Modeling Discretionary Lane Changing Decisions for Connected Vehicles Based on Fuzzy Logic

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Modeling Discretionary Lane Changing Decisions for Connected Vehicles Based on Fuzzy Logic

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Abstract

Lane changing is one of the most complex tasks during driving. Advances in vehicle technology seek to help drivers during the lane change maneuver. Researchers have conducted many attempts to address this issue. However, most of these attempts have not focused on actual driver behavior using advanced vehicle technologies. Among those advances is the vehicle-to-vehicle (V2V) communication which promises safer and more efficient driving operations. This research seeks to fill in this gap by conducting an experiment in a driving simulator environment simulating V2V communication during a lane change maneuver. The experiments allow a better understanding of driver behavior during lane changing maneuvers.

First, a literature review was completed to assess studies that focused on understanding and modeling discretionary lane changes. Then a pilot study was conducted with a small sample on a driving simulator to obtain a fuzzy logic membership function. Then a large sample was tested for the study. Adjustments were made to the model and performance measures were analyzed. A t-test was conducted to evaluate any significant differences between the two conditions with and without V2V communication. The results showed that drivers were more willing to accept smaller gaps under connected environment conditions than without V2Vcommunication. Also, the implementation of V2V communication was found to help drivers make the lane changing decision faster. The overall initial speed was reduced under the connected environment.

Acknowledgments

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Acronyms

ADAS	Advance Driver Assistance System
AFNN	Adaptive Fuzzy Neural Network
DLC	Discretionary Lane Change
FIS	Fuzzy Inference System
HMM	Hidden Markov Model
KU	University of Kansas
LC	Lane Change
MLC	Mandatory Lane Change
NGSIM	Next Generation Simulation
NHTSA	National Highway Traffic Safety Administration
NN	Neural Networks
SSN	Social Security Number
V2V	Vehicle-to-Vehicle

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1. Introduction

1.1. Background

A lane change (LC) process is a driving task that has direct impact on the operation of the traffic stream. Recently, many attempts have been made to achieve a better understanding of this process, and to improve safety and operational efficiency. In the literature, LC is referred to as either discretionary lane change (DLC) or mandatory lance change (MLC) (Yang & Koutsopoulos, 1996; Sun & Elefteriadou, 2011; Sun & Kondyli, 2010). This categorization is because the decision-making process for DLC or MLC has different motivations. While the primary motivation for DLC it is to gain a speed advantage or a better driving environment, for MLC it is to reach the planned destination. Therefore, a different driver behavior is expected for both types of LC maneuvers (Balal & Varnosfaderani, 2016).

Even though most of the existing LC models are fairly recent, it is necessary to update their suitability with modern technology. For instance, in recent years the deployment of vehicles with advanced driver assistance systems (ADAS) has been intensified. Therefore, it is necessary to evaluate how LC decisions change due to new technologies, and to incorporate these changes to advanced driving systems.

On the other hand, it is important to point out that most of the existing models have not considered drivers perception or cognitive reaction (Zheng, 2014). Therefore, it is necessary to develop models that consider human behavior and are validated using data obtained from driver assistance technologies.

1.2. Objective

The objective of this research is to assess the effect of vehicle-to-vehicle (V2V) communication technology in driver behavior during DLC. This is achieved by using fuzzy logic and naturalistic data obtained from a driving simulator. The following points list the objectives of this study.

- Revise the existent models for DLC with and without V2V.
- Develop a simplified model for DLC.
- Assess driver's performance during DLC measuring performance variables (initial speed, acceleration rate, decision time, lane-change duration and cognitive workload).
- Assess driver's performance during DLC implementing V2V.
- Propose a model for DLC in a connected environment.

1.3. Significance of the Research

In the United States, 94% of the crashes are assigned to driver error (Bulumulle & Bölöni, 2016). The National Highway Traffic Safety Administration (NHTSA) has been increasing their support for policies that push forward technologies that can reduce human error in the driving task. Therefore, the focus of this research is to model and evaluate the acceptance response to new technologies, such as V2V communication, during lane changing events.

1.1. Thesis Outline

The remaining of this document includes: a literature review of the lane changing decision models in Section 2, the proposed methodology in Section 3, the results of the study are shown in Section 4 while the summary and conclusions are presented in Section 4.

2. Literature Review

2.1. Classical Approaches of LC

Many attempts have been conducted to model LC maneuvers. Among those it is worth citing the work of Zheng (2014); who completed a comprehensive review of lane changing decision (LCD) models. In his article, he classified them as: Gipps type, utility theory, cellular automata, hazard-based, Markov process, fuzzy logic, game theory, and neural networks. A general description for each classification is provided below.

2.1.1. Gipps (1986)

These deterministic models are based on four steps: decision, lane choice, acceptable gap and execution. Yang & Koutsopoulos, (1996) introduced randomness in the initial model considering the probability of a LC for a mandatory maneuver. Among the explanatory variables are; maximum safe speed for LC vehicle with respect to the leader, deceleration rate, the time step of updating speed and position, location of the front vehicle and the effective length of the vehicle.

2.1.2. Utility theory (Sun & Elefteriadou, 2012)

This is a stochastic model that considers driver behavior based on field data observations. The experiment was conducted in an urban environment. The variables that this model considers are: density in target lane, queue length ahead, the location of the bus stop, number of people at bus stop, and driver behavior.

2.1.3. Cellular automata (CA)

This type of model consists of discretization of the road segment to an array of cells with constant dimension. Each cell can take binary values (0, 1) which represent the presence of a vehicle or gaps between vehicles. Typically, CA models consider four components: the physical environment, the cells' states, the cells' neighborhoods, and local transition rules. The model analyzes and updates the information of each cell based on the speed of the vehicles, vehicles' position, and gaps between them. This model does not consider driver behavior and is suitable for macroscopic level analysis but not for a microscopic level analysis (Maerivoet & De Moor, 2005).

2.1.4. Markov process (Toledo & Katz, 2009)

This model is based on the hidden Markov model (HMM). The assumption of this model is that at each time step the system may either remain in its current state or change to another. The model considers the utility of a LC, the probability of a LC, and the gap acceptance. Its explanatory variables are: target lane choice, gap acceptance, utility based on spacing and relative speed, and distance to an exit ramp. This model also considers the heterogeneity of drivers.

2.1.5. Hazard-based-survival (Hamdar, et al. 2008)

The main assumption in these models is that the behavior of the following vehicle (e.g., change in acceleration) is related directly to a stimulus observed or perceived by the driver, defined relative to the lead vehicle (e.g., the difference in speeds or headways). Among the variables are: acceleration, anticipation horizon, utility of a LC maneuver, and accident weighing factor.

2.1.6. Fuzzy logic 'fuzzy inference system'(Balal et al. 2016)

This model was specifically developed to simulate DLC on freeway facilities. The explanatory variables were gaps between the subject vehicle and surrounding vehicles and the distance between the leading and following vehicles in the target lane. The model was developed based on driver surveys which is an advantage, since it is considering driver perception, but has not been evaluated using actual drivers.

2.1.7. Neural Networks (NN)

Recently, the use of neural networks has been increasingly applied in traffic flow theory to simulate human behavior. Tang, et al., (2018) introduced a lane-change prediction model based on adaptive fuzzy neural networks (AFNN). They conducted an experiment in a driving simulator environment under different speed scenarios. They affirmed that the model can accurately predict the lane changing decision based on the steering angle. Their model inputs were: distance and speed between lead vehicle and subject vehicle, planar coordinates, headway, and acceleration, while the output is the steering angle. They argued that the results with the AFNN model prediction were more accurate compare to other machine learning models. However, the model required the introduction of a safe distance in the target lane since the current model just considered the safe distance in the starting lane. The following table summarizes the review conducted by (Zheng, 2014).

Table 2-1. LCD model review from Zheng 2014

LCD Model	Description	Explanatory variables	Limitations
Gipps (1986)	Steps: • Decision • Lane choice • Acceptable gap • Execution	• Safe speed • Deceleration rate • Time • Location • Vehicle length	Lane change occurs when it is safe. The interaction between the lane changer and the follower in the target lane is minimal
Utility theory (Sun & Elefteriadou, 2012)	The model defined four types of drivers (A, B, C, D). Drivers select whether to change or not base on utility	• Traffic congestion • Queue ahead • Location of the next downstream bus stop • Distance to the bus • Number of persons at the bus stop • Driver behavior	Possible bias since drivers behave differently when they know that they are being observed
Cellular automata (Maerivoet & De Moor, 2005)	Based on acceleration and breaking Wolfram rule 184	• Speed • Position • The gap with leader	Does not consider driver behavior. Better results at the macroscopic level
Markov process (Toledo & Katz, 2009)	Model based on hidden Markov model (HMM)	• Target lance choice • Gap acceptance • State dependence between variables • Utility	Does not consider driver behavior
Hazard based (survival) (Hamdar, et al. 2008)	Behavior of the following vehicle is related directly to a stimulus observed or perceived by the driver, defined relative to the lead vehicle	• Acceleration • Anticipation horizon • Utility • Accident weighing factor	It is not clear which strategy was employed in their study
Fuzzy logic 'fuzzy interface system' (Balal et al. 2016)	"Is it time to begin to move into the target lane?"	• Gap between subject and surrounding vehicles • The available distance in the target lane	The model was not developed with data obtained from drivers

These lane changing models found in the literature were based on vehicle features, gap acceptance, acceleration rates, safety distance, and the relative speed between vehicles. However, most of them do not consider driver behavior. From all models reviewed, fuzzy logic is one of the most understandable approaches to model the lane changing decision process. Moreover, fuzzy logic mimics the human decision process. In addition, its applicability to computer algorithms in driving simulators or simulation models makes this group of models less challenging than intelligent algorithms such as neural networks, game theory, and their variants.

2.2. Fuzzy Logic in LC models

Fuzzy logic is a mathematical method to represent imprecise concepts. While crisp logic takes values as 0 or 1 for logic operations, fuzzy logic allows to divide the range from 0 to 1 into different outcomes. For instance, in crisp logic we can catalog gaps between vehicles into close or far depending on the perception of the driver, however with fuzzy logic we can add another gap category such as close, medium, and far. This advantage allows us to be more flexible by considering more options in the decision-making process. However, it also adds more complexity to the process, (Royer, 2010).

Fuzzy logic has been implemented in LCD models since 1997 (Zheng, 2014). Generally, fuzzy logic requires the definition of fuzzy sets and a membership function. In addition, it typically comprises of the following four steps (Balal et al., 2016):

- Fuzzification: In this step, the crisp inputs are converted into membership values through the application of a fuzzy membership function and the means of the fuzzy sets.
- Inference: Then fuzzy rules are applied i.e., If…And…Then.
- Composition: In this step a single fuzzy set is assigned to each output parameter.
- Defuzzification: Finally, each membership output and fuzzy set are converted into a crisp value.

2.3. The Fuzzy Inference System (FIS) proposed by (Balal et al., 2016)

This section presents the considerations in (Balal et al., 2016) for the development of the FIS. First, they completed a survey among 443 drivers to determine the variables that drivers use to complete a DLC. The outcomes of this survey were the following four variables (**Figure 2-1**):

$\boldsymbol{G_{FA}}$: Gap between vehicle S and vehicle FA

$\boldsymbol{G_{PA}}$: Gap between vehicle S and vehicle PA

$\boldsymbol{D}$: Distance between vehicle PA and FA

$\boldsymbol{G_{PB}}$: Gap between vehicle S and vehicle PB

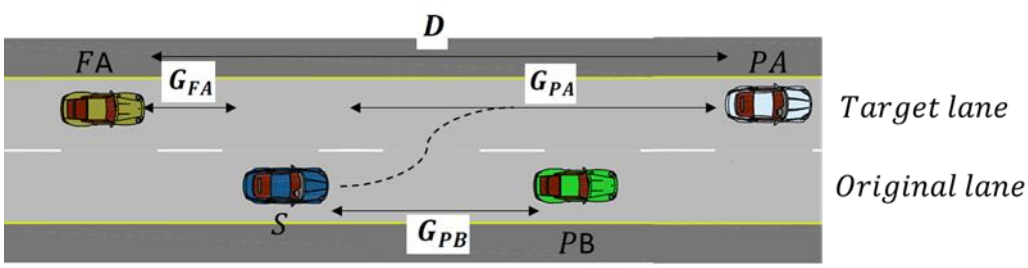


Figure 2-1. Typical vehicles considered in the LC process (Balal et al., 2016).

In their research, they calibrated and validated the model with Next Generation Simulation (NGSIM) data. Then they compared their results with TRANSMODELER's gap acceptance model for DLC on freeways. After this comparison they argued that the FIS performs better than the TRANSMODELER's model.

2.3.1. Fuzzy sets

The fuzzy set includes three linguistic values, i.e., {close, medium, far} which are applied to the decision variables obtained from the driver's survey, i.e., $\{G_{FA}, D, G_{PA}, G_{PB}\}$. The FIS output variables are yes and no.

2.3.2. Fuzzy membership functions

The fuzzy membership function for the input variables G_{FA}, G_{PA}, G_{PB} are defined in **Figure 2-2**, while the function for D is in **Figure 2-3**. The fuzzy membership function represents the number of decision variables $\{G_{FA}, D, G_{PA}, G_{PB}\}$ multiplied by the number of linguistic values {close, medium, far} i.e., $4 \times 3 = 12$. The fuzzy membership values shown in **Figure 2-2** and **Figure 2-3** were based on the Association of Car Rental Industry System Standards (ACRISS), the Texas Driver Handbook and the NGSIM data. However, it was not clear in the Balal et al. (2016) study which values were calibrated from the NGSIM data.

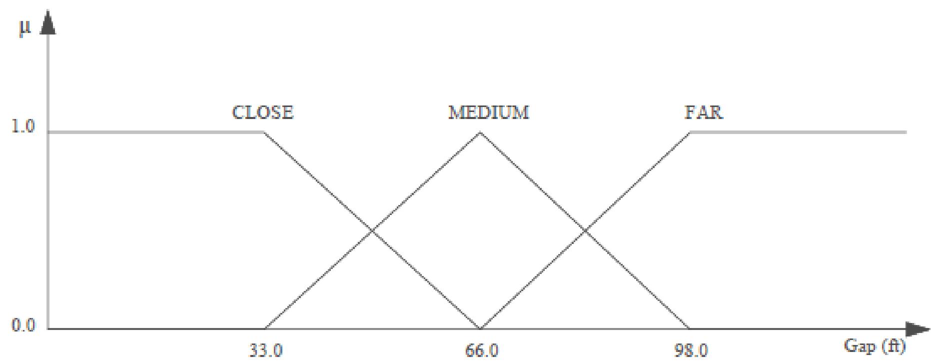


Figure 2-2. Fuzzy membership function for Gap.

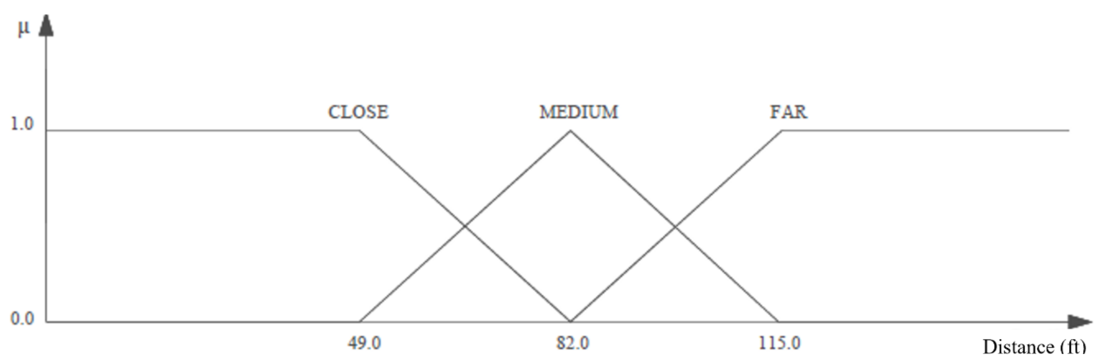


Figure 2-3.Fuzzy membership function for Distance.

2.3.3. Fuzzy rules

The fuzzy rules were initially determined to be 81, however, its number was reduced to 51 since some of them were considered infeasible. Table 2 enlists the 51 rules applied in the FIS proposed by (Balal et al., 2016).

2.3.4. Defuzzification

In this step they converted $\tilde{C}$ to a binary decision or recommendation comparing the $\tilde{C}$ value with a threshold τ which represents the output of the fuzzy inference system. This value was obtained during the training process with the NGSIM data. The fuzzy recommendation (FR) is:

$$FR = \begin{cases} 1\ for\ \ \text{"yes change lane"} & if\tilde{C} \geq \tau \\ 0\ for\ \ \text{"no, do not change lane"} & if\tilde{C} < \tau \end{cases}$$

Table 2-2. Fuzzy Rules.

Rule No.	IF				THEN
	$\widetilde{G_{FA}}$	$\widetilde{G_{PA}}$	$\widetilde{G_{PB}}$	$\tilde{D}$	$\tilde{C}$
1	Close	Close	Close	Close	No
2	Close	Medium	Close	Close	Yes
3	Close	Close	Medium	Close	Yes
4	Close	Close	Far	Close	Yes
5	Close	Close	dose	Medium	No
6	Close	Close	Close	Far	No
7	Close	Medium	Medium	Medium	Yes
8	Close	Far	Far	Far	Yes
9	Close	Close	Medium	Medium	No
10	Close	Close	Medium	Far	Yes
11	Close	Close	Far	Medium	Yes
12	Close	Medium	Close	Medium	No
13	Close	Medium	Far	Close	No
14	Close	Medium	Far	Medium	Yes
15	Close	Medium	Far	Far	Yes
16	Close	Medium	Medium	Close	No
17	Close	Far	Far	Close	Yes
18	Close	Medium	Medium	Far	No
19	Close	Medium	Close	Far	No
20	Close	Medium	Medium	Far	Yes
21	Close	Far	Far	Medium	Yes
22	Close	Far	Medium	Far	Yes
23	Medium	Medium	Medium	Medium	Yes
24	Medium	Close	Medium	Medium	Yes
25	Medium	Medium	Far	Medium	Yes

Rule No.	IF				THEN
	$\widetilde{G_{FA}}$	$\widetilde{G_{PA}}$	$\widetilde{G_{PB}}$	$\widetilde{D}$	$\widetilde{C}$
26	Medium	Medium	Medium	Far	Yes
27	Medium	Medium	Medium	Close	Yes
28	Medium	Far	Far	Far	Yes
29	Medium	Medium	Far	Far	Yes
30	Medium	Close	Medium	Close	Yes
31	Medium	Far	Far	Medium	Yes
32	Medium	Medium	Far	Close	Yes
33	Medium	Close	Far	Close	No
34	Medium	Close	Far	Medium	Yes
35	Medium	Close	Medium	Far	Yes
36	Medium	Close	Close	Far	No
37	Medium	Far	Far	Close	Yes
38	Medium	Close	Close	Close	No
39	Far	Far	Far	Far	Yes
40	Far	Medium	Medium	Medium	Yes
41	Far	Close	Far	Far	Yes
42	Far	Medium	Far	Far	Yes
43	Far	Far	Medium	Far	Yes
44	Far	Far	Far	Close	Yes
45	Far	Far	Far	Medium	Yes
46	Far	Far	Medium	Medium	Yes
47	Far	Close	Far	Close	Yes
48	Far	Medium	Far	Medium	Yes
49	Far	Medium	Far	Close	Yes
50	Far	Close	Medium	Close	Yes
51	Far	Close	Medium	Medium	Yes

2.4. Lane Changing in Connected Environment

In the last years, vehicle technology has been increasing exponentially. Several technologies have been implemented with the main purpose of making the driving task safer and more efficient. Some of those advances include V2V communication, which allows vehicles equipped with wireless communication tools to share data between them (speed, position, etc.). Nevertheless, while V2V communication is a new tool to make driving an easier task, it also introduces a new sight to the previous LCD models. The integration of V2V communication could allow drivers to have a better perception of what the surrounding vehicles are doing: are they slowing down, or accelerating, are they keeping in the lane or changing to the next one, and so on. The applicability of V2V communication is really extensive and at a proper market deployment, it will enhance traffic operations (Ye & Yamamoto, 2018).

One application of V2V communication is at on-ramps where vehicles in the mainstream and vehicles on the ramp cooperate to adjust their speed and create a safe merging gap. For instance, (Xie et al., 2014) conducted a research where vehicles communicate and cooperate with each other in order to create gaps for merging maneuvers. Their simulated results in VISSIM show that operations were enhanced using this cooperative-communicative strategy compared to the default driver behavior included in the software package. Similarly Bui & Jung, (2018) conducted an analysis of an intersection in a connected environment. Their simulated results show that a connected approach outperforms operations using traditional traffic systems without connectivity.

Bevly et al., (2016) completed a survey related to the application of V2V communication systems. They found some studies that helped drivers to plan their trajectories in advance and warn them about a collision hazard, and even help drivers make a decision related to the road's geometry. Today manufacturers are implementing V2V systems in their new cars; however, it is necessary to study how human drivers will perform with this assistance system.

2.5. Modeling V2V in a Driving Simulator

Driving simulators have been widely used for driver behavior studies. This is mainly due to the resemblance between a simulated and a real environment with the advantage that in the simulated environment, subjects are not exposed to collisions that could lead to physical injuries. Moreover, a simulator has the benefit of allowing researchers to set many subjects to identical conditions, i.e., traffic density, speed, headway, the behavior of surrounding vehicles, etc. These features allow researchers to evaluate drivers' reaction to a specific scenario, which is impossible to achieve in real world where conditions vary widely.

Kummetha (2017) provided a concise description of the mechanics and history of driving simulators and their applicability to driver behavior studies. Capustiac (2011) categorized driving simulators into high-level, mid-level, and low level simulators.. The author pointed out the disadvantage of low-level simulators, i.e., fixed-base simulators, which is known as simulation sickness. This sickness is due to the lack of perception from the ear organs and skin that allow humans to perceive motion while the eyes perceive motion cues in the simulation.

There are few driving simulator studies dedicated to the understanding of drivers' behavior during lane change maneuvers and even fewer considering V2V communication during lane changes. There are some exception though, as in (Ali, Zheng, & Haque, 2018) where they studied driving behavior during MLC in a connected environment. In their experiment, they simulated V2V communication showing drivers the available gaps in the target lane. They claim that when drivers have information about the gaps in the target lane, they tend to wait for longer gaps to merge on the target lane. Also, they argue that there is an increase in the time to complete the LC maneuver in the connected environment compared to the baseline environment, i.e., without connectivity. They indicated that a MLC in a connected environment is safer compared to those with no connectivity at all. However, it also means that the capacity is reduced.

2.6. Summary

The major findings of this literature review can be summarized in the following points:

- Most of LC models have been focused on vehicle features and do not consider driver behavior. Therefore, there is a need to integrate driver perception to LC models.
- According to Balal et al., (2016) variables such as $\{G_{FA}, D, G_{PA}, G_{PB}\}$ are strongly related to the lane changing decisions, **(Figure 2-1)**.
- Fuzzy-based models emulate the human decision process and are less complicated than others such as neural networks models.
- V2V communication has the potential to enhance traffic operations. However, there is a need to evaluate its impact during DLC.
- Driving simulators allow researchers to study driving behavior during LC maneuvers in a safe environment.
- Few driving simulator studies has tended to understand driving behavior during LC.
- According to Ali et al., (2018) MLC with V2V communication were safer but reduce capacity when drivers received information about the available gaps in the target lane.

3. Methodology

This section presents the different steps undertaken in this research. The entire experiment was performed in the driving simulator at the University of Kansas (KU) **(Figure 3-1)**.

Figure 3-1. Driving Simulator at KU.

To evaluate driver behavior during the DLC in the simulator it was crucial to induce drivers to change lanes. In other words, it was required to set conditions where it can be anticipated if drivers will decide to change lanes or not. Taking this into account, the experiment was designed to follow similar rules as the fuzzy logic model proposed by Balal et al. (2016). This model estimated the probability of a lane change depending on the gaps between the subject and surrounding vehicles. The fuzzy model type was selected because it emulates the decision making of humans and its implementation in the driving simulator does not require any alteration in the software's code. Furthermore, while the setting of the model was based on an existing model, it has been simplified by using general fuzzy rules and the fuzzy membership function. A detailed description of the design of the model is provided in the following sections. In general, the steps that were conducted in this study are presented in **Figure 3-2.**

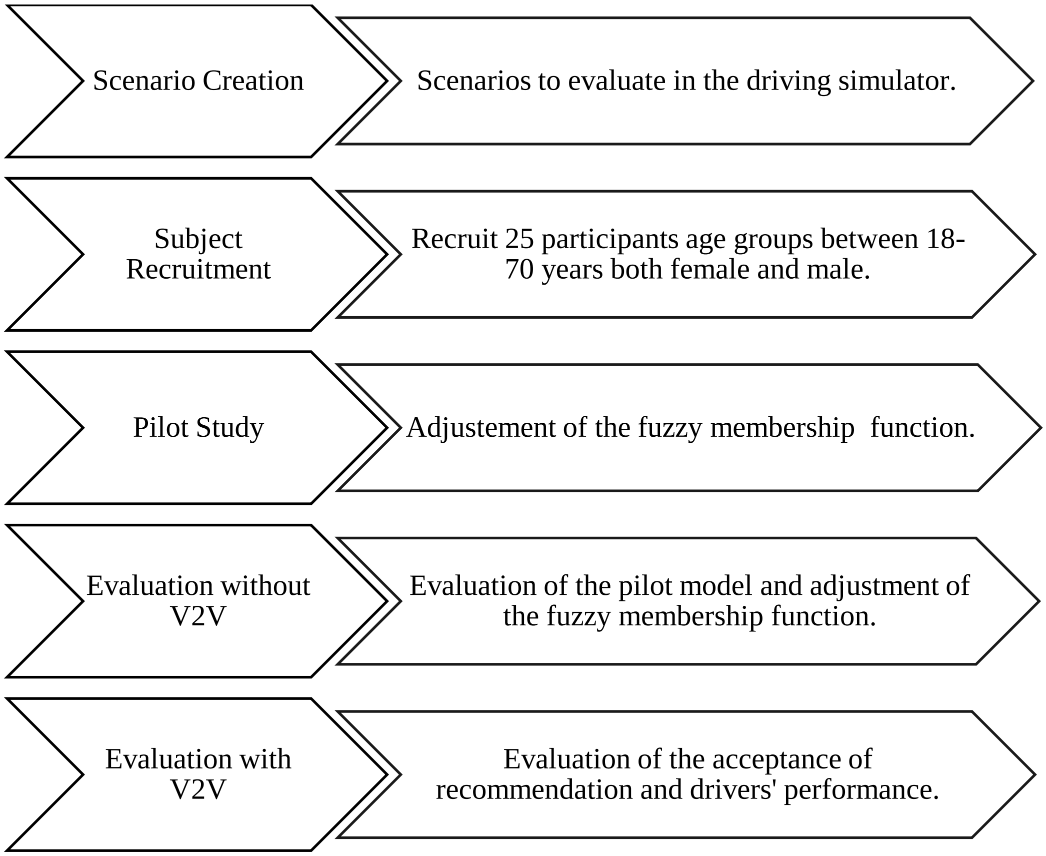


Figure 3-2. Methodology Stages

The first step includes the scenario creation. This stage was completed considering the experiment duration (30min) and the speed of the facility (70mph). The second step was the subject recruitment. A pre-screening questionnaire was developed to evaluate the eligibility of participants. The third one was the pilot data collection and modeling without connectivity. In this step, a small sample was tested to verify the applicability of the fuzzy membership function proposed by Balal et al., (2016). This step assisted in adjusting the fuzzy membership function. The fourth step was the data collection of a large sample (25 participants), and the fuzzy membership adjustment from the pilot model. In this step, a new set of fuzzy rules was developed to model DLC. The fifth step, like the previous one, was conducted using a large sample (25 participants). V2V communication was simulated in the driving simulator to evaluate driver behavior.

3.1. Step 1: Scenario Creation

3.1.1. Creating the Scenario

The scenario allowed the subjects to drive for 30 minutes, at an average speed of 70mph. It was decided that the lane changing maneuvers were to be evaluated in tangent segments. Therefore, the scenario should have segments large enough to allow drivers to complete the lane changing maneuvers (1.5 miles) in tangent rather than curve segments. On the other hand, to avoid subjects becoming uninterested, the scenario had variability in its design (curves, interchanges, etc.) To achieve this, a two-lane two-way rural highway of thirty-six miles (36.5mi) was conceptualized. As depicted in **Figure 3-3** the scenario has ten (10) tangent segments separated by interchanges or curves. This arrangement allowed setting nine events where lane changes were evaluated. An event was described as an arrangement of vehicles that keep specific gaps with each other. Each event had numerous lane changing opportunities. The maximum gap that drivers were willing to accept was measured for each lane change opportunity. Furthermore, driving behavior during lane changing was also measured.

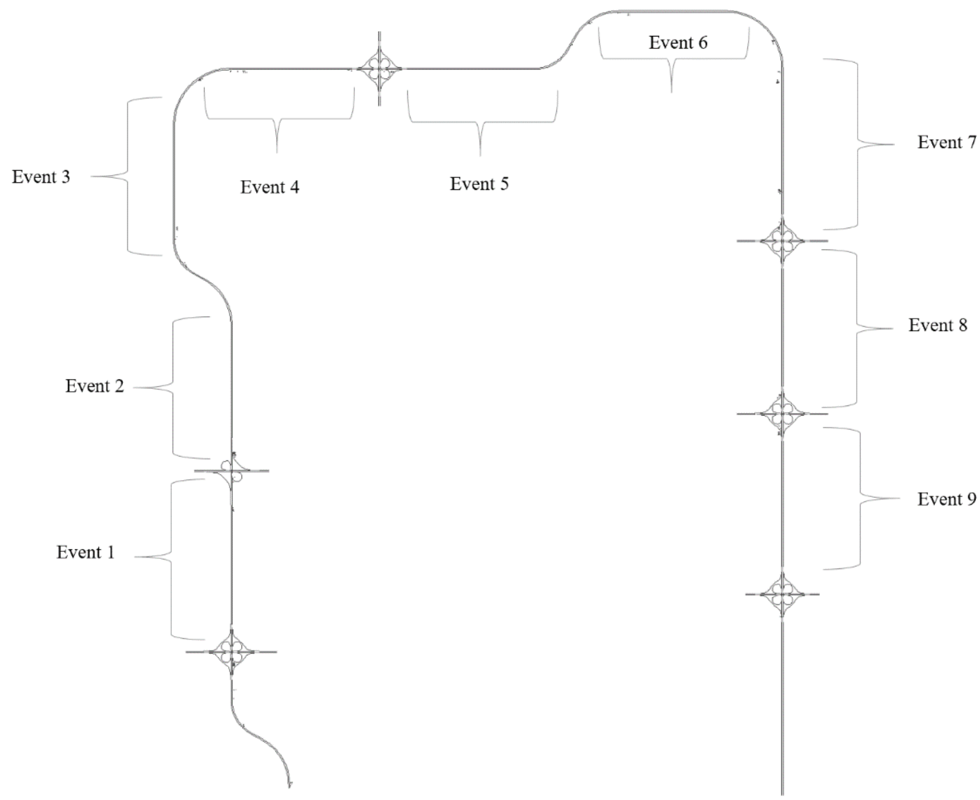


Figure 3-3. Scenario.

3.2. Step 2: Subjects Recruitment

This stage was one of the most challenging since the whole experiment relied on having subjects willing to help with the study. Also, subjects had to be a representable sample of the driving population.

To accomplish this step, flyers of the study were advertised on bulletin boards in the KU Lawrence Campus, churches, social media, Lawrence public library, and other locations around Lawrence, KS. Participants were selected through prescreening questionnaires, to ensure variability in their driving experience, and capture both male and female subjects (**Appendix A)**. Subjects' age varies from 18 to 70 years. The questionnaire included questions related to their willingness to participate in the study as well as demographics, motion sickness records, and driving habits/experience. Thirty participants were recruited. However, five of them experienced motion sickness. **Figure 3-4** and **Figure3-5** show the distribution by age and gender of the participants that completed the experiment.

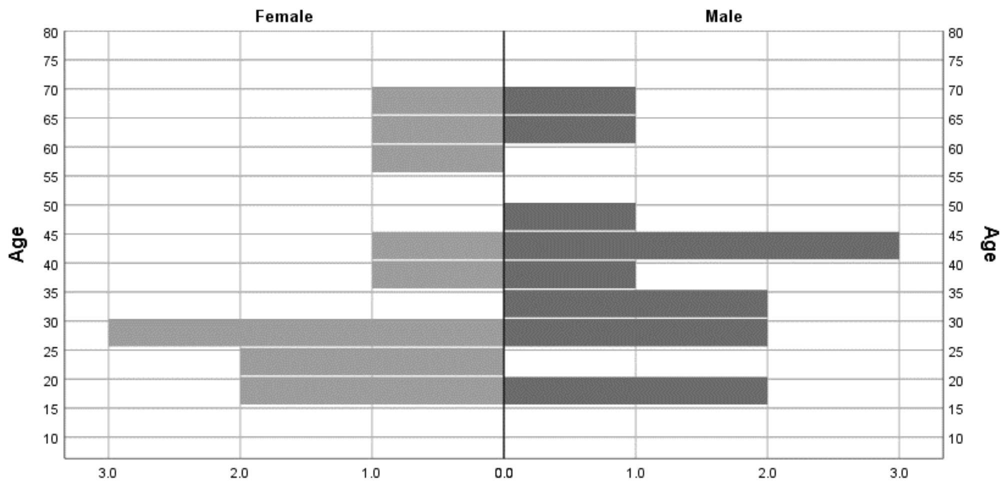


Figure 3-4. Participants' pyramid by age and gender.

Participants were asked to drive the same scenarios in the driving simulator. The whole duration of the driving simulator experiment lasts around 65 minutes including 5 minutes at the beginning of the test to allow drivers to get used to the driving environment. Participants were asked to come just once and complete the simulation with and without V2V. Also, they were monitored all the time to identify any symptoms of motion sickness.

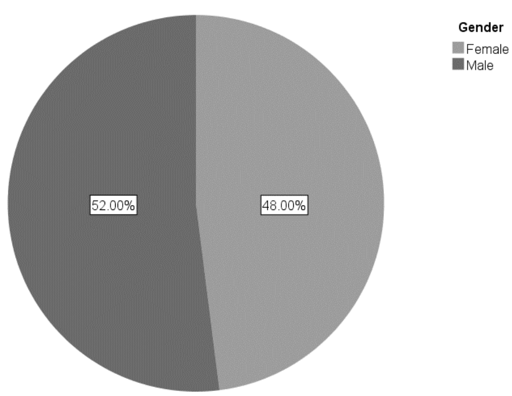


Figure 3-5. Participants' gender distribution.

3.3. Step 3: Pilot study without V2V.

3.3.1. Fuzzy model simplification

The original fuzzy membership function was developed considering four variables as described in section **2.3**, $G_{FA}, D, G_{PA}, G_{PB}$. However, D is function of G_{FA}, G_{PA}, and the vehicle S length. To simplify the model and maintain the basics of the original model, the dependent variable *D* was eliminated, and the LC decision was modeled with the remaining three variables. Therefore, the objective was to determine the values at which the three independent variables G_{FA}, G_{PA}, G_{PB} can be classified into "close", "medium", and "far". In the original function, it was determined that the linguistic values of the gap classified as medium and far were two times and three times the size of the gap classified as close, respectively. This argument reduced the problem to determine the gap size at which any of the gaps can be categorized as close and then, applied a similar criterion to classify the other gaps as medium and far.

3.3.2. Setting up the experiment

To attain this task, an experiment was designed as shown in **Figure 3-6**, where Gap_2 was set at a distance large enough that the lane change decision depended on the available gaps between vehicles *PB* and *FA*, and Gap_1. The lane changing decision was induced setting vehicles *PB, FA,* and *PA* at 10 mph below the operating speed of the facility (70 mph). Vehicles *PB*, *PA* and *FA* were set to keep a specified gap for each event. This experiment determined at which values of (G_{FA}, G_{PB}) the subject vehicle *S* decided to change lane.

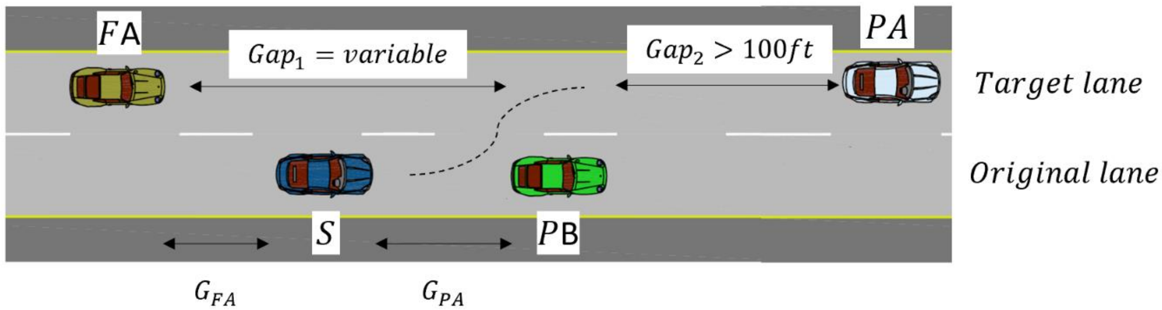


Figure 3-6. Pilot Experiment Setting.

A pilot experiment was conducted with a small sample of eight participants from the engineering school at KU. Participants were asked to drive for 60 minutes. These 60 minutes were split into two phases where each one lasted 30 minutes and included nine events. The sequence of the events was randomized for each subject to avoid bias. Participants were asked to do two simple tasks:

- Keep the operating speed of the facility (70 mph) and,
- Try to overtake slower vehicles ahead if they felt safe to.

3.3.3. Inferences of the pilot study results

The pilot study showed that when Gap_1 was less than 45 ft ($\text{Gap}_1 \leq 45\text{ft}$), half (50%) of the drivers refused to change lane, while at lower gap sizes 100% of drivers rejected the lane change maneuver. Therefore, considering the vehicle length of the simulator (Acura MDX 2013, 15.95ft) and evaluating the sizes of the gaps at which subjects change lane, an adjusted fuzzy membership function was developed (**Figure 3-7)**. It was expected that with a large sample, these thresholds would be close to those found by (Balal et al., 2016) as it is shown in the next sections.

Table 3-1. Pilot result gap acceptance study.

Event	Gap_1	LC Decision (yes =1, no=0)	G_{FA}	G_{PB}
First Run				
Event	**Gap_1**	**LC Decision (yes =1, no=0)**	**G_{FA}**	**G_{PB}**
1	100.0	100%	30.0	54.0
2	85.0	100%	14.0	55.0
3	70.0	100%	20.0	34.0
4	55.0	90%	18.0	21.0
5	40.0	50%	15.0	9.0
6	45.0	0%	-	-
7	85.0	100%	16.0	53.0
8	60.0	100%	10.0	34.0
9	50.0	90%	15.0	19.0
Second Run				
Event	**Gap_1**	**LC Decision (yes =1, no=0)**	**G_{FA}**	**G_{PB}**
1	40.0	88%	12.0	12.0
2	35.0	75%	13.0	6.0
3	33.0	0%	-	-
4	30.0	0%	-	-
5	40.0	75%	15.0	9.0
6	45.0	0%	-	-
7	85.0	100%	16.0	53.0
8	60.0	100%	10.0	34.0
9	50.0	100%	15.0	19.0

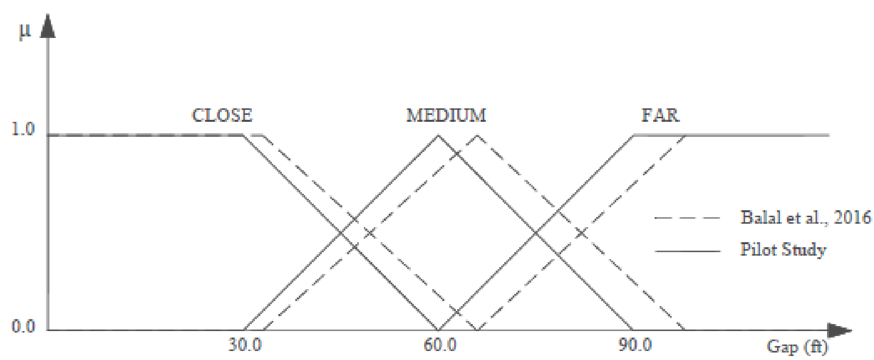


Figure 3-7. Fuzzy membership function from pilot study.

3.4. Step 4: Evaluation of the fuzzy model without V2V

3.4.1. Overview

The structure of this step (without V2V) and the next step (with V2V) was similar. However, there were some differences in the way to obtain performance measurements. The data from this stage were used to adjust the fuzzy membership function and evaluate driver performance without any guidance during lane changing maneuvers. V2V communication was only simulated in **Step 4**. Participants were asked to come once and complete both steps at the same day. Participants were monitored during the whole experiment looking for any sign of motion sickness. Furthermore, each participant had short breaks of 3 to 5 minutes during the simulation at least every 15 minutes. The scenario was the same as the pilot study; however, the events were not the same. A detailed description of the events is given in the following sections.

3.4.2. Participants

In this stage, a larger sample of 30 participants was tested. Drivers were asked to keep in mind the same two tasks as the pilot study, i.e., keep the operating speed and to overtake slower vehicles if they feel safe to do so. A message was set in the simulator to remind drivers to keep the operation speed (**Figure 3-8**). This message was crucial since subjects should be at a proper speed to allow them to catch up the slower vehicles ahead and complete the maneuvers in the tangent segment.

Figure 3-8. Speed reminder message.

3.4.3. Fuzzy Rules

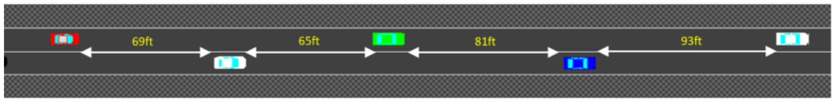
As previously described the original model was based on two fuzzy membership functions and 51 rules. These rules, depending on the combination of the gap sizes, determined the likelihood of the LC decision (yes, no). For this study, only one fuzzy membership function was developed to model the LC decision. Therefore, a set of new rules was required. Considering that each of the 3 input variables (G_{FA}, G_{PA}, G_{PB}) had 3 linguistic values (close, medium, far) then the possible combinations are, $3^3 = 27$ which also simplified the number of rules to evaluate. **Table 3-2** summarizes the combination of the rules of the adjusted fuzzy membership function. As it can be seen for those conditions, where G_{PA} and G_{PB} fall in the same category, the decision of a lane change was (*yes)* only when the gap between the subject and the leading vehicle in the target lane was larger than the gap between the subject vehicle and the leading vehicle in the original lane, $(G_{PA} > G_{PB})$.

Table 3-2. Fuzzy rules of the adjusted fuzzy membership function.

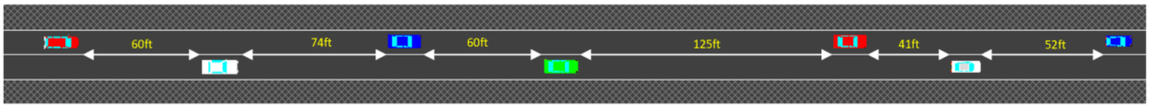
Rule No	G_{FA}	G_{PA}	G_{PB}	***Condition***	***Then***
1	Close	Close	Close		No
2	Close	Close	Medium		No
3	Close	Close	Far		No
4	Medium	Close	Close	$G_{PA} > G_{PB}$	No
5	Medium	Close	Medium		No
6	Medium	Close	Far		No
7	Far	Close	Close	$G_{PA} > G_{PB}$	Yes
8	Far	Close	Medium		No
9	Far	Close	Far		No
10	Close	Medium	Close		No
11	Close	Medium	Medium	$G_{PA} > G_{PB}$	Yes
12	Close	Medium	Far		No
13	Medium	Medium	Close		Yes
14	Medium	Medium	Medium	$G_{PA} > G_{PB}$	Yes
15	Medium	Medium	Far		No
16	Far	Medium	Close		Yes
17	Far	Medium	Medium	$G_{PA} > G_{PB}$	Yes
18	Far	Medium	Far		No
19	Close	Far	Close		Yes
20	Close	Far	Medium		Yes
21	Close	Far	Far	$G_{PA} > G_{PB}$	Yes
22	Medium	Far	Close		Yes
23	Medium	Far	Medium		Yes
24	Medium	Far	Far	$G_{PA} > G_{PB}$	Yes
25	Far	Far	Close		Yes
26	Far	Far	Medium		Yes
27	Far	Far	Far	$G_{PA} > G_{PB}$	Yes

3.4.4. Events

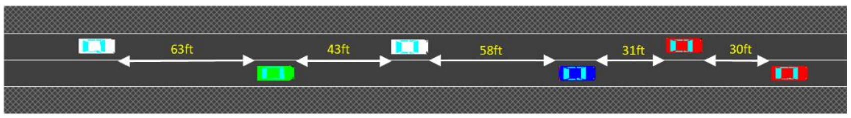
An event was defined as the arrangement of multiple vehicles set with a specific gap between each other to evaluate the lane changing maneuvers of the participants. Therefore, each event allowed the measurement of multiple lane changes. The driving simulator allowed setting specific gaps between each other. With this in consideration and knowing the sizes of the gaps at which subjects have the probability of changing lanes from the pilot study, the gaps for each event were set. A detailed description of gap sizes for each event is depicted in **Figure 3-9**.



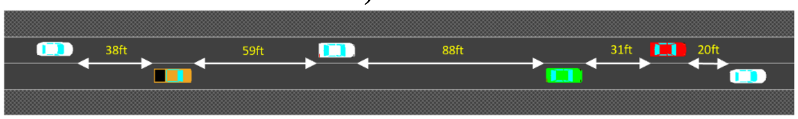
a) Event 1.



b) Event 2.

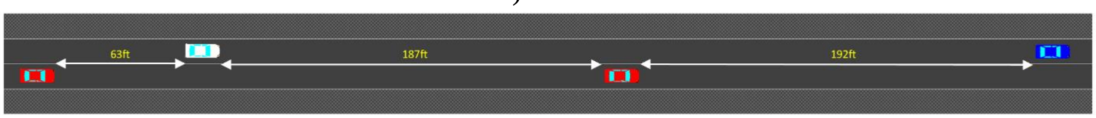


c) Event 3.

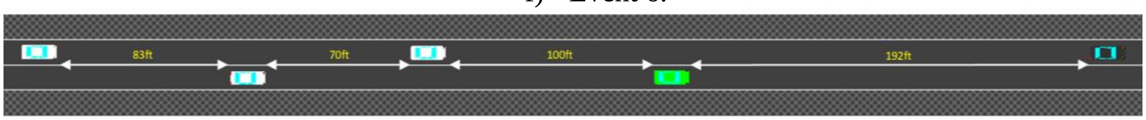


d) Event 4.

e) Event 5.

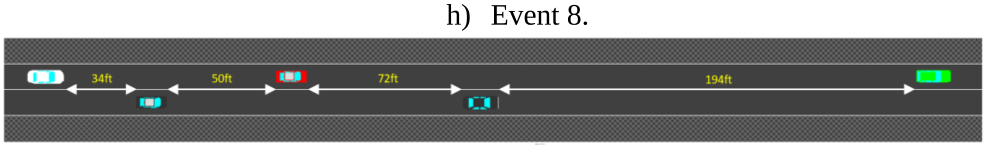


f) Event 6.



g) Event 7.

h) Event 8.



i) Event 9.

Figure 3-9. Scenario events 1 through 9 as described in Table 3-2.

As it can be observed, most of the events were set to be in gaps that fell between the medium and close categories. This was done to measure the most challenging scenarios for lane changing maneuvers and identify what was the average maximum gap that drivers select as close. Some of the gaps were also set in smaller sizes to evaluate the acceptance of the recommendation. In total there were 29 LC maneuvers where drivers were expected to accept and five LC maneuvers where they were expected to reject the gap. **Table 3-3** summarizes the available gap by the event.

Table 3-3. Lane changes to evaluate by Event.

Event	LC No	Gap ft
1	1	69
	2	65
	3	81
	4	93
2	5	60
	6	74
	7	60
	8	125
	9	41
	10	52
3	11	63
	12	43
	13	58
	14	31
	15	20
4	16	38
	17	59
	18	88
	19	31
	20	20
5	21	54
	22	54
	23	87
	24	169
	25	44
	26	2
6	27	63
	28	187
	29	192
7	30	83
	31	70
	32	100
	33	192
8	34	62
	35	83
	36	36
	37	26

Event	LC No	Gap ft
9	38	34
	39	50
	40	72
	41	194

Gaps sizes were randomized for each event. For comparison purposes, it was desired to set similar conditions for **Step 3** and **Step 4**. However, this created the problem that drivers could remember what decision they made during the non-connected stage and bias their decisions. Therefore, it was important to randomize the order in which participants drove each event to avoid making decisions based on what they could remember. On the other hand, running each event independently complicated the data management, therefore, it was assumed that the setting of two to four events in random order would be enough to solve this issue. **Table 3-4** shows the order at which the participants were asked to complete **Step 3** and **Step 4** (non-connected and connected environment respectively). It is essential to point out that not all of the lane changes were evaluated for different reasons such as slower drivers, hardware errors, or rejection of the lane changing maneuver, etc.

Table 3-4. Randomization of events.

Participant	No V2V				V2V			
	Event No				Event No			
SN01	1,2	7,8,9	5,6	3,4	8,9	3,4	5,6,7	1,2
SN02	4,5,6	1,2	8,9	3	6,7,8	1,2,3	9	4,5
SN03	5,6,7	8,9	1,2	3,4	1	2,3,4	8,9	5,6,7
SN04	1	8,9	2,3,4	5,6,7	1	6,7,8	4,5	2,3
SN05	8,9	3,4	5,6,7	1,2	1,2	7,8,9	5,6	3,4
SN06	6,7,8	1,2,3	9	4,5	4,5,6	1,2	8,9	3
SN07	1	2,3,4	8,9	5,6,7	5,6,7	8,9	1,2	3,4
SN08	1,2,3	6,7,8	4,5	9	1	9	2,3,4	5,6,7,8
SN09	2,3	4,5	6,7,8	1	3,4	1,2	8,9	5,6,7
SN10	5,6,7	3,4	1,2	8,9	2,3	4,5	6,7,8	1
SN11	6,7,8	4,5	9	1,2,3	2,3,4	1	8,9	5,6,7
SN12	9	1,2,3	6,7,8	4,5	2,3,4	8,9	1	5,6,7
SN13	1,2,3	6,7,8	4,5	9	8,9	5,6,7	1	2,3,4
SN14	4,5	9	1,2,3	6,7,8	8,9	5,6,7	2,3	1,4
SN15	6,7,8	4,5	1,2,3	9	3,4	8,9	5,6,7	1,2
SN16	8,9	3,4	5,6,7	1,2	1,2	7,8,9	5,6	3,4
SN17	6,7,8	1,2,3	9	4,5	4,5,6	1,2	8,9	3
SN18	1	2,3,4	8,9	5,6,7	5,6,7	8,9	1,2	3,4
SN19	1	6,7,8	4,5	2,3	1	8,9	2,3,4	5,6,7
SN20	1,2	7,8,9	5,6	3,4	8,9	3,4	5,6,7	1,2
SN21	4,5,6	1,2	8,9	3	6,7,8	1,2,3	9	4,5
SN22	5,6,7	8,9	1,2	3,4	1	2,3,4	8,9	5,6,7
SN23	1	8,9	2,3,4	5,6,7	1	6,7,8	4,5	2,3
SN24	3,4	1,2	8,9	5,6,7	2,3	4,5	6,7,8	1
SN25	2,3	4,5	6,7,8	1	5,6,7	3,4	1,2	8,9
SN26	2,3,4	1	8,9	5,6,7	6,7,8	4,5	9	1,2,3
SN27	2,3,4	8,9	1	5,6,7	9	1,2,3	6,7,8	4,5
SN28	8,9	5,6,7	1	2,3,4	1,2,3	6,7,8	4,5	9
SN29	8,9	5,6,7	2,3	1,4	4,5	9	1,2,3	6,7,8
SN30	3,4	8,9	5,6,7	1,2	6,7,8	4,5	1,2,3	9

3.4.5. Measured Variables

To calibrate the model and assess the effect of V2V communication for the DLC it was necessary to set some performance measurements. The following points define the variables measured during this stage (Simulation without V2V):

- Maximum gap that drivers considered close, (G_{max}): This variable was measured from the LC that drivers reject or at which drivers kept a close gap with the leading vehicle in the original lane G_{PB}. This variable allowed adjusting the fuzzy membership function from the pilot model.
- Gaps with the subject and surrounded vehicles, (G_{FA}, G_{PB}, G_{PA}): These gaps were measured to assess the accuracy of the model with and without V2V, as well as to determine the effect of the V2V communication during lane-changing maneuvers.
- Decision time, (D_t): This variable required defining an initial and final time. The initial time was assumed to be when drivers indicated their desire to change lanes with the blinkers signal, or when they saw through the mirror for those drivers that do not use blinker during lane changing maneuvers. The final time was assumed to be when drivers started the lane changing maneuver. The decision time was the difference between the initial and final time.
- Initial speed, (v_0): This variable was the average speed during the decision time.
- Lane change duration, (LC_D): In Ali et al., (2018) it was proposed the use of the lane lateral shift to spot the initial time of the LC. In this study, the lateral offset from the center lane was used to determine the duration of the maneuver. However, when drivers made a slow lane change, it was difficult to spot when the lane change occurs. Therefore, the lane change duration was identified using the videos recordings and steering wheel angle output. **Figure 3-10** shows an example of the lateral offset from the center of the lane.
- Acceleration rate, (a_r): The acceleration rate was the average acceleration measured during the LC maneuver.

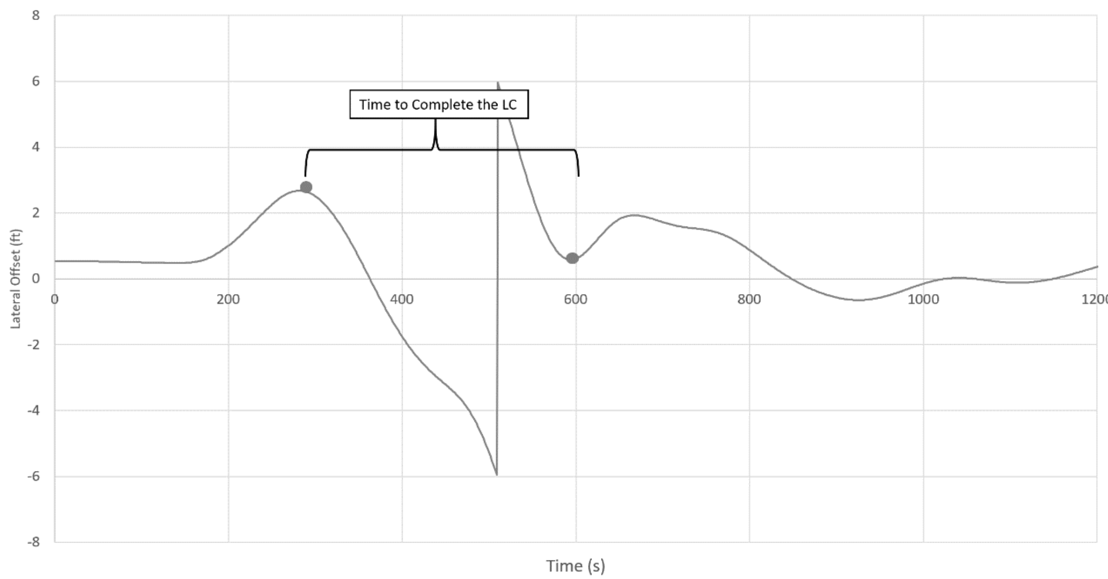


Figure 3-10. Example of lateral offset from the center of the lane.

- Cognitive workload: The cognitive workload is a subjective measure of the stress level that drivers experience during the lane changing maneuvers. The NASA-Task Load Index (TLX) was used for the collection of this subjective measure.

3.5. Step 5: Evaluation of the fuzzy model with V2V

3.5.1. Overview

The setting of this step was similar to the previous one but now implementing V2V communication. Participants were asked to drive considering the same task as in the previous steps, i.e., keep the operating speed and to overtake slower vehicles if they feel safe to do so. The simulation of the connectivity was performed throughout a text message that advised the driver if it was safe or unsafe to change lane as shown in **Figure 3-11**. This message was showed when the leading vehicle was driving below the operating speed and if it was possible to overtake the slower vehicle. The “Unsafe to Change Lane” message was displayed as soon as the subject vehicle had a gap with the follower vehicle on the target lane less than 5ft ($G_{FA} < 5ft$) and changed to "Safe to Change Lane" when the gap was greater than 5ft ($G_{FA} > 5ft$). The distance of 5 ft was assumed because it was observed to be the distance at which drivers had the follower vehicle on the blind spot but with enough length to safely change lane. Also, it was desired to test how they behaved having the message in advance and without seen the follower vehicle in the target lane. In a connected environment, it was assumed that the follower vehicle in the target lane (FA) had information about the lane changing vehicle (S). Therefore, the follower vehicle (FA) reduced its speed as soon as subject (S) vehicle started the maneuver. In this step, the fuzzy rules, the events, and the variables measured were the same as the evaluated without V2V, **Step 4**. However, the criteria used to identify the decision time (D_t) were different in this step. The initial time was defined as the time at which drivers read the "Safe to Change Lane" message. The final time of the decision time was assumed when drivers start to change lane as describes in section **3.4.5**.

Figure 3-11. Example of LC recommendation.

4. Results

This section summarizes the analysis of the results obtained from the simulation with and without V2V. The MiniSim output was migrated to the SPSS software through MATLAB and Microsoft Excel for the analysis of the performance measurements. First, the fuzzy membership function was calibrated, then the lane changes were classified according to the adjusted function and the fuzzy rules. The accuracy of the model was estimated for the No V2V condition and the acceptance of the recommendation of the V2V condition was determined. A general and a by-rule comparison was conducted. Then z-test and t-test by conditions (No V2V, V2V) were done to determine the significant difference for the general and the by-rule comparison.

4.1. Maximum Gap (G_{max}) that drivers considered as close without V2V

The maximum gap that drivers consider close was estimated from the maximum gaps that drivers kept with the leading vehicle in the original lane for rejected lane changes, i.e., G_{PB}. The first data set had 418 lane changes from which 56 lane changes were rejected. **Table 4-1** shows the result of the maximum gap that the participants considered close for non-connected environment.

Table 4-1. Descriptive Statistic, Maximum Gap G_{max} without V2V.

Condition	N	Minimum (ft)	Maximum (ft)	Mean (ft)	Std. Deviation
No V2V	56	12.40	133.27	49.09	24.39

This result is similar to Balal et al., (2016) where they found that the maximum gap that drivers considered close was around 49ft. From this result, the fuzzy membership function was adjusted. However, the medium and large distance differed from their model. In this case, the medium distance was approximately at one standard deviation above the mean. **Figure 4-1** shows the adjustment to the fuzzy membership function.

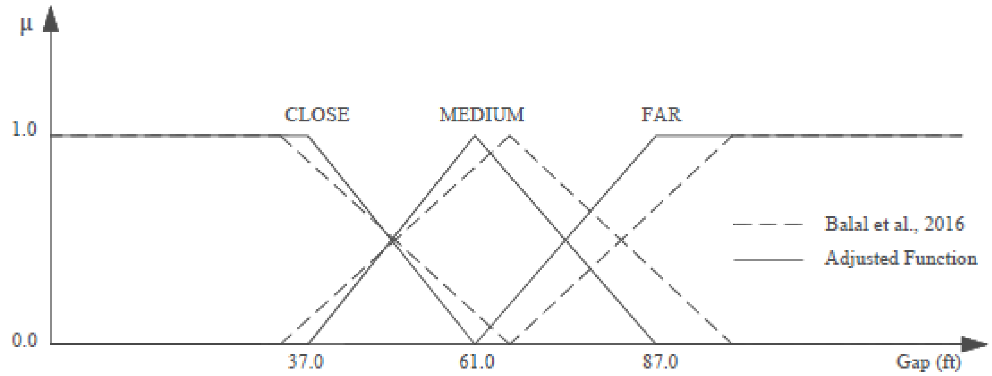


Figure 4-1. Adjusted membership function without V2V.

4.2. Accuracy of the model without V2V

The total accuracy with this adjusted fuzzy membership function without V2V was 85%. A total of 418 lane changes were evaluated for 10 rules (No. 1, 10, 11, 19, 20, 21, 23, 24, and 27) of the 27 fuzzy rules, 351 of the lane changes were as expected by the fuzzy logic model.

Table 4-2 shows the results of the experiment without V2V by rule. The accuracy of the model varied from 0% to 100% depending on the rule. It should be noted that the number of observations differed by rule. Therefore, to be more precise on the estimation of the accuracy of the rules where fewer observations were made, further studies should be conducted to estimate a more reliable accuracy of the model. This is because the main objective of this research was to develop a simplified model with an adjusted fuzzy membership function and its own set of rules. Also, the experiment had the limitation of the sample size. To evaluate the rest of the rules a bigger sample is required.

Table 4-2. Accuracy results of the model by rule without V2V.

Rule No	G_{FA}	G_{PA}	G_{PB}	***Condition***	***Then***	***Accepted***	***Rejected***	***No. Observations***	***Accuracy***
1	Close	Close	Close		No	6	0	6	0%
2	Close	Close	Medium		No	-	-	-	-
3	Close	Close	Far		No	-	-	-	-
4	Medium	Close	Close	$G_{PA} > G_{PB}$	No	-	-	-	-
5	Medium	Close	Medium		No	-	-	-	-
6	Medium	Close	Far		No	-	-	-	-
7	Far	Close	Close	$G_{PA} > G_{PB}$	Yes	-	-	-	-
8	Far	Close	Medium		No	-	-	-	-
9	Far	Close	Far		No	-	-	-	-
10	Close	Medium	Close		No	8	8	16	50%
11	Close	Medium	Medium	$G_{PA} > G_{PB}$	Yes	1	0	1	100%
12	Close	Medium	Far		Yes	-	-	-	-
13	Medium	Medium	Close		Yes	-	-	-	-
14	Medium	Medium	Medium	$G_{PA} > G_{PB}$	Yes	-	-	-	-
15	Medium	Medium	Far		No	-	-	-	-
16	Far	Medium	Close		Yes	-	-	-	-
17	Far	Medium	Medium	$G_{PA} > G_{PB}$	Yes	-	-	-	-
18	Far	Medium	Far		No	-	-	-	-
19	Close	Far	Close		Yes	163	22	185	88%
20	Close	Far	Medium		Yes	90	17	107	84%
21	Close	Far	Far	$G_{PA} > G_{PB}$	Yes	68	7	75	91%
22	Medium	Far	Close		Yes			-	-
23	Medium	Far	Medium		Yes	1	1	2	50%
24	Medium	Far	Far	$G_{PA} > G_{PB}$	Yes	14	1	15	93%
25	Far	Far	Close		Yes			-	-
26	Far	Far	Medium		Yes	4	0	4	100%
27	Far	Far	Far	$G_{PA} > G_{PB}$	Yes	7	0	7	100%
				Total Accuracy					**85%**

4.3. Acceptance of the recommendation of the model withV2V

On the other hand, 93% of the lane changes under connected environment were made as expected by the model. For this case, 465 lane changes were evaluated for eight of the fuzzy rules (rules No. 1, 10, 19, 20, 21, 23, 24, 27). A total of 434 lane changes were completed following the recommendation. The results show that there was an increase in the acceptance of the recommendation of 8% of the fuzzy logic model under connected environment compared to the non-connected environment.

On the other hand, a comparison by rule was completed for the eight fuzzy rules evaluated. **Table 4-3** shows the acceptance of the recommendation for each rule. There was an increase in the accuracy of the model by rule compared to the condition without V2V. This finding was potentially useful for lane change simulation since the lane changing behavior could be modeled more accurately under a connected environment. In other words, a lane change assistance system for the connected vehicle could normalize driver decision for DLC allowing simulation tools to be more precise in traffic studies.

Table 4-3. Accuracy results of the model by rule with V2V.

Rule No	G_{FA}	G_{PA}	G_{PB}	***Condition***	***Then***	***Accepted***	***Rejected***	***No. Observations***	***Accuracy***
1	Close	Close	Close		No	5	8	13	62%
2	Close	Close	Medium		No	-	-	-	-
3	Close	Close	Far		No	-	-	-	-
4	Medium	Close	Close	$G_{PA} > G_{PB}$	No	-	-	-	-
5	Medium	Close	Medium		No	-	-	-	-
6	Medium	Close	Far		No	-	-	-	-
7	Far	Close	Close	$G_{PA} > G_{PB}$	Yes	-	-	-	-
8	Far	Close	Medium		No	-	-	-	-
9	Far	Close	Far		No	-	-	-	-
10	Close	Medium	Close		No	7	12	19	63%
11	Close	Medium	Medium	$G_{PA} > G_{PB}$	Yes	-	-	-	-
12	Close	Medium	Far		Yes	-	-	-	-
13	Medium	Medium	Close		Yes	-	-	-	-
14	Medium	Medium	Medium	$G_{PA} > G_{PB}$	Yes	-	-	-	-
15	Medium	Medium	Far		No	-	-	-	-
16	Far	Medium	Close		Yes	-	-	-	-
17	Far	Medium	Medium	$G_{PA} > G_{PB}$	Yes	-	-	-	-
18	Far	Medium	Far		No	-	-	-	-
19	Close	Far	Close		Yes	222	7	229	97%
20	Close	Far	Medium		Yes	93	7	100	93%
21	Close	Far	Far	$G_{PA} > G_{PB}$	Yes	86	0	86	100%
22	Medium	Far	Close		Yes	-	-	-	-
23	Medium	Far	Medium		Yes	2	0	2	100%
24	Medium	Far	Far	$G_{PA} > G_{PB}$	Yes	15	0	15	100%
25	Far	Far	Close		Yes	-	-	-	-
26	Far	Far	Medium		Yes	-	-	-	-
27	Far	Far	Far	$G_{PA} > G_{PB}$	Yes	1	0	1	100%
				Total Accuracy					***93%***

4.4. Maximum Gap (G_{max}) that drivers considered as close with V2V

A similar criterion to section **4.1** was used to determine the maximum gap that the participants considered as close using V2V communication. In this case, 465 cases were evaluated,31 of them were rejected. The maximum gap that drivers considered close was determined from these 31 lane changes. **Table 4-4** shows the results of the maximum gap that drivers considered close using V2V.

Table 4-4. Descriptive Statistic, Maximum Gap G_{max} with V2V.

Condition	N	Minimum (ft)	Maximum (ft)	Mean (ft)	Std. Deviation
V2V	31	8.55	68.76	31.52	16.53

To compare the difference between the non-connected and connected environment a t-test was run on SPSS to determine the significance of the difference between these two data sets. **Table 4-5** shows the results of the t-test for the maximum gap that drivers identified as close (G_{max}) between non-connected and connected environment. The results showed that there is a significant difference at a better than 0.05 confidence interval level between the maximum gap that drivers considered as close for the non-connected and connected environment.

Table 4-5. T-test results for Maximum Gap G_{max}.

Paired Difference	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
			Lower	Upper			
No V2V_V2V	17.57	4.46	8.69	26.45	3.94	81.14	<0.01**

Note: 1. *Significant at better than 0.05 confidence interval level, ** significant at better than 0.01 confidence interval level.

This result could be due to the fact that during the experiment drivers were found to be willing to accept smaller gaps to evaluate if the recommendation would change from “Unsafe to change lane” to “Safe to change lane”. This was an important finding since when drivers had information about whether it was safe or unsafe to change lane, they were willing to accept smaller gaps. Therefore, the implementation of this type of message could lead to an increase in the capacity considering an idyllic connected environment. The sole implementation of this kind of recommendation without considering collision avoidance could lead to more crashes. On the other hand, it should be pointed out that this recommendation is also a liability, which means that if this kind of message is implemented and accidents are occurring under the recommendation of (Safe to change Lane) the provider of the recommendation could be subjected to legal issues. Therefore, the implementation of this type of messages under a connected environment should be further studied in order to provide a safe message to drivers.

Considering that drivers under a connected environment were more willing to reduce the gaps, **Figure 4-2** shows a proposed fuzzy membership function for a connected environment. However, the proposed fuzzy membership function needs to be validated by conducting further studies.

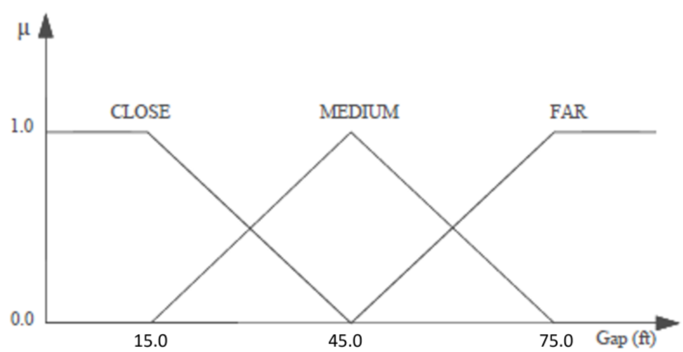


Figure 4-2. Proposed fuzzy membership function with V2V.

4.5. Gaps with the subject and surrounded vehicles, (G_{FA}, G_{PB}, G_{PA})

Gaps between the subject vehicle *S* and surrounding vehicles *FB, PB, PA,* were measured to determine if there was any effect of the message for V2V condition. **Table 4-6** shows the results and a comparison of these variables for connected and non-connected conditions.. In the comparison by rules, a z-test comparison was made for those rules with considerable sample size (N>30) and, a t-test was used for those rules with a small sample (N<30).

Table 4-6. G_{FA}, G_{PB}, G_{PA}, results for No V2V and V2V.

Variable	Condition	Mean (ft)	N	Std. Deviation	Variance	z	Sig. (2-tailed)
G_{FA}	No V2V	16.04	362.00	21.57	464.12	1.96	0.62
	V2V	16.39	431.00	17.85	196.20		
G_{PB}	NoV2V	63.26	362.00	44.36	1962.52	1.96	0.90
	V2V	63.03	431.00	48.52	2683.05		
G_{PA}	NoV2V	223.36	362.00	152.43	23170.10	1.96	0.37
	V2V	246.91	431.00	740.22	987812.00		

The comparison by rules shows that the gap between the subject and the following vehicle in the target lane (G_{FA}) was affected by the recommendation under less challenging lane changing maneuvers (rules 20, 21 when G_{PB} was medium and far respectively) (see **Table 4-9**). In these cases, drivers started the lane changing maneuver after the message was displayed. In other words, drivers without the message tend to decide to change lanes with a smaller gap with the following vehicle (G_{FA}) or before the message was displayed in the connected environment ($G_{FA} < 5ft$).For more demanding maneuvers (e.g., rule 19), the test did not show any significant difference.

Table 4-7. Descriptive statistic by condition for G_{FA}, rules 10 and 24.

Rule	Condition	N	Mean (ft)	Std. Deviation	Std. Error Mean
10	No V2V	8.00	5.74	9.10	3.22
	V2V	7.00	4.15	10.02	3.79
24	No V2V	14.00	58.62	5.73	1.53
	V2V	15.00	60.21	6.65	1.72

Table 4-8. T-test results for G_{FA}, rules 10 and 24.

Rule	Condition	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
10	No V2V - V2V	0.32	13.00	0.75	1.59	4.93	-9.07	12.25
24	No V2V - V2V	-0.69	27.00	0.50	-1.59	2.31	-6.33	3.15

Table 4-9. Descriptive by condition and z-test results for G_{FA}, rules 19, 20, and 21.

Rule	Condition	Mean (ft)	N	Std. Deviation	Variance	z Critical	z Calculated	Sig. (2-tailed)
19	No V2V	12.45	163	10.35	107.12	1.96	0.64	0.52
	V2V	11.85	222	6.96	48.50			
20	NoV2V	15.12	68	15.76	248.31	1.96	-2.03	0.04*****
	V2V	25.82	86	8.78	77.04			
21	NoV2V	15.12	68	20.48	419.37	1.96	-3.71	<0.01******
	V2V	25.83	86	13.59	184.70			

Note: 2. *Significant at better than 0.05 confidence interval level, ** significant at better than 0.01 confidence interval level.

The gap between the subject vehicle *S* and the preceding vehicle in the original lane (G_{PB}) was found to be slightly reduced for rule 20 in the connected condition. However, no significant difference was found by analyzing by rules (**Table 4-11, 4-12**).

Table 4-10. Descriptive Statistic, G_{PB} rules 10 and 24.

Rule	Condition	N	Mean (ft)	Std. Deviation	Std. Error Mean
10	No V2V	8	21.40	10.20	3.61
	V2V	7	18.90	6.77	2.56
24	No V2V	14.00	116.16	10.83	2.89
	V2V	15.00	136.58	96.03	24.79

Table 4-11. T-test results for G_{PB}, rules 10 and 24.

Rule	Condition	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
10	No V2V - V2V	0.55	13.00	0.59	2.50	4.55	-7.32	12.32
24	No V2V - V2V	-0.82	14.38	0.43	-20.43	24.96	-73.83	32.98

Table 4-12. Descriptive by condition and z-test results for G_{PB}, rules 19, 20, and 21.

Rule	Condition	Mean (ft)	N	Std. Deviation	Variance	Z Critical	Z Calculated	Sig. (2-tailed)
19	No V2V	32.86	163.00	9.25	85.49	1.96	-0.63	0.53
	V2V	33.45	222.00	8.90	79.23			
20	NoV2V	60.21	90.00	7.41	54.98	1.96	1.82	0.07
	V2V	58.36	93.00	6.29	39.58			
21	NoV2V	135.24	68.00	40.52	1641.52	1.96	-0.16	0.88
	V2V	136.41	86.00	52.80	2788.31			

For the gap between the subject vehicle S and the preceding vehicle in the original lane, (G_{PA}) there was no apparent trend between the connected and non-connected conditions, or a statistically significant difference by rule (**Table 4-14** and **Table 4-15)**.

Table 4-13. Descriptive Statistic, G_{PA} rules 10 and 24.

Rule	Condition	N	Mean (ft)	Std. Deviation	Std. Error Mean
10	No V2V	8.00	58.64	8.22	2.90
	V2V	7.00	64.64	7.16	2.70
24	No V2V	14.00	402.17	129.05	34.49
	V2V	15.00	418.66	128.60	33.20

Table 4-14. T-test results for G_{PA}, rules 10 and 24.

Rule	Condition	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
10	No V2V - V2V	-1.50	13.00	0.16	-6.00	4.01	-14.66	2.66
24	No V2V - V2V	-0.34	27.00	0.73	-16.50	47.87	-114.72	81.72

Table 4-15. Descriptive by condition and z-test results for G_{PA}, rules 19, 20, and 21.

Rule	Condition	Mean (ft)	N	Std. Deviation	Variance	z critical	z Calculated	Sig. (2-tailed)
19	No V2V	159.98	163.00	107.78	11616.78	1.96	0.57	0.57
	V2V	153.85	222.00	97.73	9551.17			
20	NoV2V	205.22	90.00	115.69	13383.47	1.96	-1.02	0.31
	V2V	223.34	93.00	125.61	15777.89			
21	NoV2V	370.89	68.00	142.02	20169.55	1.96	-0.99	0.32
	V2V	604.28	86.00	2178.39	4745386.00			

4.6. Decision Time (D_t)

According to the results, drivers had reduced decision time under the connected environment compared to the non-connected environment. The overall reduction of the decision time for the V2V condition was about 0.53s, but not significant at better than a 0.05 confidence level. **Table 4-16** illustrates the overall results for each condition, and the overall results of the t-test comparison of the decision time (D_t). This means that in general, the message helped drivers to make the lane change decision more rapidly, but the reduction was not significant in general.

Table 4-16. Decision time (D_t) results for No V2V and V2V.

Condition	Mean (s)	N	Std. Deviation	Std. Error Mean	Variance	z Critical	z Calculated	Sig. (2 tailed)
No V2V	2.04	362.00	2.88	0.15	8.27	1.96	1.90	0.06
V2V	1.54	431.00	4.38	0.21	19.11			

On the other hand, a comparison by rule was completed to evaluate the distribution of this reduction in the decision time (D_t). **Tables 4-17** to **Table 4-19** show the distribution of the decision time (D_t) with and without V2V rules 10 and 24. The rules were selected according to their differences in the sample size, i.e., enough size to allow comparison. The results showed that there was a reduction in the decision time (D_t) for 3 of the 5 rules evaluated. However, only rule 20 had a significant reduction at better than a 0.05 confidence interval level, **Table 4-19**.

This indicates that for challenging lane changes as in rule 10, the decision time (D_t) is expected to be similar for both conditions with and without V2V. On the other hand, for less demanding or more relaxed lane changing maneuvers, drivers tend to ignore the message or complete the maneuver without any influence of the recommendation.

Table 4-17. Descriptive Statistic, (D_t) rules 10 and 24.

Rule	Condition	N	Mean (ft)	Std. Deviation	Std. Error Mean
10	No V2V	8.00	1.87	0.83	0.29
	V2V	7.00	2.70	3.61	1.36
24	No V2V	14.00	1.93	1.06	0.28
	V2V	15.00	2.91	3.76	0.97

Table 4-18. T-test results for (D_t) rules 10 and 24.

Rule	Condition	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
10	No V2V - V2V	-0.60	6.56	0.57	-0.83	1.40	-4.18	2.51
24	No V2V - V2V	-0.94	27.00	0.36	-0.98	1.04	-3.12	1.16

Table 4-19. Descriptive by condition and z-test results for (D_t), rules 19, 20, and 21.

Rule	Condition	Mean (s)	Std. Deviation	Variance	z Critical	z Calculated	Sig. (2-tailed)
19	No V2V	2.04	1.77	3.13	1.96	0.42	0.68
	V2V	1.86	5.87	34.44			
20	NoV2V	2.02	2.03	4.11	1.96	4.68	<0.01**
	V2V	0.95	0.76	0.58			
21	NoV2V	1.40	1.81	3.29	1.96	1.11	0.27
	V2V	1.11	1.28	1.63			

Note: 3. *Significant at better than 0.05 confidence interval level, ** significant at better than 0.01 confidence interval level.

4.7. Initial Speed (v_0)

In general, the initial speed (v_0) was found to be significantly lower during the V2V condition as shown in **Table 4-20**. However, the comparison by rule illustrated no significant difference for both conditions with and without V2V. **Tables 4-22** to **Table 4-23** shows the results by rule of the initial speed (v_0) for the No V2V and V2V condition.

Table 4-20. Initial Speed (v_0) results for No V2V and V2V.

Condition	Mean (mph)	N	Std. Deviation	Std. Error Mean	Variance	z Critical	z Calculated	Sig. (2 tailed)
No V2V	67.49	362.00	7.72	0.41	59.39	1.96	2.29	0.02*
V2V	66.10	431.00	9.39	0.45	87.89			

Note: 4. *Significant at better than 0.05 confidence interval level, ** significant at better than 0.01 confidence interval level.

Table 4-21. Descriptive statistics for (v_0) rules 10 and 24.

Rule	Condition	N	Mean (mph)	Std. Deviation	Std. Error Mean
10	No V2V	8.00	62.61	1.22	0.43
	V2V	7.00	44.06	30.14	11.39
24	No V2V	14.00	72.45	3.93	1.05
	V2V	15.00	72.78	4.98	1.28

Table 4-22. T-test results for (v_0) rules 10 and 24.

Rule	Condition	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
10	No V2V - V2V	1.63	6.02	0.15	18.56	11.40	-9.32	46.44
24	No V2V - V2V	-0.20	27.00	0.85	-0.33	1.67	-3.76	3.11

Table 4-23. Descriptive by condition and z-test results for (v_0), rules 19, 20, and 21.

Rule	Condition	Mean (mph)	N	Std. Deviation	Variance	z Critical	z Calculated	Sig. (2-tailed)
19	No V2V	65.59	163.00	1.77	3.13	1.96	1.53	0.68
	V2V	64.45	222.00	5.87	34.44			
20	NoV2V	67.35	90.00	5.30	28.13	1.96	0.86	0.39
	V2V	66.51	93.00	7.76	60.29			
21	NoV2V	72.08	68.00	5.82	33.81	1.96	-0.71	0.48
	V2V	72.72	86.00	5.25	27.56			

4.8. Lane Change Duration (LC_D)

The overall time to complete the LC was slightly reduce according to the results shown **Table 4-26.** However, the difference was not statistically significant. Also, the comparison by rules showed that V2V did not affect the lane change duration. **Table 4-26** and **Table 4-27** show the results of the comparison by rule for LC duration (LC_D).

Table 4-24. Lane change duration (LC_D) results for No-V2V and V2V.

Condition	Mean (s)	N	Std. Deviation	Std. Error Mean	Variance	z Critical	z Calculated	Sig. (2 tailed)
No V2V	4.18	362.00	3.58	0.19	12.79	1.96	0.41	0.68
V2V	4.07	431.00	3.58	0.17	12.80			

Table 4-25. Descriptive Statistic, Lane Change Duration (LC_D) rules 10 and 24.

Rule	Condition	N	Mean (s)	Std. Deviation	Std. Error Mean
10	No V2V	8.00	11.16	21.75	7.69
	V2V	7.00	2.86	2.20	0.83
24	No V2V	14.00	4.31	1.02	0.27
	V2V	15.00	4.56	1.58	0.41

Table 4-26. T-test results for (LC_D) rules 10 and 24.

Rule	Condition	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
10	No V2V - V2V	1.07	7.16	0.32	8.29	7.74	-9.92	26.50
24	No V2V - V2V	-0.51	27.00	0.62	-0.25	0.50	-1.27	0.77

Table 4-27. Descriptive by condition and z-test results for (LC_D), rules 19, 20, and 21.

Rule	Condition	Mean (s)	N	Std. Deviation	Variance	z Critical	z Calculated	Sig. (2-tailed)
19	No V2V	3.72	163.00	1.43	2.05	1.96	-0.80	0.42
	V2V	3.84	222.00	1.37	1.88			
20	NoV2V	4.39	90.00	1.90	3.59	1.96	-0.59	0.56
	V2V	4.84	93.00	7.07	49.99			
21	NoV2V	4.16	68.00	1.45	2.10	1.96	0.28	0.78
	V2V	4.09	86.00	1.70	2.88			

4.9. Acceleration Rate (a_r)

Similar to the initial speed, no difference was found in the acceleration rates for both conditions with and without V2V. **Table 4-28** shows the general results. The overall results showed no significant difference for this variable. Similarly, the evaluation by rule does not present any significant difference either, **Table 4-30**, and **Table 4-31.**

Table 4-28. Acceleration Rate (a_r) results for No V2V and V2V.

Condition	Mean (ft/s^2)	N	Std. Deviation	Std. Error Mean	Variance	z Critical	z Calculated	Sig. (2 tailed)
No V2V	0.91	362.00	5.92	0.31	34.94	1.96	0.09	0.93
V2V	0.88	431.00	4.88	0.24	23.76			

Table 4-29. Descriptive Statistic, Acceleration rate (a_r) by rule

Rule	Condition	N	Mean (ft/s^2)	Std. Deviation	Std. Error Mean
10	No V2V	8.00	7.76	22.52	7.96
	V2V	7.00	0.14	0.55	0.21
24	No V2V	14.00	0.28	0.94	0.25
	V2V	15.00	0.09	0.75	0.19

Table 4-30. T-test results for (a_r) rules 10 and 24.

Rule	Condition	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
10	No V2V - V2V	0.96	7.01	0.37	7.62	7.97	-11.21	26.45
24	No V2V - V2V	0.60	27.00	0.55	0.19	0.31	-0.46	0.83

Table 4-31. Descriptive by condition and z-test results for (a_r) rules 19, 20 and 21.

Rule	Condition	Mean (ft/s^2)	N	Std. Deviation	Variance	z Critical	z Calculated	Sig. (2-tailed)
19	No V2V	0.83	163.00	4.83	23.30	1.96	-0.26	0.80
	V2V	0.95	222.00	4.23	17.88			
20	NoV2V	1.06	90.00	7.30	53.31	1.96	0.68	0.50
	V2V	0.54	93.00	0.67	0.44			
21	NoV2V	0.38	68.00	0.77	0.60	1.96	-0.59	0.29
	V2V	1.34	86.00	8.47	71.70			

4.10. Cognitive workload TLX

The cognitive workload was measured for each of the 25 participants. The analysis of this variable was completed using a paired t-test. After the evaluation, the results showed a reduction in the task load index for the connected condition was not significantly difference, **Table 4-32** and **Table 4-33**.

Table 4-32. Descriptive statistic for cognitive workload for No V2V and V2V.

	Mean	N	Std. Deviation	Std. Error Mean
NO V2V2	55.52	25.00	17.08	3.42
V2V	50.61	25.00	15.93	3.19

Table 4-33. Paired t-test for cognitive workload for No V2V and V2V.

Condition	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
NO V2V2 - V2V	4.91	17.22	3.44	-2.20	12.01	1.43	24	0.17

4.11. Summary of Results

The adjusted fuzzy logic model showed an increased accuracy of the prediction of lane changes of 85% for non-connected condition and of 93% for the connected condition. This means an improvement of 8% in the accuracy of the fuzzy logic model after the implementation of V2V communication for DLC. There was also a significant reduction in the gap that drivers considered as a close gap in the connected environment. From all performance variables evaluated, only the initial speed (v_0) was found to be significantly different for the connected condition. However, the initial speed v_0 was not found to be significantly different when evaluated by rule. Decision time was slightly reduced but barely not significant at the 95% confidence interval level. None of the other performance variables showed any significant difference from the baseline condition, i.e., without V2V. **Table 4-34** summarizes the overall results of the study.

Table 4-34. Summary of results with and without V2V.

Variable	Condition	Mean	Sig. (2-tailed)	Reject Null Hypothesis
G_{max}	No V2V	49.09	<0.01**	X
	V2V	31.52		
G_{FA}	No V2V	16.04	0.62	
	V2V	16.39		
G_{PB}	No V2V	63.26	0.90	
	V2V	63.03		
G_{PA}	No V2V	223.36	0.37	
	V2V	246.91		
D_t	No V2V	2.04	0.06	
	V2V	1.54		
v_0	No V2V	67.49	0.02*	X
	V2V	66.10		
LC_D	No V2V	4.18	0.68	
	V2V	4.07		
a_r	No V2V	0.91	0.93	
	V2V	0.88		
TLX	No V2V	55.52	0.17	
	V2V	50.61		

Note: 5. *Significant at better than 0.05 confidence interval level, ** significant at better than 0.01 confidence interval level.

5. Conclusions and Recommendations

This section presents the summary of this research, followed by the major conclusions regarding modeling lane changing using fuzzy logic for connected and non-connected environment. Recommendations regarding limitations of the study and future work are also offered.

5.1. Summary

This study aimed to develop a lane changing model based on the existing model proposed by (Balal et al., 2016). Moreover, the study looked into filling the gap on driver behavior during DLC in a connected environment. A simplified fuzzy logic model was developed to simulate lane changing decisions using naturalistic data obtained from a driving simulator. From the existing model, a new fuzzy membership function based on three variables was developed and adjusted with a pilot model. Then modified fuzzy logic models for both connected and non-connected environments were developed from a larger data set, and new fuzzy rules sets were created.

For the conditions evaluated in this study, the results showed that the fuzzy logic model predicted the lane changing decisions with an accuracy of 85% for the baseline condition, i.e., without V2V. The model was evaluated simulating V2V communication where drivers were informed about whether a lane changing maneuver was safe to be performed or not. It was found that the recommendation helped to normalize lane changing decisions. 93% of the drivers accepted the recommendation which makes the model prediction more accurate than without V2V. Performance variables were collected through the simulation, such as, the acceptable maximum gap, G_{max}, decision time, D_t, initial speed, v_0, acceleration rate, a_r, lane changing duration, LC_D, and cognitive workload.

5.2. Conclusions

The following conclusions are drawn from the analysis of results:

- Fuzzy logic models, like the one developed in this study, are potentially useful in predicting and simulating lane changing decisions for DLC. The proposed model had an overall accuracy of 85% for predicting lane changes.
- V2V communication has the potential to make the lane change decision more predictable in the driving task. Knowing how and when a lane change recommendation is displayed would help with the prediction or modeling of this task. Lane changes in a connected environment were found to be more predictable (by 8%) considering the fuzzy logic approach.
- Drivers were more willing to accept smaller gaps in a connected environment after they received the recommendation developed in this study. During the experiment, it was found that drivers accept smaller gaps when the message changes from “Unsafe to Change Lane” to “Safe to Change Lane”. Therefore, the implementation of this type of message should be studied further to ensure driver safety.
- The gap G_{FA} between the subject vehicle S and the follower vehicle in the target lane FA was found to be significantly reduced for rules 20 and 21. This could be due to the recommendation to change lane which appears before drivers usually consider changing lane in the baseline condition i.e., without V2V. In the baseline conditions, drivers waited considerably to decide to change lanes. However, in the connected condition after the message was displayed the results show that drivers were more willing to start the maneuver.

- V2V communication has the potential to reduce decision time during DLC. It was found that a reduction during the lane change decision was approximately 0.53s on average.
- The decision time was significantly less than in a non-connected environment for rule 20 which was a maneuver with a moderate challenge. For the baseline condition, i.e., without V2V, drivers had to evaluate traffic conditions by looking to their side or at the mirrors to make this decision while for the V2V condition, they just read a recommendation.
- For more challenging maneuvers such as rule 10, the decision time was found not significantly different from the baseline condition. This means that for more challenging situations even when drivers were reading the message “Safe to Change Lane” they preferred to evaluate the available gap on their own.
- In general, the initial speed was found to be significantly different in the connected environment. However, in the analysis by rule (rules 10, 19, 20, 21 and 24) no significant difference was found between the two conditions. Therefore, it can be concluded that there was not enough evidence in this study to suggest that the initial speed is influenced by the message during lane-changing maneuvers.
- Finally, the cognitive workload comparison was found not significant. Other types of message that provides the same information as the one developed in this study but faster should be studied.

5.3. Limitations

Since not all variables or scenarios can be tested under one experiment some limitations exist in this study:

- The partial evaluation of some of the fuzzy rules. Not all of the rules could be evaluated during this study. The main purpose of this study was to develop a simplified model for DLC. Some of the rules are more predictable than others. Five of the rules that are more uncertainty were evaluated. To evaluate the rest of the rules further studies should be conducted using a large data set as the NGSIM data.
    - Rule 10 (G_{FA}=Close, G_{PA}=Medium, G_{PB}=Close)
    - Rule 19 (G_{FA}=Close, G_{PA}=Far, G_{PB}=Close)
    - Rule 20 (G_{FA}=Close, G_{PA}=Far, G_{PB}=Medium)
    - Rule 21 (G_{FA}=Close, G_{PA}=Far, G_{PB}=Far)
    - Rule 24 (G_{FA}=Medium, G_{PA}=Far, G_{PB}=Far)
- The lane changes were assessed for the two-lane highway and mainly in tangent segments.
- For this study, it was assumed that drivers behave the same in a real environment than a simulated environment. Therefore, further studies should be a focus on evaluating the validity of this assumption. Drivers could be more willing to accept smaller gaps because in the simulation there are no consequences for crashing such as in a real environment.
- The message was set to be static and not dynamic, i.e., continuous measurement of the gaps with the surrounding vehicles.
- A large sample of participants should be tested to be more confident.
- The evaluation of only one type of message recommendation.
- The assessment of only one weather conditions such as daylight.

5.4. Future studies

The following points are recommended for future studies that could enhance this research:

- A large sample should be tested for each of the rules developed and the required adjustments made to the fuzzy membership function and fuzzy rules.
- Evaluating the addition of other variables that could help to improve the model such as the relative speed between subject and surrounding vehicles.
- Assessing different types of messages such as dynamic estimation of surrounding gaps whether using text or voice messages.
- In this study, the message was displayed when the subject vehicle was 5ft ahead of the front bumper of the follower vehicle in the target lane. A review of when it is optimum to display the message should be conducted with a larger sample.
- Evaluating the implementation of the recommendation in an urban environment.
- Study driving behavior during different scenarios such as snowing, raining and night conditions.
- Model the fuzzy model with a large data set of trajectories, such as the NGSIM data and validate the model.

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Appendix A – V2V Study Flyer

KU SCHOOL OF ENGINEERING
The University of Kansas

Participants Required for Driving Simulator Research

Objective
To study lane changing decision and driver behavior using a driving simulator.

Experimental Procedure
30 participants are required to drive specific simulated scenarios designed to study the lane changing decision simulating a connected environment.
Participants will be required to drive for **60 minutes**. Driver behavior data (speed, acceleration, reaction time, etc.) will be recorded using software and video cameras.
Participants will be invited to perform the experiment one time.

Requirements & Compensation:

- Participants must have a valid U.S. driver license with at least one year of driving experience.
- Age of participants must be 18 -65 years
- Participants will receive a $20 gift card as compensation for their time and effort.
- Participants must complete a pre-screening questionnaire. This can be obtained via email or room 2160 (see contact information below).

Valid from: 12/01/2018-05/30/2019

Location
G435, LEEP 2

Possible Risks:
Motion/simulator sickness

About the Simulator:

For More Information or To Participate:
Contact: Agustin Guerra
Email: aguerra@ku.edu
3160 Learned Hall
Department of Civil, Envir. & Arch. Engineering
Faculty Supervisor: Dr.Alexandra Kondyli

https://ceae.ku.edu/driving-simulator

Appendix B – Prescreening Questionnaire

KU Driving Simulator

What is **Adaptive Cruise Control (ACC)?**

ACC systems are similar to the conventional Cruise Control systems in terms of engaging and disengaging. However, unlike Cruise Control, ACC provides enhanced assistance by automatically adjusting vehicle speed according to the headway preference selected by the driver. This is done by either accelerating or decelerating based on the in-lane traffic flow detected by sensors, without constant input from the driver.

A Transportation Engineering graduate student is studying the **"Effects of Adaptive Cruise Control (ACC) on Drivers"**. This survey's objectives are:

- To determine users familiar with ACC systems; and
- To establish suitable candidates to participate in the driving simulator study.

CHARACTERIZATION OF YOU

1. Do you have a valid United States driver's license?
   - ☐ Yes
   - ☐ No
2. How willing are you to participate in a driving simulator study?
   - ☐ Very willing
   - ☐ Willing
   - ☐ Less willing
   - ☐ Not willing
3. What is your gender?
   - ☐ Male
   - ☐ Female
4. What is your age? __________

VEHICLE

5. What vehicle do you own/drive (make & year)?

   ____

6. Have you ever used ACC in any vehicle?
   - ☐ Yes
   - ☐ No
7. What is a safe car following (headway) distance in seconds?

   ____

8. Is your current vehicle equipped with ACC?
   - ☐ Yes
   - ☐ No
   - ☐ Not sure
9. If **YES**, how often do you use ACC in your commute?
   - ☐ Frequent (once per day)
   - ☐ Moderate (once per week)
   - ☐ Low (once per month)
   - ☐ N/A
10. If **NO,** how willing are you to try using ACC?
    - ☐ Very willing
    - ☐ Willing
    - ☐ Less willing
    - ☐ Not willing
    - ☐ N/A

MEDICAL CONDITIONS

Due to pre-existing health conditions, not all people are eligible to participate in this study.

11. Do you suffer from any health conditions? If so, please list them below **(females should include pregnancy)**.

    a) ___________________________________

    b) ___________________________________

    c) ___________________________________

12. Have you ever experienced seizures? If **YES**, please state when it occurred **(MM/YY).**

    ____

13. Have you ever experienced problems with hearing or inner ear? Please state if you use any hearing aid devices.

    ____

14. Do you suffer from a heart condition? If **YES**, please describe.

    ____

    ____

15. Do you experience motion sickness? Please state the mode of transport **(train, bus, car, and plane)** and the frequency of your motion sickness.
    Scale 0 to 5, where 0 = Never and 5 = Always

    ____

16. Please state the intensity of your motion sickness symptoms.
    Scale 0 to 5, where 0 = Low and 5 = Incapacitated

    ____

CONTACT INFORMATION

Please note that any personal information provided will not be distributed, but will solely be used for purposes relating to this research.

a) Full Name

   ____

b) Email

   ____

c) Contact number

   ____

Appendix C – Consent Form and Approval Letter

INFORMED CONSENT DOCUMENT

Modeling Lane Changing Decisions for Connected Vehicles Based on Fuzzy Logic

INTRODUCTION

The Department of Civil, Environmental, and Architectural Engineering at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

PURPOSE OF THE STUDY

The research will be used to analyze lane changing decision and driver behavior in a connected environment. The findings of this research will help us better understand how driver reacts when they have a recommendation of whether to change lane or not.

PROCEDURES

The study will recruit 30 drivers to participate in the experiments, from 18 to 65 years old. During the experiment you will be asked to drive the driving simulator for approximately 65 minutes. The first 5 minutes will be for you to familiarize with the vehicle/simulator and also to see if you have any signs of motion sickness. After that, and provided you do not have motion sickness, we will start collecting data related to your driving along the simulated scenarios. We will collect data showing changes in electrical brain activity using a wireless EEG machine. We will be recording you during the entire duration of the experiment. You will be having intermediate breaks every 30 minutes depending on the scenario. The principle investigator (PI) will be analyzing your drive and video recordings after the experiment is finished. Only people that are related to this research (Agustin Guerra-PI, and Dr. Alexandra Kondyli-Faculty Supervisor) will have access to these recordings, which will be securely stored in hard drives and kept in the Driving Simulator Lab.

The research team is committed to confidentiality. Your identity will not be revealed in the final report for this project, nor in any of the manuscripts produced. Instead, you will be assigned a participant ID number.

RISKS

The risks for this experiment are primarily related to motion sickness that you might experience as you are driving in the simulator. Motion sickness does not happen to everyone, but typical motion sickness symptoms include: general discomfort, fatigue, headache, eye strain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, fullness of head, blurred vision, dizzy eyes, vertigo, stomach awareness, and burping.

We will be monitoring you during the entire duration of the experiment for signs of motion sickness. During the frequent breaks, we will also ask you several questions on how you feel, so we determine whether you start to experience motion sickness or not.

Additionally, you might experience mild stress during decision-making during the driving portion of the study, but this stressor is no more than most people experience on a daily basis. You might also experience mild anxiety about being video recorded while you are driving.

BENEFITS

There are no direct personal benefits from participating in this research.

PAYMENT TO PARTICIPANTS

You will be given $20 compensation (in the form of a gift card) for participating in this driving simulator data collection experiment. You will be receiving cash at the end of the experiment. Investigators may ask for your social security number in order to comply with federal and state tax and accounting regulations.

PARTICIPANT CONFIDENTIALITY

Your name will not be associated in any publication or presentation with the information collected about you or with the research findings from this study. Instead, the researchers will use a study number or a pseudonym rather than your name. Your identifiable information will not be shared unless (a) it is required by law or university policy, or (b) you give written permission.

Permission granted on this date to use and disclose your information remains in effect indefinitely. By signing this form you give permission for the use and disclosure of your information for purposes of this study at any time in the future.

INSTITUTIONAL DISCLAIMER STATEMENT

In the event of injury, the Kansas Tort Claims Act provides for compensation if it can be demonstrated that the injury was caused by the negligent or wrongful act or omission of a state employee acting within the scope of his/her employment.

REFUSAL TO SIGN CONSENT AND AUTHORIZATION

You are not required to sign this Consent and Authorization form and you may refuse to do so without affecting your right to any services you are receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, if you refuse to sign, you cannot participate in this study.

CANCELLING THIS CONSENT AND AUTHORIZATION

You may withdraw your consent to participate in this study at any time, without consequence, and receive part of the compensation of $10 in gift card. If participants do not show up at appointment time or withdraw before the start of the study, no compensation will be provided.

QUESTIONS ABOUT PARTICIPATION

If you have any questions or concerns about the research study, please contact Agustin Guerra-PI or Dr. Alexandra Kondyli, Faculty Supervisor. They will be glad to answer any of your concerns (Contact information is provided below).

PARTICIPANT CERTIFICATION

I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I had regarding the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or (785) 864-7385, write the Human Research Protection Program (HRPP), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7568, or email irb@ku.edu.

I agree to take part in this study as a research participant. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form.

________________________________ ______________________

Type/Print Participant's Name Date

____

Participant's Signature

RESEARCHER CONTACT INFORMATION

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Appendix D – Sample Demographic

Subject ID	Age	Gender	Driving Experience (yrs)	Familiar with V2V
SN34	34	Male	9	0
SN01	38	Female	22	0
SN02	42	Female	25	0
SN04	39	Male	19	0
SN05	61	Male	45	0
SN08	33	Male	14	3
SN09	44	Male	29	0
SN10	41	Male	9	0
SN12	18	Male	4	0
SN13	47	Male	31	0
SN117	20	Female	4	0
SN14	22	Female	6	0
SN18	26	Female	7	0
SN19	27	Male	3.5	2
SN21	29	Female	13	0
SN103	21	Female	5	0
SN22	19	Male	4	0
SN115	27	Female	10	0
SN24	44	Male	10	0
SN25	18	Female	2	4
SN30	62	Female	45	0
SN33	70	Female	47	0
SN32	28	Male	12	0
SN333	67	Male	53	0
SN31	60	Female	40	0

Appendix E – No V2V Evaluation

GFA_No V2V	GPB_NoV 2V	GPA_NoV 2V	Decision Time_NoV2V	Initial Speed_NoV2V	Acceleration Rate_NoV2V	Time To Complete the LC_NoV2V
31.85	78.03	136.01	2.12	57.88	2.31	5.07
38.03	132.44	341.80	1.48	70.05	-0.85	0.83
46.57	130.14	500.00	1.05	75.49	0.90	3.77
35.91	142.45	500.00	1.33	72.97	0.80	3.73
13.29	40.42	121.68	1.97	64.27	-0.47	4.17
22.8	26.17	124.16	6.03	61.97	1.55	3.88
9.72	56.06	165.04	0.73	70.53	1.91	1.83
30.53	46.21	500.00	2.58	70.91	1.41	2.62
8.04	36.8	128.41	4.72	61.59	0.22	3.03
23.71	34.33	111.29	7.10	62.65	1.07	3.42
11.01	33.79	141.98	0.90	63.93	0.79	3.40
41.08	68.68	126.72	3.85	66.13	0.02	4.75
1.87	45.96	105.91	0.75	65.08	0.23	3.90
10.04	17.7	92.69	2.65	62.39	-0.54	3.02
4.48	38.39	86.33	0.68	63.10	-0.02	3.10
-6.71	28.65	104.79	0.55	69.22	-0.23	3.68
5.44	37.88	142.78	1.03	64.98	1.90	2.53
5.98	66.77	114.72	0.45	72.76	-0.23	2.95
97.74	65.51	151.97	0.65	70.19	-0.51	3.22
19.60	34.78	151.13	4.13	64.29	0.39	2.77
34.19	49.90	259.10	1.48	71.83	0.41	2.67
45.01	131.95	500.00	1.65	75.99	1.20	3.02
8.35	38.34	138.33	1.15	65.73	0.40	3.38
26.69	41.02	93.95	0.87	66.33	-0.31	3.58
-0.71	18.81	83.78	0.60	63.38	1.03	4.27
9.52	25.65	112.37	2.65	64.19	1.00	4.28
20.19	36.72	247.10	0.77	66.67	1.53	2.90
40.58	118.91	500.00	2.22	76.82	1.11	3.25
25.92	27.74	109.06	6.12	62.72	0.08	4.12
16.29	28.63	120.20	2.75	60.37	1.05	4.03
29.61	28.40	105.40	2.40	61.70	0.80	3.20
0.89	43.44	185.98	0.50	62.95	0.56	5.85
42.22	68.14	125.59	2.03	68.83	-0.19	2.87
9.16	38.58	98.57	1.88	64.67	0.72	3.85
7.53	20.11	195.16	1.18	65.36	0.17	2.08
1.28	41.44	89.35	1.57	67.40	0.23	2.92
-1.41	16.88	47.31	0.87	61.15	0.57	4.65
0.92	21.12	76.01	4.17	61.38	0.97	2.27
13.20	29.98	134.91	1.42	68.22	0.73	2.25
-0.77	73.56	121.55	1.78	70.78	-0.39	2.42

GFA_No V2V	GPB_NoV 2V	GPA_NoV 2V	Decision Time_NoV2V	Initial Speed_NoV2V	Acceleration Rate_NoV2V	Time To Complete the LC_NoV2V
6.95	31.60	102.11	0.83	67.39	0.45	2.18
-8.94	46.48	149.68	0.52	68.96	0.24	2.65
-15.99	87.85	273.95	0.47	70.31	0.59	4.62
14.68	139.07	200.19	1.55	74.18	0.25	3.77
7.72	20.58	40.66	0.62	61.15	-0.15	5.10
16.18	31.54	234.53	1.05	73.67	0.25	1.83
3.19	167.46	376.57	0.70	74.73	0.61	3.55
6.62	70.28	500.00	1.58	79.66	0.63	2.83
0.00	68.19	154.61	2.52	70.10	0.55	2.82
10.67	43.52	160.00	1.10	73.51	0.30	1.58
14.38	69.97	279.08	0.67	75.00	-0.08	2.72
16.69	39.88	500.00	1.38	75.23	0.33	5.07
24.37	22.48	122.41	0.82	62.69	0.68	2.40
8.69	58.96	111.93	1.98	64.33	-0.16	8.45
21.44	32.16	113.36	2.92	62.69	-0.81	3.47
16.76	32.28	130.25	1.92	64.03	0.59	4.62
18.99	46.68	155.63	1.33	65.29	0.27	3.55
21.06	55.73	500.00	0.85	66.64	1.66	3.07
19.15	25.62	117.14	1.03	62.28	0.75	5.27
17.88	40.05	117.08	0.75	63.18	1.04	4.43
12.06	32.61	174.59	2.00	61.17	1.21	3.98
21.67	88	146.03	1.37	62.65	0.85	4.40
18.68	6.83	83.44	6.08	60.79	60.60	3.03
21.86	24.82	500.00	0.92	61.98	2.43	3.68
16.87	30.91	90.93	1.13	61.78	1.22	3.73
13.64	14.13	89.38	1.62	60.97	1.23	3.88
12.98	29.93	77.67	1.00	63.30	0.15	5.63
9.41	5.8	53.07	2.98	59.89	-0.85	3.48
10.87	10.98	86.99	1.88	60.42	1.05	4.77
12.84	30.41	135.36	1.98	62.40	1.43	3.28
16.17	56.31	104.36	0.33	66.67	-0.02	3.53
13.72	24.97	95.56	3.57	62.41	0.54	4.25
11.41	26.89	129.98	0.53	63.58	1.17	5.07
11.72	60.33	246.47	0.87	66.63	1.61	4.53
32.07	121.7	182.81	1.43	66.80	0.03	4.75
19.08	9.04	29.56	1.03	60.05	0.30	4.20
22.12	25.31	228.70	1.72	63.16	2.07	3.53
64.16	107.13	315.61	0.92	78.12	-1.36	2.80
53.21	123.35	500.00	2.18	73.76	1.36	3.35
22.3	45.44	131.80	1.02	64.85	0.87	4.05
17.77	36.46	52.96	1.28	63.05	1.54	3.50
20.68	64.36	172.00	0.38	69.03	1.32	3.38

GFA_No V2V	GPB_NoV 2V	GPA_NoV 2V	Decision Time_NoV2V	Initial Speed_NoV2V	Acceleration Rate_NoV2V	Time To Complete the LC_NoV2V
52.15	129.29	500.00	1.13	77.80	1.02	3.77
52.86	125.51	500.00	2.02	67.67	1.64	6.47
5.76	47.9	129.70	0.80	62.86	0.04	6.53
1.59	47.37	145.49	1.73	62.80	0.39	3.87
8.79	74.55	183.55	0.18	67.09	0.21	6.03
25.81	55.35	500.00	1.57	69.33	0.33	3.98
-6.62	51.6	143.00	3.53	62.56	0.01	6.47
-9.1	67.17	144.09	1.50	62.93	0.44	5.45
3.83	40.82	182.79	4.18	63.25	-0.34	6.15
-0.1	109.68	167.76	2.12	65.87	-0.34	6.62
-7.76	166.28	109.71	2.52	61.98	0.42	5.78
-8.49	54.07	500.00	7.02	62.66	0.93	3.50
0	48.82	108.54	2.33	64.59	-0.56	6.20
-8.44	30.3	106.41	0.82	63.90	0.25	4.28
-10.25	53.68	158.56	1.17	63.52	0.60	6.00
8.21	64.31	112.34	0.93	66.92	-1.00	3.30
-2.04	40.64	111.15	1.42	64.28	-0.25	5.08
-4.24	42.53	145.62	0.97	64.75	0.35	3.92
-11.14	76.1	262.02	0.60	67.99	0.56	4.30
-2.36	156.26	217.38	0.63	72.03	0.06	3.03
-3.7	32.02	52.10	2.87	62.48	-0.38	3.63
-14.98	62.68	265.76	0.65	64.48	0.53	5.83
9.83	160.95	368.96	0.03	69.66	0.42	3.95
0	22.49	500.00	0.13	73.88	0.32	4.97
4.9	62.78	149.26	4.12	64.15	-0.22	6.48
-4.95	59.04	175.64	1.48	65.09	0.36	3.95
11.29	72.97	282.10	3.05	67.36	0.33	3.12
15.34	161.59	500.00	0.48	71.73	0.63	4.87
-6.56	53.33	153.38	1.22	65.23	-0.39	6.63
-3.23	71.06	124.09	0.03	69.66	0.42	3.95
-4.98	25.22	68.28	2.22	63.23	-0.43	5.72
-7.95	25.73	90.43	0.72	63.02	-0.20	4.93
-1.5	36.35	123.27	0.40	64.95	-0.38	2.42
-4.05	60.77	271.29	0.75	65.86	0.50	3.92
6.73	171.76	500.00	0.53	70.84	0.76	2.80
8.68	36.11	127.69	2.63	63.78	1.34	5.30
28.35	29.46	106.75	3.03	66.94	-1.89	2.83
22.09	22.58	164.57	1.03	70.81	-2.31	2.37
44.85	64.88	123.03	1.15	73.38	-1.92	2.83
0	25.6	101.81	2.98	63.32	0.88	2.78
19.57	26.64	500.00	0.45	70.89	-1.98	2.13
5.73	42	245.05	0.75	70.65	-1.32	3.27

GFA_NoV2V	GPB_NoV2V	GPA_NoV2V	Decision Time_NoV2V	Initial Speed_NoV2V	Acceleration Rate_NoV2V	Time To Complete the LC_NoV2V
43.84	126.84	336.07	0.75	72.61	1.30	3.78
45.84	131.12	500.00	0.77	78.97	0.84	3.15
23.62	60.56	267.77	2.38	66.01	0.61	2.72
67.41	109.57	500.00	2.35	73.57	0.57	3.43
3.6	42.94	143.01	0.60	68.09	-0.59	3.57
22.45	45.27	98.23	2.52	65.07	0.76	3.53
56.44	121.65	500.00	3.13	67.69	0.92	4.15
19.11	34.48	115.79	0.83	67.49	-0.62	2.87
22.23	26.83	124.95	0.73	68.28	0.50	3.03
16.41	49.43	158.42	1.10	70.86	0.25	3.18
28.7	48.09	500.00	1.28	73.47	0.38	2.53
9.48	35.4	142.58	0.92	69.00	-1.77	2.85
31.79	26.14	103.08	0.73	68.33	-0.83	2.67
20.82	23.65	165.80	2.25	65.88	0.28	2.55
56.83	52.75	110.98	1.15	70.26	0.24	3.00
2.97	22.68	98.66	1.32	68.71	-1.67	2.82
19.55	26.39	500.00	1.35	68.38	-0.69	2.75
11.42	36.44	96.31	0.93	64.25	-0.53	3.95
8.44	19.21	94.32	1.05	63.11	-0.96	2.30
14.22	28.34	76.34	0.50	66.62	-1.27	4.65
0	14.75	47.16	13.50	60.35	-0.04	4.97
4.98	10.16	500.00	12.37	61.44	1.29	2.22
8.02	13.93	89.95	0.90	61.55	-0.53	3.77
19.38	20.78	125.81	0.53	66.32	0.48	2.78
22.15	50.63	98.58	0.32	70.65	-0.15	2.62
2.09	13.78	50.49	1.12	63.23	-0.56	2.68
10.49	28.13	98.67	0.97	63.57	0.30	5.10
21.11	17.16	120.36	1.43	66.15	-1.17	1.88
30.05	41.85	227.84	0.88	69.03	-0.69	2.28
27.23	80.98	141.99	0.32	72.20	-0.21	2.62
8.75	19.53	39.76	0.27	67.27	-1.82	1.75
25.14	22.57	225.65	1.77	64.30	-0.30	4.72
47.38	123.43	332.36	1.32	69.97	0.93	4.15
34.56	142.36	500.00	0.40	76.20	-0.72	3.83
8.71	59.02	145.58	0.75	64.70	-0.72	3.83
20.62	33.67	150.17	1.93	63.00	-0.01	5.27
38.09	46.15	255.27	1.67	72.73	-1.19	2.15
25.31	151.2	500.00	1.28	66.70	1.04	3.10
10.81	35.95	136.15	0.25	70.31	-1.80	2.22
37.57	30.21	83.27	1.92	66.36	0.06	3.40
6.54	13.5	56.81	1.02	63.57	0.05	2.45
-1.18	11.61	500.00	3.53	62.15	0.72	2.18

GFA_NoV2V	GPB_NoV2V	GPA_NoV2V	Decision Time_NoV2V	Initial Speed_NoV2V	Acceleration Rate_NoV2V	Time To Complete the LC_NoV2V
3.43	14.7	79.87	0.63	65.68	-1.59	1.82
19.58	15.33	102.16	0.58	67.20	0.48	2.42
14.35	42.5	252.91	1.28	69.39	0.40	3.23
59.19	119.24	500.00	1.37	72.55	0.41	4.28
2.68	51.03	132.27	3.75	61.28	-0.01	9.53
-0.1	49.08	147.00	1.50	61.00	1.23	1.38
14.69	50.89	59.76	6.73	61.82	0.38	8.77
26.06	50.89	500.00	10.62	61.63	2.03	4.60
16.28	51.44	137.96	7.87	60.66	0.18	9.55
11.61	39.87	120.82	2.92	67.38	0.89	3.53
11.12	37.67	135.63	1.27	71.97	0.48	2.80
6.41	72.14	181.16	0.45	73.97	0.51	3.12
7.77	68.92	500.00	0.47	76.89	1.01	3.50
14.01	30.8	122.34	1.93	69.65	0.76	2.73
-17.16	75.13	152.16	0.02	71.99	0.65	3.32
13.8	31.07	172.98	0.35	76.11	0.50	2.18
0.98	108.71	166.81	0.17	77.40	0.32	2.65
8.68	39.01	98.94	0.62	65.01	0.04	4.95
-3.89	31.66	106.88	1.18	63.65	0.78	3.83
4.85	37.88	85.88	0.53	68.92	0.35	2.45
-3.18	51	253.85	1.72	72.32	-0.28	3.58
65.48	136.28	345.44	1.55	73.51	0.86	3.43
22.41	154.55	500.00	0.42	79.93	-1.23	3.90
7.04	60.65	147.14	0.83	76.98	0.50	2.73
26.49	150.65	500.00	0.40	81.23	-1.06	3.55
6.02	23.87	88.93	6.87	61.44	2.04	2.97
1.81	33.14	119.92	0.35	71.76	1.48	2.33
9.8	47.16	257.66	0.67	76.45	1.14	2.03
7.05	185.35	500.00	0.63	79.49	0.52	3.30
9.39	43.55	125.59	1.88	63.98	0.51	2.97
6.18	42.84	141.03	1.78	65.66	0.39	2.25
13.99	51.54	160.64	1.55	64.27	0.87	3.68
30.12	46.87	500.00	1.43	69.23	1.47	2.55
-5.3	49.92	141.54	1.52	58.39	0.13	9.82
54.86	99.06	160.08	0.90	68.71	-1.13	5.07
62.54	115.76	500.00	1.60	77.64	0.76	4.65
12.54	41.22	122.53	4.05	62.80	-0.28	4.53
8.17	40.67	138.75	2.90	60.56	1.18	8.37
19.96	45.67	154.66	1.10	64.23	0.87	6.47
26.77	50.01	500.00	2.60	64.51	0.99	5.57
18.88	26.03	117.59	1.08	171.18	0.60	5.62
30.03	28.42	104.96	4.28	60.44	1.45	4.08

GFA_NoV2V	GPB_NoV2V	GPA_NoV2V	Decision Time_NoV2V	Initial Speed_NoV2V	Acceleration Rate_NoV2V	Time To Complete the LC_NoV2V
25.23	20.06	161.83	0.05	61.91	1.05	6.40
17.93	29.72	89.70	4.65	62.81	0.25	5.35
-4.8	26.78	102.90	3.00	59.33	0.22	8.72
16.63	29.57	134.46	3.28	59.80	1.93	3.88
10.19	28.32	98.92	2.77	63.46	-0.38	5.23
21.15	17.08	120.26	4.00	60.62	0.95	6.82
18.69	53.2	239.16	1.27	63.02	0.57	7.12
14.08	33.69	236.64	5.52	60.92	0.08	4.67
52.63	118.13	327.12	1.13	75.67	-0.47	5.60
34.81	142.02	500.00	1.67	75.11	1.05	3.40
17.15	50.66	137.06	3.10	64.33	0.19	5.37
13.94	40.26	156.66	2.22	61.42	1.70	3.62
26.39	57.83	266.98	1.78	70.92	-1.24	2.18
43.6	133.24	500.00	0.93	70.29	0.84	4.28
22.28	24.49	124.51	2.40	60.09	2.00	5.60
28.92	38.85	91.82	2.03	61.10	9.07	0.00
19.91	33.84	115.12	1.72	64.54	0.72	3.88
18.17	31	128.97	2.85	60.73	1.51	5.03
22.81	42.93	151.95	1.17	63.86	0.33	4.47
36.76	30.14	500.00	3.03	65.41	0.60	4.50
46.76	62.87	120.86	2.22	67.50	-0.86	2.97
9.48	16.32	92.23	0.85	62.35	-0.40	2.73
26.6	19.53	500.00	4.78	65.60	-0.55	2.98
1.61	36.91	105.49	4.83	60.99	0.25	7.42
5.78	32.31	135.35	2.55	61.12	0.57	6.08
19.39	52.52	238.27	2.07	62.66	0.84	6.62
100.44	53.4	114.40	1.25	63.59	0.33	6.87
12.08	35.68	238.71	2.03	61.80	1.13	6.87
25.85	144.97	353.84	1.18	69.57	0.05	3.73
79.47	97.17	500.00	1.67	70.67	5.68	0.51
-9.58	60.2	140.43	3.55	60.36	0.40	6.25
-3.06	51.65	150.72	1.77	61.14	0.31	5.05
34.14	32.06	140.84	0.62	66.73	0.40	2.68
13.39	63.4	500.00	1.28	63.85	2.05	2.90
-10.12	55.93	146.12	1.05	59.68	0.70	6.75
5.38	63.44	140.24	0.42	61.57	0.02	5.98
2.97	44.82	144.87	4.63	61.28	1.92	2.88
10.46	57.34	110.25	2.12	62.86	-0.24	5.42
9.35	34.55	126.45	7.78	60.77	1.96	3.35
26.96	31.3	76.59	1.37	67.94	-0.94	3.05
8.96	35.25	177.94	1.28	66.70	0.98	2.62
41.72	68.52	126.05	2.20	73.45	-0.04	2.92

GFA_No V2V	GPB_NoV 2V	GPA_NoV 2V	Decision Time_NoV2V	Initial Speed_NoV2V	Acceleration Rate_NoV2V	Time To Complete the LC_NoV2V
57.83	112.7	321.81	1.42	70.61	0.41	4.28
80	96.81	500.00	2.47	69.99	0.47	3.63
81.93	96.59	500.00	1.88	69.27	0.41	3.60
42.11	66.7	124.73	6.60	64.35	-1.16	4.97
54.48	99.17	160.25	4.85	66.93	-0.89	5.35
16.31	154.53	363.52	1.58	66.74	0.36	3.85
67.49	109.35	500.00	2.47	70.06	-0.16	3.70
83.24	95.25	500.00	1.75	67.21	-1.81	2.40
-5.61	56.1	137.28	1.67	59.63	0.41	5.90
-2.51	51.57	149.49	1.50	62.22	-0.43	6.23
4.47	61.35	170.38	0.57	65.59	0.37	4.32
-1.06	77.7	500.00	0.92	73.42	-0.96	2.35
-3	47.84	139.48	1.55	61.31	0.75	8.95
38.18	56.21	133.18	1.23	66.32	-1.58	2.47
2.84	41.93	183.94	0.80	62.13	-0.21	2.53
4.4	105.4	163.48	0.17	70.83	-1.37	3.05
14.05	70.14	279.28	0.65	66.90	-0.72	2.25
34.9	142.2	500.00	0.75	74.83	0.72	3.48
8.95	161.75	370.78	0.73	68.56	0.53	6.87
27.08	149.74	500.00	0.53	73.75	0.18	3.03
36.5	141.76	500.00	1.53	70.74	-0.56	2.47
-7.08	51.92	143.44	10.23	59.97	0.16	10.57
10.52	37.28	97.28	8.53	61.70	0.43	4.95
13.23	34.56	237.53	3.22	61.28	0.91	4.05
16.93	153.89	362.80	1.82	69.58	-0.02	6.03
77.55	99.27	500.00	0.73	78.02	0.67	3.00
10.41	57.36	143.85	3.15	61.74	-0.04	8.35
0.87	51.99	133.99	3.27	65.61	0.33	4.95
8.43	40.5	138.47	3.22	67.55	1.76	2.67
25.27	40.52	149.57	0.45	69.69	0.05	2.65
27.11	49.62	500.00	1.13	71.34	1.54	2.70
5.28	39.53	131.16	0.93	68.28	0.26	2.83
-0.52	58.48	135.56	0.52	66.03	0.81	4.93
8.88	35.91	177.90	2.00	67.14	0.94	2.95
30.99	78.77	136.75	1.18	71.42	0.29	2.62
-6.06	31.96	108.00	0.63	70.42	-0.86	2.48
15.88	30.25	500.00	1.13	63.96	1.90	4.32
0	47.9	107.88	1.25	64.47	0.62	3.92
-1.38	29.14	104.08	0.85	62.35	1.04	5.62
14.86	27.97	75.93	2.67	61.18	0.02	2.88
-5.06	27.84	102.79	2.13	63.88	1.71	2.78
0.34	43.16	148.10	2.53	67.38	1.29	0.95

GFA_NoV2V	GPB_NoV2V	GPA_NoV2V	Decision Time_NoV2V	Initial Speed_NoV2V	Acceleration Rate_NoV2V	Time To Complete the LC_NoV2V
2.74	69.97	118.01	0.77	72.62	-0.64	2.80
4.81	33.7	104.26	1.98	64.96	0.55	2.97
8.79	29.41	132.52	0.82	66.95	1.44	2.25
6.67	65.25	251.29	1.20	72.78	1.07	3.13
-24.32	178.17	239.32	0.07	76.78	-0.77	4.18
-0.05	28.53	48.58	0.95	64.17	-0.11	2.70
-5.61	53.51	256.38	0.38	67.80	1.31	3.77
28.25	142.36	351.49	0.87	75.54	0.89	3.42
19.56	157.27	500.00	0.32	81.72	0.39	3.33
1.75	66.22	152.71	1.07	72.90	0.29	2.90
-1.75	55.99	172.48	0.65	72.74	0.60	2.80
11.41	73.05	282.05	0.70	75.78	0.86	3.25
11.35	165.4	500.00	0.23	79.62	0.61	3.95
-10.63	57.33	157.35	0.20	72.98	-0.31	3.22
-2.31	70.17	123.03	1.03	69.47	0.11	4.00
0	20.04	63.27	1.10	63.47	63.47	64.94
-5.07	22.97	88.01	1.30	64.26	0.83	3.10
-1.8	36.78	123.60	1.03	65.36	1.41	3.37
-7.98	64.75	275.34	0.83	91.18	0.64	4.93
43.08	135.17	500.00	1.40	76.81	1.02	3.08
-14.34	67.78	148.92	2.87	71.51	-0.39	3.63
-11.11	60.04	158.05	2.63	69.59	69.55	4.98
7.76	57.86	166.82	1.52	71.04	0.40	3.30
-0.86	77.61	500.00	0.47	73.48	0.56	3.40
36.1	73.56	131.53	0.83	64.43	0.11	6.08
12.83	158.19	367.27	2.28	73.69	0.49	7.05
-11.16	188.01	500.00	0.33	77.94	0.23	7.82
3.74	80.43	289.55	6.05	77.99	0.45	3.03
-12.2	189.07	500.00	0.27	81.09	-0.39	2.43
0	177.42	500.00	1.73	81.88	0.25	2.75
35.58	140.32	500.00	2.70	60.05	0.15	5.48
47.75	129.1	500.00	1.18	63.01	-0.50	5.03
11.1	42.85	124.09	1.28	62.67	0.56	4.18
6.26	42.72	140.67	3.37	63.68	-0.31	4.07
13.43	52.29	161.26	0.62	65.06	1.21	4.23
20.65	56.07	500.00	0.67	71.73	0.60	3.53
4.36	40.54	132.18	3.25	62.34	0.76	3.65
16.79	41.12	118.08	2.43	60.19	0.13	4.65
1.09	44.11	186.06	1.27	64.53	1.11	3.85
38.35	71.92	129.52	1.52	67.26	0.28	5.37
12.66	35.12	95.20	3.25	61.83	0.49	3.02
0	28.1	103.24	4.87	60.88	0.60	3.02

GFA_NoV2V	GPB_NoV2V	GPA_NoV2V	Decision Time_NoV2V	Initial Speed_NoV2V	Acceleration Rate_NoV2V	Time To Complete the LC_NoV2V
18.79	24.36	72.14	2.37	61.99	-0.71	2.85
0	72.95	120.90	3.15	71.98	-0.62	3.17
18.08	49.67	136.19	2.78	61.25	1.79	3.80
-4.66	59.04	175.72	0.28	66.50	1.35	4.08
5.54	89.78	298.91	0.73	71.19	1.07	3.80
38.15	138.78	500.00	0.53	79.28	0.52	4.18
-9.34	61.84	143.16	2.37	69.21	-1.03	2.77
-14.08	62.87	159.80	1.08	68.13	-0.96	5.02
-16.76	308.53	190.49	1.45	64.65	0.01	6.82
-24.18	100.37	500.00	3.00	63.96	1.72	6.67
-11.91	181.72	390.85	2.58	77.97	-1.86	5.90
-11.59	187.83	500.00	1.15	70.04	1.25	6.57
-9.93	94.15	179.90	1.63	66.94	-0.52	6.35
-13.27	66.65	183.08	8.53	61.74	0.74	3.43
-8.46	92.18	302.34	0.82	64.31	1.97	3.48
0	177.67	500.00	0.53	75.24	1.58	5.82
-14.31	60.99	160.99	3.70	67.31	0.15	2.95
-8.21	75.89	128.73	4.05	62.95	0.59	6.32
0.17	178.37	500.00	1.52	82.34	1.41	2.67
29.05	24.67	105.86	0.68	63.00	0.77	6.22
79.22	91.49	300.61	3.03	72.39	0.38	3.97
32.45	144.35	500.00	3.43	75.12	0.21	2.42
25.52	43.24	128.72	1.97	63.77	-0.23	5.18
76.53	101.73	500.00	1.07	75.18	0.16	3.90
33.18	76.53	134.60	13.67	61.01	0.39	6.53
11.31	73.22	282.30	3.67	59.67	1.00	7.27
114.16	62.84	500.00	4.50	59.51	1.66	5.23
120.97	57.49	500.00	42.85	60.11	0.99	7.97

Appendix F - V2V Evaluation

GFA_V2V	GPB_V2V	GPA_V2V	Decision Time_V2V	Initial Speed_V2V	Acceleration Rate_V2V	Time To Complete the LC_V2V
17.78	35.68	116.7	0.18	66.75	0.48	3.67
41.39	112.5	173.55	2.25	68.96	-0.40	3.57
6.51	38.29	180.93	0.85	61.78	0.97	5.75
9.02	38.71	98.65	0.47	63.38	0.00	4.78
10.72	27.55	130.88	0.85	63.30	0.20	2.52
-1.5	23.44	99.5	0.93	65.95	-0.09	9.45
14.36	53.37	106.33	0.98	65.72	0.96	3.90
4.05	17.95	94.09	1.13	60.56	1.48	2.82
4.44	17.51	93.55	0.88	60.85	0.82	3.17
7.21	20.61	95.63	0.87	60.89	62.94	6.93
41.9	23.65	132.82	1.63	63.82	0.58	4.00
19.43	64.86	273.98	0.28	74.25	0.40	2.70
8.31	19.47	94.55	0.47	62.29	1.38	2.85
36.39	73.35	131.41	0.73	66.40	0.11	4.90
10.72	62.14	110.09	0.08	69.18	-0.04	3.83
14.28	53.43	106.34	0.98	65.72	0.96	3.90
22.45	148.06	357.19	0.82	69.56	0.80	4.18
11.08	35.5	135.44	4.38	61.26	0.67	5.70
8.34	38.45	138.45	2.23	59.91	1.84	5.25
19.83	34.33	273.41	1.10	71.80	-0.40	3.70
4.88	22.96	97.92	1.20	59.71	1.43	3.63
5.84	28.97	115.8	0.18	63.90	1.15	3.90
13.88	62.8	500	0.48	68.88	0.42	3.05
29.53	54.68	263.71	0.73	75.90	1.09	2.68
12.85	54.95	107.8	0.93	64.19	-0.24	7.30
20.42	133.42	194.4	0.90	68.06	0.36	4.67
21.07	32.67	114.03	0.65	65.36	0.96	3.03
12.33	28.91	132.02	0.92	63.43	0.96	5.07
15.74	30.24	500	0.90	65.15	0.40	5.90
7.29	20.22	95.58	0.20	62.47	1.59	3.05
2.63	55.36	132.51	1.38	69.99	-0.86	3.17
11.79	56.03	142.47	0.43	70.04	0.92	2.85
23.81	85.89	143.88	0.98	69.02	0.12	3.63
7.95	30.65	101.2	0.57	71.00	-0.53	2.90
41.5	134.66	500	0.30	80.48	0.64	3.57
23.19	41.67	151.37	0.43	70.22	-0.13	2.97
27.92	148.77	500	0.70	73.16	0.48	4.45
9.48	18.89	39.07	0.00	0.00	0.00	0.00

GFA_V2V	GPB_V2V	GPA_V2V	Decision Time_V2V	Initial Speed_V2V	Acceleration Rate_V2V	Time To Complete the LC_V2V
12.4	55.55	141.92	0.70	66.69	0.77	3.63
11.63	72.49	281.63	0.97	67.87	1.24	3.85
26.67	49.55	500	0.90	66.88	1.13	2.73
13.94	20.98	107.74	0.22	70.28	0.39	2.72
53.54	117.76	326.24	1.33	77.12	0.12	4.70
5.55	19.8	76.39	0.57	61.48	1.34	3.37
7.11	36.22	141.22	1.13	60.48	1.76	5.60
39.07	139.28	500	0.82	77.05	0.95	4.08
10.45	43.29	124.48	2.45	62.56	0.75	4.50
14.04	70.13	179.33	0.72	65.54	0.15	3.42
19.56	25.23	116.88	0.93	67.39	-1.05	1.87
-8.93	24.52	71.8	0.00	0.00	0.00	0.00
-8.48	53.63	145.16	0.35	65.58	0.80	3.08
32.95	137.83	346.98	0.98	74.29	0.98	3.47
11.93	26.17	129.4	0.87	63.93	1.84	3.57
30.55	538.02	123.47	1.08	72.85	-0.77	5.03
24.11	60.12	269.18	1.03	71.22	1.15	3.87
43.29	127.52	336.64	0.98	76.79	79.21	3.00
39.28	137.6	500	2.32	69.88	2.15	4.20
16.96	50.59	103.53	1.07	65.87	-0.38	6.15
22.29	87.42	145.58	0.88	70.10	0.36	3.67
10.36	57.17	157.24	0.63	71.70	0.09	3.27
-6.77	32.45	108.42	1.18	67.52	1.81	3.10
7.13	49.7	260.2	0.98	69.66	1.14	3.25
54.73	482.18	500	2.98	71.05	-0.64	2.72
46.57	130.14	500	1.05	75.49	0.90	3.77
10.25	34.64	126.2	1.12	61.18	0.93	4.85
27.77	150.58	500	0.32	74.18	0.38	4.37
11.14	46.8	123.96	1.33	63.98	0.16	4.95
10.56	37.3	97.33	0.30	65.36	-0.21	3.20
20.23	33.49	114.71	0.62	65.09	0.90	4.05
0.55	17.41	82.39	1.05	61.41	1.25	4.13
15.5	94.35	152.22	0.20	71.62	0.37	3.57
22.92	86.89	144.91	2.38	64.79	0.08	6.77
8.6	101.13	159.17	1.40	62.65	-0.39	3.20
8.37	145.38	20643	1.58	74.09	-1.20	3.47
31.15	139.65	348.62	0.18	71.34	0.83	5.75
10.05	28.41	98.99	1.42	61.78	1.59	3.65
6.53	22.34	59.19	2.08	60.42	0.80	3.72
9.65	48.72	125.77	0.52	65.25	0.09	3.02
18.75	46.96	156.2	0.90	68.94	0.65	2.65
13.62	96.24	154.28	0.25	71.30	-0.31	3.82

GFA_V2V	GPB_V2V	GPA_V2V	Decision Time_V2V	Initial Speed_V2V	Acceleration Rate_V2V	Time To Complete the LC_V2V
12.73	64	500	1.08	65.60	0.86	4.95
8.24	168.64	500	1.78	58.51	1.39	5.82
27.47	82.23	140.36	0.88	71.36	0.14	4.57
9.93	57.84	110.68	0.20	68.90	0.07	3.20
17.57	160.49	500	0.58	69.25	0.68	3.28
10.24	34.52	125.95	0.90	62.50	1.11	4.52
6.94	37.89	179.86	0.28	64.36	1.09	3.57
29.29	141.4	350.55	1.45	69.21	-0.16	4.70
-5.86	31.65	107.8	0.67	60.82	-0.12	7.15
18.18	29.5	89.51	0.50	67.65	-1.41	2.75
12.56	53.31	162.14	1.37	72.20	0.68	2.45
6.81	35.92	83.94	0.40	63.67	0.42	3.43
13.34	41.04	157.3	0.87	66.53	0.46	3.70
11.68	56.1	142.64	0.73	65.43	0.04	8.00
8.68	39.24	242.19	0.97	62.17	0.93	4.60
7.96	57.74	166.79	1.28	62.71	1.56	4.55
18.08	47.06	156	0.65	70.25	0.24	3.60
8.65	57.03	223.9	0.87	63.57	0.63	4.93
4.97	79.15	288.35	1.57	61.33	0.46	2.58
5.74	22.04	97	12.02	60.16	1.08	6.40
16.38	51.35	137.85	1.77	64.93	0.71	5.93
22.29	31.29	112.59	3.75	63.06	1.06	3.20
12.68	30.16	500	0.95	63.96	1.96	3.15
2.89	106.52	164.54	0.15	72.84	0.45	4.53
12.88	52.94	162.02	1.45	64.05	1.67	5.33
9.07	38.67	98.51	3.42	60.22	0.54	4.38
16.88	55.26	241.44	0.48	68.56	0.27	2.58
10.79	14.92	91.07	0.98	60.14	1.90	3.23
0	38.87	142.07	2.15	63.64	1.56	3.50
9.57	63.22	111.17	0.50	64.66	-0.46	3.25
15.25	29.72	121.3	1.52	63.85	0.44	4.30
14.83	53.29	140.07	1.23	64.66	0.00	3.95
22.7	155.51	500	0.33	80.29	0.07	4.27
22.03	43.66	152.76	0.50	69.22	-0.02	3.17
19.66	34.02	115.32	2.52	64.73	0.42	5.57
20.41	63.54	272.69	0.57	70.44	0.33	3.63
6.66	51.37	128.44	0.32	66.12	-0.30	3.98
-6.6	24.72	89.69	0.32	61.27	0.93	5.23
15.96	27.37	132.38	0.67	62.88	0.30	2.58
72.23	106.1	500	3.67	69.89	0.69	6.97
10.92	35.91	135.78	0.68	64.96	-0.47	4.22
12.19	25.92	129.23	1.00	62.84	0.56	4.17

GFA_V2V	GPB_V2V	GPA_V2V	Decision Time_V2V	Initial Speed_V2V	Acceleration Rate_V2V	Time To Complete the LC_V2V
39.17	137.67	500	1.15	76.89	0.31	2.87
18.43	29.28	89.3	1.38	60.74	0.06	5.75
18.82	28.86	231.89	2.28	62.42	1.79	6.05
8.71	37.95	137.99	0.42	64.40	0.98	5.15
6.39	38.28	180.26	1.70	61.42	1.06	3.38
12.44	41.24	122.5	2.45	69.01	0.14	4.08
-2.91	64.65	117.63	0.23	66.59	-0.91	5.37
3.43	50.4	131.24	3.08	60.57	1.12	4.90
18.59	24.31	72.38	1.80	64.40	-0.01	2.83
9.97	38	98.24	1.02	62.18	0.36	3.95
26.92	21.94	120.08	0.35	61.76	1.23	3.80
13.44	32.65	500	0.32	69.08	0.82	3.02
38.34	138.46	500	0.80	75.15	0.03	3.12
4.93	62.65	149.28	0.68	68.29	0.37	2.50
9.18	25.8	112.57	0.20	62.52	0.08	2.68
16.09	31.58	91.58	0.85	63.54	-0.09	2.55
31.56	145.12	500	0.90	75.08	0.80	4.08
36.11	142.23	500	0.88	76.21	0.83	3.83
0	25.71	102.07	0.55	59.85	0.39	3.45
10.7	11.18	87.26	0.52	62.85	0.70	2.48
2.27	43.65	500	0.15	75.19	1.17	3.63
6.94	11.13	76.14	0.73	60.41	0.03	2.00
13.46	33.25	133.23	0.87	65.09	-0.20	3.10
24.88	59.24	268.31	0.92	62.57	1.32	4.27
11.4	42.83	159.26	0.95	64.94	1.69	2.80
7.83	45.95	127.17	2.10	61.45	0.72	5.97
45.98	130.93	500	0.95	86.93	0.11	3.88
34.92	141.91	500	0.87	78.71	0.25	3.87
14.54	31.11	121.07	0.75	66.50	-0.09	3.52
29.16	24.52	105.81	0.20	62.49	1.46	3.23
3.71	69.04	117.06	1.97	68.99	0.24	3.12
6.71	15.29	91.39	3.25	60.84	-0.64	2.65
11.66	34.89	500	0.92	64.21	0.81	6.05
3.85	23.98	98.98	1.05	71.32	-1.63	2.42
15.45	29.26	171.23	1.72	64.44	-0.61	3.65
9.42	28.87	131.97	1.32	61.77	1.40	4.18
17.34	159.65	500	2.47	77.86	0.18	7.42
6.13	11.91	76.92	0.57	60.28	1.34	3.23
10.1	57.68	110.67	2.65	60.52	0.31	7.93
5.78	19.86	94.91	0.25	61.90	1.84	3.10
18.84	35.01	103.94	0.37	72.38	-0.61	3.98
13.82	33.74	136.59	0.95	63.17	1.98	3.22

GFA_V2V	GPB_V2V	GPA_V2V	Decision Time_V2V	Initial Speed_V2V	Acceleration Rate_V2V	Time To Complete the LC_V2V
23.25	24.53	227.56	3.75	63.26	0.81	3.70
22.92	53.89	500	0.63	70.69	0.73	3.68
7.6	40.12	243.16	0.92	68.04	2.11	3.13
9.49	28.53	131.77	0.72	63.13	1.17	3.67
19.14	58.46	500	1.00	75.67	-0.57	3.18
-3.26	68.81	177.82	0.80	68.67	1.25	2.63
41.05	135.65	500	0.85	80.72	0.88	3.65
25.23	32.99	110.06	3.97	63.61	0.82	4.33
10.38	44.01	160.41	0.50	65.45	1.13	3.95
8.23	162.46	371.56	0.95	76.67	1.11	3.80
20.14	33.58	114.83	69.85	69.74	1.03	3.37
5.92	38.9	180.83	1.00	61.84	0.92	5.98
8.75	37.46	500	0.68	63.05	0.89	5.35
2.29	46.88	144.73	1.23	62.14	0.71	3.40
19.04	52.77	238.85	0.95	69.80	0.26	3.22
5.02	78.59	129.83	2.35	61.04	1.04	4.92
21.82	27.12	125.1	4.58	63.92	-0.46	2.42
11.3	36.51	239.42	0.38	65.36	0.64	3.42
11.98	16.28	36.44	0.00	0.00	0.00	0.00
19.94	47.88	134.21	0.52	71.66	-0.01	2.87
8.19	34.94	139.98	0.42	64.37	1.06	3.45
11.86	72.41	281.45	1.37	66.05	-0.25	9.37
7.86	46.27	162.9	1.30	61.97	1.10	3.83
28.9	20.16	117.94	2.67	71.30	-0.56	2.37
12.13	36.79	134.85	0.83	66.03	0.80	3.27
9.8	17.92	92.95	0.35	63.84	0.09	3.75
31.85	78.03	136.01	2.12	57.88	2.31	5.07
46.97	129.73	500	0.85	85.88	-0.79	2.62
13.05	31.63	173.75	0.22	71.94	0.18	2.20
28.19	39.63	126.08	14.75	60.84	0.98	4.33
12.39	36.66	134.69	0.93	65.30	0.59	4.27
13.78	33.64	236.94	2.70	62.34	1.81	3.75
38.03	132.44	341.8	1.48	70.05	-0.85	0.83
-7.73	75.4	128.43	0.63	65.12	0.37	4.98
9.4	47.39	257.92	0.72	64.09	0.72	2.72
33.46	137.28	346.24	1.10	74.54	0.09	3.50
10	18.29	38.5	0.83	64.44	-0.56	2.13
8.69	40.55	138.51	2.97	62.79	1.10	3.73
4.51	40.34	131.9	3.35	61.38	0.46	6.02
6.73	37.66	179.72	0.45	63.51	0.53	4.30
27.93	49.09	500	0.70	70.83	0.35	2.83
10.04	33.27	138.25	0.20	64.31	1.03	3.65

GFA_V2V	GPB_V2V	GPA_V2V	Decision Time_V2V	Initial Speed_V2V	Acceleration Rate_V2V	Time To Complete the LC_V2V
8.37	34.52	82.36	0.50	68.08	-0.47	3.15
38.11	138.77	500	0.87	76.50	0.49	3.38
28.02	87.85	162.99	0.77	73.31	0.11	1.75
8.71	18.92	93.87	0.78	61.82	0.48	4.28
21.72	46.25	132.8	0.75	68.72	0.41	2.68
13.4	59.26	107.32	0.75	67.70	0.18	3.32
4.06	17.81	94.01	0.22	61.73	1.02	4.53
14.72	163.58	500	0.97	66.78	0.65	3.03
56.86	96.86	157.94	4.00	67.83	-0.92	7.97
43.8	134.51	500	1.47	70.76	0.15	5.15
13.27	40.98	157.44	6.98	60.90	1.24	3.85
14.7	28.62	133.6	1.02	62.49	1.02	3.40
8.57	40.4	138.47	1.38	65.13	0.26	4.43
20.92	50.88	236.99	1.53	66.89	0.34	3.28
7.86	38.68	500	0.47	63.86	0.27	4.47
6.43	129.08	187.11	0.47	70.48	0.10	5.18
24.23	59.93	269.01	1.05	69.12	1.50	4.57
5.2	43.92	141.8	0.50	66.30	1.33	3.38
11.97	30.73	78.66	0.85	63.19	0.02	6.15
10.67	27.93	98.44	0.32	63.34	0.62	5.62
16.16	22.01	125.21	12.08	67.25	0.24	1.98
45.21	131.82	500	1.10	75.58	0.50	6.38
34.93	141.91	500	0.08	78.40	0.45	4.85
8.03	30.41	100.96	0.43	62.79	0.59	3.80
43.27	66.48	124.55	2.78	64.29	0.01	8.92
-2.04	19.98	84.95	0.67	66.57	0.64	3.02
48.75	128.12	500	0.92	79.28	0.85	3.18
24.96	153.21	500	0.82	73.12	1.08	6.12
11.18	56.42	109.33	0.60	66.04	0.29	3.57
4.67	63.19	149.67	0.67	62.20	0.56	5.18
-0.91	54.67	135.86	0.03	70.02	1.42	2.87
36.79	31.04	83.94	0.70	62.96	0.54	4.25
19.59	19.86	90.42	0.38	59.42	2.17	4.15
10.15	6.72	43.39	0.00	0.00	0.00	0.00
6.61	103.01	161.14	4.30	70.79	-0.34	8.27
17.02	50.79	103.63	0.63	66.36	-0.23	3.72
27.29	143.44	352.44	0.73	73.08	0.37	-5.57
16.54	29.43	129.35	1.43	61.22	0.98	4.03
21.91	88	145.99	0.68	71.04	-0.26	3.68
3.64	173.16	500	0.70	76.59	0.88	6.05
15.74	44.1	254.65	0.35	67.77	0.50	3.33
6.63	19.24	95.14	0.35	61.77	0.42	2.52

GFA_V2V	GPB_V2V	GPA_V2V	Decision Time_V2V	Initial Speed_V2V	Acceleration Rate_V2V	Time To Complete the LC_V2V
19.76	57.07	500	1.32	67.00	0.70	3.80
10.67	7.45	72.33	10.02	60.05	0.01	3.92
29.52	141.3	350.3	1.33	69.28	0.79	5.93
8.33	36.42	178.49	0.05	64.21	0.43	5.13
2.85	72.95	500	0.38	66.32	0.46	7.35
9.9	62.9	110.86	1.10	63.43	0.55	3.40
15.73	44.98	154.05	1.48	65.57	1.09	4.47
-0.15	77.29	500	1.38	75.04	0.78	2.33
7.96	19.66	74.94	1.03	59.30	0.97	3.22
17.22	48.42	157.29	0.33	67.71	0.36	3.73
55.22	121.74	500	1.78	66.82	0.25	5.72
16.53	68.18	277.12	1.22	65.73	2.08	4.00
14.88	29.88	121.55	1.37	64.16	0.97	4.00
14.78	30.03	141.92	0.70	66.57	0.33	3.28
19.74	150.91	360	1.00	69.64	0.79	5.10
10.51	32.18	80.26	0.38	65.10	0.23	2.40
11.89	55.77	108.67	1.18	63.45	1.12	3.47
45.03	131.85	500	0.23	75.34	0.30	4.22
6.07	38.89	130.53	1.68	60.19	0.39	6.05
7.18	18.66	94.52	0.90	60.54	0.78	4.63
19.54	53.32	101.27	1.05	68.57	-0.42	3.58
8.14	30.5	100.98	0.90	62.31	0.48	4.25
-8.92	24.63	61.45	0.42	63.43	0.91	3.48
6.98	37.91	129.56	0.32	63.10	0.98	3.98
7.96	39.92	99.72	2.37	61.03	0.05	6.90
4.62	20.69	97.25	0.78	60.18	1.32	5.10
7.3	41.66	139.7	0.67	64.07	1.20	2.42
19.5	34.13	42.5	0.47	67.73	0.74	2.58
6.12	59.56	190.33	0.63	62.53	2.13	3.22
6.91	60.9	147.39	0.40	64.27	1.58	3.85
0	25.99	101.84	0.90	64.88	0.37	4.00
16.74	48.75	157.78	0.35	70.00	0.10	3.57
17.16	30.7	233.57	0.72	66.76	0.76	3.33
28.87	55.23	264.36	0.50	75.29	0.35	2.43
11.21	165.66	500	11.28	67.34	0.38	1.32
19.49	52.43	238.48	0.83	69.55	0.47	2.33
23.99	48.04	234.02	0.78	71.57	1.33	3.22
9.21	39.62	137.57	0.38	69.70	0.37	3.27
12.41	32.33	174.3	6.25	64.45	1.00	0.98
66.09	110.72	500	1.73	79.15	0.64	2.72
14.29	57.5	243.56	0.62	67.85	0.44	5.25
9.44	44.22	140.88	0.97	62.53	0.15	12.20

GFA_V2V	GPB_V2V	GPA_V2V	Decision Time_V2V	Initial Speed_V2V	Acceleration Rate_V2V	Time To Complete the LC_V2V
13	44.92	121.92	0.53	70.92	0.18	3.05
64.4	112.41	500	1.88	76.99	0.18	3.22
3.98	54.06	131.03	0.60	62.22	0.36	4.30
25.47	80.31	138.43	1.17	65.99	0.46	4.02
9.72	58.61	156.56	0.40	75.19	-1.58	2.10
11.08	56.52	109.5	1.63	62.28	1.10	3.97
17.24	36.42	117.63	1.43	60.07	0.39	5.00
21	46.74	133.33	1.25	65.57	0.94	5.50
3.69	45.4	143.38	0.57	64.48	-0.22	3.97
9.84	35.08	126.68	0.60	64.06	1.05	3.22
1.16	85.26	294.34	0.38	68.03	1.11	3.02
9.69	48.24	125.2	1.02	64.67	0.63	4.75
65.85	111.07	500	1.27	78.62	1.02	4.62
15.48	32.08	234.93	0.80	64.97	0.77	2.87
66.66	111.65	500	3.58	70.17	-0.20	3.95
9.3	39.73	137.67	0.82	66.90	0.14	-4.08
7.1	58.79	167.78	0.78	63.05	1.33	3.38
18.23	157.59	500	0.92	69.24	0.55	3.30
33.49	43.48	500	0.85	73.63	0.46	2.45
8.08	68.7	500	1.35	63.25	0.98	8.07
32.44	144.29	500	1.10	73.30	1.26	3.53
10.48	57.25	143.76	0.82	64.05	0.98	4.13
7.97	30.55	101.13	0.42	63.43	0.91	3.48
33.16	137.64	346.68	1.07	74.32	1.22	3.73
12.87	25.63	96.33	1.03	64.55	0.41	3.32
22.81	24.89	127.74	0.65	63.39	0.36	4.58
21.12	157.18	500	0.37	73.86	0.40	6.38
16.27	49.39	158.62	5.23	62.23	0.61	8.18
1.47	52.74	169.12	0.77	72.10	0.76	2.95
21.97	31.69	112.73	0.63	67.48	-0.80	3.45
3.79	43.9	246.75	0.85	69.49	0.93	2.82
11.71	34.91	135.03	0.75	64.38	0.80	3.63
10.5	24.67	111.48	1.78	61.99	1.86	3.08
35.14	118.68	179.79	0.78	75.29	0.13	4.23
12.29	64.49	500	0.62	65.74	0.39	4.08
11.83	31.45	136.39	0.88	63.47	0.67	2.33
16.09	68.13	277.08	0.25	74.34	0.26	3.00
11.88	42.45	158.81	1.37	72.30	0.32	2.70
1.8	55.07	265.61	0.53	71.50	0.21	4.30
9.49	38.38	241.26	0.63	63.47	0.82	4.98
10.39	61.46	247.54	0.57	66.39	0.31	3.13
8.72	39.07	99.12	0.65	62.79	-0.06	5.58

GFA_V2V	GPB_V2V	GPA_V2V	Decision Time_V2V	Initial Speed_V2V	Acceleration Rate_V2V	Time To Complete the LC_V2V
5.43	43.35	141.45	1.07	64.16	1.54	4.63
12.14	36.54	134.54	1.23	66.07	0.84	5.52
6.51	38.32	129.98	1.02	60.81	1.24	4.75
13.08	59.67	107.6	0.83	65.24	-0.02	3.58
21.78	148.93	358.04	0.48	73.38	0.24	7.22
50.62	62.16	500	0.43	70.47	0.53	2.73
12.81	58.86	244.97	0.47	70.45	1.39	3.42
5.05	66.77	252.79	1.27	70.37	0.61	70.89
9.4	38.34	98.04	0.97	62.97	1.45	3.83
11.37	159.13	368.36	0.27	70.41	0.83	4.05
21.97	45.79	98.79	0.68	80.39	0.42	3.70
13.27	163.55	500	0.08	75.36	0.46	5.70
8.96	13.46	89.56	1.92	60.90	0.29	3.57
-4.43	50.37	500	1.92	68.14	2.33	2.82
8.31	39.36	99.38	0.93	62.52	0.84	4.02
8.1	26.33	91.31	0.63	65.42	1.43	2.68
43.81	120.77	500	1.78	78.34	1.38	2.68
8.7	34.39	82.26	0.37	64.62	0.97	3.33
12.97	45.06	122.06	0.32	70.19	0.51	2.52
20.71	63.62	272.65	0.70	71.02	0.66	3.83
11.26	46.86	123.88	1.58	63.25	0.58	3.80
9.79	44.7	160.99	0.40	65.32	0.72	2.88
19.35	52.62	238.71	0.82	69.39	0.76	3.90
15.44	33.56	131.62	35.30	61.22	1.58	3.93
16.9	29.16	500	1.07	65.44	0.55	4.28
5.26	43.65	141.54	1.83	62.75	0.84	6.37
11	56.7	109.78	0.68	64.94	-0.17	4.42
20.8	26.06	125.87	2.35	60.92	1.60	4.08
38.4	132.25	341.38	1.00	76.74	0.98	4.37
10.58	32.14	80.16	0.95	62.56	0.74	3.35