2005

Quality Of Service Measures At Signalized Intersections

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QUALITY OF SERVICE MEASURES AT SIGNALIZED INTERSECTIONS

by

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B. Tech., Indian Institute of Technology Delhi, New Delhi, India 2003

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Civil and Environmental Engineering
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Fall Term
2005

ABSTRACT

The concept of using qualitative measures to describe the quality of service at signalized intersections provided by different designs and controls has been discussed in numerous conferences. Such measures may include drivers' comfort, convenience, anxiety, and preferences. The primary objective of this study was to demonstrate the feasibility of using the University of Central Florida's interactive driving simulator to execute several scenarios involving different unusual design and operation practices to measure the quality of service at a signalized intersection. This thesis describes the scenarios, the experiments conducted, the data collected, and analysis of results.

Signalized intersections with 3 types of characteristic features were identified for this study. They included

1. A lane dropping on the downstream side of the intersection
2. Misalignment of traffic lanes between the approach and downstream side
3. Shared left turn and through traffic lane or separate lanes for each approaching the intersection

The experimental phase consisted of a brief orientation session to get acclimated to the driving simulator followed by two driving scenarios presented to all subjects. Each scenario consisted of a drive through an urban section of the simulator's visual data base where each subject encountered a Type 1, 2 and 3 intersections.

A total of 40 subjects, 25 males and 15 females were recruited for the experiment. Data logging at 60 Hz for each scenario consisted of time-stamped values of x-position and y-position of the simulator vehicle, steering, accelerator and brake inputs by the driver, and vehicle speed. After the experiment a questionnaire soliciting opinions and reactions about each intersection was administered.

Simulator experiment results showed that there was a significant difference between the merge lengths for the two cases of Type 1 intersection (lane drop on the downstream side of the intersection). For Type 2 intersection (misalignment of traffic lanes between the approach and downstream side) there was a considerable difference between the average paths followed by subjects for the two cases. For Type 3 intersection (shared left and through traffic lane approaching the intersection) the simulator experiment supported the fact that people get frustrated when trapped behind a left turning vehicle in a joint left and through lane intersection and take evasive actions to cross the intersection as soon as possible.

ACKNOWLEDGMENTS

First, I would like to express my gratitude to my advisor Dr. Essam Radwan. Without his valuable guidance and constant support this thesis would not have taken its present shape. I would like to acknowledge the support and help of Dr. Harold Klee to the simulation experiment fulfillment. I would also like to acknowledge the support of my committee members, Dr. Mohamed Abdel-Aty and Dr. Xuedong Yan.

I would also like to thank members of my research group Bobby and Dahai for their continuous support and assistance with driving simulator.

Last but not the least I would like to acknowledge the blessings of Lord Hanuman, my grand father, my parents and younger sister Sucheta back in India that helped me sail through my toughest times.

I would like to dedicate this thesis to my late grand mother Smt. Bimla Goyal who was always inspirational and special to me and always will be.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Background

Signal features including mode (fixed cycle, partially or fully actuated), offsets, cycle time, R, G, Y phase split, phase order with protected and unprotected left turn signals, and right turn on red permission, have an effect on a driver's sense of frustration, discomfort and feeling of safety. Indeed, a poorly designed intersection (e.g. confusing lane striping, insufficient holding capacity for turning vehicles) or one that operates counter intuitive to a driver's expectations (e.g. improper sequence of cycle phases) may induce heightened levels of anxiety for the driver while at the same time providing acceptable level of service (LOS).

Microscopic traffic simulation models have been used successfully to evaluate traffic flows, delays, operating speeds, and queue lengths at intersections with varying traffic demands and alternative signal timing control strategies. These models are capable of computing microscopic measures of performance; however they do not reflect qualitative measures of driver satisfaction.

This research effort is a simulator-based pilot study to compute qualitative measures of drivers at different intersection scenarios. The bonus of having an interactive driving simulator is the ability to measure factors related to driver workload and conduct interviews with subject to elicit their opinions about qualitative issues which impact the overall operational effectiveness of the transportation facility. This leads to the second phase of research which involves creation of a questionnaire to provide supplementary information needed to determine the Quality of Service, a more robust measure than a quantitative level of service (LOS).

In this study three different cases has been examined to measure the Quality of Service concept for signalized intersections with two alternatives for each case. These three cases include lane drop after intersection, misalignment of lanes, and left and through shared lanes. These three intersection cases are explained in detail with figures in Chapter 3. Quality of service for signalized intersection is a broad concept and not limited to these three intersection cases discussed here. There can be many more intersection cases and situations where driver feels aggravated. The results from this thesis can be used to identify the factors that relate to quality of service and even develop models to predict the quality of service at signalized intersections.

1.2 Research Objectives

The main objectives of this study were:

1. Select three cases to be used for testing the Quality of Service concept.
2. Identify measures of effectiveness (MOEs) and other subjective measures.
3. To demonstrate the feasibility of using The University of Central Florida's interactive driving simulator to perform traffic engineering studies.

CHAPTER 2: LITERATURE REVIEW

In order to understand and develop the "Quality of Service" concept one need to know the different uses and limitations of driving simulator, human factors involved in transportation, and different situations where a driver feels uncomfortable. This literature review is divided into three segments.

1. Various applications of driving simulator in transportation studies
2. Transportation studies involving human factors
3. Road Safety Audits (RSA)

2.1 Various Applications of Driving Simulator in Transportation Studies

Today, driving simulators are widely used not only for training but also for research. A driving simulator is a virtual reality tool that gives a driver on board impression that he/she drives an actual vehicle by predicting vehicle motion caused by driver input and feeding back corresponding visual, motion, and audio cues to the driver. The simulator normally consists of several subsystems as follows: a real-time vehicle simulation system performing real-time simulation of vehicle dynamics; motion, visual and audio systems reproducing vehicle motion, driving environment scenes and noise sensed by a driver during driving; a control force loading system acting as an interface between the driver and the simulator; an operator console for monitoring system operation; and system integration managing information and data transfer among subsystems and synchronization (Woon-Sung, 1998).

It enable researchers to conduct multi-disciplinary investigations and analyses on a wide range of issues associated with traffic safety, highway engineering, Intelligent Transportation System (ITS), human factors, and motor vehicle product development (Blana, 1999). The use of a modern advanced driving simulator for human factors research has many advantages over similar real world or on-road driving research. These advantages include experimental control, efficiency, expense, safety, and ease of data collection (Stuart, 2002). One of the obvious advantages of driving simulation is the ability to reproduce dangerous driving conditions and situations in a safe and controlled environment (Woon-Sung, 2002). In addition, many researches (Alicandri, 1986 and Stuart, 2002) indicated that simulator measures are valid for sign detection and recognition distances, speed, accelerator position changes and steering wheel reversals, because of a high correspondence between real world and simulator data sets.

Comte et al. (2000), made a comparison between four speed-reducing methods (Variable Message Sign, in-car advice, speed limiter and transverse bars) against the baseline condition using a driving simulator. Fifteen males and 15 females took part in the experiment. The subjects were to drive a road network with equal number of left and right curves. For each segment average values of speed, acceleration, and lateral position were derived. In addition to absolute performance measures, indicators of 'safe' behavior were also derived. The percentage of speed reduction completed before curve entry was calculated as measure of anticipatory behavior. Total heading errors, number of lane departures and minimum time-to-line crossing were also recorded in the curve, as an indication of controlled curve negotiation. The data were analyzed using multivariate analysis of variance. The percentage speed reduction at the curve approach was calculated for each system and was concluded that speed reduction was not at a constant rate in baseline condition. It was found that of all the systems, the speed limit surpassed all the other systems in terms of effectively reducing speed on approach to curves and consequently having additional positive effects on lateral control in curve negotiation.

Cheng et al. (2002), investigated driver's responses to a forward vehicle collision warning by driving simulator experiments. Thirty-six subjects were disposed randomly to the following three kinds of dangerous scenes while the subjects were intentionally distracted (like a subtask which was a mental arithmetic calculation): closing to a preceding vehicle, sudden cut-in of a vehicle from an adjacent lane, and lane departure of own vehicle. Audible means of warning were used consisting of different kinds of warning sounds corresponding to the scene. The response of each subject was measured a total of 10 times, which was twice for each of the five warning sounds. The responses of the subjects to the forward vehicle collision warning only in the cut-in scene were analyzed and were evaluated in two aspects: the correctness of the evasive action and the response time to the warning sound. It was confirmed that all of the subjects were able to identify the dangerous situation after the warning sound was issued and able to take the demanded evasive action to avoid a collision.

Smith et al. (2002) proposed a crash avoidance database structure that is based on driver judgments. The structure comprises four driving conflict states (low risk, conflict, near crash, and crash) that correspond with advisory warning, crash-imminent warning, and crash mitigation countermeasures. The crash state and conflict and near-crash state boundaries estimation was carried out. Next, the reliability of this database structure and its use to develop a crash avoidance database was done using driver performance data from an on-road naturalistic driving study and a driving simulator-controlled experiment. It was found that in both scenarios, most drivers initiate their braking action in response to a stopped lead car in the low-risk driving state.

McGehee et al.(1999), used the Iowa driving simulator to study the effects of various rear-end crash warnings on driver behavior. It was found that warnings to be most effective when headways are shortest. Warnings were also found confusing or aggravating when they are issued too early, when drivers are already braking, and when drivers are being distracted.

In another study, McGehee et al (1999) conducted research examining driver crash avoidance behavior and the effects of ABS, Antilock Braking System, on drivers' ability to avoid collision in a crash-imminent situation. The study was conducted on Iowa Driving Simulator and examined the effects of ABS versus conventional brakes, speed limit, ABS instruction and Time to Intersection on driver behavior and crash avoidance performance. Drivers' reactions in terms of steering and braking and their success in avoiding the incursion vehicle were recorded. This study found that alert drivers do tend to brake and steer in realistic crash avoidance situations and that excessive steering also occurs at times.

Martin et al. (2001) tested how a single data record may be used to characterize an impending two-car, rear-end collision in which a lead vehicle and following-vehicle are initially separated by a range. A set of seven single valued covariates (speed of both vehicles, deceleration of both vehicles, brake application time of both vehicles and range between the vehicles) was calculated to describe the actions of both vehicles. In other words, these seven covariates may be used to derive theoretical time-histories that match the experimental ones. The procedure makes use of only the experimental range and following vehicle speed data. Using these, the time-histories of speed and decelerations were computed. Using Marquardt's non-linear regression, seven covariates were deduced. A comparison was made between theoretical time-histories derived from the seven covariates and the experimental time histories for a typical Driving Simulator run. The same thing was done for an intelligent cruise Control test run. Also Time-to-Collision was evaluated using kinematics equations. It was found that theoretical time-histories fit all the covariates very well for the simulator run. For the intelligent Cruise control test, the fit was found to be reasonably good up to a point where the driver of the following vehicle lets off the brake.

Winsum et al. (1999) studied the relation between perceptual information and the motor response during lane-change maneuvers in a fixed-based driving simulator. Eight subjects performed 48 lane changes with varying vehicle speed, lane width and direction of movement. Three sequential phases of the lane change maneuver are distinguished. During the first phase the steering wheel is turned to a maximum angle. After this the steering wheel is turned to the opposite direction. The second phase ends when the vehicle heading approaches a maximum that generally occurs at the moment the steering wheel angle passes through zero. During the third phase the steering wheel is turned to a second maximum steering wheel angle in opposite direction to stabilize the vehicle in the new lane. Duration of the separate phases were analyzed together with steering amplitudes and Time-to-Line Crossing in order to test whether and how drivers use the outcome of each phase during the lane change maneuver to adjust the way the subsequent phase is executed. Using standard, ANOVA and regression techniques, it was found that steering actions were controlled by the outcome of previous actions in such a way that safety margins are maintained. The results also suggest that the driver uses visual feedback during lane change maneuvers to control steering actions, resulting in flexible and adaptive steering behavior.

Comte (2000) evaluated positive and negative outcomes of Intelligent Speed Adaptation (ISA) using University of Leeds Advanced driving simulator. Three variants of ISA - Driver select system, Mandatory system and Variable system were evaluated. The critical scenarios of interest were speed and speed adaptation, system use, gap acceptance, following behavior, overtaking, violations, attention to surprise events, mental workload and acceptability. It was found that Mandatory system was the most useful of the systems, in terms of acceptability. While in terms of satisfaction, they found that the drivers preferred the idea of a Driver Select system even though the Mandatory system would be the most useful.

2.2 Factors Affecting the Performance of Drivers

Alexander et al. (2002), studied the factors influencing the probability of an incident at an intersection using an interactive driving simulator. A model was build for predicting the probability of an incident (a crash or a 'near miss') occurring as a result of a right-turn across traffic (note that right turn in the UK is equivalent to left turn in the US). The sample population used consisted of 40 volunteers, 30 aged 65 and over and the rest below 65. The main part of the evaluation consisted of eight spells of driving, featuring different combinations of lighting condition (day/night), traffic speed (30/60 mph) and status of in-vehicle device (on/off). The effect of various factors (order of the gap, age, sex, velocity, vehicle size, vehicle color, the electronic device and day or night-time conditions) on the median acceptable gap was examined using Probit analysis. It was found that as number of gaps rejected increased there is an overall increase in the median accepted gap. The speed of the on-coming vehicle had a great effect on the median accepted gap size. The drivers were found more reticent to turn left (in the US) across slower moving vehicles than faster moving vehicles at the same gap size. The probability of a crash or near miss at gap size is taken to be the product of the probability of gap size being accepted and the probability that time taken to cross is greater than gap size – 1 second (near miss). It was concluded that the probability that a driver will have a crash or a near miss when turning right across a stream of traffic is dependent on both the size of the gap that driver will accept in an on-coming stream of traffic and the time taken to cross the intersection once the gap has been accepted. The factors affecting size of gap and time taken to cross were age, sex, speed, size and color of the on-coming vehicle and the order of the gap.

Various studies were based on trying to find a correlation between driving performance in the older drivers with factors like vision, visual perception, cognition, reaction time, and driving knowledge. It was found that there was considerable relation among these factors. Ikeda et al. (2002), observed the effects of mental and physical deterioration of elderly drivers when facing an accident, using a driving simulator. Twelve subjects, three young (20-25), three middle aged (35-45) and six old (over 60) were made to drive 2km (10min) before the intersection, in the driving simulator. In order to reproduce such deterioration in the aged drivers, the subjects were required to do multiple tasks while driving, e.g., following traffic signals and signs, preceding cars. The reaction time was measured in three categories detection time, recognition/judgment time, and operation time. They found that there are differences in reaction time between the old, the young and middle-aged were 0.3 and 0.42 seconds on an average respectively, which showed an aging effect. It was concluded that once another vehicle is detected, the time required for recognition and judgment by the aged driver is rather shorter than that of the younger ones, compensating for the delay due to age. The older driver becomes worse at simultaneous processing of multiple tasks due to deterioration of information processing, but it seems that they have action patterns through experience to react to various recognized objects, which makes them able to complete recognition/judgment of individual tasks in a short time.

Roge (2001), France, made an attempt to confirm the existence of a relation between the occurrence of certain behaviors and the variations of the level of arousal during a monotonous simulated car drive. There exist two types of behavioral activities: those necessary to the performance of the task and those that are not directly imposed by the task. The latter are called non-specific activities, subsidiary activities, or collateral activities. Scientists distinguish five categories of such behaviors, which can be defined as follows. ‘Postural adjustments’ are movements of one or several parts of the body in space. ‘Verbal exchanges’ are exchanges that do not include any piece of information about the activity itself. ‘Ludic activities’ are movements implying the manipulation of objects. ‘Self-centered’ gestures are movements of one or both hands towards the body. Finally, ‘non-verbal activities’ are changes that can be observed on the face. The occurrence of a decrement in vigilance can be assessed by means of alpha and theta electroencephalographic indices, whose decreasing indicates the occurrence of dozing-off episodes during driving at work. Eight women and nine men, aged 20 – 30, drove for 2 hours on the Vigilance Analysis Driving Simulator. The effect of the ‘driving duration’ variable on the length of the low vigilance episodes and on the number of behavioral activities in each category was analyzed by means of non-parametric tests (Friedman’s test). This result indicates a progressive decrease in the level of arousal, the low vigilance periods becoming longer as the experiment was prolonged. It was observed that drivers developed more behavioral activities as the experiment was prolonged. They concluded that duration of driving had a significant effect on self-centered gestures, on non-verbal activities and on postural adjustments. Non-verbal activities are the only precursory signs of a decrease in vigilance in the context of monotonous car driving.

Mourant at al. (2000), studied the simulator sickness in virtual environments driving simulator. They examined whether the severity and type of simulator sickness differs due to the type of driving environment or the gender of the driver. Thirty subjects (15 males and 15 females) were told to drive in either a highway, rural or city environment. Simulator sickness Questionnaire and postural stability tests were used to gather data before and after participants drove the virtual environments based driving simulator. ANOVA was used to analyze the experimental design results. It was found that most of the subjects reported to have oculomotor discomfort, i.e. eye strain, headaches, difficulty focusing, and blurred vision. Also vehicle velocity was found to be a factor in driving simulator sickness.

Lee et al. (1997) made a similar study on simulator sickness. The study was done to determine whether there was a relationship between simulator sickness and measures of driver inputs, vection, and postural sway. Eleven undergraduate students from University of Central Florida (four females and seven males) between the ages 19 and 28 were used as test subjects. Subjects drove the University of Central Florida (UCF) driving simulator for five minutes at 30 miles per hour. Data were collected for four dependent measures: vection, postural stability, simulator sickness and driving performance. It was found that ten out of the eleven subjects reported sickness. Also eight of the nine subjects who reported vection also reported sickness. That is, subjects who experienced vection tended to have sickness as well.

Braking time is a critical component in safe driving, and various approaches have been applied to minimize it. In congested high-speed driving, braking time becomes critical. With short headways, the likelihood of rear-end collisions increases sharply. Shinar et al. (2002) analyzed the components of braking time in order to assess the effects of age, gender, vehicle transmission type, and event uncertainty, own its two primary components, perception-reaction time and brake-movement time. Perception-reaction time and brake-movement time were measured at the onset of lights for 72 subjects in a simulator. The six experimental conditions were three levels of uncertainty conditions (none, some, and some false alarms) and two types of transmission (manual and automatic). It was found that transmission type did not significantly affect either perception-reaction time or brake-movement time. Also, perception-reaction time increased significantly as uncertainty increased and also with age while brake-movement time did not change.

Philip et al. (2002) studied about the effect of fatigue on performance measured by a driving simulator in automobile drivers. One hundred and fourteen drivers who stopped at a rest area were recruited for the study. Also, the test was done on 114 control subjects who had normal sleep wake schedule and absence of long driving on the same day. The demographic information between experimental and control groups was analyzed using nonparametric tests. The steering error from the ideal curve on the driving simulator and its relation to sex, age and driving and sleeping behaviors was then studied through logistic regression analysis. It was found that drivers performed significantly worse than control subjects. It was concluded that steering errors on a driving simulator could be used to measure fatigue.

Roge et al. (2003) studied the effect of sleep deprivation and driving duration on the useful visual field in younger and older subjects during simulator driving. Nine older subjects (40-51 years) and 10 younger subjects (18-30 years) took part in two one-hour driving sessions. The subjects had to respond to certain critical signals for both tasks- Central and Peripheral. Two control parameters lateral and longitudinal instability were also analyzed. It was found that sleep deprivation and duration of driving had a significant effect on lateral and longitudinal instability. Also sleep deprivation and duration of driving affected the number of correct responses in both the central and peripheral tasks.

Zhang et al. (2002) developed a model to combine delay and safety to get a comprehensive LOS indicator, the delay and safety index (DS). The case study of two intersections showed that if potential conflict is not considered, the signal timing plan with the permitted left-turns delivers a better LOS than that with protected left-turns. However, if potential conflict is considered, the LOS under protected left-turn phasing is better than the LOS under permitted left-turn phasing according to DS, when the safety weight factors exceed a certain value. The proposed method models the tradeoff between safety and efficiency explicitly, and considers both vehicle-to-vehicle and vehicle-to-pedestrian conflicts associated with left turns.

2.3 Road Safety Audits

Every year, a large number of people are killed and injured on roads in developed and developing countries. Every year, states, counties, regions and municipalities spend considerable amount of resources on trying to reduce crashes by reconstructing and improving the roads. This work - crash reduction - is still necessary and should continue to be of high priority (15 Briefs Issue, 2004). The main aim of Road Safety Audit improvements is to reduce crashes and make driver feel more comfortable while driving. Road Safety Audits are independent of Level of Service and Quality of Service concept. But the two Road Safety Audits and Quality of Service share a common goal to improve the safety of a transportation facility. Quality of Service concept is still in its initial stages of development while the Road Safety Audits is fully developed and is applied to various parts of the World.

A road safety audit (RSA) is a formal safety performance examination of an existing or future road or intersection by an independent audit team. RSAs are in essence, crash prevention. The purpose is to make new roads as safe as possible - before the projects are implemented, and before any crashes happen. RSAs require an independent and systematic formal procedure for assessing or checking the crash potential and safety performance of a new road project or existing roads. The central principle of an RSA is the independence of the auditors. The auditors exclusively evaluate the road safety of projects - and not participants in the planning or design of the project itself. Furthermore, it is not the task of the auditors to weigh safety considerations against other considerations, e.g., economic criteria although they may be aware of them (15 Briefs Issue, 2004).

Road safety audits can be applied to both small as well as large projects, regardless of whether the project concerns new construction or the rebuilding of existing roads. It will often be advantageous to carry out an audit several times during the course of a project, depending on its size, complexity and character. Therefore, the following five stages have been defined:

Stage 1: Planning

Stage 2: Preliminary Design

Stage 3: Detailed Design

Stage 4: Construction

Stage 5: Monitoring Existing Projects

It is essential that the suggestions of the RSA are consistent with the stage of the project. For example, audit suggestions related to design details are inappropriate at the planning phase, and audit suggestions that require major design alterations are inappropriate at the detailed design phase. Experienced auditors will limit the safety audit suggestions to items that can still be practically and cost-effectively addressed at the stage of the project (15 Briefs Issue, 2004).

The final design-related decisions are always the responsibility of the design team and the project owner. The auditors simply provide input, and the design team and owner have absolute flexibility to accept or reject any of the audit suggestions, with proper justification and documentation (15 Briefs Issue, 2004).

2.3.1 Typical Improvements

Typical improvements suggested in Road Safety Audits include:

- Removal of sight distance obstructions
- Addition/design changes to turn lanes
- Improvement to acceleration/deceleration lane design
- Illumination
- Median barrier placement
- Consideration of pedestrian's ability to cross a street
- Improvements to super elevation
- Drainage improvements
- Roadway shoulder and lane width modifications
- Access management/consolidation of driveways
- Realignment of intersection approaches (Road Safety Audits Brochure, 2005)

2.3.2 Steps to Conduct RSA's

1. Identify project or existing road to be audited (Responsibility - Design Team/Project Owner)
2. Select interdisciplinary audit team (Responsibility - Design Team/Project Owner)
3. Conduct a Pre-audit meeting to review project information and drawings (Responsibility - Audit Team and Design Team/Project Owner)
4. Perform field reviews under various conditions (Responsibility - Audit Team)
5. Conduct audit analysis and prepare report of findings (Responsibility - Audit Team)
6. Present Audit findings to Project/Owner Design Team (Responsibility - Audit Team and Design Team/Project Owner)
7. Prepare formal response (Responsibility - Audit Team)
8. Incorporate findings into the project when appropriate (Responsibility - Design Team/Project Owner)(Road Safety Audits Brochure, 2005)

2.3.3 Benefits

It is difficult to quantify the benefits of road safety audits, since by definition audits are preventing crashes from occurring. Studies that have attempted to quantify the benefits of audits have yielded impressive results. In the United Kingdom, a local authority has estimated the benefit-cost ratio of an RSA to be 15:1, while TRANSIT New Zealand has estimated the benefit to cost ratio as 20:1. Cost-benefit analysis of safety-audited projects in Denmark yielded an expected average first year rate of return of 146 percent.

With the low cost of conducting road safety audits, it is fair to say that audits need only to prevent a very low number of crashes, injuries and fatalities over the life of the project to provide a high benefit to cost ratio. The main benefits from RSA are summarized below:

- Helps produce designs that reduce the number and severity of crashes
- May reduce costs by identifying safety issues and correcting them before projects are built
- Promotes awareness of safe design practices
- Integrates multimode safety concerns
- Considers human factors in all facets of design (Road Safety Audits Brochure, 2005)

2.3.4 Who Needs RSA Guidelines?

RSAs should be an integral part of highway planning, design, construction and maintenance. Therefore, there needs to be an explicit commitment to safety amongst elected officials, management in any transportation organization, together with an awareness of the role and benefits of safety audits.

The RSA process requires an objective approach to the assessment of crash risk. The principal method of ensuring this objectivity is through the **independent** safety assessment of projects by persons not connected with the original design. Designers and planners need to be familiar with procedures and practices, and provide the necessary background information required for the audit to be undertaken. A designated audit team should undertake the audit with experience conducting road safety engineering techniques (15 Briefs Issue, 2004).

2.3.5 What Resources are Needed?

RSAs require the assembly of a RSA team, and some resources from the design team and the owner to compile information, attend meetings and respond to the audit suggestions. The cost of a road safety audit is often an insignificant amount compared to the overall project cost. In the United States and Canada, highly complex RSAs for major projects (with a capital cost in the hundreds of millions of dollars) have been conducted at a cost of $30,000 to $40,000. Small audits for relatively minor projects can be completed for a cost of $15,000 or less. Audits can be conducted by in-house transportation department staff or from a consulting organization (15 Briefs Issue, 2004).

The cost of implementing the acceptable suggestions from the RSA (including re-design) may be relatively low and manageable, since by definition RSA suggestions need to be compatible and cost-efficient relative to the phase of the project. Allowance should be made in the original design costing and time schedule of projects for both audit and possible redesign (15 Briefs Issue, 2004).

2.3.6 Who is now Using or Planning to Use Road Safety Audits?

The RSA concept was originally developed and introduced in the United Kingdom (UK) in 1989. The benefits of such systematic checking were soon recognized by many safety professionals around the world and the following countries, among many others, are actively conducting RSAs: USA, Canada, UK, Australia, New Zealand, Denmark, Norway, Ireland, Singapore, India, Italy and Malaysia (15 Briefs Issue, 2004).

2.3.7 Road Safety Audits in the United States and Canada

There are many successful on-going RSA programs in the United States and Canada. The states of Pennsylvania, Iowa, New York, Minnesota and South Carolina are actively conducting RSAs. The first RSA for a mega-project was conducted in 2003 at the Marquette Interchange in Milwaukee, Wisconsin. In Canada, the provinces of British Columbia, Alberta and New Brunswick have been actively implementing RSAs. RSA training is available in both countries, through the National Highway Institute (NHI) in the United States and through TAC in Canada (15 Briefs Issue, 2004).

2.3.8 Why Should We Conduct Road Safety Audits?...We Already do Safety Reviews.

RSAs are different from existing safety reviews in most States because RSAs are proactive, consider all road users and all factors that may contribute to a crash, include day and night field reviews, and are conducted by a multidisciplinary and independent team. It is important to understand the difference between the road safety reviews that are commonly performed and newer road safety audits. The main differences between the two are shown below (Road Safety Audits, 2005):

Table 2-1: Difference between road safety reviews and RSAs

Road Safety Reviews	RSAs
A safety review uses a small (1-2 people) team with design expertise.	A safety audit uses a larger (3-5 person) interdisciplinary team.
Safety review team members are usually involved in the design.	Safety audit team members are usually independent of the project.
Field reviews are usually not part of safety reviews.	The field review is a necessary component of the safety audit.
Safety reviews concentrate on evaluating designs based on compliance with standards.	Safety audits use checklists and field reviews to examine all design features.
Safety reviews do not normally consider human factors issues. This includes driver error, and visibility issues.	Safety audits are comprehensive and attempt to consider all factors that may contribute to a crash.
Safety reviews focus on the needs of roadway users.	Safety audits consider the needs of pedestrians, cyclists, large trucks as well as automobile drivers.
The safety review is reactive. Hazardous locations are identified through analysis of crash statistics or observations and corrective actions are taken.	Safety audits are proactive. They look at locations prior to the development of crash patterns to correct hazards before they happen.

CHAPTER 3: EXPERIMENT METHODOLOGY

3.1 Subjects

As shown in Table 3-1, a total of 40 test subjects in three age groups (15 younger, 23 middle aged and 2 older) were recruited for the experiment. The ages of younger group were below 25 years, the ages of middle aged group were between 25 to 55 years, and the ages of older group were above 55 years. According to gender, there were 25 males and 15 females. Every participant has a full Florida Driving License with a minimum of one year driving experience. Every participant was paid $10 for their participation.

Table 3-1: Age distribution of subjects

Gender	Age Distribution		
	Above 55	between 25 and 55	Below 25
Males	2	15	8
Females	0	8	7

3.2 UCF Driving Simulator

The UCF driving simulator uses three big size plane screens (1 forward, 2 side views) and two rear-mirrors to create a 180-degree forward field-of-view, which is shown as Figure 3-1. The driving simulator is an I-Sim Mark-II system, which consists of a simulator cab, Simview, motion base, scenario editor, operation console and Application Programmer Interface (API) for reading real-time data.

Figure 3-1: UCF driving simulator

- Simulator Cab: It is a Saturn model that has an automatic transmission, an air condition, a left back view mirror and a center back view mirror inside the cab, as shown as Figure 3-1.
- Simview: The software that generates the graphical display.
- Motion base: It provides motion, when the driver is driving. It plays a very important role on driving fidelity during the simulation. It provides six degrees of freedom (roll, pitch, heave, and yaw).

- Scenario Editor: It is very important software, which stores all types of roads, buildings and other physical features of the roads. In addition, traffic signs and ambient traffic can be laid out based on scenarios.
- APIs for reading real-time data: Currently, APIs can read real-time data from Simview. The data include steering wheel, accelerator, brake, every car's speed and coordinates, and time stamp. The sampling frequency is 60Hz.

The UCF driving simulator comes with traffic management software for constructing specific traffic scenarios. The Scenario Editor provides the capability for populating the simulated environment with autonomous vehicles and scripted vehicles. The first class consists of vehicles whose movements are controlled by car-following models. Their movements are pseudo-random in the sense that their trajectories cannot be determined a prior. In contrast, scripted vehicles follow predefined paths and can be triggered to respond in different ways based on their position, speed or location in the visual scene. Triggering can also be based on the states of other elements such as a traffic signal phase, locations of pedestrians, and proximity to other vehicles.

3.3 Experimental Design

There are many situations which can cause frustration and anxiety to drivers such as inappropriate turning radius, confusing lane striping and signage, insufficient holding capacity for turning vehicles, misalignment of lanes, presence of sight distance obstructions, inappropriate super elevation, and illumination.

Based on the resources availability and driving simulator limitations three types of characteristic features were identified in signalized intersection for this experiment. They included

1. A lane drop on the downstream side of the intersection (Type 1)
2. Misalignment of traffic lanes between the upstream side and downstream side (Type 2)
3. Shared left turn and through traffic lane or separate lanes for each approaching the intersection (Type 3)

Each of these three types of intersection had two alternative cases, case A and case B. The experimental phase consisted two different driving scenarios presented to all subjects, Scenario A and Scenario B. Each scenario consisted of a drive through an urban section of the simulator's visual data base. Scenario A consisted Type 1 case A, Type 2 case B, and Type 3 case A intersections. Scenario B consisted Type 1 case B, Type 2 case A, and Type 3 case B intersections. These scenarios are explained in detail in the later part of this chapter.

3.3.1 Lane Dropping

After crossing the intersection, the right most through lane was merged with the adjacent through lane. Due to traffic in the adjacent left lane, subjects were forced to cross the intersection in the right most through lane and then merge from two lanes into one. The length of the dropped lane was considerably shorter in one of the scenarios compared with the other. The two cases are referred to as 1-A and 1-B, where 1-A refers to the case where the dropped lane was shorter in length then 1-B as shown in Figure 3-2.

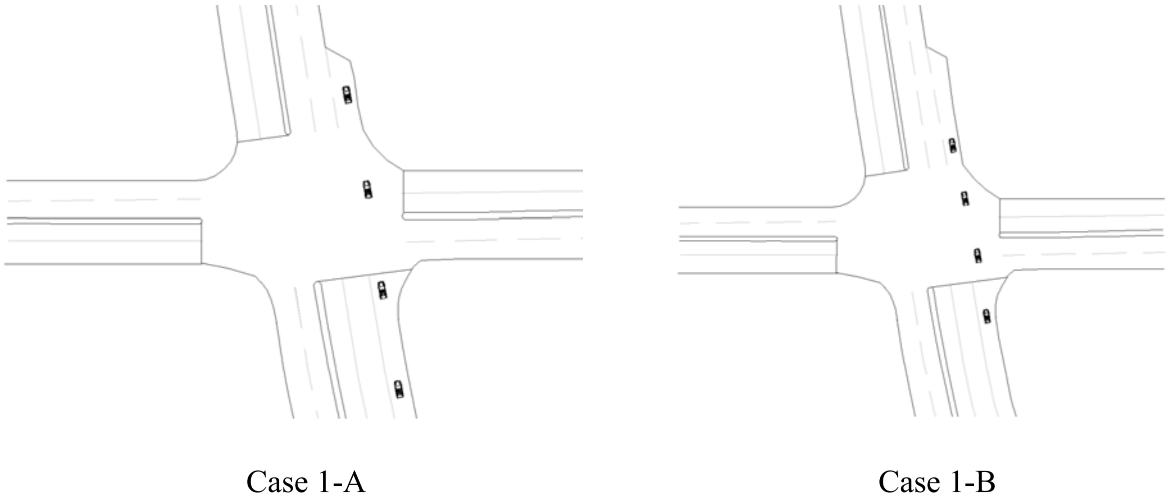


Figure 3-2: Lane drop intersection cases

The tapered length (L), as shown in Figure 3-3, was same in both the cases, which was calculated according to the Manual on Uniform Traffic Control Devices (MUTCD), 2003 Edition. The calculation for tapered length (L) is described below for speed limit of 35 MPH.

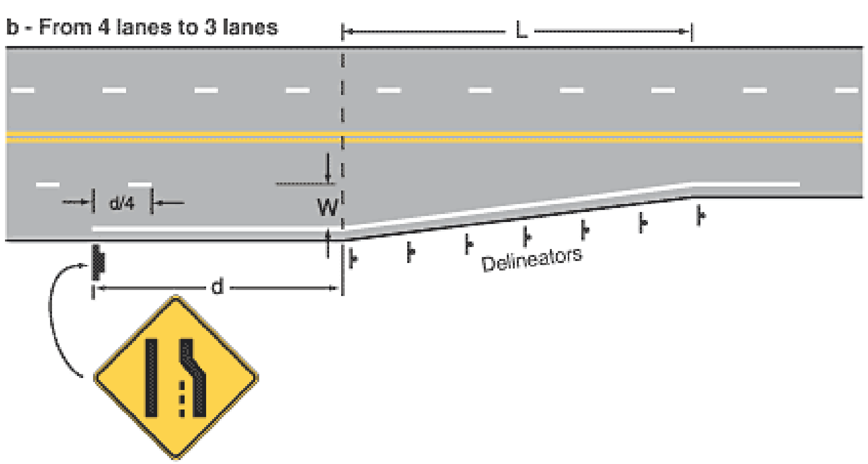


Figure 3-3: Lane drop length determination

For speed 70 km/h (45 mph) or more:

L = 0.62 WS (L = WS)

For speed less than 70 km/h (45 mph):

$L = WS^2/155$ ($L = WS^2/60$)

L = Length in meters (feet)

S = Posted, 85th percentile, or statutory speed in km/h (mph)

W = Offset in meters (feet)

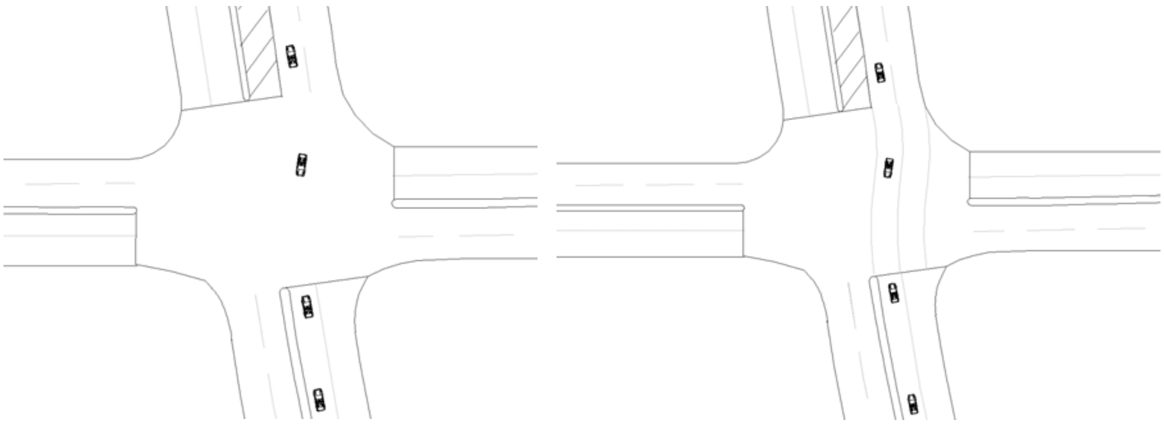
d = Advance warning distance

The whole driving simulation experiment had posted speed limit (S) 35 mph and lane width (W) of 12 feet. Based on these values the tapered length (L) comes out to be 245 feet. Case 1-A had shorter ‘d’, as shown in Figure 3-3, distance then Case 1-B.

3.3.2 Misalignment of Lanes

The second type of intersection was one in which the lanes on either side of the intersection were misaligned. If a driver fails to notice the misaligned lanes in advance then it can lead to a potential sideswipe crash or a collision with the median present at the downstream side of the intersection. If downstream side of the intersection is undivided then it might lead to a head on collision with the incoming traffic.

Drivers encountered this intersection in one of the scenarios without the aid of lane striping in the intersection. In contrast, the other scenario provided marking stripes within the intersection to guide the driver into the proper lane downstream of the intersection. The lanes before the intersection and after the intersection were misaligned by one lane width i.e. 12 feet. The case of the misaligned intersection without lane striping is referred to as 2-A while the case with striping present is denoted 2-B as shown in Figure 3-4.



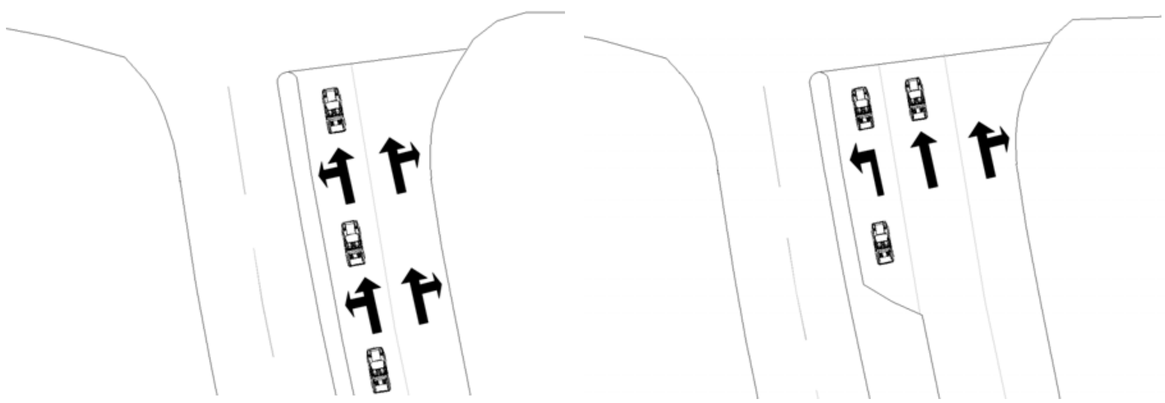
Case 2-A Case 2-B

Figure 3-4: Misalignment of lanes intersection cases

3.3.3 Shared Left and Through Traffic Lanes

The third type of intersection in study had shared left and thru lanes. This type of intersection aggravates the drivers who wants to go through the intersection and are trapped behind a left turning vehicle. This can lead to excessive delay or an attempt to lane change can lead to a crash.

During the experiment subjects were instructed to drive straight through this intersection. Different configurations were present in each of the two scenarios. In one scenario, the driver was positioned in a shared left turn and through lane with a left turning vehicle directly in front. Vehicles were placed in the adjacent lane to prevent drivers from changing lanes. In the other scenario, a dedicated left turn lane was added and the subject had unrestricted access through the intersection by driving in a through lane. The former design, referred to as 3-A and the latter was designated 3-B as shown in Figure 3-5.



Case 3-A Case 3-B

Figure 3-5: Shared left and through intersection cases

The two scenarios are classified by the intersection cases present. Scenario A consisted of the following cases:

- Short lane drop after crossing the intersection (Case 1-A)
- Misalignment of lanes with striping (Case 2-B)
- Joint left turn and through lane (Case 3-A)

Scenario B included 3 intersections with the following cases:

- Longer lane drop after crossing the intersection (Case 1-B)
- Misalignment of lanes and no striping (Case 2-A)
- Separate left turn and through lanes (Case 3-B)

3.4 Experiment Procedure

Upon arrival the subject were given a registration form and a consent form to fill up. The purpose of registration form was to get the subject's information such as name, age, and years of driving experience. The Institutional Review Board (IRB) at University of Central Florida (UCF) requires every research volunteer to sign a consent form for any personal injury or property damage suffered during the research project. A copy of registration form and consent form is provided in the Appendix.

The subjects were also given an informational briefing. In order to avoid driver bias, the participants were informed that the objective of the study was to assess the fidelity of the simulator and they should obey traffic laws and rules when driving the simulator.

Before the formal experiments began, all subjects were provided a brief orientation session to get acclimated to the driving simulator. During the course of this process, subjects practiced straight driving, acceleration, deceleration, left/right turn, and other basic driving maneuvers.

After the orientation, the formal experiment began during which all subjects faced the same set of 2 driving scenarios. The subjects were divided into two groups, Group 1 and Group 2. The subjects in Group 1 drove the Scenario A first and than Scenario B. Group 2 drove the Scenario B first and than Scenario A. The intention of dividing the subjects into two groups was to eliminate any bias in the result due to the sequence of Scenario presented. After each Scenario the subject was given at least 2 minutes to rest before running the next scenario.

CHAPTER 4: ANALYSES OF EXPERIMENT DATA OUTPUT AND TRAFFIC PARAMETERS

4.1 Data File Output

The computer program of the driving simulator automatically record data related to simulator vehicle in the system every 1/60th second, including vehicle position (X and Y coordinates), speed, acceleration, brakes, and steering movement. The following section documents samples of this data for illustration purpose. These samples also serve as verification of the simulation process.

4.1.1 Simulator Vehicle Position

The position of simulator vehicle was determined based on the x-coordinate and y-coordinate recorded during the experiment. The computer program only records the coordinate of center point of the simulator vehicle. The length and width of simulator vehicle were 4.7 meters and 1.75 meters, respectively. The right edge and left edge of vehicle was estimated by adding and subtracting the 0.875 meter from the y-coordinate recorded by the computer program, respectively. Similarly the front edge and rear end were estimated by adding and subtracting the 2.35 meters from the x-coordinate recorded by the computer program, respectively. The following figures 4-1, 4-2, 4-3 and 4-4 show the track of the simulator vehicle for lane drop and misaligned cases.

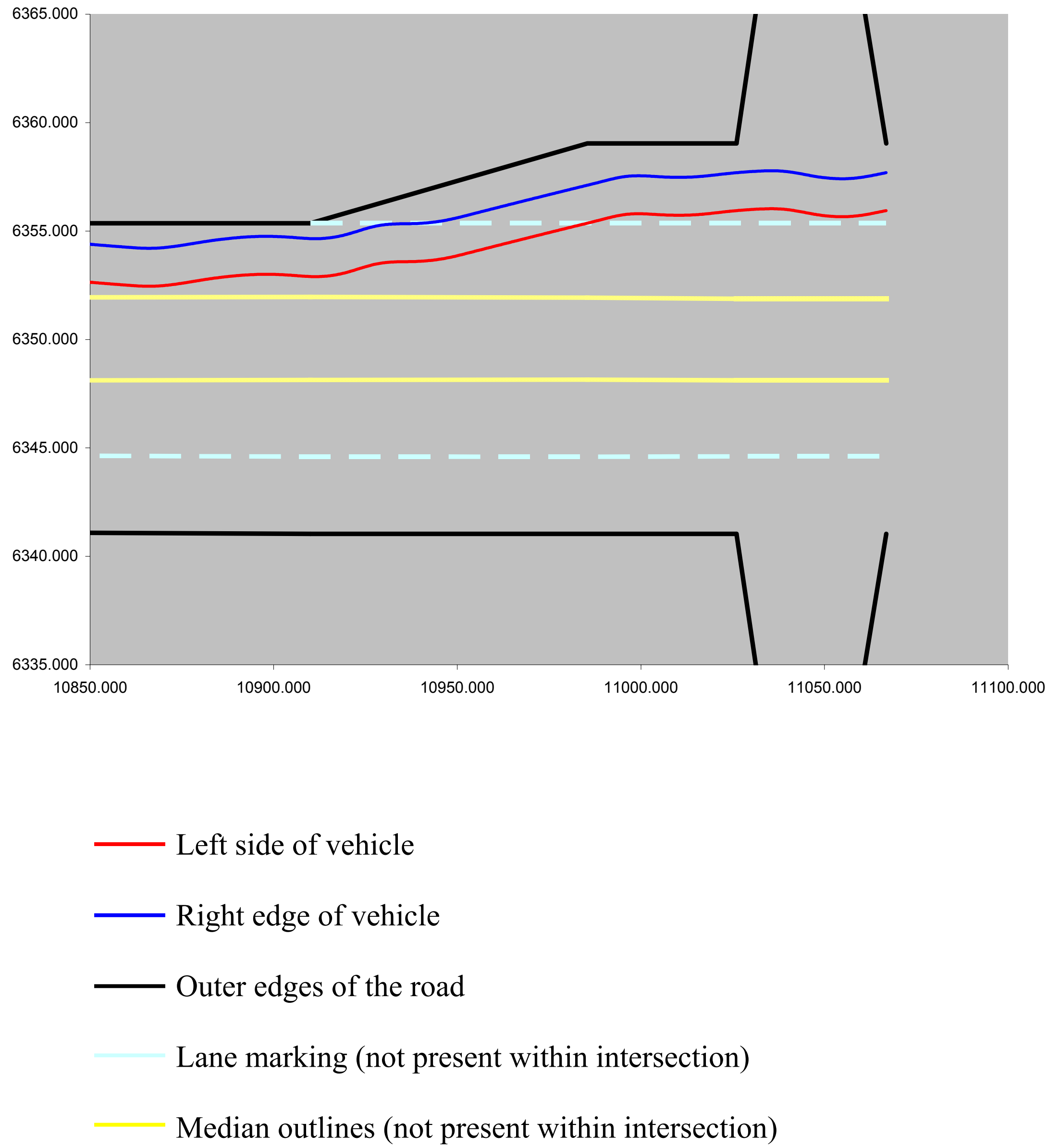


Figure 4-1: The track of the simulator vehicle during the lane drop case 1-A

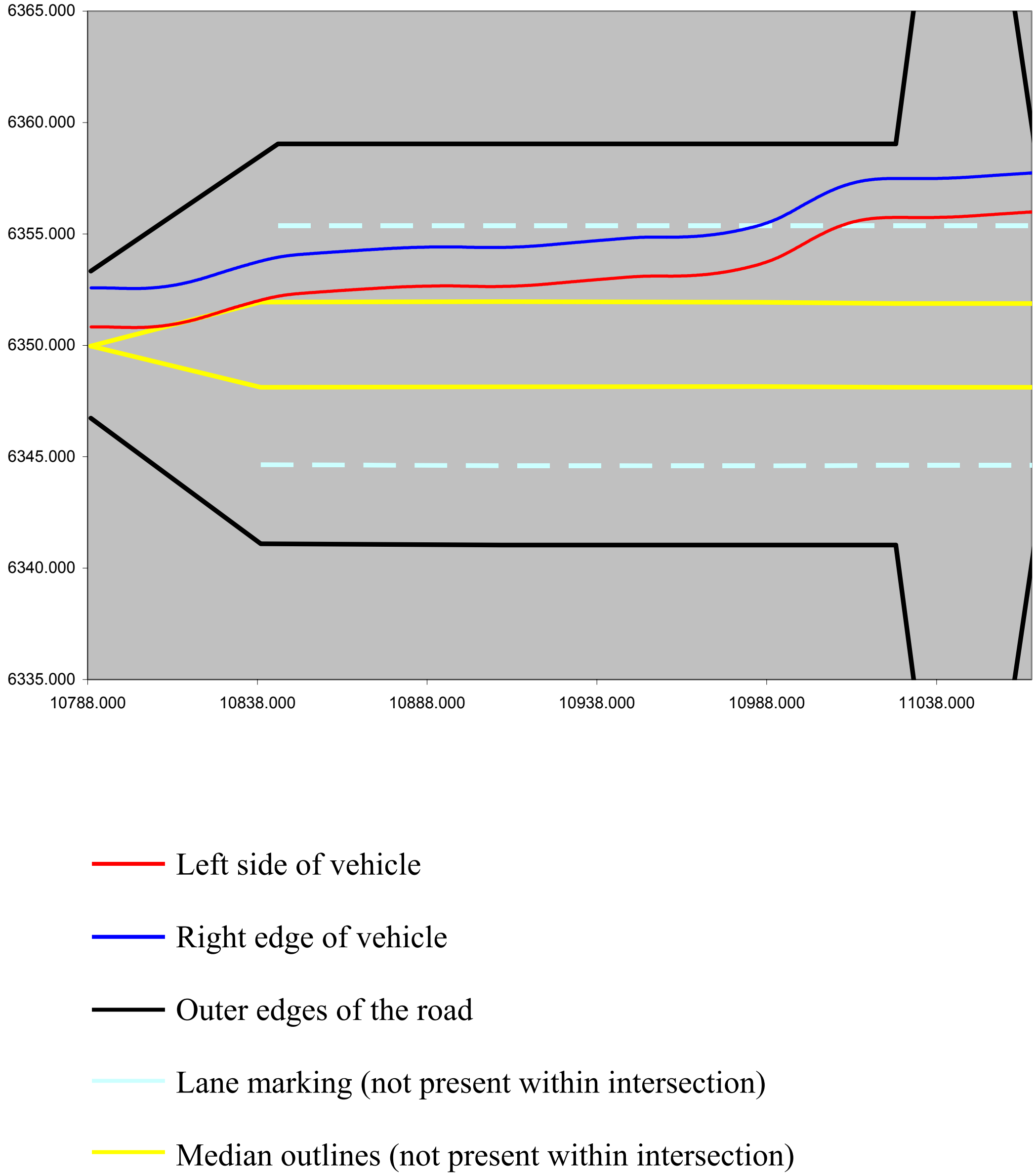


Figure 4-2: The track of the simulator vehicle during the lane drop case 1-B

During the experiment there were no marking on the ground for misaligned case 2-A. In the following graph imaginary markings were placed to track the simulator vehicle position with respect to intersection and lanes.

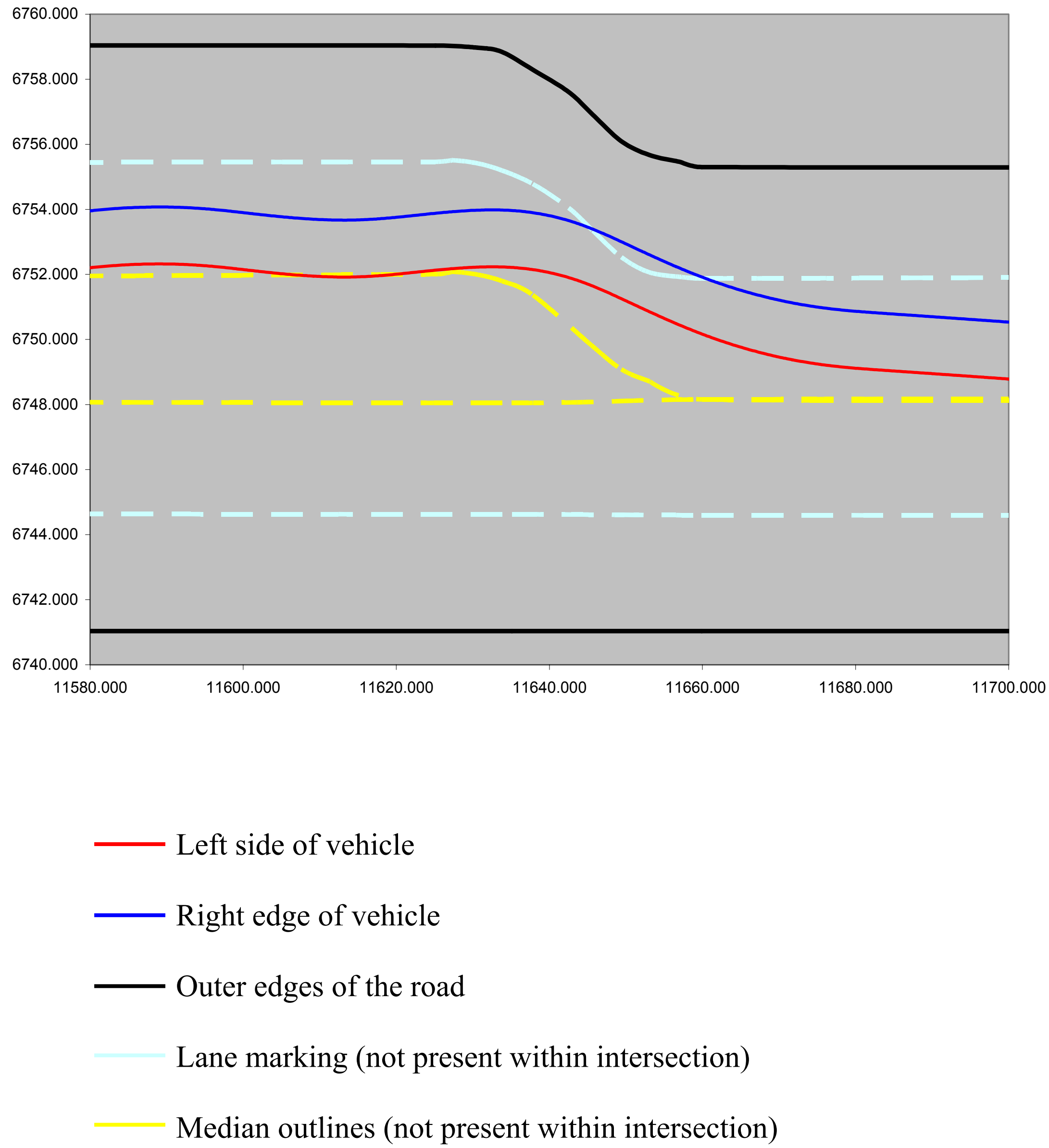


Figure 4-3: The track of the simulator vehicle during the misaligned case 2-A

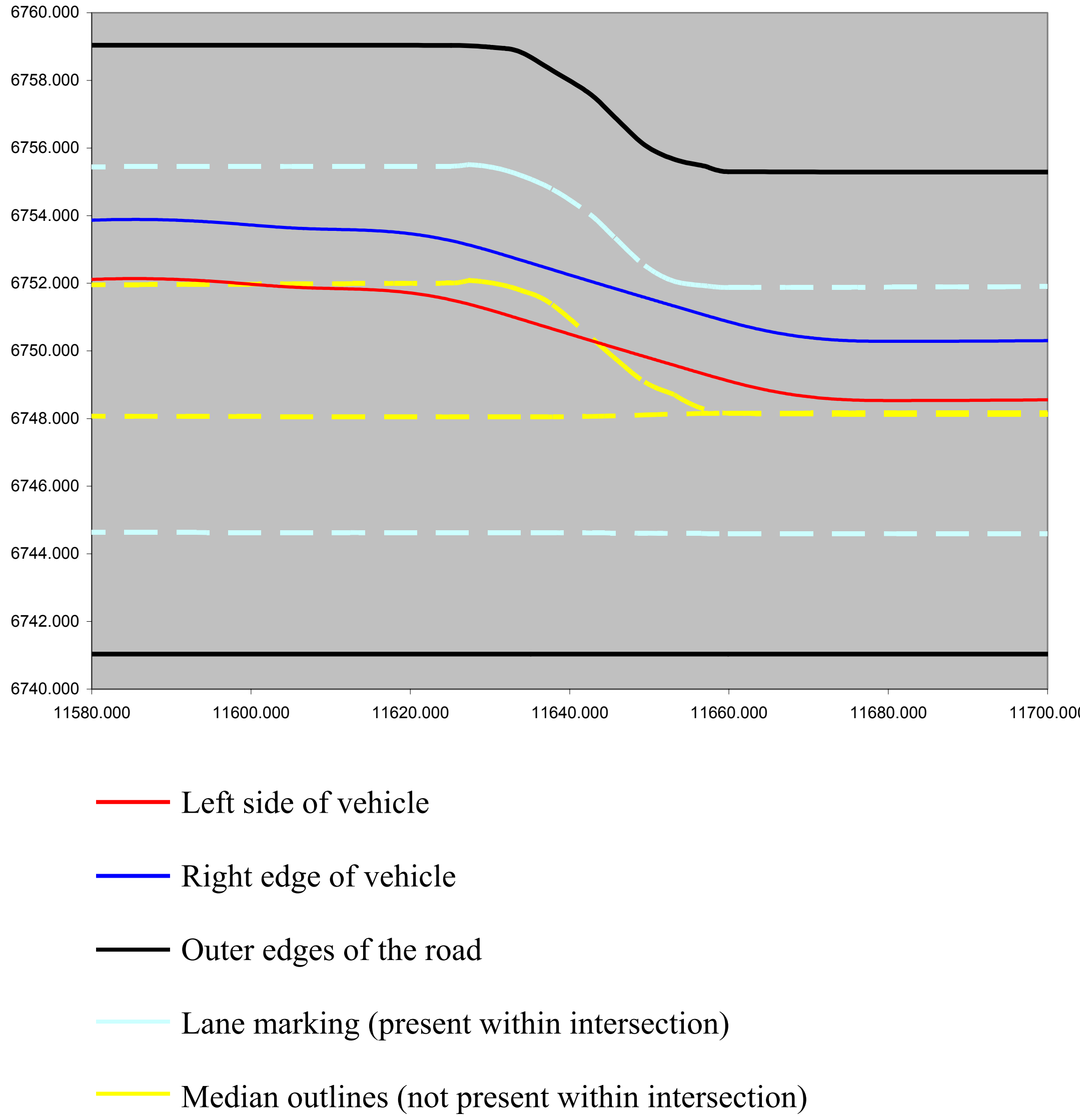


Figure 4-4: The track of the simulator vehicle during the misaligned case 2-B

4.1.2 Vehicle Speed

The instant speed of simulator car can be derived from the difference between adjacent positions of the vehicle divided by sampling time. During the course of the experiment, the instant speed of simulator vehicle was recorded at every 1/60th second. The following figures 4-5, 4-6, 4-7 and 4-8 show the speed profile of simulator vehicle for lane drop and misaligned cases. Figures 4-5 and 4-6 shows that as the subject approach the lane drop intersection their instant speed decreases. After crossing the intersection and merging to the adjacent lane subject accelerates to a higher speed.

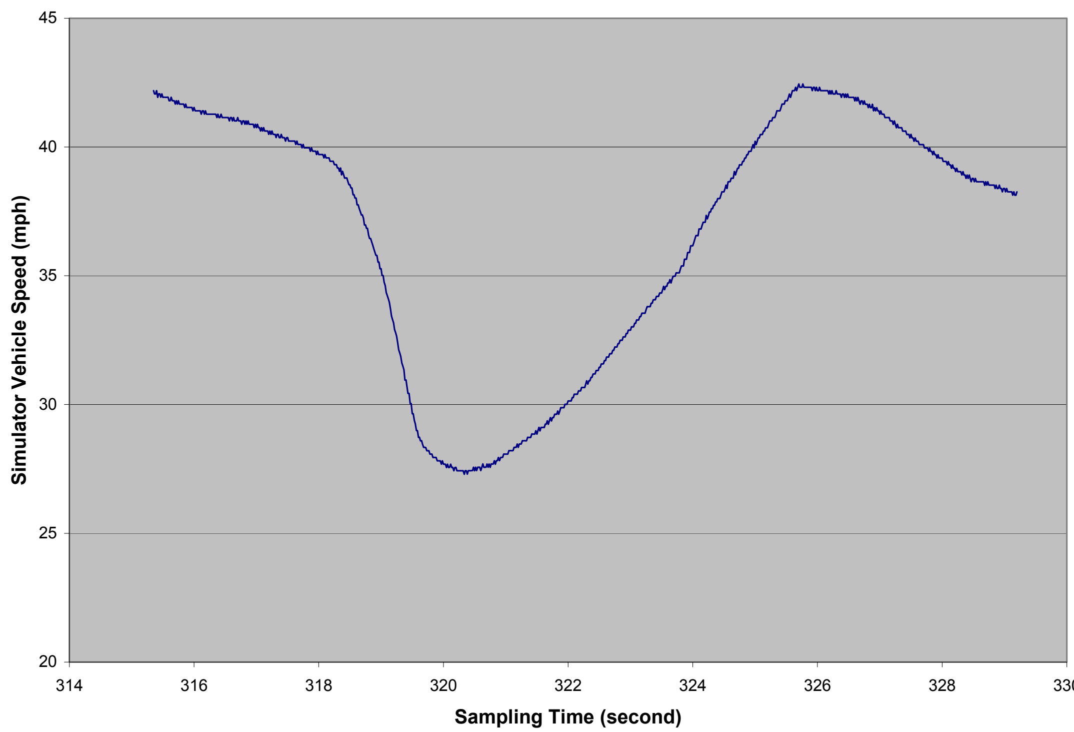


Figure 4-5: Typical speed distribution of simulator vehicle during lane drop case 1-A

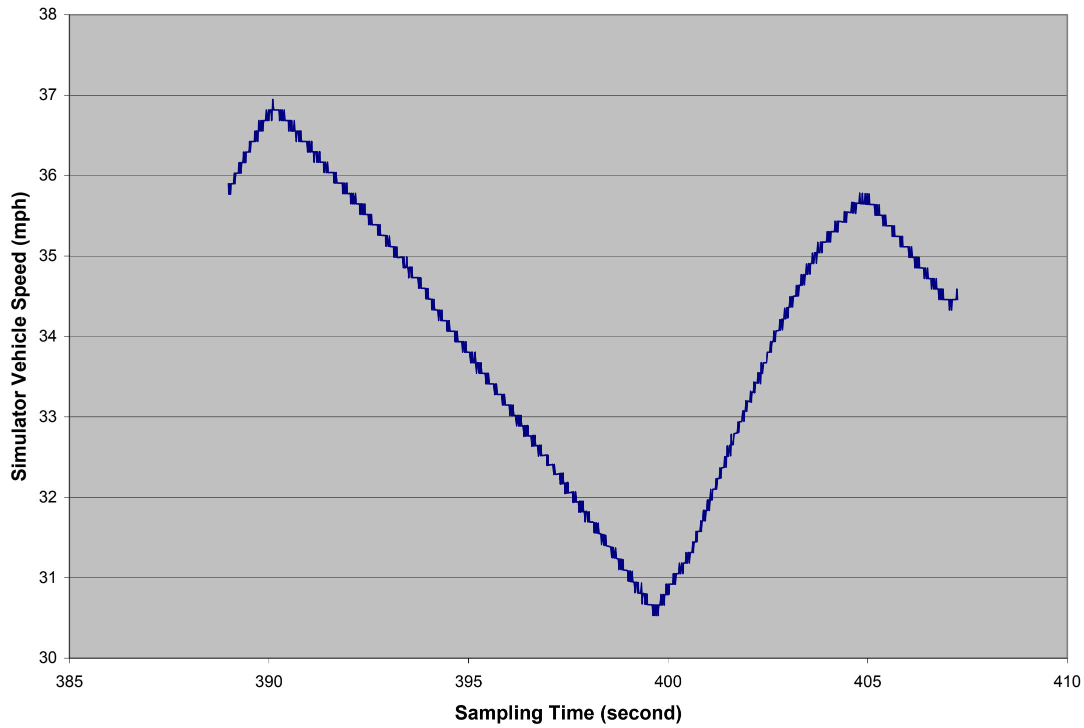


Figure 4-6: Typical speed distribution of simulator vehicle during lane drop case 1-B

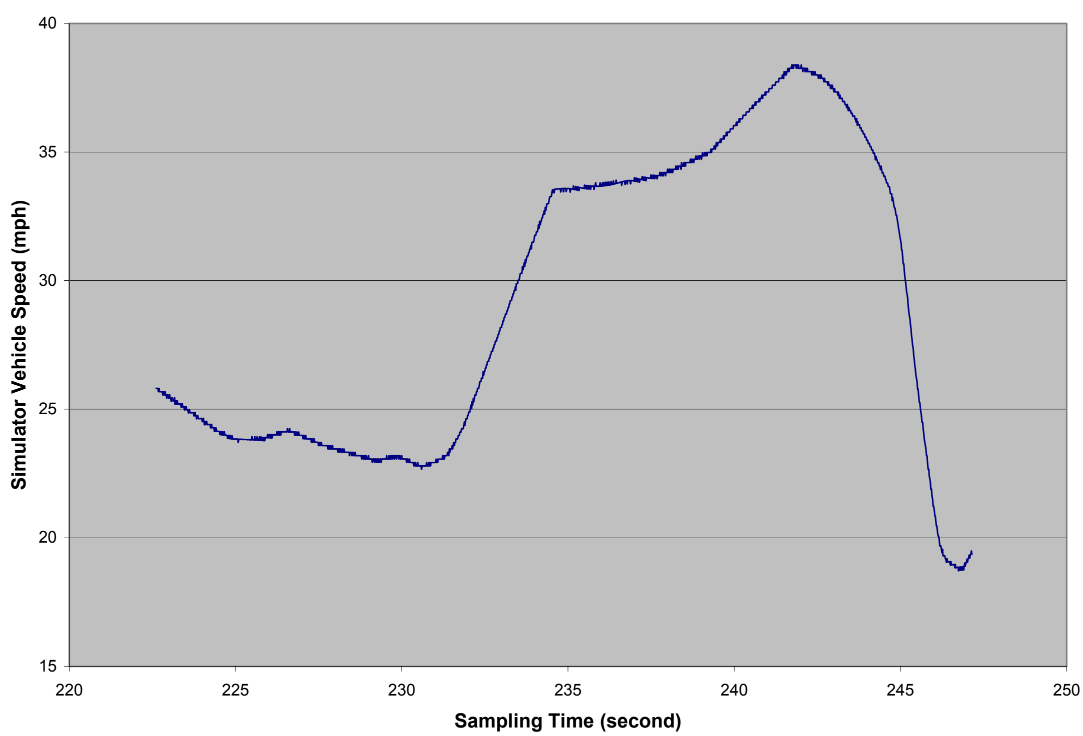


Figure 4-7: Typical speed distribution of simulator vehicle during misaligned case 2-A

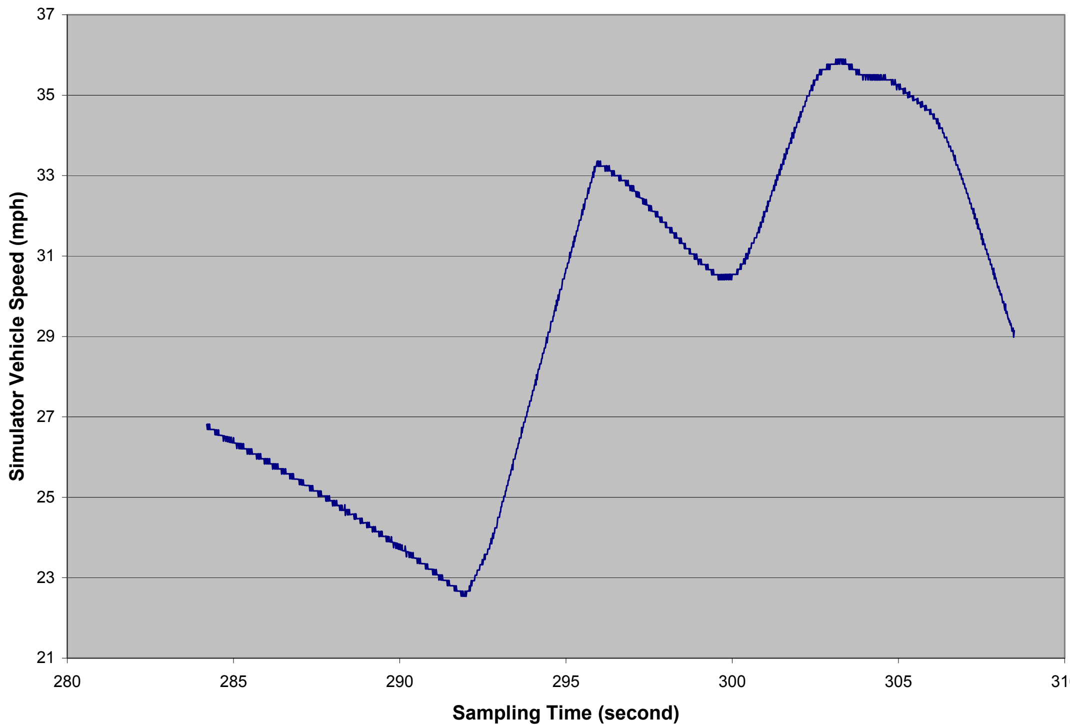


Figure 4-8: Typical speed distribution of simulator vehicle during misaligned case 2-B

4.1.3 Acceleration and Brake

During the experiment acceleration and brake input of each pedal type was recorded for every 1/60th second. As a pedal is depressed, the corresponding data represent the percentage of total pedal depression. The following figures 4-9, 4-10, 4-11 and 4-12 show the brake pedal input profile of simulator vehicle for lane drop and misaligned cases.

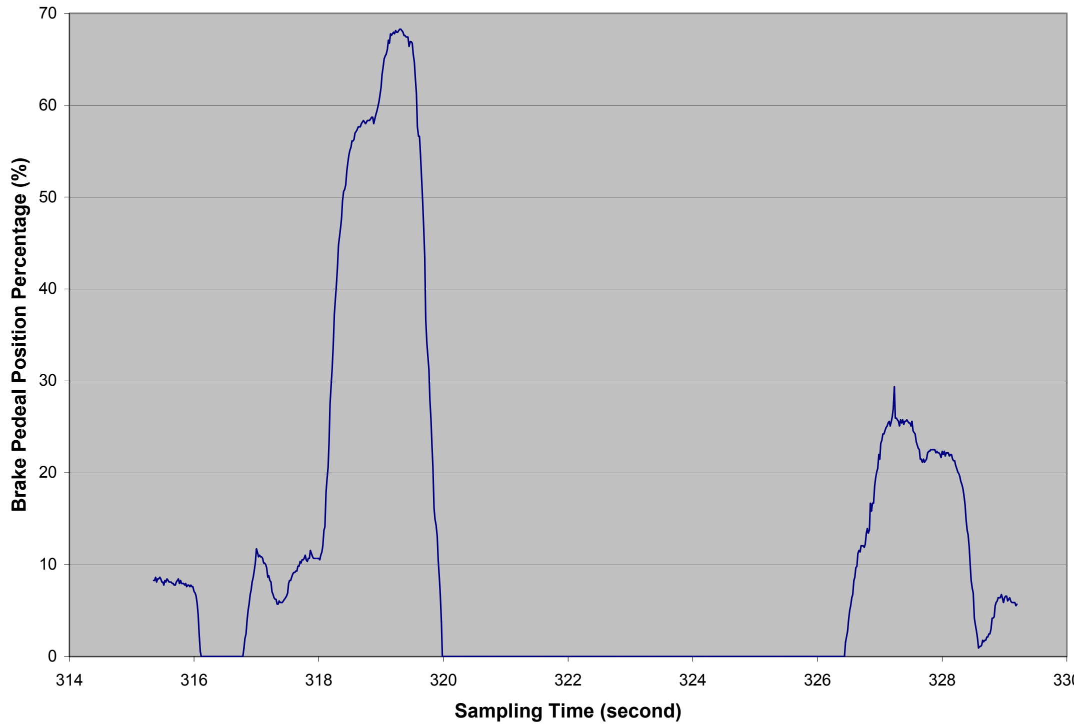


Figure 4-9: Brake pedal input profile of a subject during lane drop case 1-A

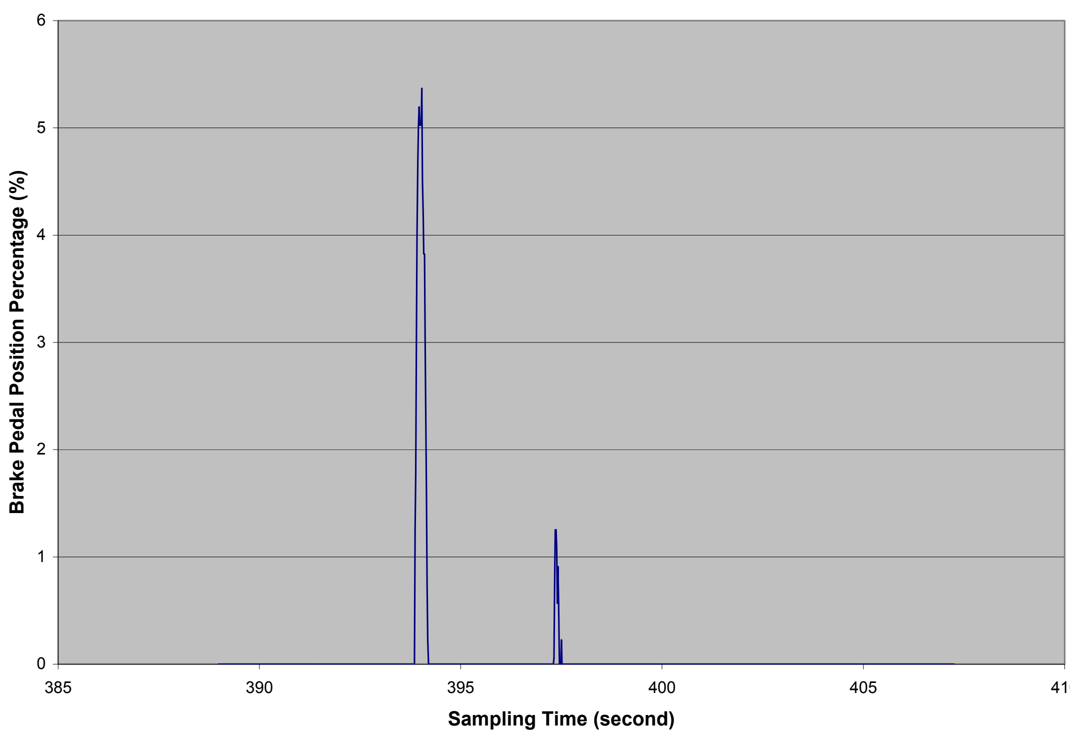


Figure 4-10: Brake pedal input profile of a subject during lane drop case 1-B

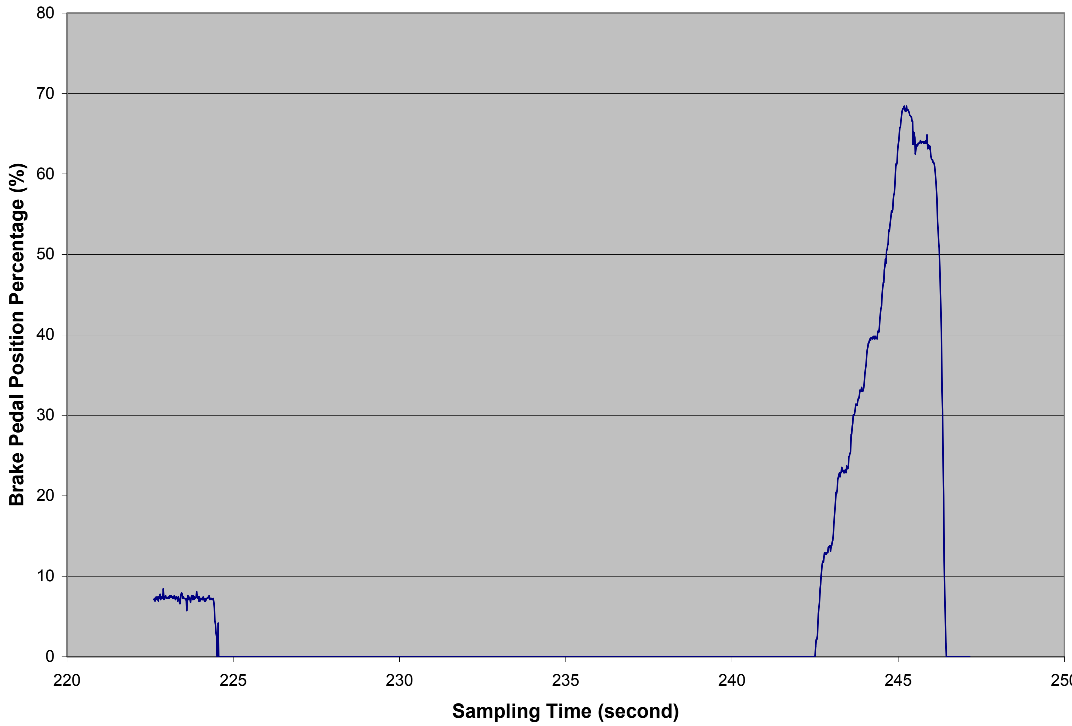


Figure 4-11: Brake pedal input profile of a subject during misaligned case 2-A

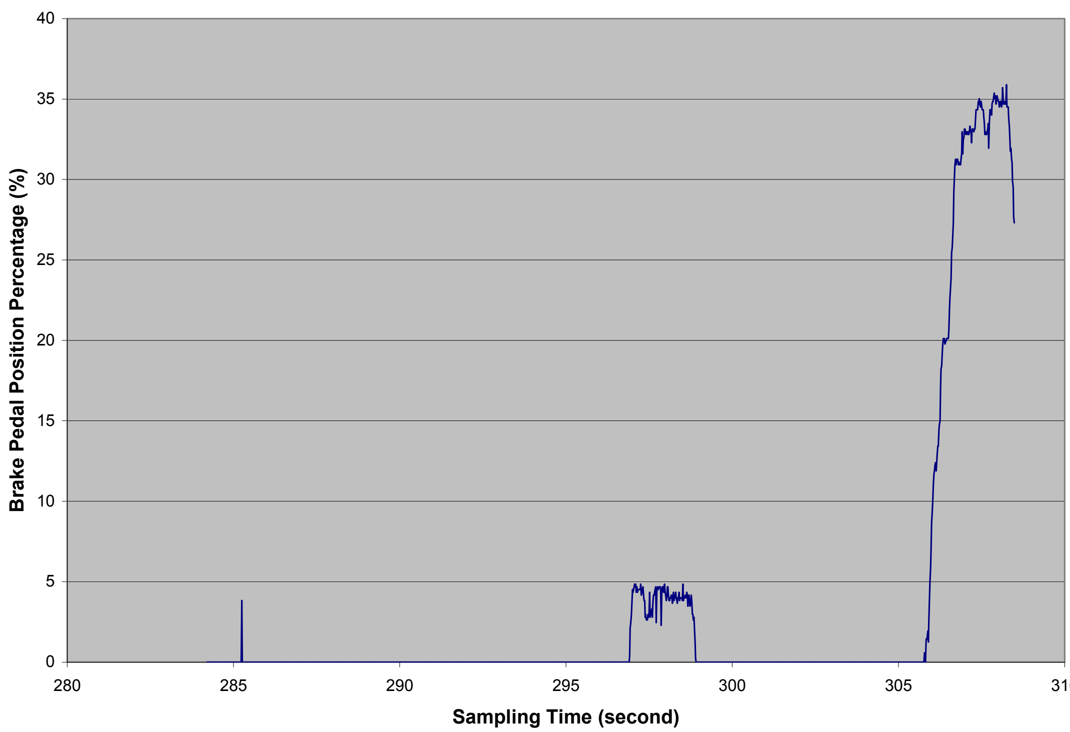


Figure 4-12: Brake pedal input profile of a subject during misaligned case 2-B

The following figures 4-13, 4-14, 4-15 and 4-16 shows the acceleration pedal input profile of simulator vehicle for lane drop and misaligned cases.

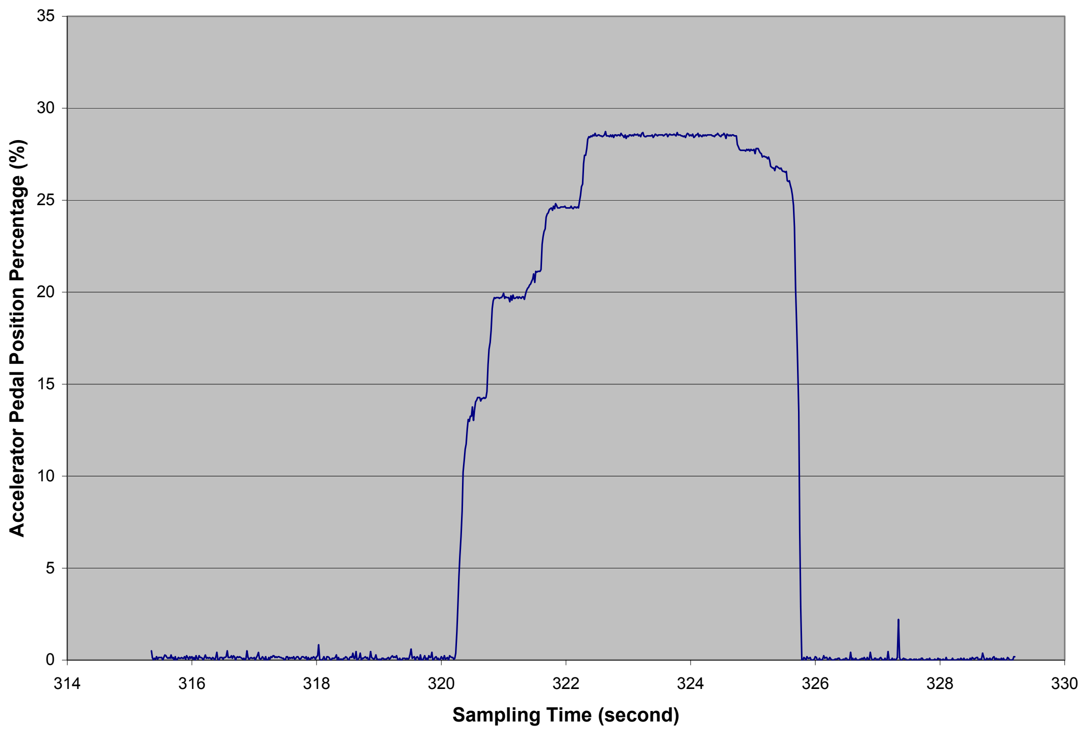


Figure 4-13: Acceleration pedal input profile of a subject during lane drop case 1-A

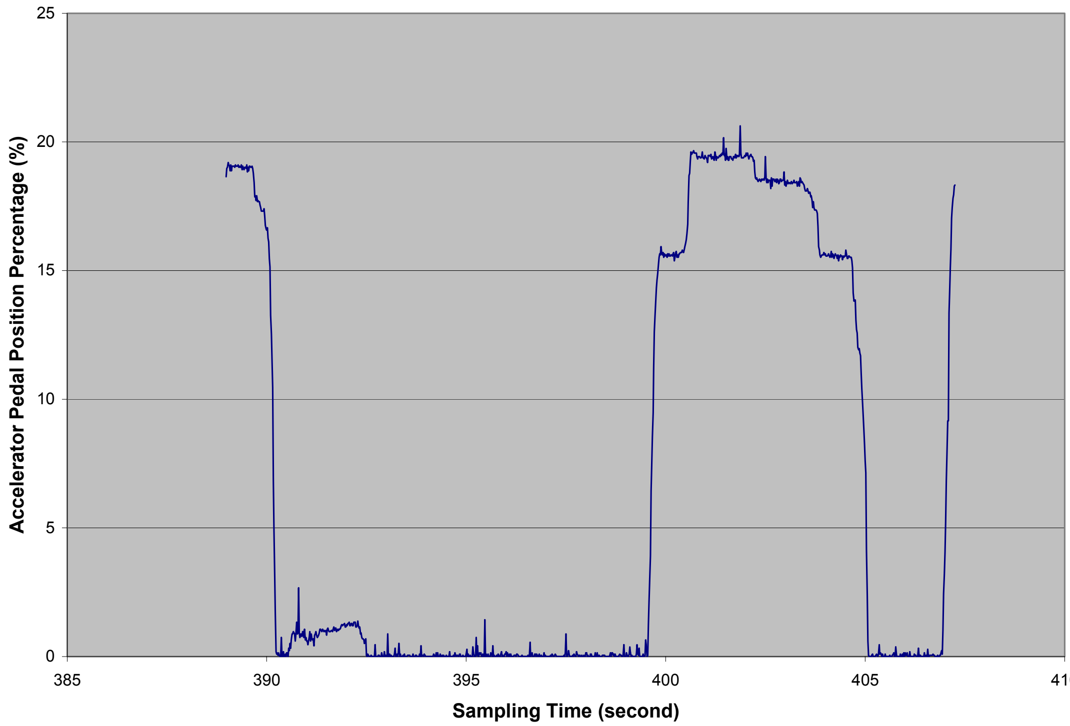


Figure 4-14: Acceleration pedal input profile of a subject during lane drop case 1-B

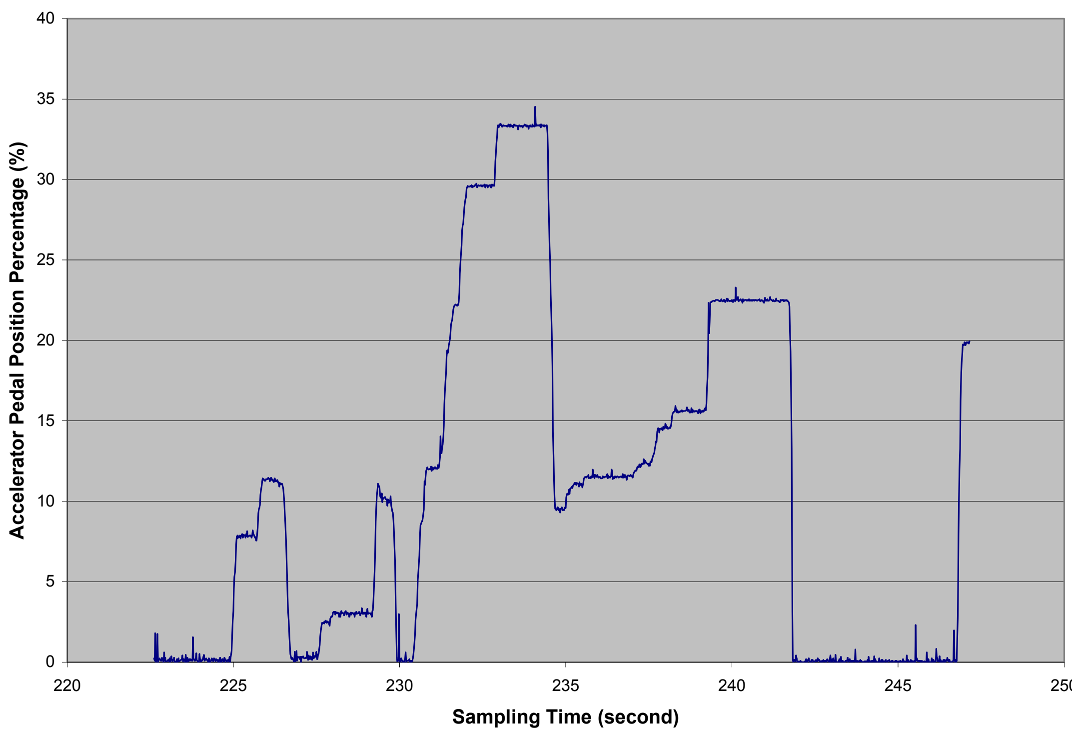


Figure 4-15: Acceleration pedal input profile of a subject during misaligned case 2-A

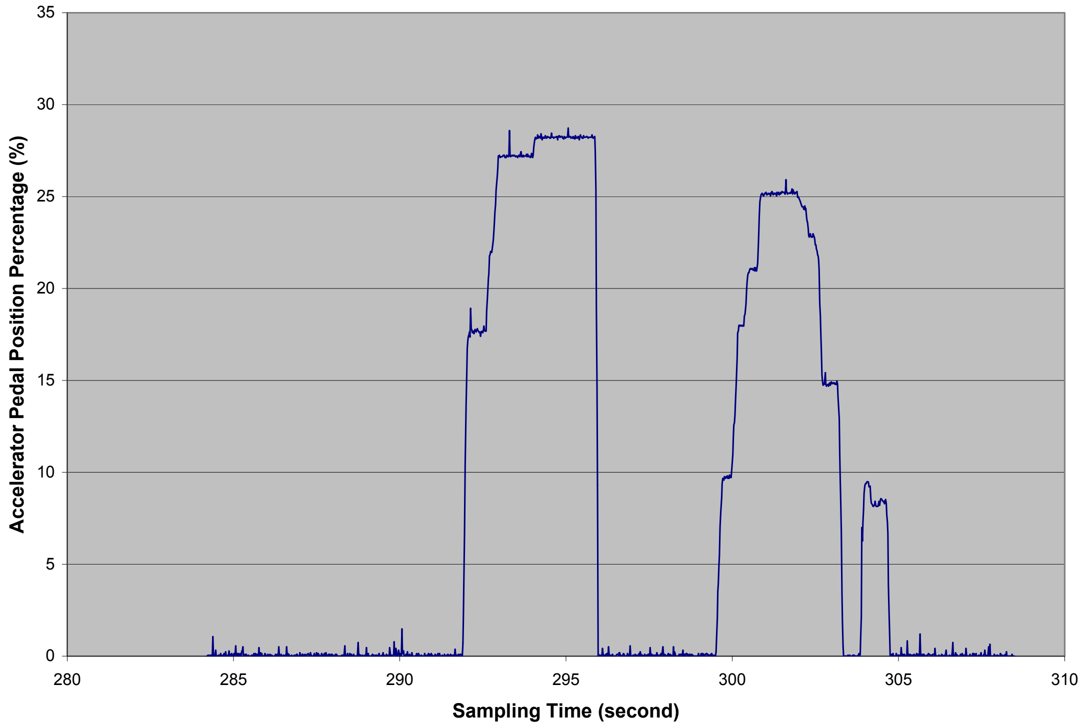


Figure 4-16: Acceleration pedal input profile of a subject during misaligned case 2-B

4.1.4 Steer Control

The steering output data display the current angle of the selected simulator's steering wheel during the experiment sampling time. Figures 4-17, 4-18, 4-19 and 4-20 show the steering position of the simulator vehicle during lane drop and misaligned cases. If the values of the steer angle approach zero, it means that the driver is driving straight. The crest part in the following figures shows that the driver is turning the steering wheel to move left and the sag part shows that the driver is turning the steering wheel to move right.

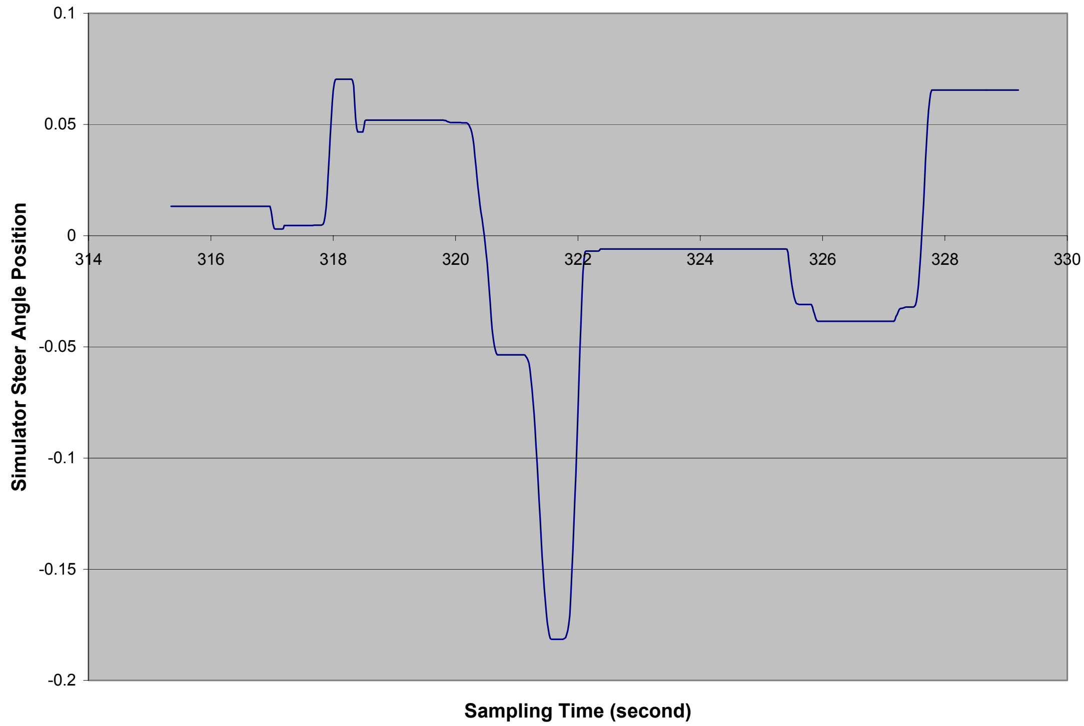


Figure 4-17: Steering profile of a subject during lane drop case 1-A

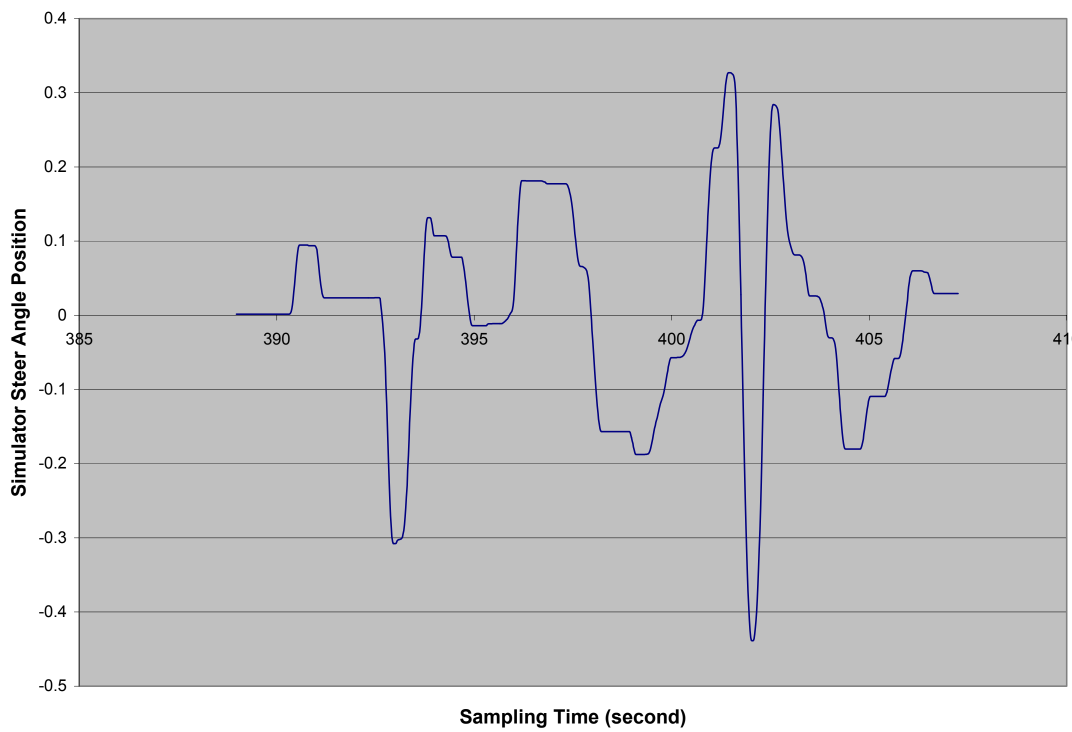


Figure 4-18: Steering profile of a subject during lane drop case 1-B

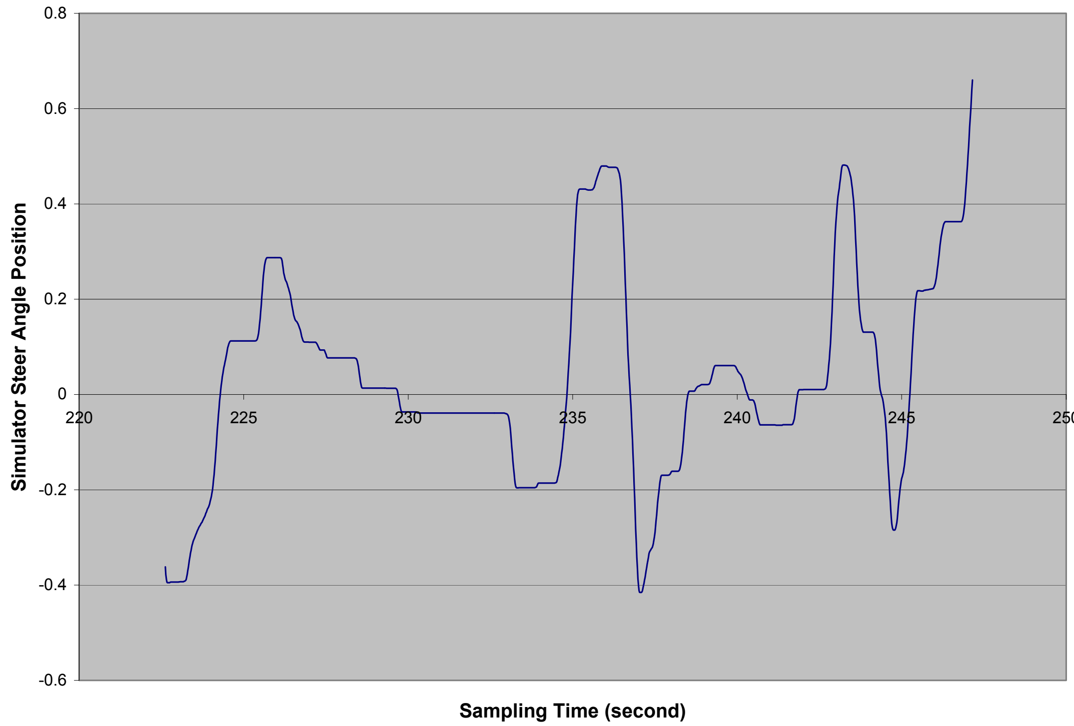


Figure 4-19: Steering profile of a subject during misaligned case 2-A

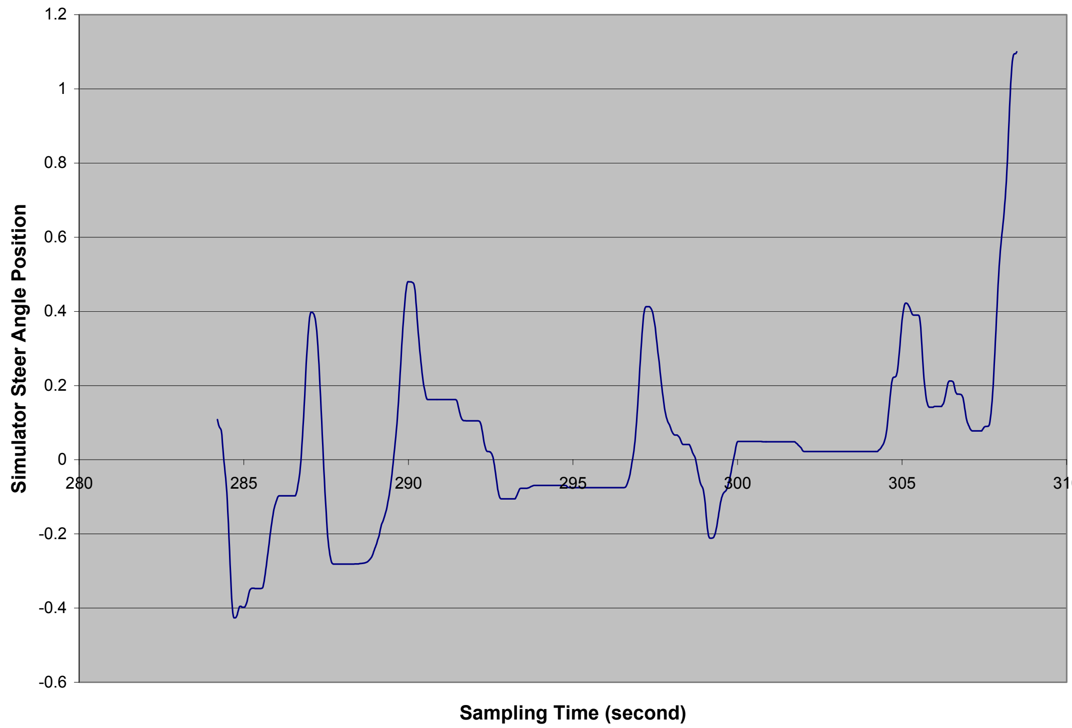


Figure 4-20: Steering profile of a subject during misaligned case 2-B

During the experiment, the number of crashes (if any) was noted by one of the researchers located in the simulator observation room. Any other notable behaviors of the subject were also recorded.

4.2 Program for Calculation of Experiment Variables

To organize and processing the data generated from the experiments, a SAS computer program was created to manipulate the experiment data output files. A sample of output file and the SAS program is provided in the Appendix.

CHAPTER 5: EXPERIMENT RESULT AND DATA ANALYSES

The experimental results for each of the six intersection cases are presented below.

5.1 Lane Drop After Crossing the Intersection

Case: 1-A (Dropped Lane – Short Length)

A sample of the short dropped lane intersection is shown in Figure 5-1. There are 2 full lanes for a distance of 133 ft followed by an additional 247 ft over which the right lane narrows from 12 ft to zero. The path followed by one of the subject is indicated by the blue (right side of vehicle) and red (left side of vehicle) lines. A vehicle is considered to have merged from the dropped lane when the right side of the vehicle enters the left lane.

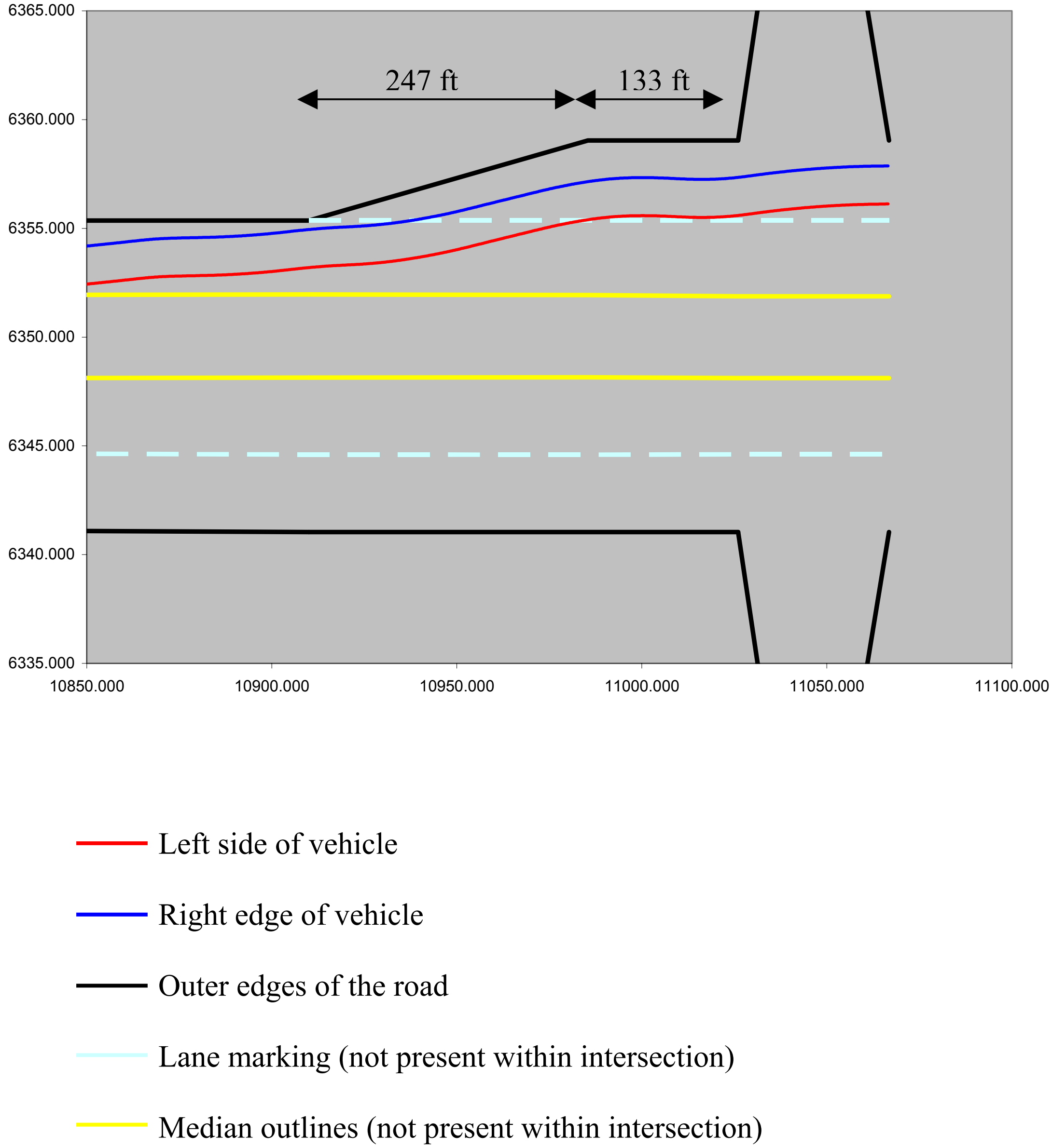


Figure 5-1: Sample of lane drop intersection case 1-A with short dropped lane

The distance (measured from where the two lanes begin after the intersection) to complete the merge was obtained from the logged data. A negative value indicates the merge was completed within the intersection. Results are shown in Tables 5-1 and 5-2.

Table 5-1: Merge distance for females at intersection with short dropped lane

Female No.	X1	Y1	X2	Y2	Lane change distance in feet
1	11026	6353.36	10978.2	6353.36	156.94
2	11026	6353.36	11027.7	6353.36	-5.55
3	11026	6353.36	10940.1	6353.36	281.88
4	11026	6353.36	10934.5	6353.36	300.15
5	11026	6353.36	10955.3	6353.36	232.12
6	11026	6353.36	10960.6	6353.36	214.44
7	11026	6353.36	10947.0	6353.36	259.15
8	11026	6353.36	10973.4	6353.36	172.52
9	11026	6353.36	10934.0	6353.36	301.85
10	11026	6353.36	10978.2	6353.36	156.94
11	11026	6353.36	10944.5	6353.36	267.44
12	11026	6353.36	10971.5	6353.36	178.75
13	11026	6353.36	10958.5	6353.36	221.62
14	11026	6353.36	10955.1	6353.36	232.48
15	11026	6353.36	10997.1	6353.36	95.02

Table 5-2: Merge distance for males at intersection with short dropped lane

Male No.	X1	Y1	X2	Y2	Lane change distance in feet
1	11026	6353.36	10967.6	6353.36	191.68
2	11026	6353.36	10947.7	6353.36	256.88
3	11026	6353.36	10937.5	6353.36	290.37
4	11026	6353.36	10973.0	6353.36	173.83
5	11026	6353.36	10941.0	6353.36	278.79
6	11026	6353.36	10982.0	6353.36	144.51
7	11026	6353.36	10960.3	6353.36	215.62
8	11026	6353.36	10971.6	6353.36	178.39
9	11026	6353.36	10950.8	6353.36	246.65
10	11026	6353.36	10977.9	6353.36	157.93
11	11026	6353.36	11002.6	6353.36	76.75
12	11026	6353.36	10968.1	6353.36	189.84
13	11026	6353.36	10985.8	6353.36	131.85
14	11026	6353.36	10953.6	6353.36	237.47
15	11026	6353.36	10942.0	6353.36	275.74
16	11026	6353.36	10948.9	6353.36	252.95
17	11026	6353.36	10948.3	6353.36	254.85
18	11026	6353.36	10958.6	6353.36	221.10
19	11026	6353.36	10960.9	6353.36	213.62
20	11026	6353.36	10928.6	6353.36	319.53
21	11026	6353.36	10974.5	6353.36	169.14
22	11026	6353.36	10943.5	6353.36	270.76
23	11026	6353.36	10922.5	6353.36	339.47
24	11026	6353.36	11046.1	6353.36	-65.77
25	11026	6353.36	10956.0	6353.36	229.66

The average speed during the merging maneuver was also obtained from the logged data. Results for average merge speed for females and males are shown in Tables 5-3 and 5-4, respectively. In these tables Time1 represents the time when the subject had just crossed the intersection and Time2 represents the time when the subject had just finished the lane merging maneuver.

Table 5-3: Average merge speed for females at intersection with short dropped lane

Female No.	Lane change distance in feet	Time 1	Time 2	Time Difference	Speed in MPH
1	156.94	317.55	320.75	3.20	33.44
2	-5.55	380.80	380.68	-0.12	32.42
3	281.88	560.45	566.38	5.93	32.39
4	300.15	346.78	353.42	6.63	30.85
5	232.12	424.35	428.55	4.20	37.68
6	214.44	364.57	368.73	4.17	35.09
7	259.15	391.63	396.97	5.33	33.13
8	172.52	379.67	383.08	3.42	34.43
9	301.85	371.65	378.33	6.68	30.79
10	156.94	317.55	320.75	3.20	33.44
11	267.44	415.05	419.95	4.90	37.21
12	178.75	430.62	433.85	3.23	37.69
13	221.62	409.27	413.00	3.73	40.48
14	232.48	386.20	390.72	4.52	35.09
15	95.02	352.98	354.35	1.37	47.40

Table 5-4: Average merge speed for males at intersection with short dropped lane

Male No.	Lane change distance in feet	Time 1	Time 2	Time Difference	Speed in MPH
1	191.68	483.60	486.73	3.13	41.71
2	256.88	340.40	347.65	7.25	24.16
3	290.37	337.58	343.35	5.77	34.33
4	173.83	350.43	353.23	2.80	42.33
5	278.79	533.72	540.57	6.85	27.75
6	144.51	344.67	347.53	2.87	34.37
7	215.62	426.58	430.47	3.88	37.86
8	178.39	400.15	404.23	4.08	29.79
9	246.65	392.70	398.45	5.75	29.25
10	157.93	326.55	329.28	2.73	39.39
11	76.75	405.10	406.40	1.30	40.25
12	189.84	342.78	346.55	3.77	34.36
13	131.85	337.58	339.95	2.37	37.98
14	237.47	407.38	412.22	4.83	33.50
15	275.74	391.70	397.15	5.45	34.50
16	252.95	294.75	300.57	5.82	29.65
17	254.85	402.45	408.13	5.68	30.57
18	221.10	322.92	325.48	2.57	58.73
19	213.62	332.27	335.38	3.12	46.73
20	319.53	441.38	448.50	7.12	30.61
21	169.14	400.40	403.20	2.80	41.19
22	270.76	457.70	463.68	5.98	30.85
23	339.47	305.52	310.40	4.88	47.40
24	-65.77	324.92	323.70	-1.22	36.86
25	229.66	384.42	389.77	5.35	29.27

Case: 1-B (Dropped Lane – Longer Length)

The intersection with a longer dropped lane is shown in Figure 5-2. The full two lanes continue for a distance of 597 ft followed by the same 247 ft where the right lane narrows from 12 ft to zero. Figure 5-2 also shows the path of simulator vehicle driven by one of the subjects. Tables 5-5 and 5-6 summarize the results for female and male subjects.

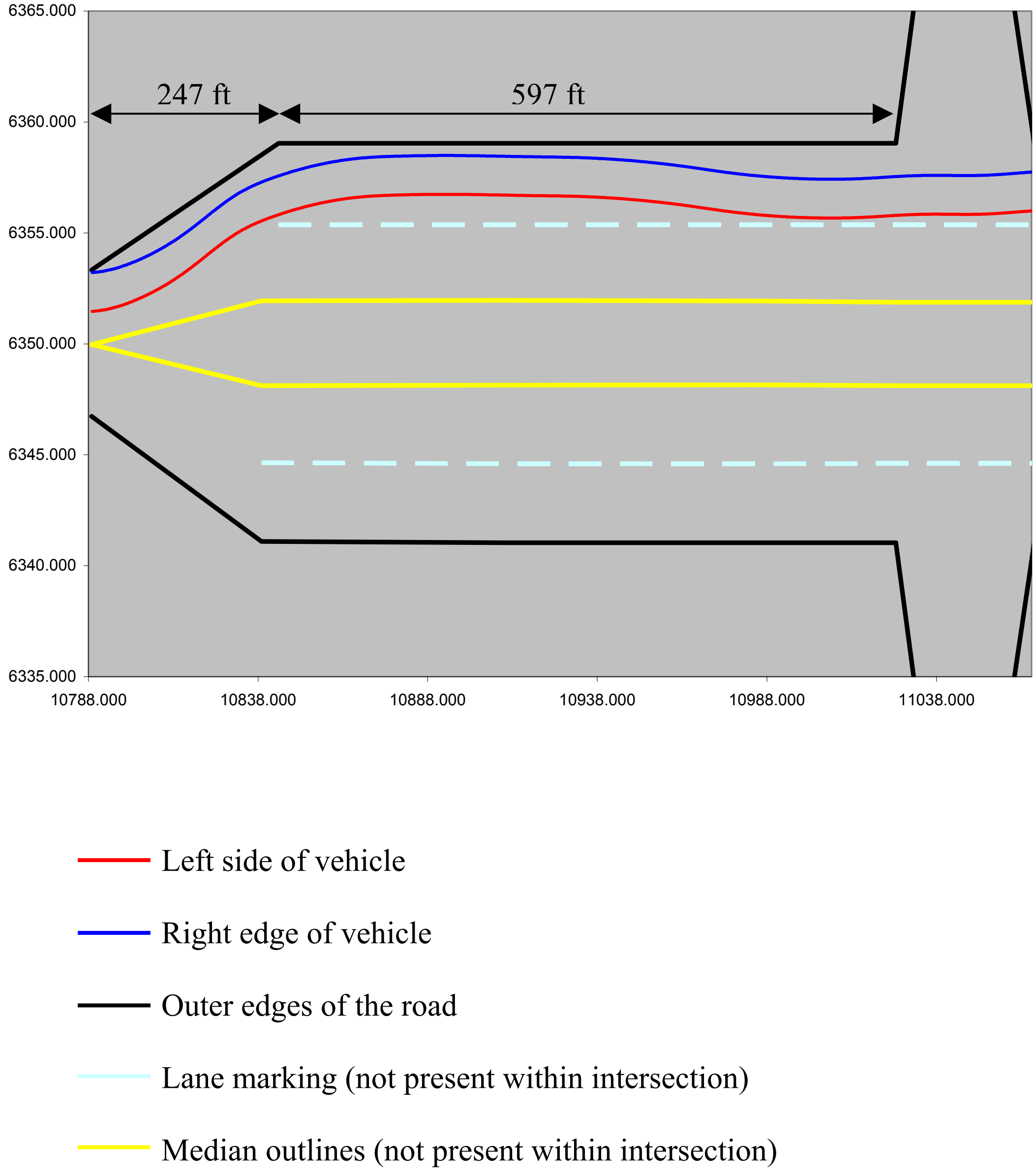


Figure 5-2: Sample of lane drop intersection case 1-B with longer dropped lane

Table 5-5: Merge distance for females at intersection with longer dropped lane

Female No.	X1	Y1	X2	Y2	Lane change distance in feet
1	11026	6353.36	10911.7	6353.36	374.96
2	11026	6353.36	10813.9	6353.36	695.65
3	11026	6353.36	10823.9	6353.36	662.85
4	11026	6353.36	10818.9	6353.36	679.51
5	11026	6353.36	10825.2	6353.36	658.81
6	11026	6353.36	10985.3	6353.36	133.72
7	11026	6353.36	10827.7	6353.36	650.65
8	11026	6353.36	10830.4	6353.36	641.56
9	11026	6353.36	10822.9	6353.36	666.19
10	11026	6353.36	10825.0	6353.36	659.31
11	11026	6353.36	10817.5	6353.36	683.87
12	11026	6353.36	10822.0	6353.36	669.11
13	11026	6353.36	10840.8	6353.36	607.55
14	11026	6353.36	10848.2	6353.36	583.34
15	11026	6353.36	10954.9	6353.36	233.23

Table 5-6: Merge distance for males at intersection with longer dropped lane

Male No.	X1	Y1	X2	Y2	Lane change distance in feet
1	11026	6353.36	10819.8	6353.36	676.36
2	11026	6353.36	10877.4	6353.36	487.34
3	11026	6353.36	10814.9	6353.36	692.40
4	11026	6353.36	10865.4	6353.36	526.86
5	11026	6353.36	10815.9	6353.36	689.35
6	11026	6353.36	10831.1	6353.36	639.36
7	11026	6353.36	10829.4	6353.36	644.84
8	11026	6353.36	10972.2	6353.36	176.69
9	11026	6353.36	10816.0	6353.36	688.83
10	11026	6353.36	10953.6	6353.36	237.63
11	11026	6353.36	10796.3	6353.36	753.54
12	11026	6353.36	10816.0	6353.36	688.79
13	11026	6353.36	10867.7	6353.36	519.15
14	11026	6353.36	10826.3	6353.36	655.11
15	11026	6353.36	10818.2	6353.36	681.64
16	11026	6353.36	10817.5	6353.36	683.94
17	11026	6353.36	10868.3	6353.36	517.35
18	11026	6353.36	10987.5	6353.36	126.21
19	11026	6353.36	10880.9	6353.36	476.05
20	11026	6353.36	10822.5	6353.36	667.64
21	11026	6353.36	10946.8	6353.36	259.80
22	11026	6353.36	10814.2	6353.36	694.66
23	11026	6353.36	10805.9	6353.36	722.09
24	11026	6353.36	11038.0	6353.36	-39.17
25	11026	6353.36	10823.3	6353.36	664.78

The average speed during the merging maneuver was also obtained from the logged data. Results for average merge speed for females and males are shown in Tables 5-7 and 5-8, respectively. In these tables Time1 represents the time when the subject had just crossed the intersection and Time2 represents the time when the subject had just finished the lane merging maneuver.

Table 5-7: Average merge speed for females at intersection with longer dropped lane

Female No.	Lane change distance in feet	Time 1	Time 2	Time Difference	Speed in MPH
1	374.96	391.48	399.10	7.62	33.57
2	695.65	278.42	291.28	12.87	36.86
3	662.85	271.28	283.35	12.07	37.45
4	679.51	334.73	346.93	12.20	37.98
5	658.81	281.40	293.02	11.62	38.67
6	133.72	329.67	332.22	2.55	35.75
7	650.65	326.30	339.33	13.03	34.04
8	641.56	286.58	298.73	12.15	36.00
9	666.19	325.93	339.90	13.97	32.52
10	659.31	363.95	376.43	12.48	36.01
11	683.87	311.73	324.83	13.10	35.59
12	669.11	285.58	297.98	12.40	36.79
13	607.55	366.45	377.25	10.80	38.36
14	583.34	290.35	302.57	12.22	32.56
15	233.23	547.87	552.55	4.68	33.95

Table 5-8: Average merge speed for males at intersection with longer dropped lane

Male No.	Lane change distance in feet	Time 1	Time 2	Time Difference	Speed in MPH
1	676.36	319.42	330.15	10.73	42.96
2	487.34	319.10	328.08	8.98	36.99
3	692.40	288.47	301.03	12.57	37.57
4	526.86	422.10	433.00	10.90	32.96
5	689.35	321.88	336.25	14.37	32.72
6	639.36	369.18	381.73	12.55	34.74
7	644.84	298.63	310.25	11.62	37.85
8	176.69	299.97	302.92	2.95	40.84
9	688.83	380.62	396.02	15.40	30.50
10	237.63	357.82	361.83	4.02	40.34
11	753.54	251.73	262.02	10.28	49.96
12	688.79	271.33	285.55	14.22	33.03
13	519.15	264.85	273.35	8.50	41.64
14	655.11	256.92	268.27	11.35	39.35
15	681.64	272.68	284.18	11.50	40.41
16	683.94	330.18	342.15	11.97	38.97
17	517.35	321.85	331.05	9.20	38.34
18	126.21	258.07	260.15	2.08	41.31
19	476.05	248.27	254.93	6.67	48.69
20	667.64	334.17	349.08	14.92	30.52
21	259.80	313.88	319.27	5.38	32.90
22	694.66	345.37	361.95	16.58	28.56
23	722.09	225.97	236.50	10.53	46.74
24	-39.17	345.20	344.72	-0.48	55.26
25	664.78	319.90	334.68	14.78	30.66

A comparison of merging distances for case 1-A (short dropped lane) and case 1-B (longer dropped lane) is shown in Figure 5-3 for females and in Figure 5-4 for males.

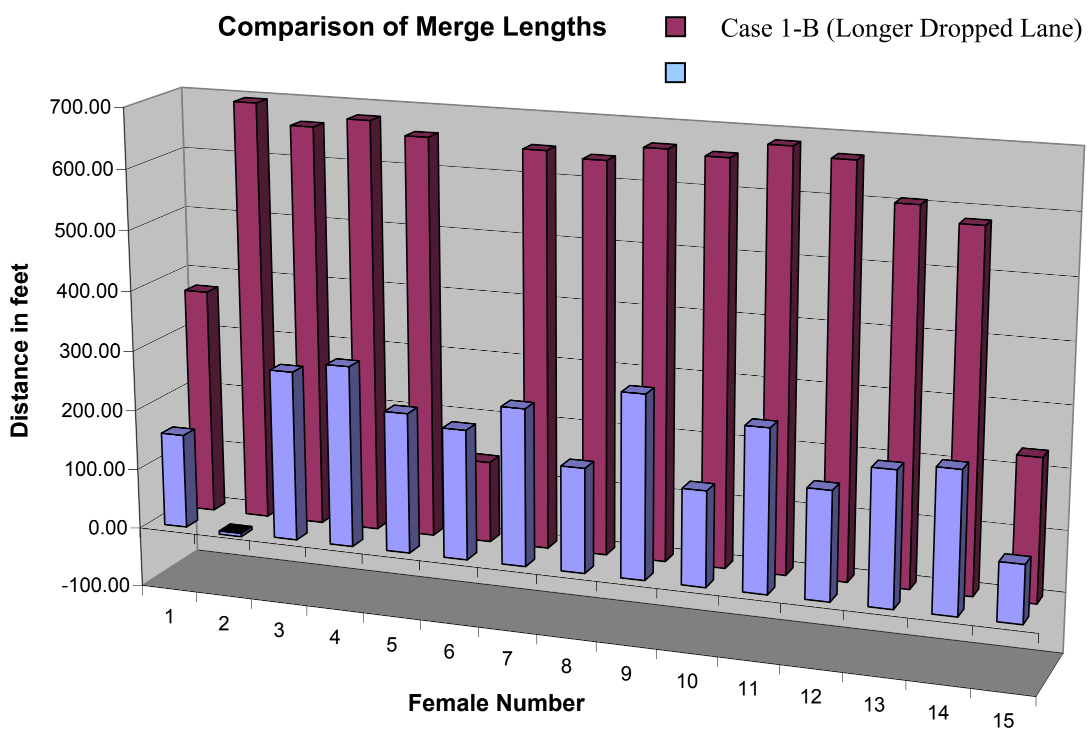


Figure 5-3: Comparison of merge distances (females) with short and longer dropped lanes

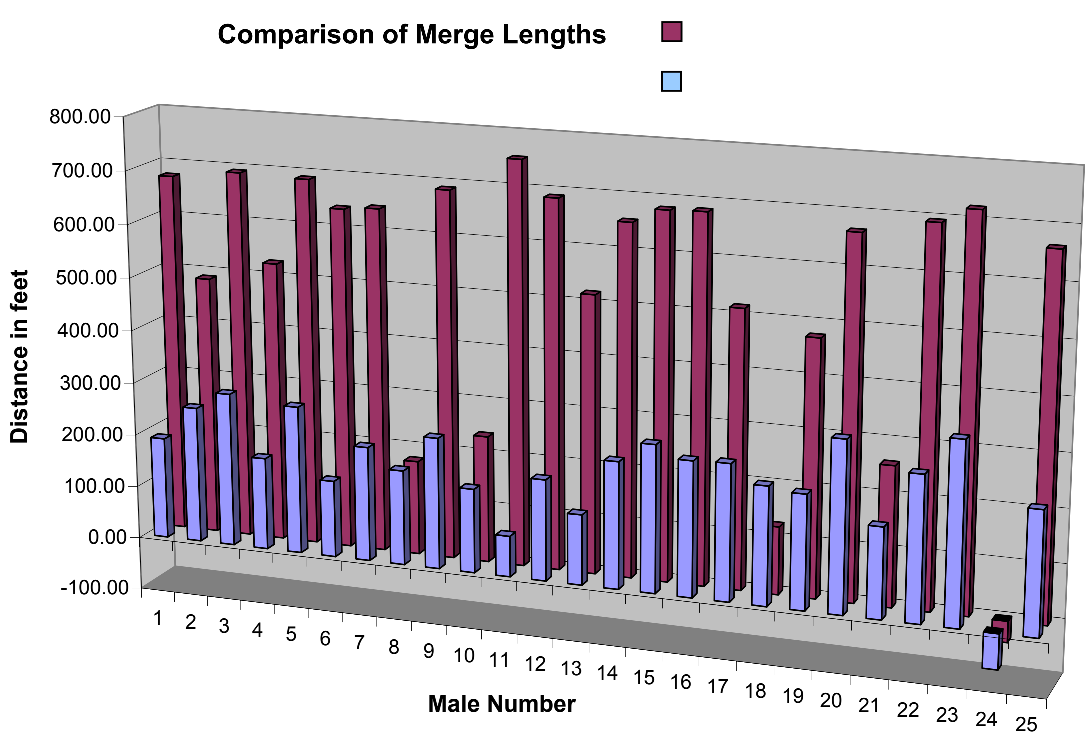


Figure 5-4: Comparison of merge distances (males) with short and longer dropped lanes

The average merge distances for each sex and the combined average is given in Table 5-9. The total available lane merge distance for case 1-A was 380 feet while for case 1-B it was 844 feet. This table also shows the percentage of combined distance to total available distance for both the cases. Table 5-10 shows the average merge speed for each sex and the combined average. Table 5-11 shows the descriptive statistics of merge length and merge speed for case 1-A and case 1-B.

Table 5-9: Results of average merging distances for intersection with dropped lane

Intersection Case	Female	Male	Combined	% of total available distance
1-A (Short dropped lane)	204 ft	210 ft	208 ft	54.7
1-B (Longer dropped lane)	573 ft	541 ft	553 ft	65.5

Table 5-10: Results of average merging speed for intersection with dropped lane

Intersection Case	Female	Male	Combined
1-A (Short dropped lane)	35.44 mph	36.14 mph	35.87 mph
1-B (Longer dropped lane)	35.74 mph	38.55 mph	37.50 mph

Table 5-11: Descriptive statistics of merge length and merge speed during lane drop event

	Length (feet)		Speed (mph)	
	Case 1-A	Case 1-B	Case 1-A	Case 1-B
N	40	40	40	40
Mean	207.93	553.29	35.87	37.50
Median	221.36	656.96	34.40	36.93
Std. Deviation	82.34	201.48	6.49	5.54
Variance	6780.07	40594.81	42.06	30.70
Minimum	-65.77	-39.17	24.16	28.56
Maximum	339.47	753.54	58.73	55.26

The mean analysis for the merge length and merge speed was done by SAS Software and the results are displayed in Table 5-12. Results showed that there is a significant difference between the merge length for Lane Drop Case 1-A and Case 1-B for male subjects, female subjects and combined subjects as highlighted in Table 5-12. With the 95% Confidence Interval (CI) we can say that the merge length in Lane Drop Case 1-B was much longer than the merge length in Lane Drop Case 1-A for male subjects, female subjects and combined subjects. There was no significant difference found between the speed for the Lane Drop Case 1-A and Lane Drop Case 1-B.

Table 5-12: One Sample Test for the mean comparison of merge length and merge speed between lane drop case 1-A and lane drop case 1-B

Parameter		Lane Drop Case 1-A				Lane Drop Case 1-B				Mean Difference		
		N	Mean	95% CI		N	Mean	95% CI		Mean	95% CI	
				Lower	Upper			Lower	Upper		Lower	Upper
Length	Male	25	210.06	177.24	242.89	25	541.25	456.03	626.47	331.19	259.35	403.02
	Female	15	204.38	162.52	246.25	15	573.35	483.73	662.98	368.97	279.45	458.50
	Total	40	207.93	182.42	233.45	40	553.29	490.85	615.73	345.36	289.71	401.00
Speed	Male	25	36.14	33.17	39.11	25	38.55	35.94	41.16	2.42	-0.49	5.32
	Female	15	35.44	33.27	37.61	15	35.74	34.72	36.76	0.30	-2.06	2.66
	Total	40	35.87	33.86	37.88	40	37.50	35.78	39.21	1.62	-0.40	3.65

Several pictures of the intersection for both cases are shown in Figures 5-5 to 5-8. Note, the simulator vehicle is the light blue car in Figures 5-7 and 5-8.

Figure 5-5: Approaching intersection with short dropped lane

Figure 5-6: Approaching end of short dropped lane

Figure 5-7: Approaching intersection with longer dropped lane

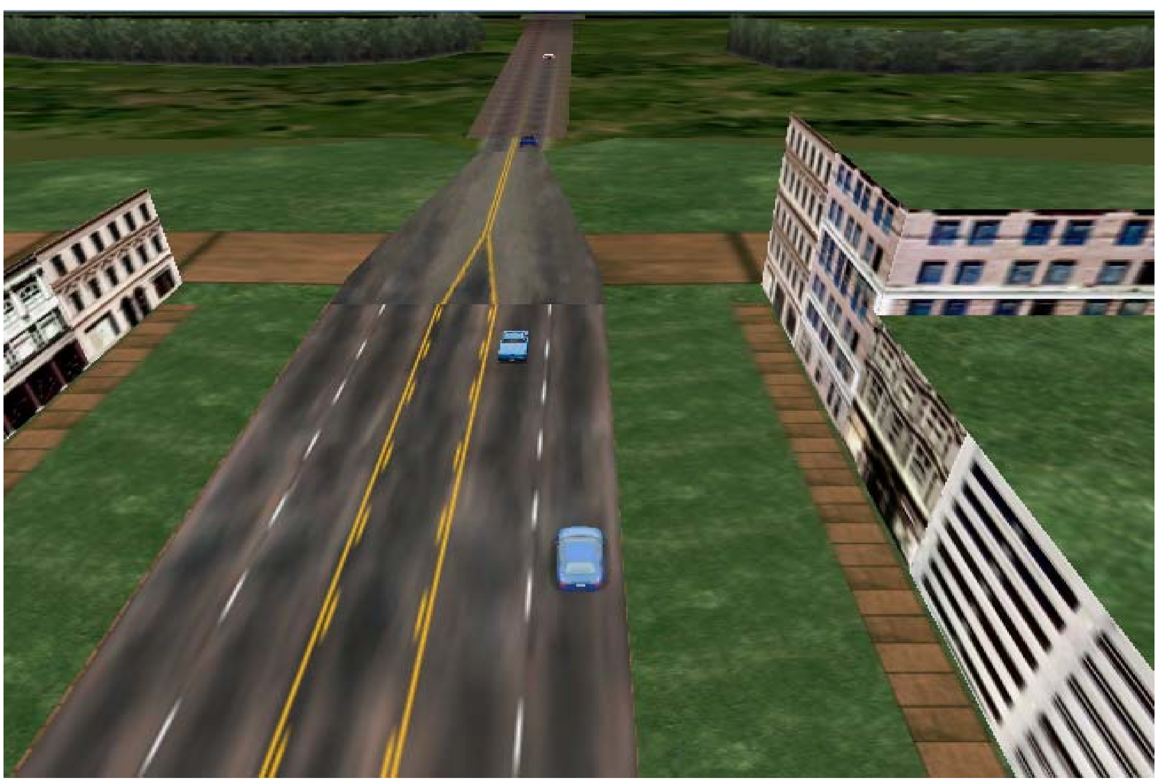


Figure 5-8: Approaching end of longer dropped lane

5.2 Misalignment of Lanes

During the misalignment experiment path of all the subjects were categorized into three different patterns. These three patterns are explained below under each case and the number of people who followed these patterns.

Case: 2-A (Misalignment of Lanes and No Markings on the Ground)

A total of 8 subjects out of 40 (4 out of 15 females and 4 out of 25 males) or 20% subjects were able to stay entirely in the same lane on either side of the intersection and stay within the imaginary lane boundaries while crossing the intersection. The path followed by one such driver is shown in Figure 5-9.

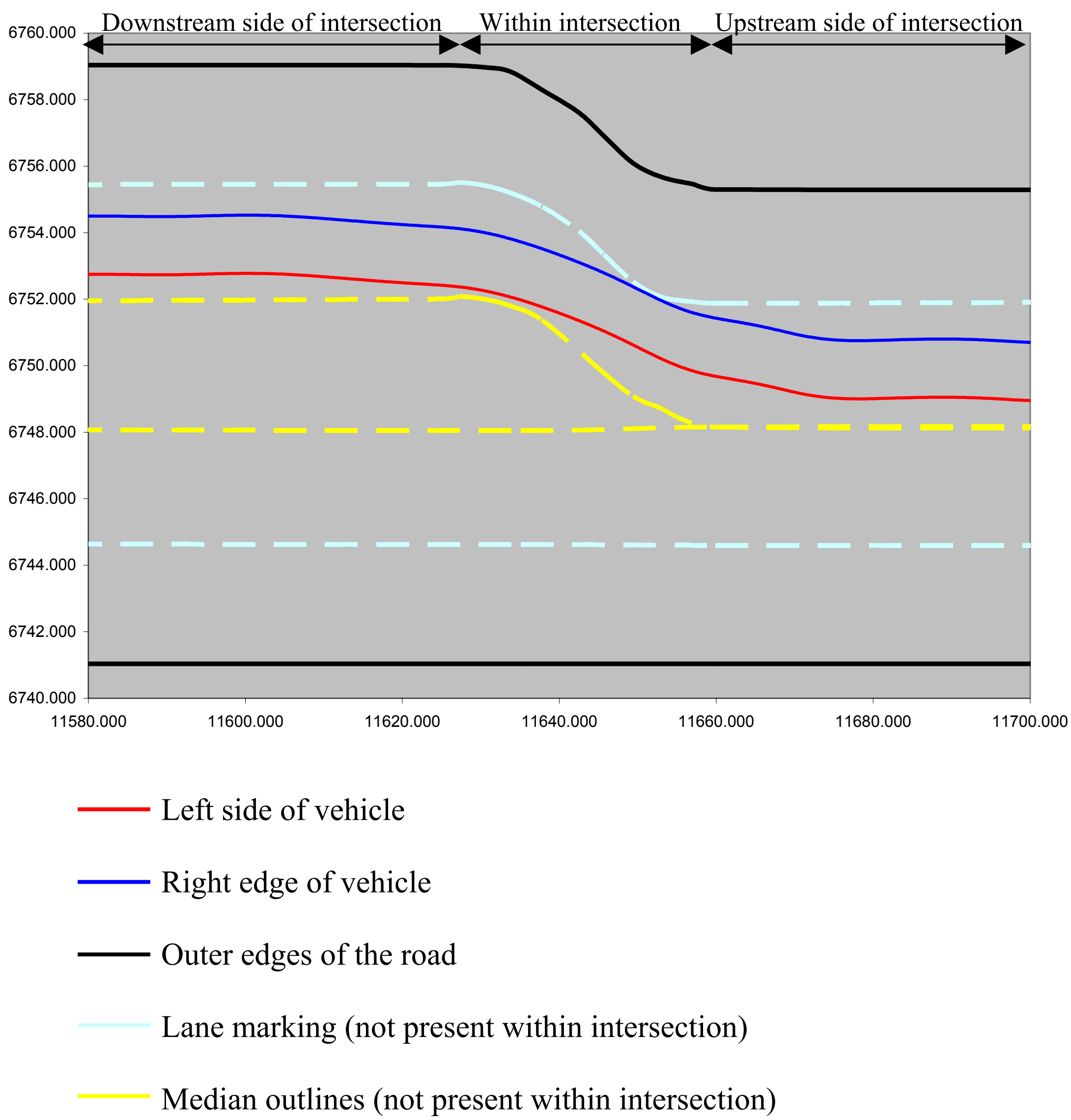


Figure 5-9: Sample path of a subject who maintained proper positioning at all times

A total of 28 subjects out of 40 (9 out of 15 females and 19 out of 25 males) or 70% subjects deviated slightly from the path described previously, i.e. went outside the actual or virtual lane marking at some point. The path followed by one such driver is shown in Figure 5-10.

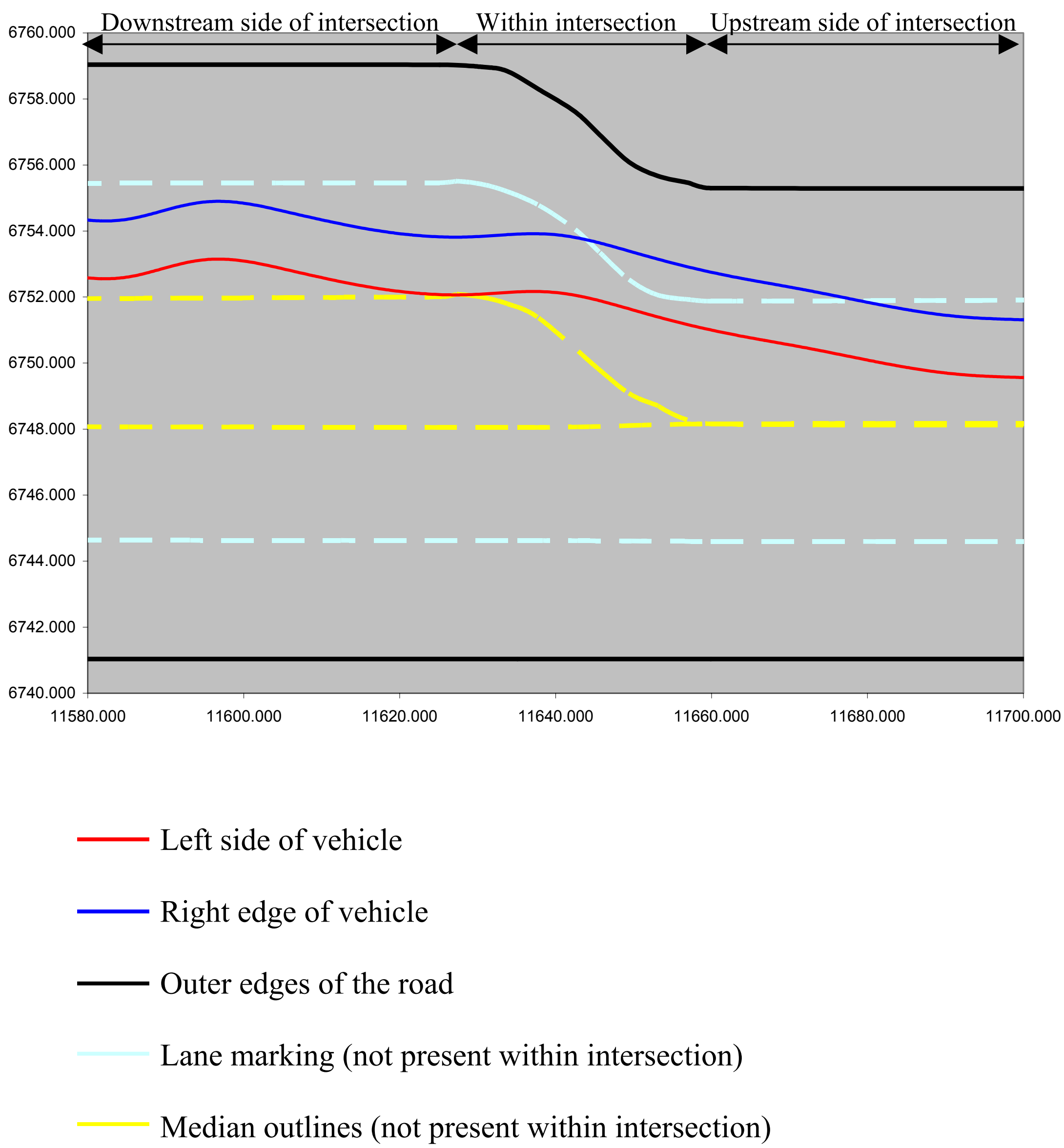


Figure 5-10: Sample path of a subject who deviated slightly outside approach lane

The remaining 4 subjects (2 females and 2 males) or 10% subjects had the most difficulty with the lane misalignment. Each of these drivers wound up in a different lane after crossing the intersection. Figure 5-11 illustrates the path of one such driver who began in the right lane and unintentionally steered the simulator vehicle into the left lane on the downstream side of the intersection.

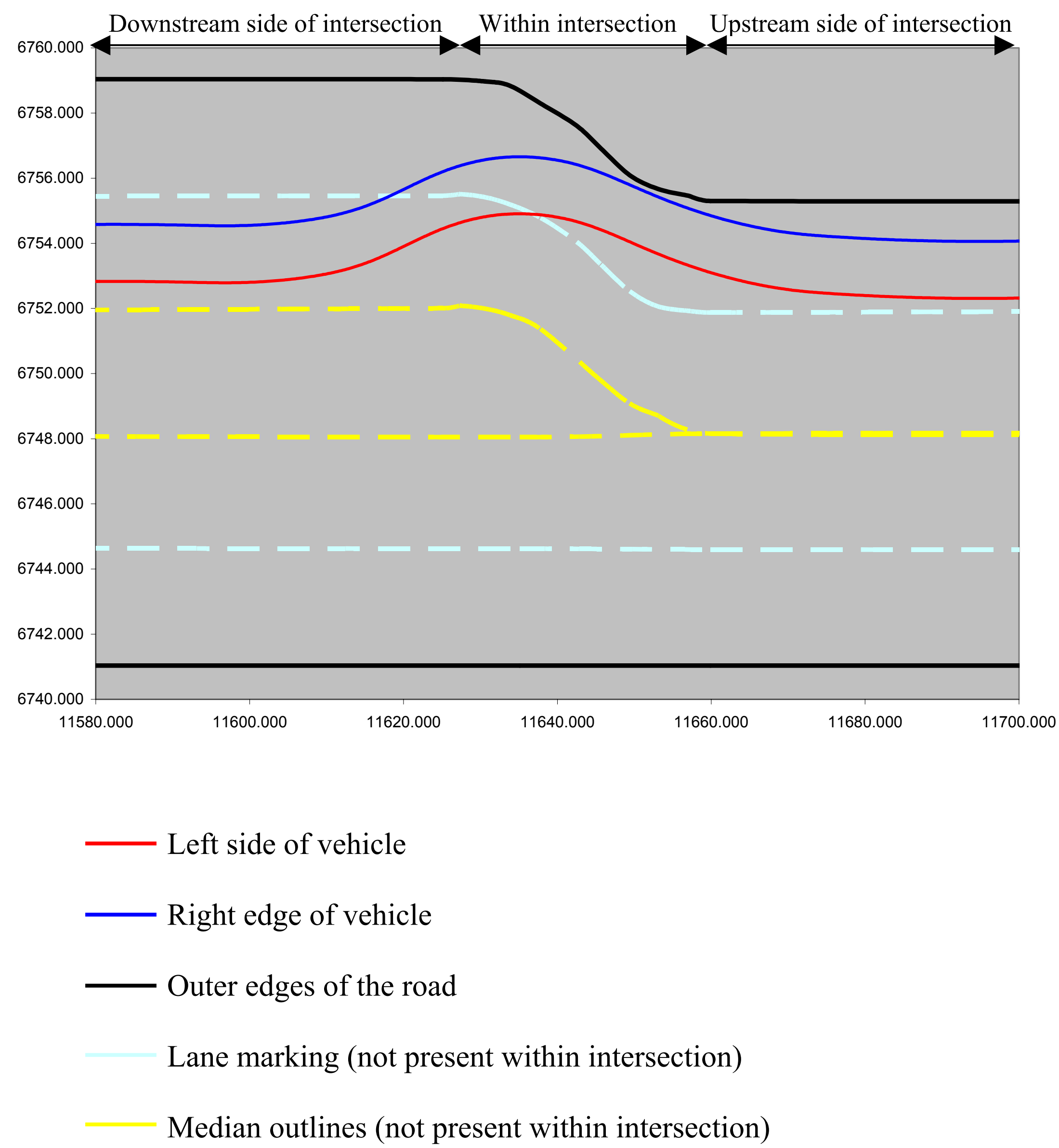


Figure 5-11: Sample path of a subject who switched lanes across intersection

The average speed during the misaligned lane intersection with no marking was obtained from the logged data. Results for average speed for females and males are shown in

Tables 5-13 and 5-14, respectively. In these tables Time1 represents the time when the subject had just entered the misaligned intersection and Time2 represents the time when the subject had just crossed the misaligned intersection.

Table 5-13: Average speed for females at misaligned intersection with no marking

Female No.	X1	X2	Width of intersection in feet	Time 1	Time 2	Time Difference	Speed in MPH
1	11659.92	11625.12	114.14	234.22	236.53	2.32	33.59
2	11659.92	11625.12	114.14	294.38	296.75	2.37	32.88
3	11659.92	11625.12	114.14	471.77	473.93	2.17	35.92
4	11659.92	11625.12	114.14	268.88	270.72	1.83	42.45
5	11659.92	11625.12	114.14	318.40	321.20	2.80	27.79
6	11659.92	11625.12	114.14	267.42	269.75	2.33	33.35
7	11659.92	11625.12	114.14	256.56	259.10	2.54	30.64
8	11659.92	11625.12	114.14	287.28	289.93	2.65	29.37
9	11659.92	11625.12	114.14	280.78	282.95	2.17	35.92
10	11659.92	11625.12	114.14	234.22	236.53	2.32	33.59
11	11659.92	11625.12	114.14	303.45	306.15	2.70	28.82
12	11659.92	11625.12	114.14	322.53	325.02	2.48	31.34
13	11659.92	11625.12	114.14	303.03	305.52	2.48	31.34
14	11659.92	11625.12	114.14	281.67	284.30	2.63	29.55
15	11659.92	11625.12	114.14	260.33	262.65	2.32	33.59

Table 5-14: Average speed for males at misaligned intersection with no marking

Male No.	X1	X2	Width of intersection in feet	Time 1	Time 2	Time Difference	Speed in MPH
1	11659.92	11625.12	114.14	387.90	390.12	2.22	35.11
2	11659.92	11625.12	114.14	262.58	264.92	2.33	33.35
3	11659.92	11625.12	114.14	240.30	242.65	2.35	33.12
4	11659.92	11625.12	114.14	264.85	267.35	2.50	31.13
5	11659.92	11625.12	114.14	419.32	421.93	2.62	29.74
6	11659.92	11625.12	114.14	266.68	269.08	2.40	32.43
7	11659.92	11625.12	114.14	311.60	313.70	2.10	37.06
8	11659.92	11625.12	114.14	284.23	286.43	2.20	35.38
9	11659.92	11625.12	114.14	299.38	302.07	2.68	29.00
10	11659.92	11625.12	114.14	233.83	236.32	2.48	31.34
11	11659.92	11625.12	114.14	320.87	322.95	2.08	37.36
12	11659.92	11625.12	114.14	257.75	260.27	2.52	30.92
13	11659.92	11625.12	114.14	252.45	255.40	2.95	26.38
14	11659.92	11625.12	114.14	316.05	318.47	2.42	32.20
15	11659.92	11625.12	114.14	293.52	295.45	1.93	40.26
16	11659.92	11625.12	114.14	212.25	215.10	2.85	27.31
17	11659.92	11625.12	114.14	300.12	302.73	2.62	29.74
18	11659.92	11625.12	114.14	250.97	252.67	1.70	45.78
19	11659.92	11625.12	114.14	251.25	252.90	1.65	47.17
20	11659.92	11625.12	114.14	325.38	328.37	2.98	26.09
21	11659.92	11625.12	114.14	314.87	317.53	2.67	29.19
22	11659.92	11625.12	114.14	334.65	337.20	2.55	30.52
23	11659.92	11625.12	114.14	239.60	241.53	1.93	40.26
24	11659.92	11625.12	114.14	237.98	240.57	2.58	30.13
25	11659.92	11625.12	114.14	282.78	285.47	2.68	29.00

Case: 2-B (Misalignment of lanes with markings on the ground)

The results for this case are summarized in Table 5-15.

Table 5-15: Results for intersection with misaligned lanes and lane striping present

	Female	Male	Total	% Total Subjects
Within lanes at all times	5	15	20	50
Slight deviation from lane	6	8	14	35
Switched lanes	4	2	6	15

The average speed during the misaligned lane intersection with marking was obtained from the logged data. Results for average speed for females and males are shown in Tables 5-16 and 5-17, respectively. In these tables Time1 represents the time when the subject had just entered the misaligned intersection and Time2 represents the time when the subject had just crossed the misaligned intersection.

Table 5-16: Average speed for females at misaligned intersection with marking

Female No.	X1	X2	Width of intersection in feet	Time 1	Time 2	Time Difference	Avg. Speed in MPH
1	11659.92	11625.12	114.14	295.48	297.87	2.38	32.65
2	11659.92	11625.12	114.14	197.13	199.32	2.18	35.64
3	11659.92	11625.12	114.14	196.93	199.62	2.68	29.00
4	11659.92	11625.12	114.14	225.95	227.87	1.92	40.60
5	11659.92	11625.12	114.14	190.85	193.23	2.38	32.65
6	11659.92	11625.12	114.14	228.28	230.62	2.33	33.35
7	11659.92	11625.12	114.14	218.88	221.57	2.68	29.00
8	11659.92	11625.12	114.14	190.18	192.55	2.37	32.88
9	11659.92	11625.12	114.14	234.58	236.88	2.30	33.83
10	11659.92	11625.12	114.14	241.30	244.27	2.97	26.23
11	11659.92	11625.12	114.14	206.47	208.72	2.25	34.59
12	11659.92	11625.12	114.14	195.82	198.28	2.47	31.55
13	11659.92	11625.12	114.14	258.65	261.18	2.53	30.72
14	11659.92	11625.12	114.14	188.77	190.88	2.12	36.77
15	11659.92	11625.12	114.14	436.98	439.47	2.48	31.34

Table 5-17: Average speed for males at misaligned intersection with marking

Male No.	X1	X2	Width of intersection in feet	Time 1	Time 2	Time Difference	Avg. Speed in MPH
1	11659.92	11625.12	114.14	249.55	251.53	1.98	39.24
2	11659.92	11625.12	114.14	236.60	239.03	2.43	31.98
3	11659.92	11625.12	114.14	192.05	194.58	2.53	30.72
4	11659.92	11625.12	114.14	317.28	319.37	2.08	37.36
5	11659.92	11625.12	114.14	220.05	222.50	2.45	31.77
6	11659.92	11625.12	114.14	280.30	282.55	2.25	34.59
7	11659.92	11625.12	114.14	189.50	191.60	2.10	37.06
8	11659.92	11625.12	114.14	203.57	206.22	2.65	29.37
9	11659.92	11625.12	114.14	290.60	293.17	2.57	30.32
10	11659.92	11625.12	114.14	259.78	262.08	2.30	33.84
11	11659.92	11625.12	114.14	174.47	176.43	1.97	39.57
12	11659.92	11625.12	114.14	186.17	188.48	2.32	33.59
13	11659.92	11625.12	114.14	184.75	186.88	2.13	36.48
14	11659.92	11625.12	114.14	186.80	189.35	2.55	30.52
15	11659.92	11625.12	114.14	184.57	187.18	2.62	29.74
16	11659.92	11625.12	114.14	230.35	232.52	2.17	35.92
17	11659.92	11625.12	114.14	225.25	227.85	2.60	29.93
18	11659.92	11625.12	114.14	183.65	185.55	1.90	40.96
19	11659.92	11625.12	114.14	174.77	176.20	1.43	54.30
20	11659.92	11625.12	114.14	213.40	216.05	2.65	29.37
21	11659.92	11625.12	114.14	222.72	225.55	2.83	27.47
22	11659.92	11625.12	114.14	210.95	213.75	2.80	27.79
23	11659.92	11625.12	114.14	159.32	160.85	1.53	50.76
24	11659.92	11625.12	114.14	233.68	235.83	2.15	36.20
25	11659.92	11625.12	114.14	211.77	214.32	2.55	30.52

The descriptive statistics of average speed during misaligned intersection was calculated using SAS for both cases 2-A and 2-B and is displayed in Table 5-18. The average speed for all the 40 subjects for case 2-A and case 2-B were 33 mph and 34.01 mph, respectively.

Table 5-18: Descriptive statistics of average speed during misaligned intersection for case 2-A and case 2-B

	Speed (mph)	
	Case 2-A	Case 2-B
N	40	40
Mean	33.00	34.01
Median	31.77	32.77
Std. Deviation	4.86	5.65
Variance	23.61	31.94
Minimum	26.09	26.23
Maximum	47.17	54.30

Table 5-19 shows the summary of results for both case 2-A and case 2-B. The table shows that the percentage of subjects who stayed in their lanes within the intersection increased from 20% to 50% and the percentage of subjects who deviated slightly within the intersection decreased from 70% to 35%. This supports the fact that the lane marking within the intersection helped subjects to stay within their respective lanes.

Table 5-19 Summary of results for case 2-A and case 2-B

	Case 2-A (Without Marking)				Case 2-B (With Marking)			
	Females	Males	Total	Total %	Females	Males	Total	Total %
Within lanes all times	4	4	8	20	5	15	20	50
Slight deviation	9	19	28	70	6	8	14	35
Switched lanes	2	2	4	10	4	2	6	15

The average trajectory of center line of simulator vehicle for all the 40 subjects was also determined and is shown in Figure 5-12 for both Case 2-A and Case 2-B. The average trajectory for Case 2-B stays entirely within the marking present at the intersection. At the other hand the average trajectory for Case 2-A goes outside the lane marking within the intersection. This average graph of the trajectories concludes the fact that lane marking within the intersection helped people stay within their respected lanes.

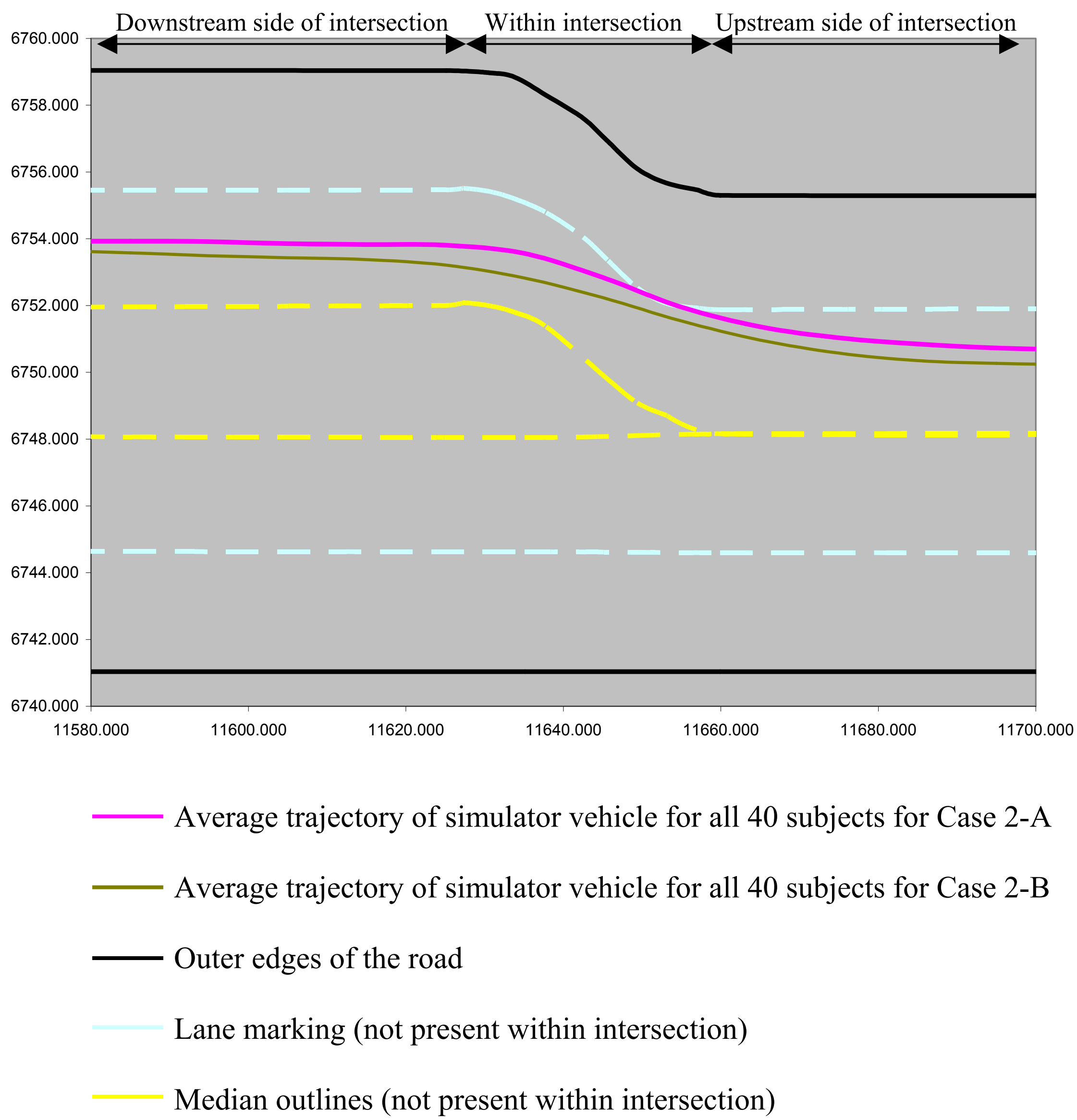


Figure 5-12: Comparison of average trajectory of simulator vehicle for case 2-A and case 2-B

The mean analysis of the average speed during misaligned intersection was done by SAS software and the results are displayed in Table 5-20. The results showed that there was no significant difference found between the average speed during the misaligned intersection for case 2-A and case 2-B.

Table 5-20: One sample test for the mean comparison of average speed during the misaligned intersection for case 2-A and case 2-B

<table>
<tr><th colspan="2" rowspan="3">Parameter</th><th colspan="4">Misaligned Case 2-A</th><th colspan="4">Misaligned Case 2-B</th><th colspan="3">Mean Difference</th></tr>
<tr><th rowspan="2">N</th><th rowspan="2">Mean</th><th colspan="2">95% CI</th><th rowspan="2">N</th><th rowspan="2">Mean</th><th colspan="2">95% CI</th><th rowspan="2">Mean</th><th colspan="2">95% CI</th></tr>
<tr><th>Lower</th><th>Upper</th><th>Lower</th><th>Upper</th><th>Lower</th><th>Upper</th></tr>
<tr><td rowspan="3">Speed</td><td>Male</td><td>25</td><td>33.20</td><td>31.03</td><td>35.36</td><td>25</td><td>34.77</td><td>32.20</td><td>37.35</td><td>1.58</td><td>-0.38</td><td>3.54</td></tr>
<tr><td>Female</td><td>15</td><td>32.68</td><td>30.83</td><td>34.53</td><td>15</td><td>32.72</td><td>30.96</td><td>34.48</td><td>0.04</td><td>-2.08</td><td>2.17</td></tr>
<tr><td>Total</td><td>40</td><td>33.00</td><td>31.50</td><td>34.51</td><td>40</td><td>34.01</td><td>32.25</td><td>35.76</td><td>1.00</td><td>-0.46</td><td>2.47</td></tr>
</table>

Figures 5-13 to 5-16 are photos of the intersection without lane striping (case 2-A). Figure 5-16 shows the simulator vehicle driver veering into the median after crossing the intersection. Figures 5-17 to 5-19 are pictures of the same intersection (case 2-B) with markings to help drivers maintain the correct lane. Again, the simulator vehicle is a light blue passenger car in all of the figures in which it appears.

Figure 5-13: View through the windshield of simulator vehicle approaching the intersection with lane misalignment and no striping

Figure 5-14: Overhead view of simulator vehicle approaching the intersection with lane misalignment and no striping

Figure 5-15: Overhead view of simulator vehicle in intersection with lane misalignment and no striping

Figure 5-16: Overhead view of simulator vehicle exiting intersection with lane misalignment and no striping

Figure 5-17: Overhead view of simulator vehicle upstream from intersection with lane misalignment and striping present

Figure 5-18: Approaching intersection with lane misalignment and striping present

Figure 5-19: Overhead view of simulator vehicle within intersection with lane misalignment and striping present

5.3 Joint Left and Through Lane Scenario

Case 3-A (Joint Left and Through Lane)

Case 3-A refers to the presence of a joint left turn and through lane at the intersection. Figure 5-20 shows the simulator vehicle stopped at a red light behind a lead vehicle in a joint left turn and through lane. In Figure 5-21 the traffic signal is green and the lead vehicle is waiting for an acceptable gap before turning left. The simulator vehicle is stuck behind the lead car. Note the simulator vehicle is blocked from switching lanes due to the heavy traffic in the adjacent lane.

Figure 5-20: Simulator vehicle stopped at red light in a joint left and through lane

Figure 5-21: Simulator vehicle waiting for left turning vehicle to clear before proceeding through intersection

Case 3-A was created to have the lead vehicle turn left during the amber phase as shown in Figure 5-22. The subjects in the simulator vehicle were confronted with three choices:

1. Remain stopped at the intersection and wait for the next green phase
2. Run the red light and proceed through the intersection
3. Try to move in right lane

Nine males and 5 females ran the red light. One male and 3 females tried to pull out around the left turning vehicle and got involved in accident. Seven males and 3 females blew the horn in the simulator vehicle waiting for the car ahead to turn left.

Figure 5-22: Lead vehicle turning left during amber

Case 3-B (Separate Left Turn Lane)

A dedicated left turn lane was present in this case. In this case none of the subjects tried to switch lanes and none of them crossed the intersection when signal light was red. Figure 5-23 shows the simulator vehicle approaching the intersection in the through lane. Figure 5-24 is the view from a camera inside the simulator.

Figure 5-23: Simulator vehicle approaching intersection in through lane

Figure 5-24: View approaching intersection

Figure 5-25: View of simulator vehicle stopped at red light in through lane

Figure 5-26: Side view of simulator vehicle stopped at red light in through lane

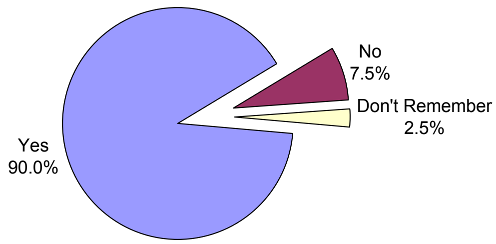
5.4 Survey

This section presents results of the survey questionnaire administered to all the subjects after completing both scenarios. Table 5-21 shows the response of subjects to lane drop intersection and Figure 5-27 shows these response in terms of pie chart format.

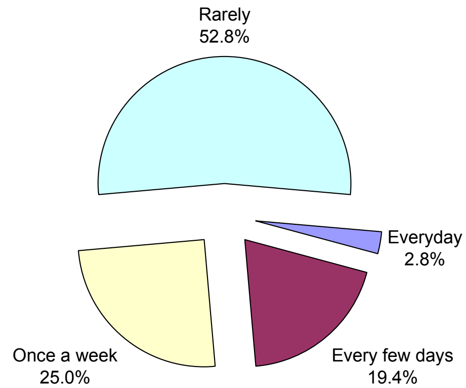
Table 5-21: Questions related to lane drop intersection

No.	Question	Male	Female	Total	%
Q.1	Have you ever experienced a sudden lane drop after crossing an intersection when driving in your motor vehicle?				
a	Yes	21	15	36	90.0
b	No	3		3	7.5
c	Don't Remember	1		1	2.5
Q.2	If Yes to Q1, how often				
a	Everyday	1		1	2.78
b	Every few days	3	4	7	19.44
c	Once a week	8	1	9	25.00
d	Rarely	9	10	19	52.78
Q.3	If Yes to Q1, was the length of the merge lane sufficient to merge safely?				
a	Yes	2	4	6	16.7
b	No	5	2	7	19.4
c	Sometimes	14	9	23	63.9
Q.4	Check which is applicable				
a	Lane merging always causes frustration and anxiety	3	3	6	14.3
b	Insufficient length of lane merge causes frustration and anxiety	21	11	32	76.2
c	Lane merging maneuver doesn't bother you at all	2	2	4	9.5
Q.5	In the driving simulator, did your experience of a lane drop cause frustration and anxiety?				
a	Yes	13	6	19	47.5
b	No	12	9	21	52.5
c	Don't Remember				0.0
Q.6	If Yes to Q5, please rate your frustration level				
a	Mild	11	1	12	60.0
b	Routine	3	3	6	30.0
c	Extreme		2	2	10.0
Q.7	If Yes to Q5, for the two designs 1-A and 1-B below				
a	1-A was more frustrating	11	4	15	75.0
b	1-B was more frustrating	1	1	2	10.0
c	1-A and 1-B were equally frustrating	2	1	3	15.0
Q.8	Do you think design 1-B is better than 1-A and will improve the conditions for merging?				
a	Yes	21	12	33	82.5
b	No	1	1	2	5.0
c	Not Sure	3	2	5	12.5
Q.9	If Yes to Q8, please rate the potential improvement				
a	Satisfactory	7	1	8	24.2
b	Good	11	11	22	66.7
c	Excellent	3		3	9.1

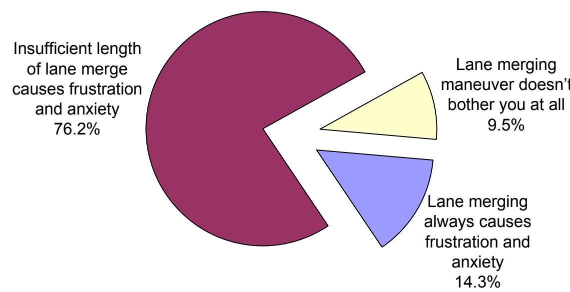
1. Have you ever experienced a sudden lane drop after crossing an intersection when driving in your motor vehicle



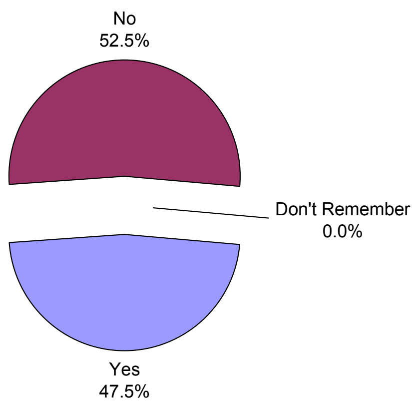
2. If Yes to Q1, how often



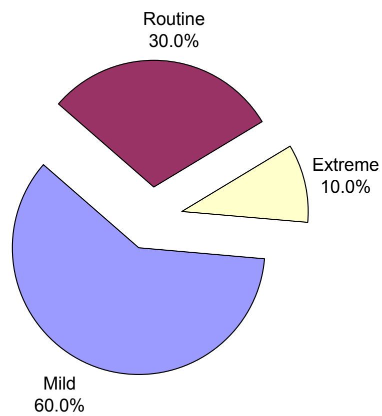
4. Check which is applicable:

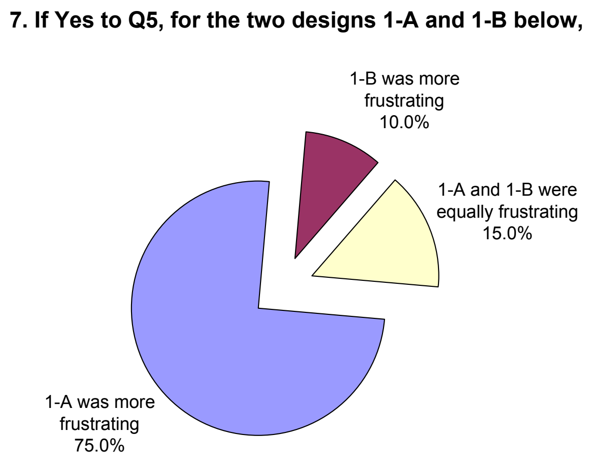


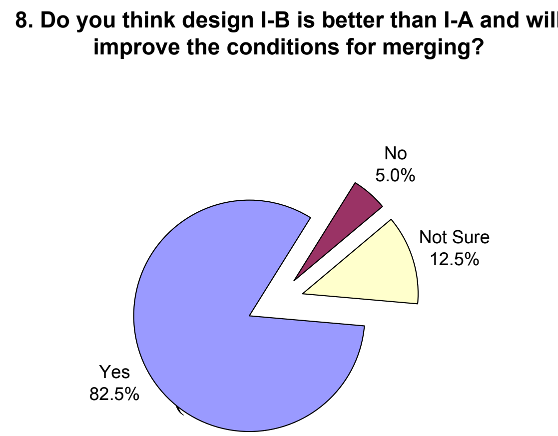
5. In the driving simulator, did your experience of a lane drop cause frustration and anxiety?



6. If Yes to Q5, please rate your frustration level.







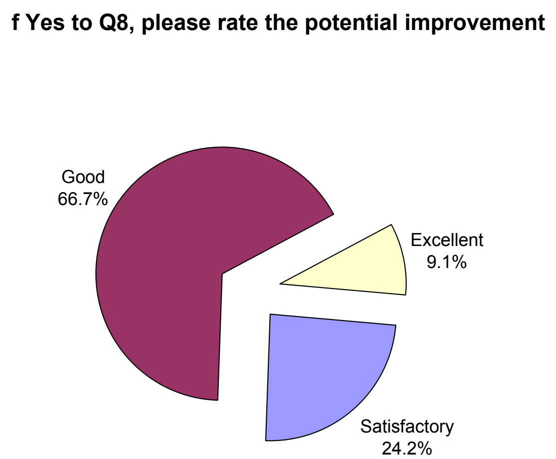


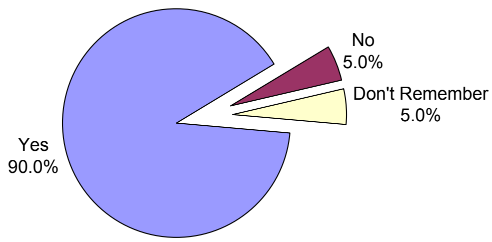
Figure 5-27: Results of survey questionnaire for lane drop scenario

Table 5-22 shows the response of subjects to lane misalignment intersection and Figure 5-28 shows these response in terms of pie chart format.

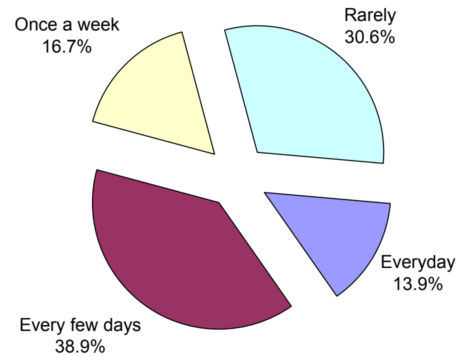
Table 5-22: Questions related to lane misalignment intersection

No.	Question	Male	Female	Total	%
Q.10	Have you ever experienced a non alignment of lanes on either side of an intersection while driving a motor vehicle?				
a	Yes	23	13	36	90.0
b	No	1	1	2	5.0
c	Don't Remember	1	1	2	5.0
Q.11	If Yes to Q10, how often				
a	Everyday	3	2	5	13.89
b	Every few days	10	4	14	38.89
c	Once a week	2	4	6	16.67
d	Rarely	8	3	11	30.56
Q.12	If Yes to Q10, was there a pavement marking in the intersection to guide you to the other side?				
a	Yes	11	3	14	38.9
b	No	8	9	17	47.2
c	Don't Remember	4	1	5	13.9
Q.13	In the driving simulator did your experience of a non alignment of lanes at an intersection cause frustration and anxiety?				
a	Yes	14	7	21	52.5
b	No	11	8	19	47.5
c	Don't Remember				0.0
Q.14	If Yes to Q13, please rate your frustration level				
a	Mild	6	3	9	42.9
b	Routine	5	3	8	38.1
c	Extreme	3	1	4	19.0
Q.15	If Yes to Q13, for the two designs 2-A and 2-B below				
a	2-A was more frustrating	15	7	22	100.0
b	2-B was more frustrating				0.0
c	2-A and 2-B were equally frustrating				0.0
Q.16	Do you think design 2-A is better than 2-B and will improve conditions for traveling through the intersection?				
a	Yes	23	15	38	95.0
b	No				0.0
c	Not Sure	2		2	5.0
Q.17	If Yes to Q16, please rate the potential improvement				
a	Satisfactory	4	1	5	13.2
b	Good	11	10	21	55.3
c	Excellent	8	4	12	31.6

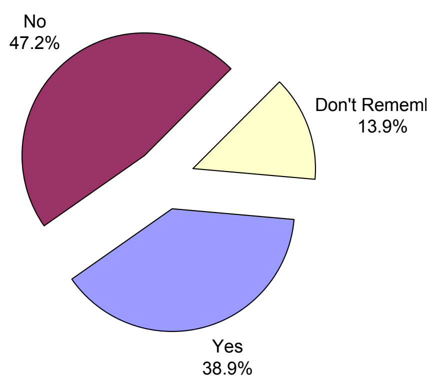
10. Have you ever experienced a non alignment of lanes on either side of an intersection while driving a motor vehicle?



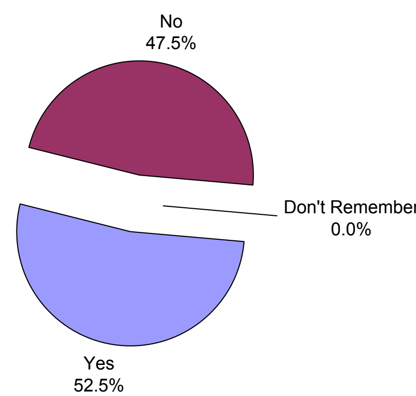
11. If Yes to Q10, how often



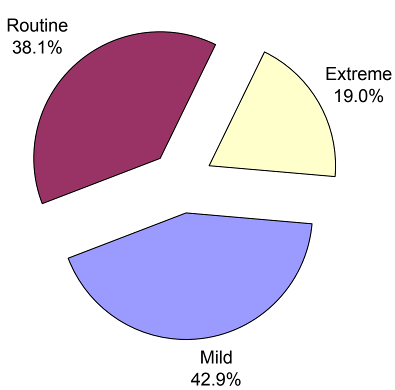
12. If Yes to Q10, was there a pavement marking in intersection to guide you to the other side?



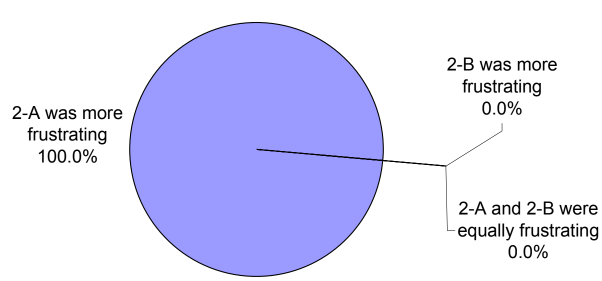
13. In the driving simulator did your experience of a non alignment of lanes at an intersection cause frustration and anxiety?

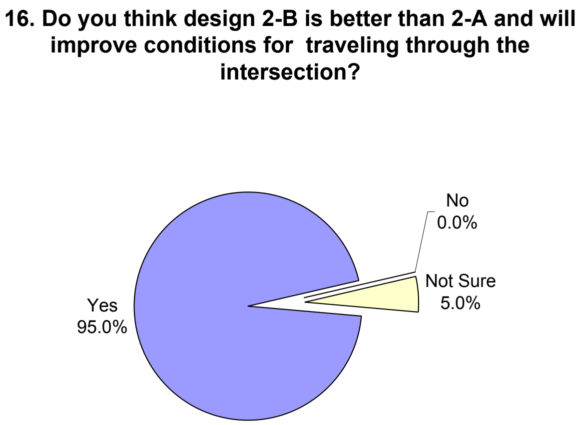


14. If Yes to Q13, please rate your frustration level.



15. If Yes to Q13, for the two designs 2-A and 2-B below,





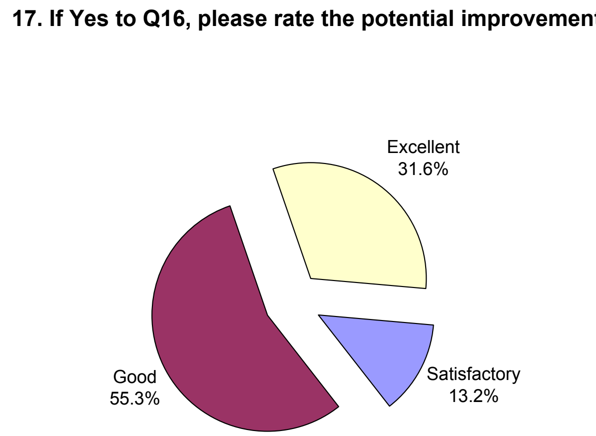


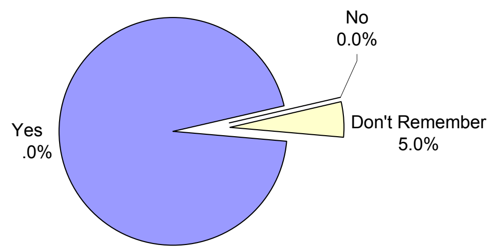
Figure 5-28: Results of survey questionnaire for lane misalignment scenario

Table 5-23 shows the response of subjects to joint left turn and through lane intersection and Figure 5-29 shows these response in terms of pie chart format.

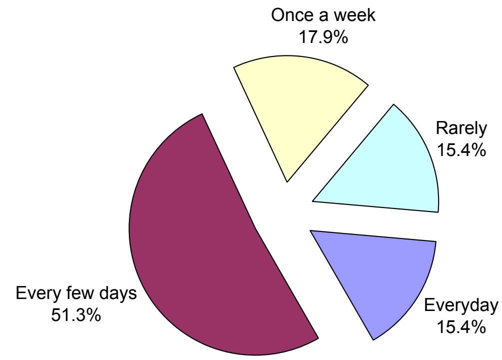
Table 5-23: Questions related to a joint left turn and through lane scenario

No.	Question	Male	Female	Total	%
Q.18	Have you ever been stuck behind a left turning vehicle in a joint left and thru lane when driving a motor vehicle?				
a	Yes	24	14	38	95.0
b	No				0.0
c	Don't Remember	1	1	2	5.0
Q.19	If Yes to Q18, how often				
a	Everyday	4	2	6	15.38
b	Every few days	14	6	20	51.28
c	Once a week	2	5	7	17.95
d	Rarely	4	2	6	15.38
Q.20	If Yes to Q18, what was the longest amount of time you were forced to wait behind the left turning vehicle before going thru the intersection?				
a	Less then 15 sec		1	1	2.7
b	Between 15 and 30 sec	9	4	13	35.1
c	More than 30 sec	15	8	23	62.2
Q.21	Have you ever been stuck behind a left turning vehicle for more than one cycle of the signal (time period between one red light to another red light)				
a	Yes	17	9	26	66.7
b	No	5	4	9	23.1
c	Don't Remember	2	2	4	10.3
Q.22	If Yes to Q21, how often do you experience this situation				
a	Everyday		1	1	3.33
b	Every few days	2	1	3	10.00
c	Once a week	5		5	16.67
d	Rarely	13	8	21	70.00
Q.23	In the driving simulator, did getting stuck behind a left turning vehicle cause frustration and anxiety?				
a	Yes	24	13	37	92.5
b	No	1	2	3	7.5
c	Don't Remember				0.0
Q.24	If Yes to Q23, please rate your frustration level				
a	Mild	9	3	12	32.4
b	Routine	7	5	12	32.4
c	Extreme	8	5	13	35.1
Q.25	If Yes to Q23, for the two designs 3-A and 3-B below				
a	3-A was more frustrating	24	13	37	100.0
b	3-B was more frustrating				0.0
c	3-A and 3-B were equally frustrating				0.0
Q.26	Do you think design 3-B is better than 3-A and will improve conditions for traveling through the intersection?				
a	Yes	25	14	39	97.5
b	No		1	1	2.5
Q.27	If Yes to Q26, please rate the potential improvement				
a	Satisfactory	1	1	2	5.0
b	Good	8	6	14	35.0
c	Excellent	16	8	24	60.0

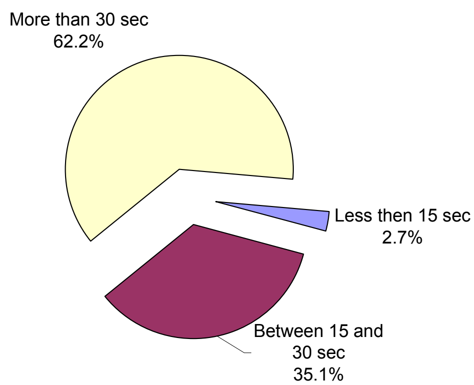
18. Have you ever been stuck behind a left turning vehicle in a joint left and thru lane when driving a motor vehicle?



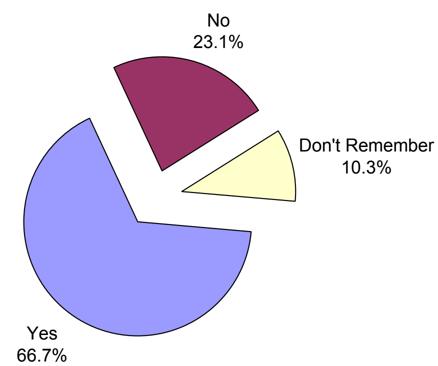
19. If Yes to Q18, how often



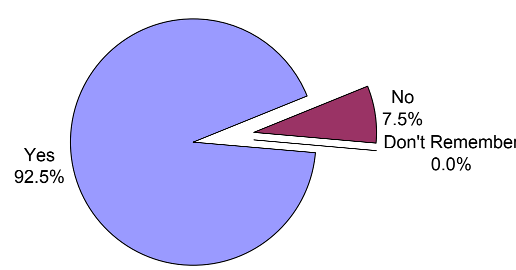
20. If Yes to Q18, what was the longest amount of time you were forced to wait behind the left turning vehicle before going thru the intersection?



21. Have you ever been stuck behind a left turning vehicle for more than one cycle of the signal (time period between one red light to another red light)



23. In the driving simulator, did getting stuck behind a left turning vehicle cause frustration and anxiety?



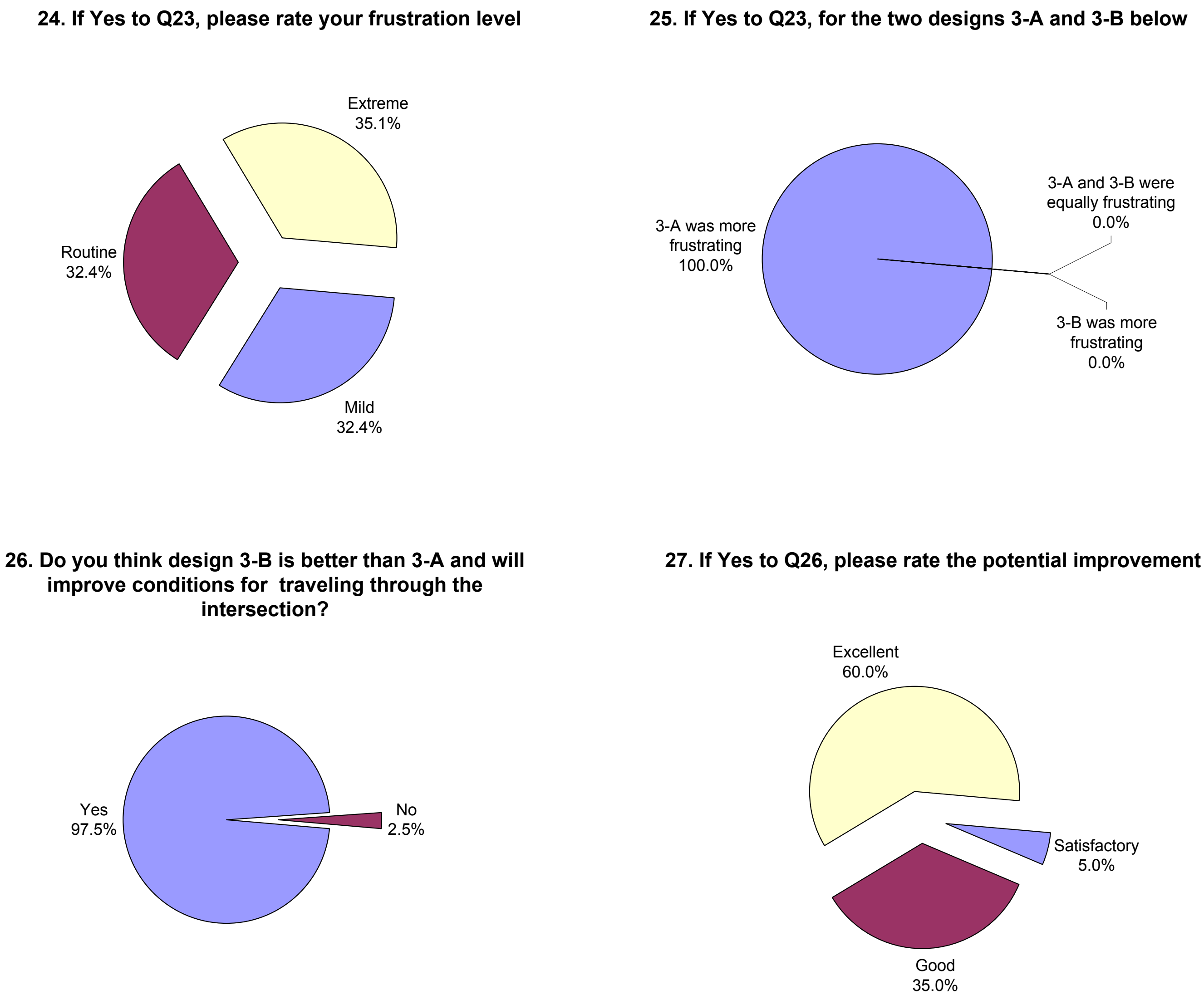


Figure 5-29: Results of survey questionnaire for joint left and through lane scenario

CHAPTER 6: CONCLUSIONS

The conclusions from this study have been divided into three sections based upon different intersection cases. The results from the lane drop intersection cases are as follows:

1. Simulator experiment results showed that there was a significant difference between the merge lengths for Case 1-A (short dropped lane) and Case 1-B (longer dropped lane). The average merge length for Case 1-A was 208 feet and the average merge length for Case 1-B was 553 feet. The average merge length for Case 1-A was 54.7% of the total available distance for merge (380 feet) while the average merge length for Case 1-B was 65.5% of the total available distance for merge (844 feet).

2. No significant difference was found between the speeds of the simulator car during the merging maneuver for Case 1-A and Case 1-B. The average merge speed for Case 1-A was 35.87 mph while the average merge speed for Case 1-B was 37.50 mph.

3. In the survey questionnaire 90% people admitted to have a sudden lane drop experience in the real World, out of the 40 people that participated in the driving simulator experiment. 47.22% people experience the sudden lane drop once or more then once a week.

4. During the simulator experiment 47.5% people felt frustration and anxiety at the lane drop event. 82.5% people felt that Case 1-B (longer dropped lane) is better than Case 1-A (short dropped lane) and would result in less frustration and anxiety.

The conclusions from misalignment of lane intersection cases are as follows:

5. Simulator experiment results showed that there was a considerable difference between the average path followed by subjects for Case 2-B (with lane marking) and Case 2-A (without lane marking). The percentage of subjects who stayed in their lanes within the intersection increased from 20% to 50% and the percentage of subjects who deviated slightly within the intersection decreased from 70% to 35% which supports the fact that lane marking within the intersection helped subjects to stay in their respective lanes before and after the intersection.

6. No significant difference was found between the average speeds of the simulator car during the misalignment of lane event for Case 2-A and Case 2-B. The average speed during misalignment for Case 2-A was 33.00 mph while the average merge speed for Case 2-B was 35.76 mph.

7. In the survey questionnaire 90% people admitted to have experienced misalignment of lanes in the real World, out of the 40 people that participated in the driving simulator experiment. 69.44% people experience the misalignment of lanes once or more then once a week.

8. During the simulator experiment 52.5% people felt frustration and anxiety at the misaligned lanes event. 95% people felt that Case 2-B (with lane marking) is better than Case 2-A (without lane marking) and would result in less frustration and anxiety.

The conclusions from joint left and through lane intersection cases are as follows:

9. During the simulator experiment 9 males and 5 females ran the red light during joint left and through lane event. 1 male and 3 females tried to pull out in the right lane and got involved in the accident. This supports the fact that people get frustrated when trapped behind a left turning vehicle in a joint left and through lane intersection and take evasive actions to cross the intersection as soon as possible. This situation can be improved by separating the left and through lanes.

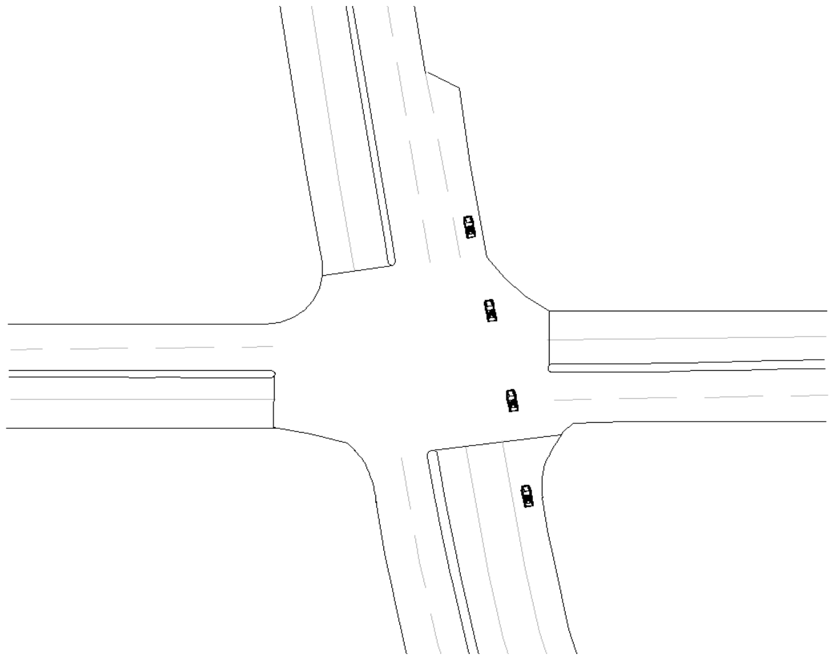
10. In the survey questionnaire 95% people admitted to got stuck behind a left turning vehicle in a joint left and through lane in the real World, out of the 40 people that participated in the driving simulator experiment. 84.62% people experience the joint left turn and through lane once or more then once a week.

11. During the simulator experiment 92.5% people felt frustration and anxiety at the joint left and through lane event. 97.5% people felt that Case 3-B (with separate left and through lane) is better than Case 3-A (joint left and through lane) and would result in less frustration and anxiety.

APPENDIX: SURVEY QUESTIONNAIRE, REGISTRATION FORM, CONSENT FORM, AND SAS COMPUTER CODE

SURVEY FOR "QUALITY OF SERVICE"

1. Lane drop after crossing the intersection



1. Have you ever experienced a sudden lane drop after crossing an intersection when driving in your motor vehicle?

   a) ___ Yes   b) ___ No   c) ___ Don't remember

2. If Yes to Q1, how often

   a) ___ Every day   b) ___ Every few days   c) ___ Once a week
   d) ___ Rarely

3. If Yes to Q1, was the length of the merge lane sufficient to merge safely?

   a) ___ Yes   b) ___ No   c) ___ Sometimes

4. Check which is applicable:

   a) ___ Lane merging always causes frustration and anxiety.
   b) ___ Insufficient length of lane merge causes frustration and anxiety.
   c) ___ Lane merging maneuver doesn't bother you at all.

5. In the driving simulator, did your experience of a lane drop cause frustration and anxiety?

   a) ___ Yes   b) ___ No   c) ___ Don't remember

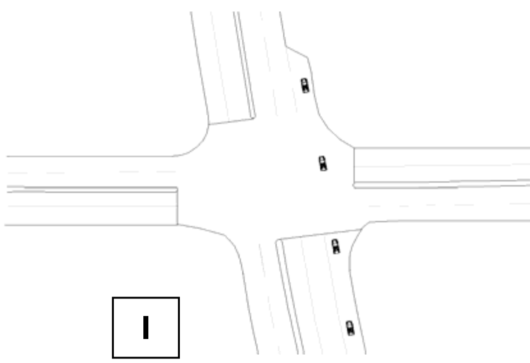
6. If Yes to Q5, please rate your frustration level.

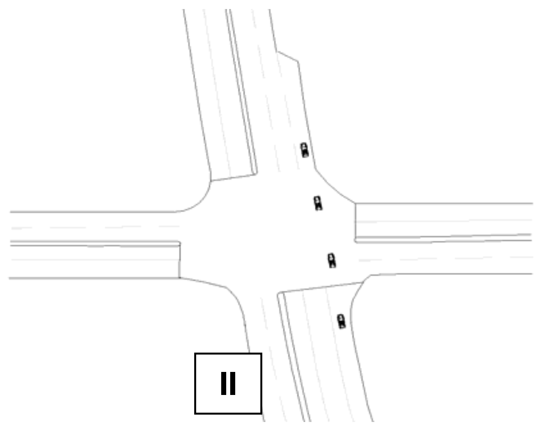
   a) ___ Mild   b) ___ Routine   ___ c) Extreme

7. If Yes to Q5, for the two designs **I** and **II** below,

   a) ___ **I** was more frustrating   b) ___ **II** was more frustrating

   c) ___ **I** and **II** were equally frustrating





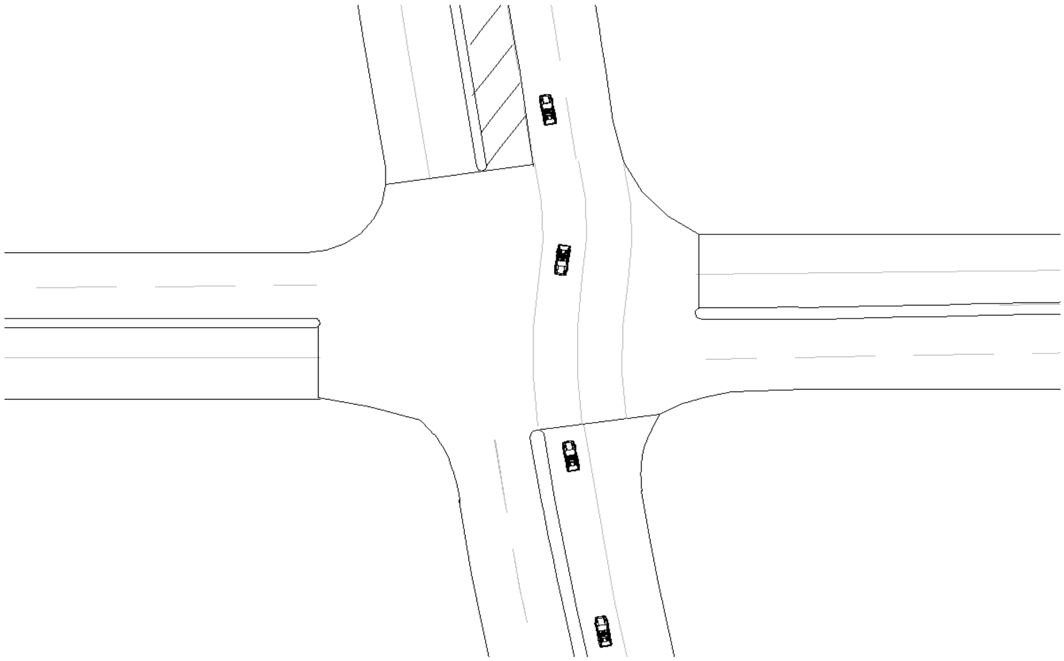
8. Do you think design **II** is better than **I** and will improve the conditions for merging?

   a)___ Yes   b) ___ No   c) ___ Not sure

9. If Yes to Q8, please rate the potential improvement

   a) ___ Satisfactory   b) ___ Good   c) ___ Excellent

2. Misalignment of lanes



10. Have you ever experienced a misalignment of lanes on either side of an intersection while driving a motor vehicle?

    a) ___ Yes b) ___ No c) ___ Don't remember

11. If Yes to Q10, how often

    a) ___ Every day b) ___ Every few days c) ___ Once a week
    d) ___ Rarely

12. If Yes to Q10, was there a pavement marking in the intersection to guide you to the other side?

    a) ___ Yes b) ___ No c) ___ Don't remember

13. In the driving simulator did your experience of a misalignment of lanes at an intersection cause frustration and anxiety?

    a) ___ Yes b) ___ No c) ___ Don't remember

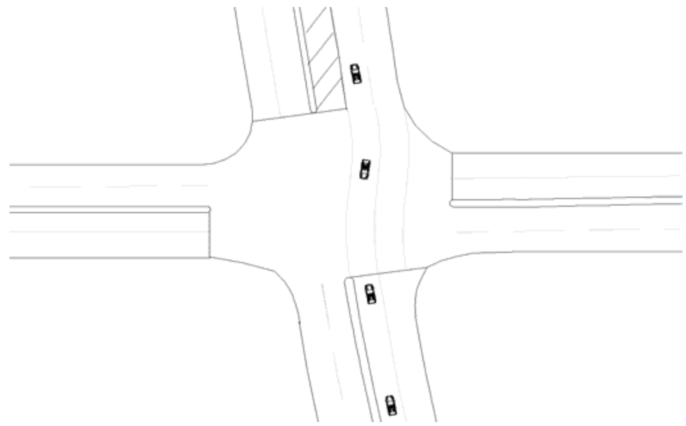
14. If Yes to Q13, please rate your frustration level.

    a) ___ Mild b) ___ Routine ___ c) Extreme

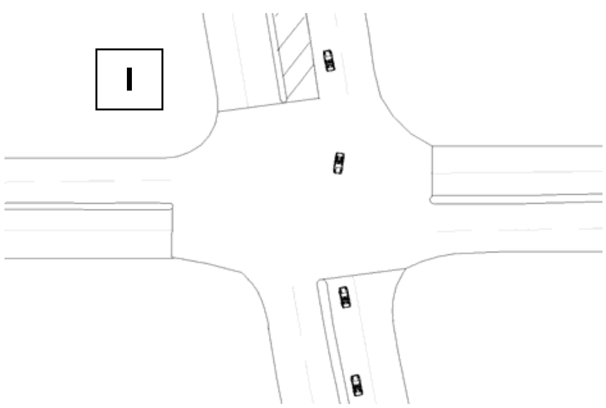
15. If Yes to Q13, for the two designs **I** and **II** below,

a) ___ **I** was more frustrating   b) ___ **II** was more frustrating

c) ___ **I** and **II** were equally frustrating



I



II

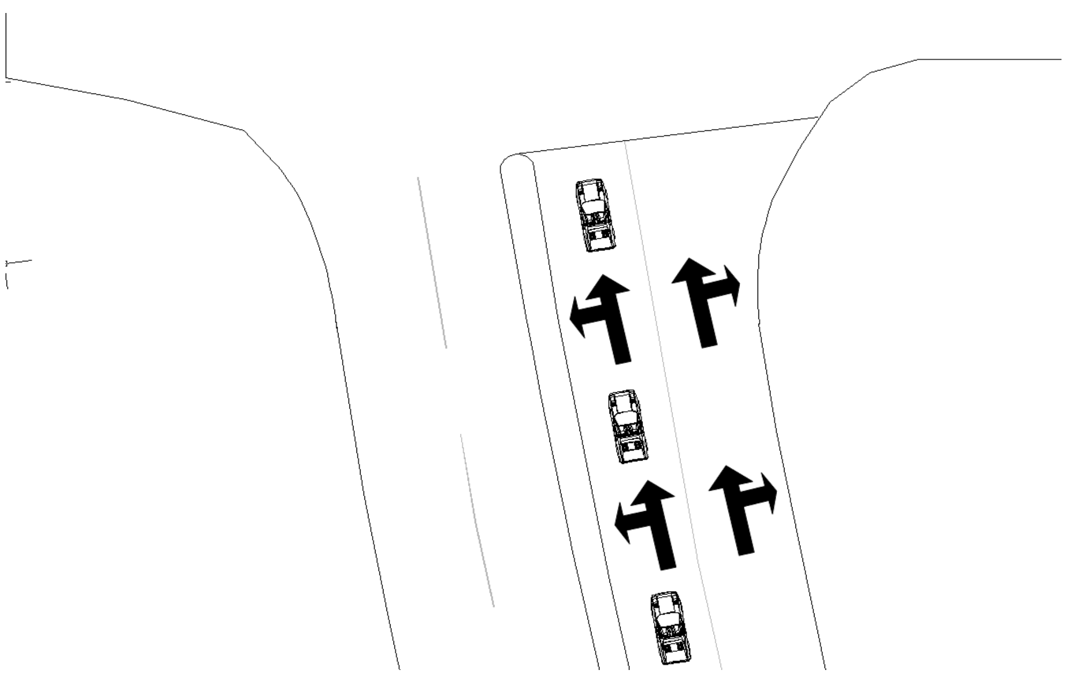
16. Do you think design **II** is better than **I** and will improve conditions for traveling through the intersection?

a)___ Yes   b) ___ No   c) ___ Not sure

17. If Yes to Q16, please rate the potential improvement

a) ___ Satisfactory   b) ___ Good   c) ___ Excellent

3. Effect of joint left and through lane



18. Have you ever been stuck behind a left turning vehicle in a joint left and through lane when driving a motor vehicle?

a) ___ Yes b) ___ No c) ___ Don't remember

19. If Yes to Q18, how often

a) ___ Every day b) ___ Every few days c) ___ Once a week
d) ___ Rarely

20. If Yes to Q18, what was the longest amount of time you were forced to wait behind the left turning vehicle before going through the intersection?

a) ___ Less then 15 sec b) ___ Between 15 and 30 sec
c) ___ More than 30 sec

21. Have you ever been stuck behind a left turning vehicle for more than one cycle of the signal (time period between one red light to another red light)

a) ___ Yes b) ___No c) ___ Don't remember

22. If Yes to Q21, how often do you experience this situation

a) ___ Everyday b) ___ Couple of days c) ___ Once a week
d) ___ Rarely

23. In the driving simulator, did getting stuck behind a left turning vehicle cause frustration and anxiety?

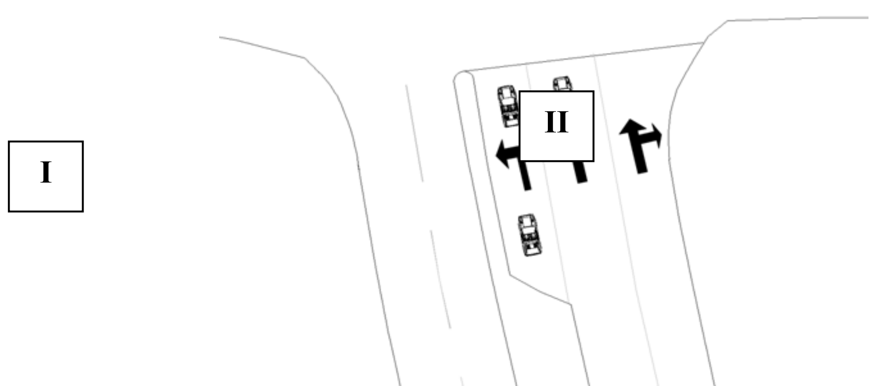
a) ___ Yes b) ___ No c) ___ Don't remember

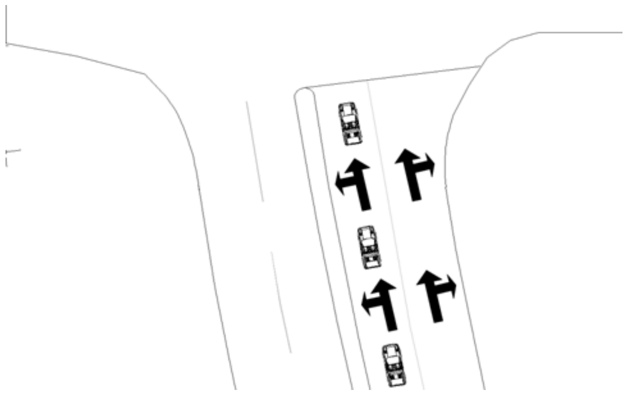
24. If Yes to Q23, please rate your frustration level.

a) ___ Mild b) ___ Routine ___ c) Extreme

25. If Yes to Q23, for the two designs **I** and **II** below

a) ___ **I** was more frustrating b) ___ **II** was more frustrating
c) ___ **I** and **II** were equally frustrating





26. Do you think design **II** is better than **I** and will improve conditions for traveling through the intersection?

    a) ___ Yes b) ___ No

27. If Yes to Q26, please rate the potential improvement

    a) ___ Satisfactory b) ___ Good c) ___ Excellent

<u>"QUALITY OF SERVICE" REGISTRATION FORM</u>

Name ________________________________

Age ________________________________

Address ________________________________

____

Driving Experience (how many years?)

____

Phone ________________________________

E-mail ________________________________

Date ____________________________________

Note for participants: The objective of the study is to assess the fidelity of the simulator. Please obey to the traffic laws and rules just like what you do in the real world when driving the simulator.

For Internal Use Only

Sub ID ____________________________________

Seq ____________________________________

Sickness (Y or N) ______________________________

"QUALITY OF SERVICE" CONSENT FORM

Please read this consent document carefully before you decide to participate in this study.

Project Title: Traffic Engineering Studies Using a Driving Simulator

Purpose of the research study:

The purpose of this study is to obtain subjects reactions to driving in a simulator and how closely they believe it represents a real world driving experience.

What you will be asked to do in this study:

Volunteer participation in this research project will take place in the UCF College of Engineering's new Driving Simulator Laboratory located in Room 117 in the new engineering building. Following an informal briefing about the UCF driving simulator, you will be given an opportunity for a three minute test drive to become familiar with the controls and get acclimated to the virtual environment. After a short rest period, you will be asked to drive the simulator for approximately 10-15 minutes. The research team will be recording information related to your driving habits (steering, gas and break pedal inputs) as well as location of the simulator vehicle and its proximity to certain objects in the visual scene. There will be no rating, rank ordering or any attempt to assess individual driving performance.

Time Required: Approximately 20 minutes

Risks: There is a small risk of subjects developing what is ordinarily referred to a simulator sickness. It occurs infrequently to subjects who are exposed to prolong continuous testing in simulated environments. Symptoms consist of nausea and a feeling of being light headed.

Benefits/Compensation: There is no direct benefit to you from participation in this study. All volunteers will receive $10 for completing this study. Partial compensation may be available for those who do not complete the experiment.

Confidentiality: Your identity will be kept confidential. Your name will not be used in any report. The recorded data will be assigned a code number. A list correlating participant names and code numbers will be locked up in the office of the principal investigator from UCF.

Voluntary participation: Your participation in this study is voluntary. You have the right to withdraw from this study at any time without consequence.

Questionnaire: On the questionnaire, you do not have to answer any question you do not wish to answer.

More information: For more information or if you have questions about this study, contact

Mr. Kamal Goyal	Dr. Essam Radwan
321-947-1060	407-823-0808
kamaliitd@yahoo.com	aeradwan@mail.ucf.edu

If you believe you have been injured during participation in this research project, you may file a claim against the State of Florida by filing a claim with the University of Central Florida's Insurance Coordinator, Purchasing Department, 4000 Central Florida Boulevard, Suite 360, Orlando, FL 32816, (407) 823-2661. The University of Central Florida is an agency of the State of Florida and the University's and the State's liability for personal injury or property damage is extremely limited under Florida law. Accordingly, the University's and the State's ability to compensate you for any personal injury or property damage suffered during this research project is very limited.

Information regarding your rights as a research volunteer may be obtained from:

Chris Grayson
Institutional Review Board (IRB)
University of Central Florida (UCF)
12443 Research Parkway, Suite 207
Orlando, FL 32826-3252
Telephone: (407) 823-2901

☐ I have read the procedure described above

☐ I voluntarily agree to participate in the procedure

Participant ________________________ Date ____________

Principal Investigator (UCF) ________________ Date ____________

SAS COMPUTER CODE FOR DATA ANALYSIS

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PROC IMPORT OUT= THESIS.V18F
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     SCANTEXT=YES;
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     SCANTIME=YES;


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if (11466.816<=x_position<=11788.137 and
6748.193<=y_position<=6759.036) then output;
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RUN;


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set thesis.V18F;
if sim_time=. then delete;

if (10839.012<=x_position<=11066.816 and
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     SHEET="V18F";
RUN;
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     USEDATE=YES;
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6748.193<=y_position<=6759.036) then output;
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data thesis.lanedrop_V111f;
set thesis.V111f;
if sim_time=. then delete;
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if (10839.012<=x_position<=11066.816 and
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run;
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     MIXED=NO;
     SCANTEXT=YES;
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data thesis.unaligned_V113f;
set thesis.V113f;
if sim_time=. then delete;

if (11466.816<=x_position<=11788.137 and
6748.193<=y_position<=6759.036) then output;
run;
PROC EXPORT DATA= THESIS.Unaligned_V113f
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     SHEET="V113f";



data thesis.lanedrop_V113f;
set thesis.V113f;
if sim_time=. then delete;

if (10839.012<=x_position<=11066.816 and
6351.876<=y_position<=6359.036) then output;
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PROC EXPORT DATA= THESIS.lanedrop_V113f
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     MIXED=NO;
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     SCANTIME=YES;
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data thesis.unaligned_V114f;
set thesis.V114f;
if sim_time=. then delete;

if (11466.816<=x_position<=11788.137 and
6748.193<=y_position<=6759.036) then output;
run;
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Documents\Kamal Thesis\QOS Data\v1\female\unaligned.xls"
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data thesis.lanedrop_V114f;
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if sim_time=. then delete;

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     MIXED=NO;
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     USEDATE=YES;
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data thesis.unaligned_V115f;
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6748.193<=y_position<=6759.036) then output;
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data thesis.lanedrop_V115f;
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6351.876<=y_position<=6359.036) then output;
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     SCANTEXT=YES;
     USEDATE=YES;
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set thesis.V116f;
if sim_time=. then delete;
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data thesis.lanedrop_V116f;
set thesis.V116f;
if sim_time=. then delete;

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6351.876<=y_position<=6359.036) then output;
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6748.193<=y_position<=6759.036) then output;
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     SCANTIME=YES;



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if sim_time=. then delete;

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6748.193<=y_position<=6759.036) then output;
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data thesis.lanedrop_V121f;
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if sim_time=. then delete;

if (10839.012<=x_position<=11066.816 and
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PROC IMPORT OUT= THESIS.V128f
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     MIXED=NO;
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     USEDATE=YES;
     SCANTIME=YES;
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data thesis.unaligned_V132f;
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if sim_time=. then delete;

if (11466.816<=x_position<=11788.137 and
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PROC EXPORT DATA= THESIS.Unaligned_V132f
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data thesis.lanedrop_V132f;
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6351.876<=y_position<=6359.036) then output;
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PROC EXPORT DATA= THESIS.lanedrop_V132f
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**********************************************/



PROC IMPORT OUT= THESIS.V135f
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     USEDATE=YES;
     SCANTIME=YES;
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set thesis.V135f;
if sim_time=. then delete;
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```
if (11466.816<=x_position<=11788.137 and
6748.193<=y_position<=6759.036) then output;
run;
PROC EXPORT DATA= THESIS.Unaligned_V135f
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Documents\Kamal Thesis\QOS Data\v1\female\unaligned.xls"
            DBMS=EXCEL REPLACE;
     SHEET="V135f";



data thesis.lanedrop_V135f;
set thesis.V135f;
if sim_time=. then delete;

if (10839.012<=x_position<=11066.816 and
6351.876<=y_position<=6359.036) then output;
run;
PROC EXPORT DATA= THESIS.lanedrop_V135f
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     SHEET="V135f";

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PROC IMPORT OUT= THESIS.V137f
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if (11466.816<=x_position<=11788.137 and
6748.193<=y_position<=6759.036) then output;
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6351.876<=y_position<=6359.036) then output;
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     SHEET="V137f";

/************************************************************************
***********************************************/



PROC IMPORT OUT= THESIS.V138f
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     MIXED=NO;
     SCANTEXT=YES;
     USEDATE=YES;
     SCANTIME=YES;



data thesis.unaligned_V138f;
set thesis.V138f;
if sim_time=. then delete;

if (11466.816<=x_position<=11788.137 and
6748.193<=y_position<=6759.036) then output;
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Documents\Kamal Thesis\QOS Data\v1\female\unaligned.xls"
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data thesis.lanedrop_V138f;
set thesis.V138f;
if sim_time=. then delete;

if (10839.012<=x_position<=11066.816 and
6351.876<=y_position<=6359.036) then output;
run;
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Documents\Kamal Thesis\QOS Data\v1\female\lanedrop.xls"
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RUN;
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data thesis.unaligned_V139f;
set thesis.V139f;
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if (11466.816<=x_position<=11788.137 and
6748.193<=y_position<=6759.036) then output;
run;
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data thesis.lanedrop_V139f;
set thesis.V139f;
if sim_time=. then delete;

if (10839.012<=x_position<=11066.816 and
6351.876<=y_position<=6359.036) then output;
run;
PROC EXPORT DATA= THESIS.lanedrop_V139f
            OUTFILE= "C:\Documents and Settings\Kamal Goyal\My
Documents\Kamal Thesis\QOS Data\v1\female\lanedrop.xls"
            DBMS=EXCEL REPLACE;
     SHEET="V139f";
RUN;
/*****************************************************************************
**********************************************/



PROC IMPORT OUT= THESIS.V140f
            DATAFILE= "C:\Documents and Settings\Kamal Goyal\My
Documents\Kamal Thesis\QOS Data\v1\female\40fv1.xls"
            DBMS=EXCEL REPLACE;
```

```
     GETNAMES=YES;
     MIXED=NO;
     SCANTEXT=YES;
     USEDATE=YES;
     SCANTIME=YES;


data thesis.unaligned_V140f;
set thesis.V140f;
if sim_time=. then delete;

if (11466.816<=x_position<=11788.137 and
6748.193<=y_position<=6759.036) then output;
run;
PROC EXPORT DATA= THESIS.Unaligned_V140f
            OUTFILE= "C:\Documents and Settings\Kamal Goyal\My
Documents\Kamal Thesis\QOS Data\v1\female\unaligned.xls"
            DBMS=EXCEL REPLACE;
     SHEET="V140f";



data thesis.lanedrop_V140f;
set thesis.V140f;
if sim_time=. then delete;

if (10839.012<=x_position<=11066.816 and
6351.876<=y_position<=6359.036) then output;
run;
PROC EXPORT DATA= THESIS.lanedrop_V140f
            OUTFILE= "C:\Documents and Settings\Kamal Goyal\My
Documents\Kamal Thesis\QOS Data\v1\female\lanedrop.xls"
            DBMS=EXCEL REPLACE;
     SHEET="V140f";
RUN;
/***********************************************************************
**********************************************/
```

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