance rates of different age groups are compared without decomposing to the gender groups, we observe similar response behavior among all the age groups. Age group 4 has the lowest compliance rate among the groups. The other three age groups demonstrated similar compliance rate, ranging from 79% to 84%, which is not statistically significant (Figure 4a). The Chi-square test indicates that there is a statistically significant difference in compliance rate between age group 4 and the other three other groups, such as age group 1 [$\chi2(1, N=189,81) = 7.179$, $p = 0.007376$], age group 2 [$\chi2(1, N=135,81) = 6.713$, $p = 0.009571$], and age group 3 [$\chi2(1, N=207,81) = 7.3017$, $p = 0.006889$].

When compliance rates within an age group are compared between the male and female participants, we observe similar compliance behavior for age groups 1 and 2. In both of these groups female participants have a slightly higher compliance rate than that of male participants (Figure 4b). However, the difference of compliance rates between male and female participants within each age group has no statistical significance. For age group 3, the compliance rate of female participants is close to 84% and that of male participants is approximately 73%. The difference between male and female participants is statistically significant [$\chi2(1, N=117,90) = 2.757$, $p < 0.10$]. Overall, the compliance rates of both female and male participants are lower compared to all the other groups. Even in this group, female participants have higher compliance rate 66%, compared to the 61% rate of the male participants. However, this difference in is not statistically significant [$\chi2(1, N=27,54) = 0.0596$, $p > 0.10$], and it would not be prudent to reach any conclusion about the response behavior with such a small sample size.



(a) Compliance rate across different age groups



(b) Compliance rate across different gender-age groups

Figure 4: Compliance across different age groups

Discussion on Compliance results

Age group and gender: Compliance data on both male and female participant drivers indicate that there is no significant difference in most cases. In some cases female participants demonstrated better compliance rate than their male participants. This behavior may be explained may be with the fact that male and female drivers have different level of risk perception. Though research studies have shown that in some cases male drivers are likely to demonstrate risky driving behavior, risky driving behavior may not necessarily mean higher advisory compliance rate. Though not statistically significant higher female compliance rate may indicate they were more aware of the dynamic traffic condition than their male counterparts and were able to follow the advisories more frequently. However, to reach a strong conclusion regarding gender effect on compliance behavior, it is necessary to conduct extensive investigation on both laboratory and field setting.

When aggregated compliance rate is considered among the different age groups without decomposing into the two gender groups, it is interesting to see significant difference in compliance rate of older driver participants with the other three age groups. This decrease in compliance rate may be in some cases due to the diminishing driving skills and risk perception with age, however with a very small sample size it is very difficult to reach this conclusion. In addition, it is also need to be proven that the older drivers are lacking in those two critical abilities. Another aspect of lower compliance rates among older drivers may be due to the fact older drivers becoming more cautious and the perception among younger drivers of being immune from the effects of high level risk [10] and consequently being more aggressive in accepting gaps or change lanes.

The compliance rates of female participants within each of four age groups are higher than the compliance rate of the male participants. However, the difference of compliance rates between male and female participants was not statistically significant except for the age group 3. Again the higher compliance rate among female drivers can be supported with argument that the female drivers may be more cautious while driving and had better perception of the risk of lane changing. This awareness of the situation may have led them to accept the gaps more frequently than male participants.

Perception-Reaction Time Analysis

One of the main goal of this experiment was to investigate whether response behavior among gender and different age groups. We used linear mixed model with Restricted Maximum Likelihood (REML) approach to analyze both PRT and LCT data sets. Linear mixed effects model is a better approach than ANOVA as the later one requires full data set for all the scenarios. However, all the 68 participants did not comply in all the scenarios, so linear mixed model is a more robust approach in this case with missing data points. In addition, in comparison with ML estimation REML provides more unbiased estimation of variance and covariance parameters [20]. In the following sections, we present a detailed analysis for perception reaction time and lance changing times.

We conducted a statistical analysis in order to examine what factors are significant factor for perception reaction times. In addition, subject was added as random effect to account for the idiosyncratic variation because of individual differences among the participants. In addition, interaction terms also added to account for an interaction and confounding effects. Table-3 presents the fixed factor parameter estimation output generated in SPSS. As hypothesized, both gap size ($p = 0.002$) and strategy ($p = 0.001$) were found highly statistically significant. We have discussed in detail the effects of gap size and strategy in perception reaction time in another paper [21]. In this paper, we will discuss the effects of gender and agegroup in PRT, if any.

PRT analysis between genders

In figure 4, the box plots of PRT for each gap size and for each algorithm for gender groups are presented. From the figure 5(a) in Appendix-a, it seems that female drivers have slightly higher PRT for small and large gaps.
From table-2, we can see that gender was not found as significant factor with significance level, $p = 0.465$. In addition, pairwise comparison revealed that there is no significant difference of PRTs between female ($M = 4.406$, $SD = 0.230$) and male ($M = 4.185$, $SD = 0.218$). This indicates that overall both male and female drivers perceive and react similarly with merge advisories.

Table 2: Fixed Effects of Linear Mixed Model for PRT

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	84.958	698.807	.000
GapSize	2	55.160	5.368	.007
Strategy	2	75.996	6.801	.002
Gender	1	84.958	.191	.663
AgeGroup	3	86.261	3.189	.028
GapSize * Gender	2	55.160	.462	.632
GapSize * Strategy	4	59.212	.665	.619
Strategy * Gender	2	75.996	2.321	.105
GapSize * AgeGroup	6	52.119	1.207	.318
Strategy * AgeGroup	6	74.715	.966	.454
Gender * AgeGroup	3	86.261	1.874	.140
GapSize * Strategy * AgeGroup	12	59.131	1.440	.174
GapSize * Strategy * Gender	4	59.212	1.093	.369
GapSize * Strategy * Gender * AgeGroup	24	63.036	1.590	.073

Perception Reaction time comparison in terms of GapSize between gender

We added an interaction term GapSize*Gender to investigate whether different gap sizes have different effects on PRTs between genders. Model estimation shows no significant interaction between gender and gap sizes with significance level of 0.566 ($p>0.05$). In addition, pairwise comparison did not show any significant differences in PRTs between male and female drivers for any of the gap sizes. However estimates show increasing trend in PRTs for both groups with decreasing gap sizes. This indicates that drivers require more time to perceive and react when gaps are small. This could be also due to drivers tend be more cautious with smaller available gaps and want to avoid any potential conflicts. Figure 5(a) presents the boxplot of PRT across gender for each gap sizes

Perception Reaction Times comparison in terms of Strategy between gender

From figure 5(b), it can be observed that both female and male drivers have relatively higher PRTs for VSL than the two strategies. As presented in Table-2, strategy was a significant factor ($p = 0.001 < 0.05$). So, we included an interaction term Strategy*Gender to find out whether there is any difference in advisory comprehension and preference between male and female drivers. However, no statistically significant interaction was found between strategy and gender with $p = 0.310$ ($p> 0.05$). Pairwise comparison indicates only significant difference in male and female participant for LCA strategy ($p= 0.018$).

PRT analysis among age groups

As mentioned earlier, the field test participants' age ranged from 18 to 79 to represent the overall demographics of US driver population. Recruited participants were divided into four age groups with Age group 1 from 18-34 years, Age Group 2 from 35-49 years, Age Group 3 50 to 64 years and Age group 4 from 65 years and above. Though initially it was planned to maintain the actual percentages of US driver population for each groups, due to difficulty in participant recruitment it was not possible to maintain that distribution. From Table -2, it can be observed that AgeGroup was statistically significant with p = 0.028. Figure 6 presents the boxplot of PRT across different age groups.

Table 3(a) presents the estimate of PRT for each age group and in Table 3(b), the pairwise comparison revealed that there are significant differences in PRTs of age group 4 with the two relatively younger participants group of 1 and 2. This indicates that older drivers require significantly longer time to perceive and react to the advisories.

Table 3(a); Perception-reaction Time estimates for each age group

Age Group	Mean	Std. Error	df	95% Confidence Interval	
				Lower Bound	Upper Bound
1	3.567	.250	82.415	3.070	4.064
2	4.021	.275	90.439	3.475	4.566
3	4.183	.236	92.720	3.714	4.651
4	5.140	.465	81.621	4.216	6.064

Table 3(b): Pairwise comparison of PRT among different age groups

(I) Age Group		Mean Difference (I-J)	Std. Error	df	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
1	2	-.454	.371	86.736	.225	-1.192	.284
	3	-.616	.344	87.146	.077	-1.298	.067
	4	-1.573*	.527	81.901	.004	-2.622	-.524
2	1	.454	.371	86.736	.225	-.284	1.192
	3	-.162	.362	91.423	.656	-.881	.557
	4	-1.119*	.540	83.983	.041	-2.193	-.046
3	1	.616	.344	87.146	.077	-.067	1.298
	2	.162	.362	91.423	.656	-.557	.881
	4	-.958	.521	83.909	.070	-1.994	.079
4	1	1.573*	.527	81.901	.004	.524	2.622
	2	1.119*	.540	83.983	.041	.046	2.193
	3	.958	.521	83.909	.070	-.079	1.994

Perception Reaction time comparison in terms of GapSize among age groups

With the interaction term GapSize*AgeGroup, we wanted to investigate whether younger drivers react differently than older drivers in different traffic conditions that is with different available gap sizes. However, no significant interaction was found between AgeGroup and gapsize though mean estimates also indicated that as gap size decreases the PRT increases for each of the age groups (Figure 6(a)).

Furthermore, Table 4 presents the statistically significant pairwise comparison between the different age groups for all the gap sizes. We did not report the pairs that were found not significant. As reported in the table, for large gap size Age group 4 drivers have significant differences with all the groups. And for all gap sizes the difference PRT between age group 4 &1 were found statistically significant. Again, this indicates clearly older drivers will perceive and react significantly slower than younger drivers in all traffic conditions.

Table 4: Pairwise comparison of PRT among different age groups for each gap size

Gap Size			Mean Difference (I-J)	Std. Error	df	Sig.[c]	95% Confidence Interval for Difference[c]	
							Lower Bound	Upper Bound
Large	1	4	-1.623*	.570	89.679	.005	-2.755	-.491
	2	4	-1.445*	.583	90.771	.015	-2.602	-.287
	3	4	-1.121*	.561	90.471	.049	-2.235	-.007
	4	1	1.623*	.570	89.679	.005	.491	2.755
		2	1.445*	.583	90.771	.015	.287	2.602
		3	1.121*	.561	90.471	.049	.007	2.235
MID	1	4	-1.177*	.543	72.151	.034	-2.260	-.094
	4	1	1.177*	.543	72.151	.034	.094	2.260
SMALL	1	2	-1.071*	.512	71.808	.040	-2.092	-.050
		4	-1.919*	.745	88.812	.012	-3.398	-.440
	2	1	1.071*	.512	71.808	.040	.050	2.092
	4	1	1.919*	.745	88.812	.012	.440	3.398

Perception Reaction time comparison in terms of Strategy among age groups

We also added the interaction term Strategy*AgeGroup to see whether there is any difference in comprehension and preference of advisories among different agegroups. No interactions ($p=0.286 > 0.05$) was found between agegroup and strategy which indicates regardless of age all drivers perceive and reacted to the different advisories in similar manner (Figure 6(b)).

Lane Changing Time Analysis

Similar to PRT analysis, a linear mixed effect model approach was used to analyze the effects of different factors and interaction term on lane changing times. As presented in table-5, the fixed effects results indicate only Strategy as a statistically significant factor (p= 0.035). Both Gender and AgeGroup were found not statistically significant. In addition, interestingly GapSize was failed to attain any significance. This indicates that once drivers started to change lane after perceiving, making decision and reacting to an advisory, the lane changing time did not vary much for different gap sizes as well as for the different strategies.

Table 5: Fixed Effects of Linear Mixed Model for LCT

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	174.506	4624.544	.000
GapSize	2	29.085	.260	.773
Strategy	2	62.542	3.549	.035
Gender	1	174.506	3.425	.066
AgeGroup	3	174.468	2.136	.097
GapSize * Gender	2	29.085	.128	.880
GapSize * Strategy	4	62.725	.125	.973
Strategy * Gender	2	62.542	.139	.871
GapSize * AgeGroup	6	28.068	1.132	.370
Strategy * AgeGroup	6	59.789	.502	.804
Gender * AgeGroup	3	174.468	.649	.585
GapSize * Strategy * AgeGroup	12	55.481	.597	.836
GapSize * Strategy * Gender	4	62.725	.855	.496
GapSize * Strategy * Gender * AgeGroup	24	46.513	.756	.768

LCT analysis between genders

Even though mixed model fixed effect results indicate there is not much difference in LCT between male and female drivers, we conducted pairwise comparison between male and female drivers for each of the gap size. However, there was no statistically significant difference in any of the pairs. As indicated in Table-6, Strategy was significant factor in LCT analysis, however there was no interaction between Strategy and Gender as the interaction term Strategy*Gender was found not significant (p=0.973). In Appendix-A, Figure 7 presents the boxplots of LCT across gender for each gap size (Figure-7(a)) and for each strategy (Figure-7(b)).

LCT analysis among age groups

Unlike in the PRT analysis result, AgeGroup was found as not statistically significant (p=0.097) for lane changing times among the participants. In addition, there were no interactions between GapSize and AgeGroup (interaction term GapSize*AgeGroup with p = 0.370) and Strategy and AgeGroup (interaction term Strategy*AgeGroup with p = 0.804). Furthermore, pairwise comparison among the age groups for gap size and strategy failed to produce any interesting statistically significant results. It would be reasonable to conclude that actual lane changing times did not change much once drivers make the decision to change a lane and unlike PRT, older drivers did not take relatively longer time to change lane when compared with younger drivers. In Appendix-A, Figure 8 presents the boxplots of LCT across age groups for each gap size (Figure-8(a)) and for each strategy (Figure-8(b)).

Conclusion

Connected vehicle technology promises the gaps in current transportation system by providing seamless communication between different entities of this system. Therefore a comprehensive understanding of drivers' response behavior to this new generation of personalized dynamic advisory is of utmost importance for successful deployment and implementation of CV-based mobility applications. Given the significance of the proper understanding of drivers' response behavior in this paper we presented and discusses the findings from a field test that included naïve participants. Based on the drivers' behavior data collected in this research and analysis conducted we have the following major findings:

1. In most cases, there were no significant differences in the Compliance rates between male and female participant drivers. In some cases female participants demonstrated better compliance rate may be explained by different level of risk perception between genders. Higher female compliance rate may indicate they were more aware of the dynamic traffic condition than their male counterparts and low hazard sensitivity among males; hence less awareness. However, to reach a strong conclusion regarding gender effect on compliance behavior, it is necessary to conduct extensive investigation on both laboratory and field setting.

2. Older drivers demonstrated lower compliance rates than the younger drivers. This can be attributed to diminishing cognitive skills and slower information processing among older drivers. Another reason can be with experience driver become more aware of their situation and younger drivers' perception of high immunity from hazards.

3. No significant difference was found in perception reaction times between male and female drivers. However, for both groups it was observed that as available gap size decreases the PRT increased. This indicates with decreasing gap size driver become more cautious and thus require longer time to perceive, make decisions and react. In terms of strategy, neither group demonstrated any significant preference for any strategy in terms of decreased PRT. However, overall both groups have higher PRT for VSL strategies which indicate a quicker response for other two strategies. Both LCA and MCA advisories were more direct in nature than the VSL; therefore it is recommended to deliver more direct advisories in dynamic conditions.

4. Older drivers demonstrated higher perception-reaction times when compared to the younger two groups. As explained earlier, with age related deficits drivers may take longer time to perceive, process and make decisions. There were no significant difference in PRT among age groups in terms of the different strategies.

5. For actual lane changing time, we did not observe any significant differences for both gender and age groups. In addition, it did not also vary much with the type of advisories delivered or the available gap size on the left lane. This indicates once a drivers starts to change lane, the lane changing time did not vary much.

The findings discussed in this paper is necessary for developing, evaluating and implementing of CV-based mobility applications. The results specifically indicate that there are significant differences in how drivers of different age will response to these new generation of advisories. With aging driver population, it will be necessary to investigate more how the mobility applications can be used to improve and enhance the mobility and safety of older drivers in the future.

References

[1] "Ramp Management and Control Handbook | Chapter 5 Ramp Management Strategies - FHWA Operations." [Online]. Available: http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/5_1.htm.

[2] M. Bierlaire, M. Thémans, and K. Axhausen, "Analysis of driver's response to real-time information in Switzerland," vol. 34, pp. 21–41, 2006.

[3] S. Peeta and J. Ramos, "Driver response to variable message signs-based traffic information," *IEE Proceedings-Intelligent Transp. Syst.*, vol. 153, no. 1, 2006.

[4] J. D. Lee, D. V McGehee, T. L. Brown, and M. L. Reyes, "Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator.," *Hum. Factors*, vol. 44, no. 2, pp. 314–34, Jan. 2002.

[5] C. Nowakowski, D. Vizzini, S. Gupta, and R. Sengupta, "Evaluation of Real-Time Freeway End-of-Queue Alerting System to Promote Driver Situational Awareness," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2324, pp. 37–43, Dec. 2012.

[6] T. J. Ayres, L. Li, D. Schleuning, and D. Young, "Preferred time-headway of highway drivers," *ITSC 2001. 2001 IEEE Intell. Transp. Syst. Proc. (Cat. No.01TH8585)*, no. 1980, pp. 827–830, 2001.

[7] E. M. Grey, T. J. Triggs, and N. L. Haworth, "Driver Aggression: The Role of Personality, Social Characteristics, Risk and Motivation," *Stay. 58*, 1989.

[8] "Sex differences in driving and insurance risk." [Online]. Available: http://www.sirc.org/publik/driving.pdf. [Accessed: 25-Nov-2015].

[9] D. L. Massie, K. L. Campbell, and A. F. Williams, "Traffic Accident involvement rates by driver age and gender," *Accid. Anal. Prev.*, vol. 27, no. 1, pp. 73–87, Feb. 1995.

[10] M. L. Matthews and A. R. Moran, "Age differences in male drivers' perception of accident risk: The role of perceived driving ability," *Accid. Anal. Prev.*, vol. 18, no. 4, pp. 299–313, Aug. 1986.

[11] A. Borowsky, D. Shinar, and T. Oron-Gilad, "Age, skill, and hazard perception in driving.," *Accid. Anal. Prev.*, vol. 42, no. 4, pp. 1240–9, Jul. 2010.

[12] B. A. Jonah, "Accident risk and risk-taking behaviour among young drivers," *Accid. Anal. Prev.*, vol. 18, no. 4, pp. 255–271, Aug. 1986.

[13] "Teen Drivers: Get the Facts | Motor Vehicle Safety | CDC Injury Center." [Online]. Available: http://www.cdc.gov/motorvehiclesafety/teen_drivers/teendrivers_factsheet.html. [Accessed: 26-Nov-2015].

[14] E. L. Glisky, "Changes in Cognitive Function in Human Aging." CRC Press/Taylor & Francis, 2007.

[15] F. E. Weinert and W. Schneider, *Memory Performance and Competencies: Issues in Growth and Development*. Psychology Press, 1995.

[16] "Transportation: The Silent Need," *National Center for Senior Transportaiton*. [Online]. Available: http://www.n4a.org/files/Transportation_TheSilentNeed.pdf. [Accessed: 26-Nov-2015].

[17] University of Virginia Center for Transportation Studies, "Freeway Merge Assistance." .

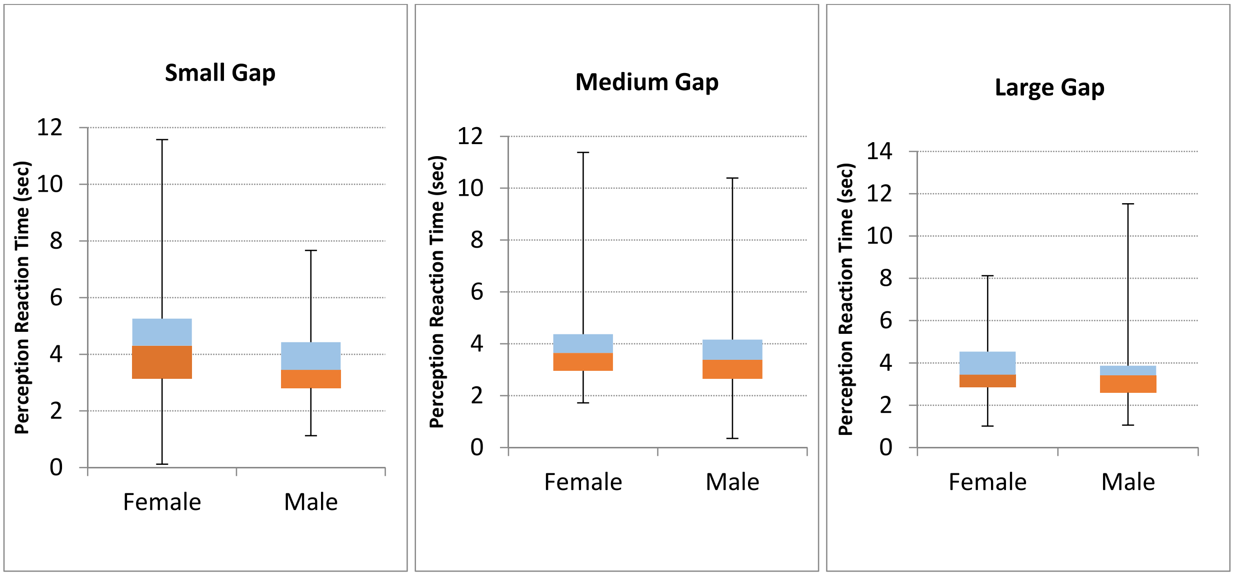
[18] H. Park, C. S. Bhamidipati, and B. Smith, "Development and Evaluation of an Enhanced IntelliDriveSM Enabled Lane Changing Advisory Algorithm to Address Freeway Merge Conflict," in *Proceeding of 90th Transportation Research Board Annual Meeting*.

[19] F. Ye and Y. Zhang, "Vehicle Type-Specific Headway Analysis Using Freeway Traffic Data," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2124, no. -1, pp. 222–230, Dec. 2009.

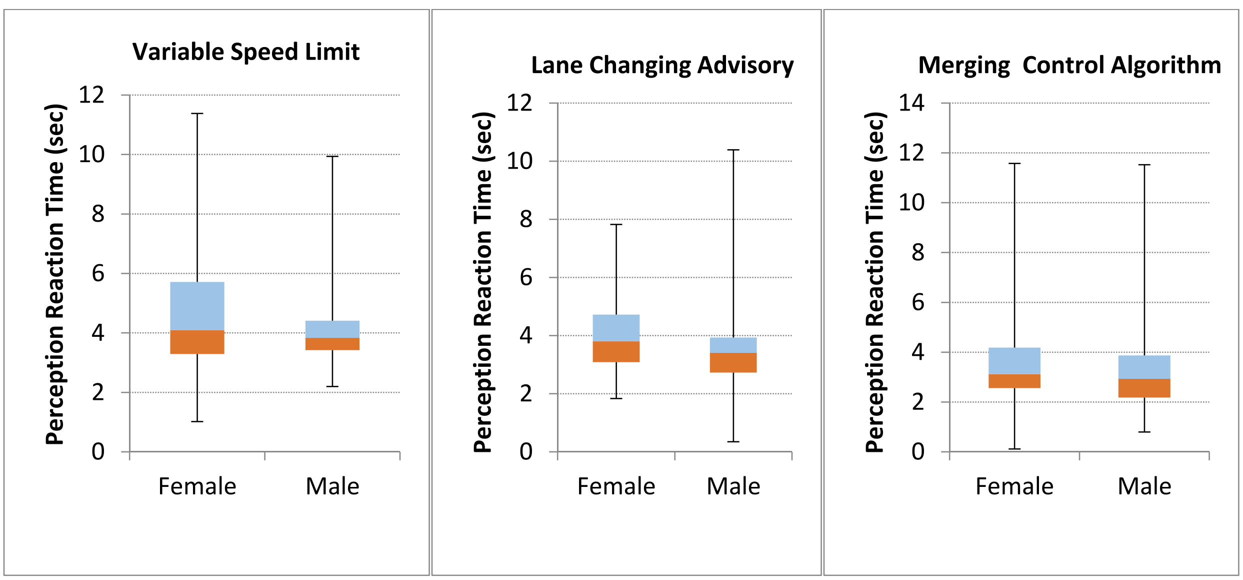
[20] B. T. West, K. B. Welch, and A. T. Galecki, *Linear Mixed Models: A Practical Guide Using Statistical Software, Second Edition*. CRC Press, 2014.

[21] T. Hayat, H. Park, and B. L. Smith, "Investigating Drivers' Response Time To Freeway Merge Management Advisory Messages In A Connected Vehicle Environment," Accepted for presentation and reviewed for publiction in *Transp. Res. Rec. J. Transp. Res. Board*, 2016.

Appendix A

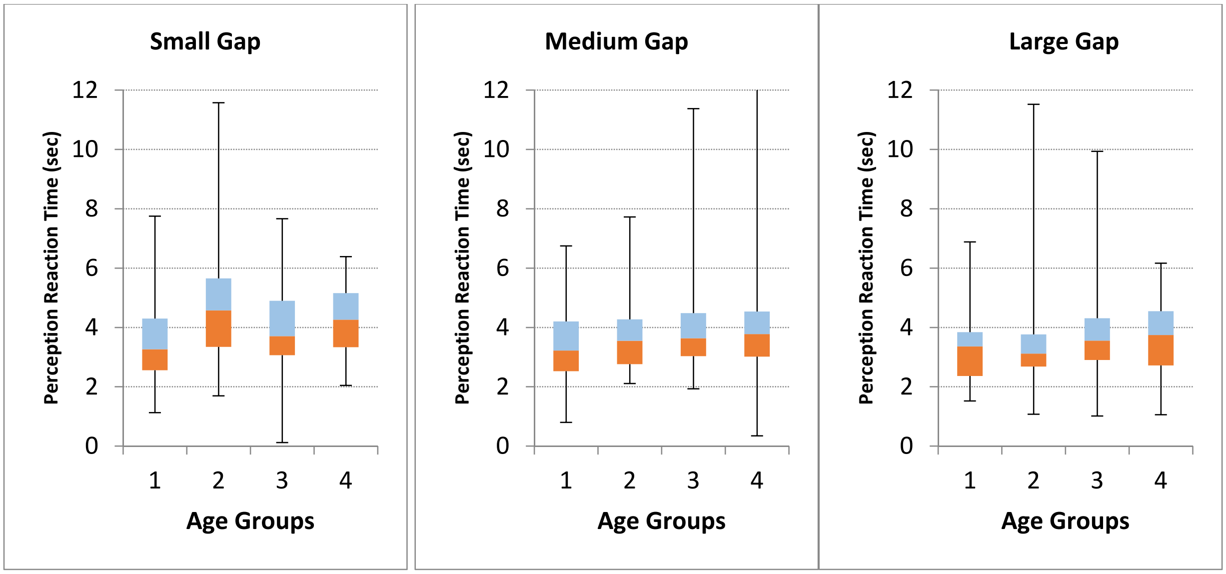


(a) Perception Reaction Times across genders for each gap size

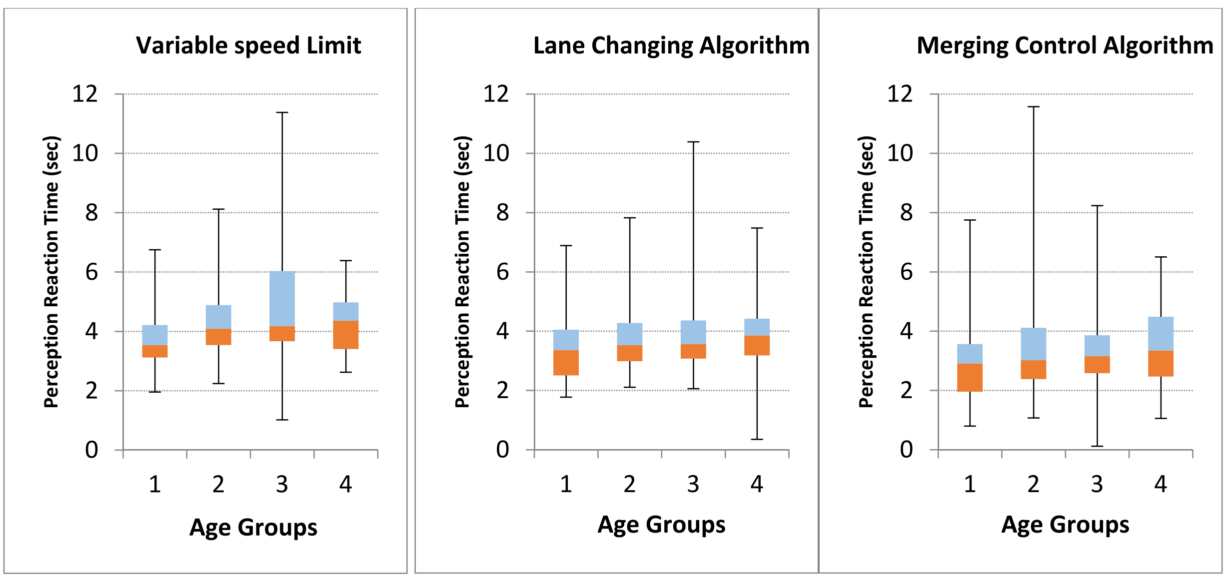


(a) Perception Reaction Times across genders for each strategy

Figure 5: Perception Reaction Times across genders

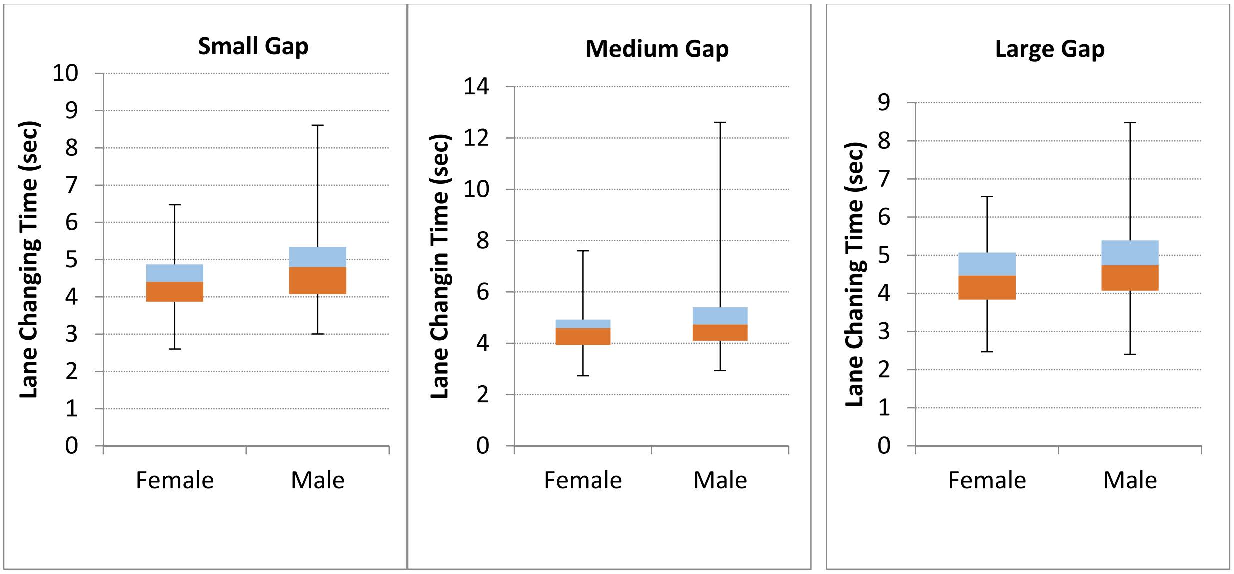


(a) Perception Reaction Times across age groups for each gap size

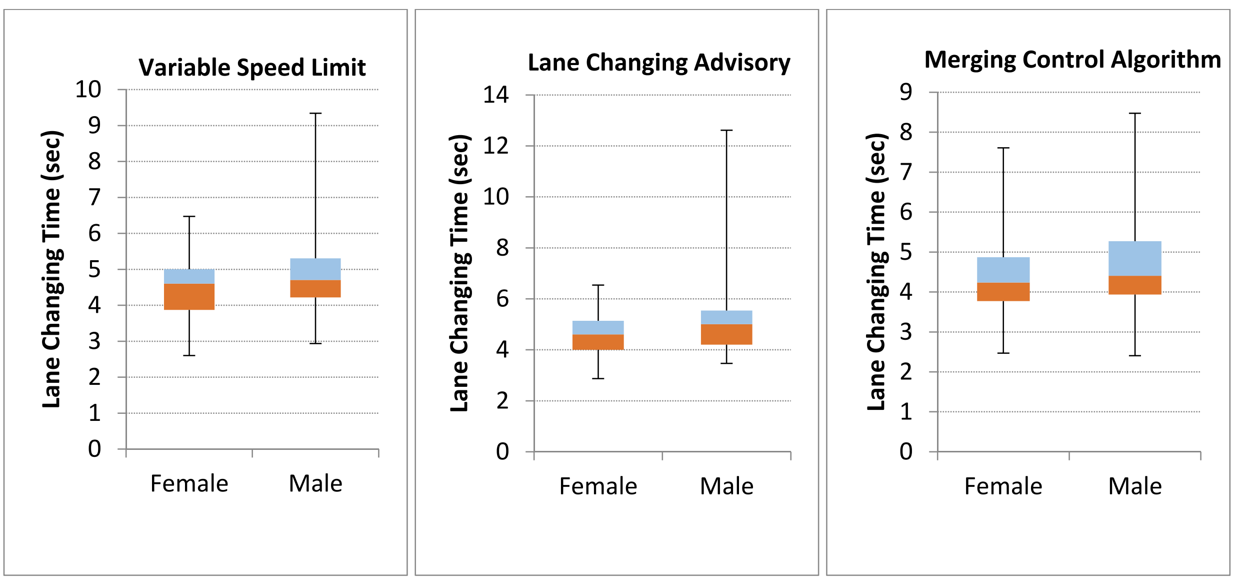


(a) Perception Reaction Times across age groups for each strategy

Figure 6: Perception Reaction Times across age groups

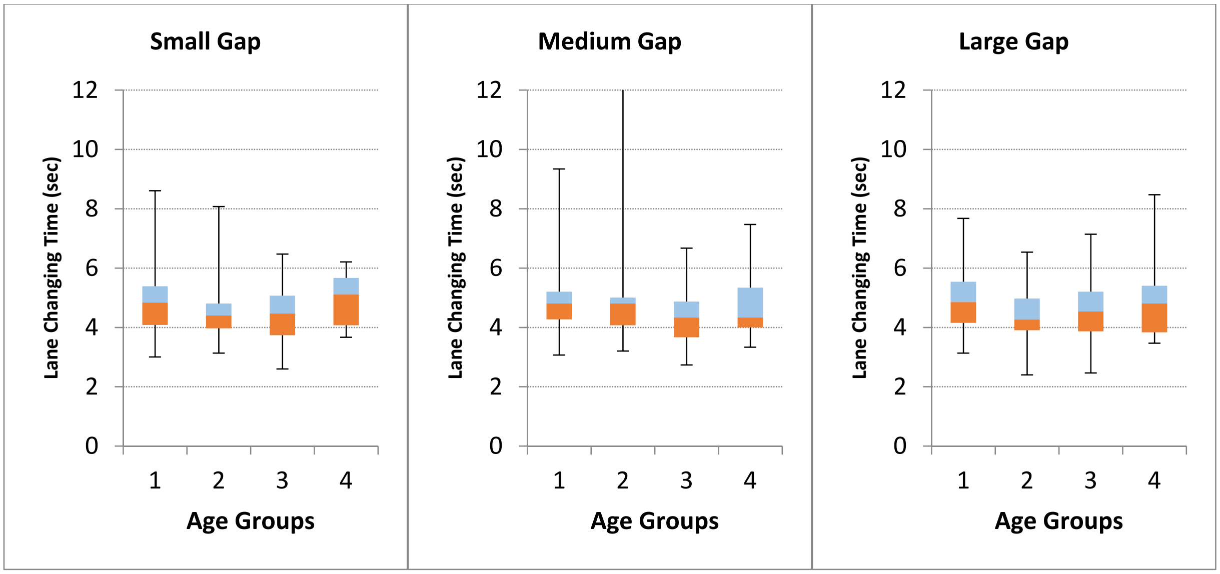


(a) Lane Changing Times across genders for each gap size

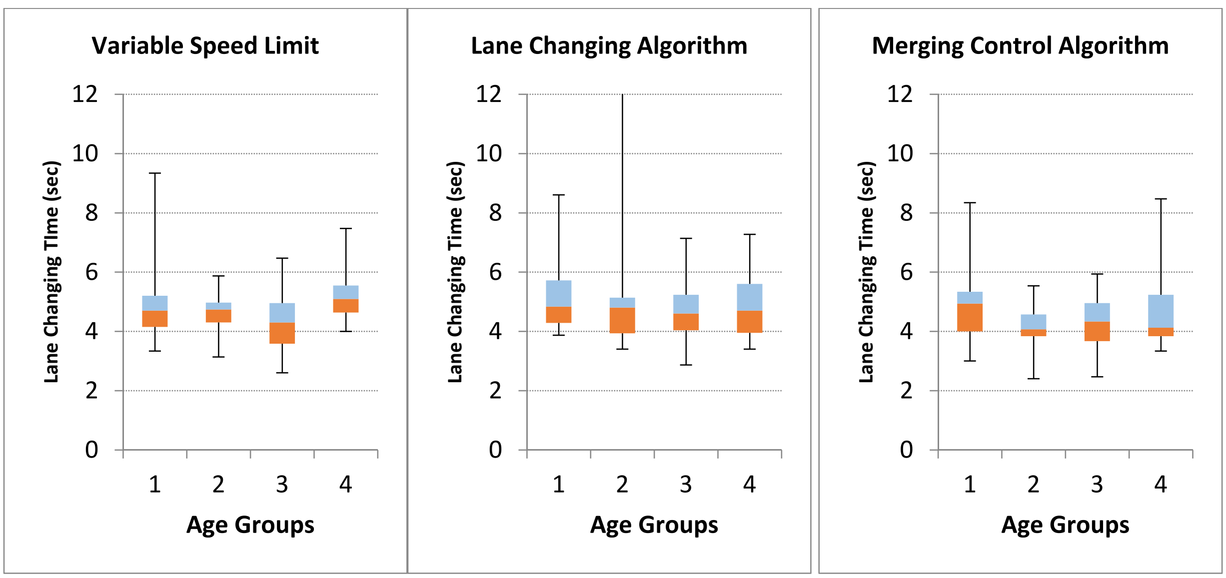


(b) Lane Changing Times across genders for each strategy

Figure 7: Lane Changing Times across genders



(b) Lane Changing Times across age groups for each gap sizes



(b) Lane Changing Times across age groups for each strategy

Figure 8: Lane Changing Times across age groups

Conclusion and Future Research

This research presents a field study conducted to understand drivers' response behavior to a new generation of dynamic advisory messages. Connected-vehicle enabled mobility applications such Freeway Merge Assistance system provides more proactive and cooperative solution to address current freeway congestion problems by ensuring a safer and more efficient merging operations. As the effectiveness of the CV-based mobility application depends on driver response behavior, it is necessary to comprehensively evaluate these systems under different traffic conditions and understand the variability of driver responses. To address this problem, a field study with naïve participants were conducted to collect data on advisory compliance and response times. From the data gathered from the field-test, it is evident that when gaps in the target lane are either large or medium size, drivers are most comfortable complying with the advisories. As gap size decreases drivers compliance also decreases. This indicates that the FMAS will be most effective under free-flow and medium congestion situations. However compliance in small gap scenarios also indicates that the system has potential to improve merging operation even in highly congested conditions. In case of response time, drivers responded quickly in large and medium gap scenarios whereas for small gap scenario drivers reacted more cautiously which resulted in higher response time. Another important finding from this study was that for higher compliance it is desirable to deliver advisories directly to drivers. Indirect advisory messages results in both lower compliance and slower response time from the drivers as observed with the Variable speed limit advisory scenarios. Overall, no significant differences in both compliance rate and perception-reaction time were found in this study between male and female participants. However, older driver groups demonstrated significantly lower compliance and higher perception-reaction time when compared with the younger driver groups.

Recommendation for Implementing Freeway Merge Assistance System

This research study provided some key contributions to body of the transportation engineering knowledge. With the advancement of surface transportation technology, it is important to understand how drivers interact with the new driver assistance system. This new domain of knowledge will help to properly design, evaluate, implement and optimize the functionality and benefits of these new generation of connected vehicle enabled mobility applications. Based on the findings of this research following are some recommendation for implementation of Freeway Merge Assistance System:

1. From collected compliance data, it was observed that drivers tend to comply with larger (88%) and medium-sized (85%) gaps which tend to occur in light to medium traffic conditions. Although a Traffic Engineer is usually interested in managing the worst case scenario of high demand traffic conditions with small gaps, the 58% advisory compliance rate under small-gap size conditions has the potential to improve capacity and safety at the merge area as well as prevent the formation of bottlenecks. Therefore, it is recommended that the FMAS should be adopted by managers of freeway facilities to mitigate the effects of merging conflicts in merging areas. And further investigation is also recommended to evaluate the benefits of implementing FMAS in congested conditions.

2. The lower compliance rate to VSL advisories compared with those of MCA and LCA demonstrates the importance of how to communicate information to drivers. The intended purpose of VSL was to trigger lane changes to higher speed lanes; However, this wasn't relayed clearly enough to the drivers. Therefore, transportation system managers must ensure that the content of traffic advisories to drivers are directly tied to the intended purpose of the advisories. And advisory messages should delivered in a more direct manner so that drivers can easily understand the message content. With respect to VSL, alternative advisories (other than speed limit signs) such as 'MOVE TO FASTER LANES" may be adopted. As the manner and content of messages influence the effectiveness of these type of cooperative CV-based applications, further research can be carried out to understand the impact of advisory message content to driver behavior.

3. A perception reaction time increases as an available gap size decreases. Regardless of the algorithms implemented, drivers reacted more quickly when a larger gap is available. The 0.46 sec difference in average perception reaction times observed from a large gap case (3.62 sec) and a small gap case (4.08 sec) can make a huge difference in the performance of an application implemented and possibly cause unintended safety related issues. On the other hand, with smaller gaps drivers took longer time to react. Therefore, when designing a system or its' strategy, the size of available gaps should be taken into consideration. Simply assuming a uniform perception reaction time regardless of various traffic conditions may lead to an undesirable consequence. And further research should be carried out to investigate what safety implications with difference in PRT with varied traffic conditions. In addition, it is also necessary to understand the optimal delivery time of these message. Sending the messaged too early or too late may have unintended consequences towards safety and mobility.

4. As discussed earlier with respect to compliance rate, a perception reaction time decreases as the advisory becomes more direct and active. Drivers responded more promptly to the merging control algorithm (most direct and active), followed by the lane changing algorithm (medium), and a variable speed limit algorithm (least direct and active). On average, a perception reaction time can be reduced by 1.20 sec (from 4.55 sec of variable speed limit to 3.35 sec of merging control) by providing most direct advisories, which can result in a significant improvement in system performance as well as less unsafety situations. It is therefore recommended that developing and implementing an application that provides more direct advisory messages is desirable.

5. Compliance rate between male and female drivers did not vary much. In addition, there was no significant differences in perception-reaction times and lane changing times between these two groups. This indicates in general both male and female drivers demonstrate similar skills in perceiving and reacting to the advisory messages. However, studies have indicated male driver demonstrating more aggressive and risky behavior than female drivers. Therefore further research should be carried out to investigate any variability in advisory response behavior in dynamic traffic conditions.

6. Older drivers require longer time to process new information, make decisions and react. The data on compliance rate indicated significantly lower compliance rate (63%) among older groups when compared with all other age groups (compliance rate ranged-79%-84%). In addition, the perception-reaction time was significantly higher for the older drivers compared with the younger

drivers. As age-related deficits impact cognitive skills of older drivers, they took longer time to react to advisory messages. Both crash and fatality rates increases for drivers over 65. The compliance rate and average response data collected in this study indicates that design requirements for in-vehicles technologies such as FMAS needs to adjust for drivers with declining skills. This can not only be viewed from the perspective of system engineers to accommodate drivers of all age groups but also it is a great opportunity for traffic safety engineers to utilize these systems to compensate for declining driving ability thus improve safety for older driver population. These systems can be customized to meet the special needs of individual drivers and improve their mobility.

7. A lane changing time does not change much regardless of the types of advisories given and the size of gaps available for a lane change. It was found out that once a driver initiates a lane change (after receiving and understanding advisories, making an appropriate decision, and possibly already finding a gap for a lane change), the time required to complete a lane change does not vary much, ranging between 4.43 sec and 4.97 sec. In addition, at more specific there were no significant difference in lane changing times for both gender and age groups. Once a driver starts to change lane, the total time required for the complete the lane change does not vary much. This knowledge will help system designers to focus on the perception-reaction time which varies different factors as discussed above.

As a future direction of research, a more comprehensive approach can be undertaken to further understand how other situational factors such as vehicle speed, lane geometry, etc. may impact drivers' response behavior. One approach may be to extend this current research in a traffic simulation environment where there will be more flexibility in creating different scenarios to obtain large and diverse sample size data. As CV technology becomes more ubiquitous, a field study with large sample size in real-world environment will give investigate more accurate and significant results. Continuous efforts to understand drivers' response behavior will help effective evaluation and deployment of CV-based applications to improve the safety and mobility of future transportation system.

References

[1] "Ramp Management and Control Handbook | Chapter 5 Ramp Management Strategies - FHWA Operations." [Online]. Available: http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/5_1.htm.

[2] H. Park, C. S. Bhamidipati, and B. Smith, "Development and Evaluation of an Enhanced IntelliDriveSM Enabled Lane Changing Advisory Algorithm to Address Freeway Merge Conflict," in *Proceeding of 90th Transportation Research Board Annual Meeting*.

[3] "Fact Sheet: Improving Safety and mobility Through Connected Vehicle Technology." [Online]. Available: http://www.its.dot.gov/safety_pilot/pdf/safetypilot_nhtsa_factsheet.pdf. [Accessed: 27-Nov-2015].

[4] "Efficient and Safe Merging Solutions - Advanced Freeway Merge Assistance: Harnessing The Potential of Connected Vehicles ." [Online]. Available: http://www.fhwa.dot.gov/advancedresearch/pubs/14045/. [Accessed: 07-Aug-2015].

[5] "Advanced Freeway Merge Assistance: Harnessing the Potential of Connected Vehicles, Exploratory Advanced Research Program (EARP) | Center for Transportation Studies." [Online]. Available: http://www.cts.virginia.edu/advanced-freeway-merge-assistance-harnessing-the-potential-of-connected-vehicles-exploratory-advanced-research-program-earp/. [Accessed: 01-Aug-2015].

[6] H. J. Cho and K. Kim, "Applying stated preference methods to investigate effects of traffic information on route choice," in *Proceedings of the 1st international conference on Advances in hybrid information technology*, 2006, pp. 83–92.

[7] S. Peeta and J. Ramos, "Driver response to variable message signs-based traffic information," *IEE Proceedings-Intelligent Transp. Syst.*, vol. 153, no. 1, 2006.

[8] T. Hayat, H. and Park, and B. Smith, "Investigating drivers response to merge management advisory messages in a connected vehicle environment," *Transp. Res. Board 86th Annu. Meet.*, 2015.

[9] A. Khattak, "Effect of traffic reports on commuters' route and departure time changes," *Veh. Navig. …*, pp. 669–679, 1991.

[10] J. Ma, B. L. Smith, M. D. Fontaine, and F. Zhou, "Examining the Effectiveness of In-Vehicle Auditory Public Traffic Information Compared with Roadside Dynamic Message Signs," in *Transportation Research Board 94th Annual Meeting*, 2015.

[11] M. Rimini-doering, T. Altmueller, U. Ladstaetter, and M. Rossmeier, "Effects of lane departure warning on drowsy drivers' performance and state in a simulator," in *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design.*, 2005.

[12] J. D. Lee, D. V MCGEHEE, T. L. Brown, and M. L. Reyes, "DRIVER DISTRACTION, WARNING ALGORITHM PARAMETERS, AND DRIVER RESPONSE TO IMMINENT REAR-END COLLISIONS IN A HIGH-FIDELITY DRIVING SIMULATOR."

[13] C. Nowakowski, D. Vizzini, S. Gupta, and R. Sengupta, "Evaluation of Real-Time Freeway End-of-Queue Alerting System to Promote Driver Situational Awareness," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2324, pp. 37–43, Dec. 2012.

[14] K. A. Harder, J. Bloomfield, and B. J. Chihak, "The Effectiveness of Auditory Side- and

Forward - Collision Warnings in Winter Driving Conditions," *No. 156. Draft Tech. Rep. Submitt. under Mn/DOT Agreem. No. 74708—Work Order.*, 2003.

[15] J. P. O. Intelligent Transportation System, "Dynamic Mobility Application." [Online]. Available: http://www.its.dot.gov/dma/index.htm. [Accessed: 30-Jun-2015].

[16] "Technical Report on Prototype Intelligent Network Flow Optimization (INFLO) Dynamic Speed Harmonization and Queue Warning." [Online]. Available: http://ntl.bts.gov/lib/55000/55300/55304/100030614-601_Technical_Report_on_Prototype_Intelligent_Network_Flow_Optimization_Final_.pdf. [Accessed: 27-Nov-2015].

[17] "Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design ." [Online]. Available: http://ntl.bts.gov/lib/54000/54800/54895/FHWA-JPO-14-168.pdf. [Accessed: 27-Nov-2015].