EVALUATING ROADWAY CROSS-SECTIONAL DESIGN ELEMENTS AND ITS IMPACT ON DRIVER BEHAVIOR USING A DRIVING SIMULATOR

Bhavana Gongalla

Follow this and additional works at: https://scholarworks.umass.edu/cee_transportation

Part of the Transportation Engineering Commons

Gongalla, Bhavana, "EVALUATING ROADWAY CROSS-SECTIONAL DESIGN ELEMENTS AND ITS IMPACT ON DRIVER BEHAVIOR USING A DRIVING SIMULATOR" (2016). Transportation Engineering Masters Projects. 3.

Retrieved from https://scholarworks.umass.edu/cee_transportation/3

This Article is brought to you for free and open access by the Civil and Environmental Engineering at ScholarWorks@UMass Amherst. It has been accepted for inclusion in Transportation Engineering Masters Projects by an authorized administrator of ScholarWorks@UMass Amherst. For more information, please contact scholarworks@library.umass.edu.
EVALUATING ROADWAY CROSS-SECTIONAL DESIGN ELEMENTS AND ITS IMPACT ON DRIVER BEHAVIOR USING A DRIVING SIMULATOR

A Project Presented

By

Bhavana Gongalla

Submitted to the Graduate School of the University of Massachusetts Amherst in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE IN CIVIL and ENVIRONMENTAL ENGINEERING
EVALUATING ROADWAY CROSS-SECTIONAL DESIGN ELEMENTS AND ITS IMPACT ON DRIVER BEHAVIOR USING A DRIVING SIMULATOR

A Project Presented

by

BHAVANA GONGALLA

Approved as to style and content by:

_________________________________
Michael A. Knodler, Jr. Chair

_________________________________
Eleni Christofa, Member

______________________________
Richard N. Palmer, Department Head
Department of Civil and Environmental Engineering
ACKNOWLEDGEMENT

Firstly, I would like to express my deep gratitude towards my advisor and mentor Dr. Michael A. Knodler for providing me a wonderful opportunity to pursue the degree in his group. Dr. Knodler has always been a great source of inspiration, support and guidance throughout this journey. I would also like to thank Dr. Cole Fitzpatrick for his time and advice with my project.

I would also like to thank all the members of Human Performance Lab for their time and contribution to my research. I would also like to thank all the drivers who participated in my research study. A special note of thanks to Jodi Ozdarski and Kris Stetson for always having time to patiently listen and answer my questions and address my concerns throughout my study at UMass.

Thank you to my loving and caring family. I would also like to thank my friend Venkat Lakshmi for teaching me what it is to be alive and live healthily, you will be remembered forever.

A very special thank you to my husband Dr. Kishore Raghuapthi, for his endless support and unconditional love. I am greatly thankful to Kishore for inspiring me and for making me a person that I am today.
ABSTRACT

EVALUATING ROADWAY CROSS-SECTIONAL DESIGN ELEMENTS AND ITS IMPACT ON DRIVER BEHAVIOR USING A DRIVING SIMULATOR

December 2016

BHAVANA GONGALLA

B.S., JNTU HYDERABAD, INDIA
M.S., UNIVERSITY OF MASSACUSETTS AMHERST

Directed by: Prof. Michael A. Knodler, Jr.

This research explores the relationship between the cross-sectional design elements and the impact on selected driver attributes such as speed profiles and lateral positioning. In this experiment a traditional collector type base roadway of 1.5 miles with 14 ft travel lane and 8 ft shoulder was modeled using a fixed base driving simulator. The base scenario was subsequently reconfigured with four different cross-sectional design with various elements within the same physical right-of-way. Specific design elements included, narrower lanes, bicycle lanes, raised center median and a curvilinear roadway profile. A within subject’s design of twenty participants who drove each of the five developed scenarios, which were presented in a counterbalanced fashion to mitigate any potential order effect. Participants’ speed and lateral position was recorded throughout each of the drives. Across the virtual scenarios the same performance measures were analyzed by comparing data at each of five controlled collection points (checkpoints). Analysis of experiment results was performed using both descriptive and inferential statistical tests of speed and lateral position data.
The obtained results show that the mean participants’ speed was higher than the posted speed limit in all scenarios, except the for the curvilinear profile scenario. There was no statistically significant difference in speeds between the base scenario (Sc1), narrower lane width (Sc2), bicycle lane (Sc3) and raised median (Sc4); however, for curved scenario (Sc5), the difference in speeds were statistically significant. There were significant differences in lateral position between the scenarios across the checkpoints. Overall, the results suggest that narrower lanes, or bicycle lanes, or raised median has no significant influence on reducing the speed. Nevertheless, narrower lanes have influence on maintaining the vehicle lateral position towards the center lane.

**Key words:** Roadway cross sectional features, guardrails, lane width, vegetation, speed, driving simulator, driver behavior, sense of safety.
# TABLE OF CONTENTS

ABSTRACT .................................................................................................................... v  

TABLE OF CONTENTS .............................................................................................. VI  

LIST OF TABLES ......................................................................................................... VIII  

LIST OF FIGURES ....................................................................................................... IX  

CHAPTER I ..................................................................................................................... 1  
INTRODUCTION ........................................................................................................... 1  
1.1 PROBLEM STATEMENT .......................................................................................... 2  
1.2 RESEARCH OBJECTIVES ...................................................................................... 2  
1.3 KEY OBJECTIVES OF THE STUDY ..................................................................... 3  

CHAPTER II .................................................................................................................. 4  
BACKGROUND ............................................................................................................. 4  
2.1 DRIVING SIMULATOR .............................................................................................. 4  
2.2 ROADWAY GEOMETRY ......................................................................................... 5  
2.3 DESIGN FACTORS AFFECTING CRASH RATES ................................................... 5  

CHAPTER III ................................................................................................................ 8  
METHODOLOGY .......................................................................................................... 8  
3.1 APPARATUS ............................................................................................................ 8  
3.2 SCENARIO DEVELOPMENT .................................................................................. 10  
3.3 MEASURE ............................................................................................................. 12  
3.4 PARTICIPANTS AND PROCEDURE .................................................................... 13  
3.5 EXPERIMENTAL DESIGN ..................................................................................... 14
CHAPTER IV ..........................................................................................................................................18
RESULTS ........................................................................................................................................18
  4.1 SPEED ...................................................................................................................................18
  4.2 LATERAL POSITIONING ........................................................................................................22
CHAPTER V ........................................................................................................................................31
DISCUSSION ...................................................................................................................................31
  5.1 SPEED AND LATERAL POSITION .........................................................................................31
  5.2 LIMITATIONS ........................................................................................................................33
  5.3 FUTURE WORK .......................................................................................................................33
APPENDICES ...................................................................................................................................34
INFORMED CONSENT FORM .........................................................................................................34
PAYMENT VOUCHER .....................................................................................................................38
PRE-STUDY QUESTIONNAIRE .........................................................................................................39
SIMULATOR SICKNESS QUESTIONNAIRE (SSQ) .......................................................................41
REFERENCE ....................................................................................................................................44
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE 1: RESEARCH HYPOTHESES</td>
<td>3</td>
</tr>
<tr>
<td>TABLE 2: LATIN SQUARE DESIGN TO VARY PRESENTATION ORDER</td>
<td>12</td>
</tr>
<tr>
<td>TABLE 3: DESCRIPTIVE STATISTICS FOR SPEED</td>
<td>19</td>
</tr>
<tr>
<td>TABLE 4: INFERENTIAL DIFFERENCE MEAN SPEED (MPH) AND PAIRED T-TEST P VALUES</td>
<td>21</td>
</tr>
<tr>
<td>TABLE 5: DESCRIPTIVE STATISTICS FOR LATERAL POSITION</td>
<td>23</td>
</tr>
<tr>
<td>TABLE 6: INFERENTIAL DIFFERENCE MEAN LATERAL POSITION (FT) AND PAIRED T-TEST P VALUES</td>
<td>30</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURES</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIGURE 1: PERCENTAGE CRASH CAUSES IN USA (FHWA.GOV)</td>
<td>1</td>
</tr>
<tr>
<td>FIGURE 2: UNIVERSITY OF MASSACHUSETTS DRIVING SIMULATOR</td>
<td>8</td>
</tr>
<tr>
<td>FIGURE 3: ASL EYE TRACKER</td>
<td>9</td>
</tr>
<tr>
<td>FIGURE 4: ROADWAY PROFILE IN CIVIL3D, BLENDER AND ISA</td>
<td>11</td>
</tr>
<tr>
<td>FIGURE 5: EXISTING BURNETT ROAD, CHICOPEE MA, USA: 14FT TRAVEL LANE, 8 FT SHOULDER, NO MEDIAN</td>
<td>15</td>
</tr>
<tr>
<td>FIGURE 5.1: BASE SCENARIO (Sc1): 14FT TRAVEL LANE, 8FT SHOULDER, NO MEDIAN</td>
<td>15</td>
</tr>
<tr>
<td>FIGURE 5.2: NARROWER LANE (Sc2): 12FT TRAVEL LANE, 6FT SHOULDER, NO MEDIAN</td>
<td>16</td>
</tr>
<tr>
<td>FIGURE 5.3 BICYCLE LANE (Sc3): 14FT TRAVEL LANE, 5FT BIKE LANE, 1FT BUFFER ZONE, NO MEDIAN AND SHOULDER</td>
<td>16</td>
</tr>
<tr>
<td>FIGURE 5.4 RAISED MEDIAN (Sc4): 14FT TRAVEL LANE, 2FT SHOULDER, 6FT MEDIAN</td>
<td>17</td>
</tr>
<tr>
<td>FIGURE 6.a PARTICIPANTS SPEED PROFILE SCENARIO 1</td>
<td>25</td>
</tr>
<tr>
<td>FIGURE 6.b PARTICIPANTS SPEED PROFILE SCENARIO 2</td>
<td>25</td>
</tr>
<tr>
<td>FIGURE 6.c PARTICIPANTS SPEED PROFILE SCENARIO 3</td>
<td>26</td>
</tr>
<tr>
<td>FIGURE 6.d PARTICIPANTS SPEED PROFILE SCENARIO 4</td>
<td>26</td>
</tr>
<tr>
<td>FIGURE 6.e PARTICIPANTS SPEED PROFILE SCENARIO 5</td>
<td>27</td>
</tr>
<tr>
<td>FIGURE 7.a PARTICIPANTS LATERAL POSITION SCENARIO 1</td>
<td>27</td>
</tr>
<tr>
<td>FIGURE 7.b PARTICIPANTS LATERAL POSITION SCENARIO 2</td>
<td>28</td>
</tr>
<tr>
<td>FIGURE 7.c PARTICIPANTS LATERAL POSITION SCENARIO 3</td>
<td>28</td>
</tr>
<tr>
<td>FIGURE 7.d PARTICIPANTS LATERAL POSITION SCENARIO 4</td>
<td>29</td>
</tr>
<tr>
<td>FIGURE 7.e PARTICIPANTS LATERAL POSITION SCENARIO 5</td>
<td>29</td>
</tr>
</tbody>
</table>
CHAPTER I

INTRODUCTION

The impacts of cross-sectional design elements on traffic crashes has been a major attention to transportation engineers, planners and agencies. Driving a vehicle on a typical roadway is a composite activity. It involves numerous psychological aspects like perceiving and processing visual information, vehicle performance, other vehicles on the road combined with a road’s geometric features and ever changing environmental conditions. The interaction of such aspects characterizes driving as a control task in which drivers select the information applied to that roadway situation to drive safely. During risk control and adjustment to the driving conditions, the facts that the road conveys to the driver is crucial for the driver to balance the driving control parameters like breaking, making decisions at speed etc., and avoid unsafe performance. Traffic accidents worldwide are closely related to these interactions between driver, vehicle, road, and environmental factors, such as road geometry, tire–road friction, speeding, vehicle performances, driving behaviors, pavement environments, and traffic flow.

![Venn Diagram of Crash Causes with percentages](image.png)

**FIGURE 1**: Percentage Crash Causes in USA (fhwa.gov)
From 2006 to 2010 there were mean of 37,654.4 (crash data by National highway traffic safety administration NHTSA) annual road deaths in the United States. On a positive side this figures seems to be declining from 2011 to 2014. The recent reports from NHTSA (1) showcases that a 7.7 percent increase in motor vehicle traffic deaths in 2015, and an estimated 35,200 people died in 2015 up from 32,675 reported fatalities in 2014. It also explains that ninety-three percent of crashes can be tied back to human choice and error. The primary purpose of this study is to explore the relationship between cross-sectional design elements on selected driver attributes.

1.1 Problem Statement

At present, there is a notable gap in literature that quantifies the impact from cross-sectional roadway design elements employed to reduce speed on driver performance in maintaining the vehicle lateral position. Speed selection is hazardous to roadway safety as higher speeds result in higher crash risks and more severe crashes (2)(3). More recently, practices related to complete streets have translated into a revised approach to managing roadway speeds that are necessitated for accommodating multiple modes within a single space. Previous studies have demonstrated the efficacy of various devices that when implemented, individually or in treatment combinations, can effectively decrease roadway-related crashes and fatalities. Nevertheless, there is a gap on specific roadway design elements and their direct impact on the resulting driver behaviors.

1.2 Research Objectives

The objective of this research is to explore the relationship between cross-section design elements and driver performance as measured by vehicle speed profiles, lateral positioning, and a perceived sense of safety.
1.3 Key objectives of the study

(1) evaluate if the drivers’ behavior is affected when subjected to various geometric roadway designs; (2) evaluate the effectiveness of different types of combined speed-reducing measures; (3) extend the evaluation to aspects which were generally not addressed in the previous studies, such as the speed and the lateral position profiles on a bike lane, on a raised median.
CHAPTER II

BACKGROUND

In the current road-safety literature, the importance and significance of lane width, shoulder width, road width and various geometric roadway elements such as bike path, raised median has been well documented. It is expected that the effects of speed and lateral position might not be the same in the different settings. Thus, the literature reviews in this section grouped together the previous findings in each context.

2.1 Driving simulator

To date in most of the articles a high fidelity driving simulator is used to model the base roadway condition with typical travel lanes, shoulder and other roadway elements and calibrated the data retrieved from the real-time simulator. The simulator was not predominately used earlier because for its expensive cost and lack of technology to determine the various factors like eye movement, lateral positioning of vehicle, speed control, braking movement, detection of hazards, etc. Usage of simulators over the course of time increased due to improved technology and to get more robust results by developing the virtual scenarios in the simulators to drive subjects and obtain real time data. The driving simulation has proved to be an advantageous and operative technique for studying driver behavior prompted by road patterns (4). The reasons behind the increasing use of simulators to examine how the configurations of the road affect driver performance when subjected to a high degree of realism, involves low costs in conducting experiments, easy data collection, the highest degree of safety for test drivers, controlled experimental conditions (weather, traffic, and drivers) as well as the consistency and dependability of the quantities which have been obtained.
2.2 Roadway geometry

Road geometry, environmental, and vehicle aspects are crucial in influencing dangerous driver behaviors such as speeding and drunk driving which contribute to traffic crashes (5). The identification of factors affecting crash rates is very important to transportation planners and engineers because it helps in detecting hazardous locations, or sites which require safety treatments. One such crucial factor is the cross-sectional design of the roadway. According to AASHTO, cross-sectional roadway is the view obtained in a section between the right-of-way lines cut perpendicular to direction of travel along the road. The design elements include travel way, median area, shoulder, bicycle and pedestrian facilitates, utility and landscape areas, drainage channels and side slopes, clear zone width.

2.3 Design Factors Affecting Crash Rates

According to AASHTO cross-sectional roadway is defined as the view obtained in a section between the right-of-way lines cut perpendicular to direction of travel along the road. The design elements include travel way, median area, shoulder, bicycle and pedestrian facilitates, utility and landscape areas, drainage channels and side slopes, clear zone width (6). In this study, the following list of geometric elements were specifically considered due to their effects on crash rates. Lane width, median area, bicycle facility, clear zone, shoulder width, curved roadway profile.

Based on a hierarchical tree-based regression research study aiming to find the relationship between rural road geometric characteristics, accident rates and their prediction, indicates that the lane width and serviceability index largely impact crash rates on rural two lane roadways. Whereas, on rural multilane roads, median width and access control are major factors (7).
A fundamental feature of travel lane is the lane width; it is limited by the physical dimensions of automobiles and trucks to range between 9 ft to 12 ft but 12 ft wide lanes are desirable on both rural and urban facilities (AASTHO 2001). Though lane width varies from country to country and even city to city, in most cases 12 ft is considered as the maximum lane width for arterials and 12 ft for local roads (8). In a rural two-lane or multilane road environment, elements of road geometry associated to road width, such as number of lanes, lane width were substantial and are associated with crash risk(9). Correspondingly, findings for urban areas seem to have variations with regard to the effect of lane width. Many studies in urban areas show that wider lanes resulted in higher crash rate than narrower lanes (10)(11)(12). A similar study on urban arterials found that increases in lane width and decreases in shoulder width reduced both roadside and midblock crashes(13).

The median dimension should be in accordance with the roadway cross-section. In general, median width ranges from 4-80 ft in rural areas. AASTHO 2001 suggest the use of raised median treatment are recognized in alleviating the operational and safety deficiencies for arterial streets. There are different types of medians: flush Two-Way-Left-Turn-Lanes (TWLTL), continuous raised, and barrier type medians. A public opinion survey results indicate that majority of respondents for Knox Country Tennessee residents preferred the raised median, while business owners, operators showed interest in TWLT median lanes(14). In order to substantially affect driver behavior, raised median island are strongly recommended in the United States (15). Raised curb medians provide lower vehicle crash rates and pedestrian crash rates than both TWLTL and undivided cross sections. While TWLTL medians in Central Business District (CBD) areas had lower vehicle accident rate (property damage only) than both raised curb and undivided cross-section medians (16).
Cyclists have become an increasingly important factor in the roadway design process. A study found using driving simulator on comparing vehicle speeds and lateral positioning at midblock locations with and without bicycle lanes indicate that the speeds on roadways with bicycle lanes had slightly higher speeds than without those without bicycle lanes. The presence of bicycle lanes had an impact on lane position as the participants traveled further from edge line than when bicycle lanes were not present. Separated bicycle lanes with raised medians and buffer zones add more comfort to bicyclists as well as drivers. However, separated bicycle lanes introduce challenges at intersections when they motorists and cyclists must interact.

AASTHO define clear zone as an unobstructed traversable roadside area designed to enable a driver to stop safely or regain control of a vehicle that has accidentally left the roadway. Findings on the effect of clear zone width and roadside vegetation on driver behavior shows that clear zone size/vegetation density combinations influence both driver speed and lane position of vehicle.

According to AASTHO 2001, roadway paved shoulder enables driver to stop safely and pull off, and serves as a recovery area for driver error. However, the increase in shoulder width has positive effect on decreasing the crash rate. A field experiment in Greece with three nonconsecutive road sections containing various curves were used to study risk perception regarding different road geometric elements. The results specified that curvilinear roadway profile highly affected drivers’ safety perception. Therefore, a conventional straight road was perceived as less risky than curved one.
CHAPTER III

METHODOLOGY

A within-subjects experimental design was developed based upon existing literature to examine the effect of cross-section design on key driver performance measures such as speed and lateral position which influence roadway safety. The following section outlines the research tasks that were employed to address the objectives of this study.

3.1 Apparatus

3.1.1 Driving Simulator

The driving simulator used for the study comprises of a fully equipped fixed-base 1995 Saturn sedan positioned in front of three screens subtending 135 degrees horizontally.

FIGURE 2: University of Massachusetts Driving Simulator

The virtual environment is projected on each screen at a resolution of 1400 × 1050 pixels and at a frequency of 60 Hz. The virtual environment is projected on each screen through a network
of four advanced Realtime Technologies (RTI) simulator servers. The participant sits in the car and operates the controls, moving through the virtual world according to his or her inputs to the car. The audio is controlled by a separate system that consists of four high frequency speakers located on the left and right sides of the car and two sub-woofers located under the hood of the car. This system provides realistic road, wind and other vehicle noises with appropriate direction, intensity, and Doppler shift.

3.1.2 Eye Tracker

A portable head mounted ultra-lightweight eye tracker (Mobile Eye developed by Applied Science Laboratories) was used to collect the eye-movement data for each driver (Figure 2). It has a lightweight optical system consisting of an eye camera and a color scene camera mounted on a pair of safety goggles.
The images from these two cameras are interleaved and recorded on a remote recording system, thus ensuring no loss of resolution. The eye tracker has a visual angle range of 50 degrees in the horizontal direction and 40 degrees in the vertical direction. The system’s accuracy is 0.5 degrees of visual angle (Applied Science Laboratories 2013). The interleaved video can then be transferred to a PC where the images are separated and processed. The eye movement data are converted to a crosshair, representing the driver’s point of gaze at 30 Hz, which is superimposed upon the scene video recorded during the drive. This provides a record of the driver’s point of gaze on the driving scene while in the simulator. The remote recording system is battery powered and can record up to 90 minutes of eye and scene information at 60Hz in a single trial.

3.2 Scenario Development
For this research experiment five various geometric roadway scenarios are modeled in Civil 3D which is capable of creating 3D view of the proposed road environment. A typical arterial roadway section approximately 1.5 miles was created based on an existing roadway section in Chicopee Springfield, Massachusetts, USA. This study is limited to rural and residential area. Initially the mapped location was laid into Civil 3D and the corridor with profiles were developed using assemblies and subassemblies from Civil3D. Autodesk Civil 3D was selected because of its ability of exporting 3D surfaces of proposed roads, which can later be uploaded in Blender. Blender is a robust 3D modeling tool available as an open source product for free of cost. Blender 2.49b version is used for providing the texture to the roadway profile. Texturing and converting a dxf file into the Virtual Reality Modeling Language (VRML) file format is done using Blender. VRML file format is adaptable to Internet Scene Assembler (ISA). Apart from Civil 3D and Blender one other software tool were used ISA. Among the scenario creation Blender plays a key role in manipulation of dxf files which contain a surface of a project created from 3D CAD drawing using design
software such as Civil 3D. The virtual scenarios for driving simulator are developed by using a 3D modeling software called Internet Scene Assembler (ISA), which utilizes the VRML file format.

**FIGURE 4: Roadway Profile in CIVIL3D, Blender and ISA**
3.3 Measure

The independent variables for the current study were lane width, bicycle facility, curb median, clear zone, and shoulder. To not inhibit participants’ speed choice, there was no traffic in the participant’s direction of travel. In the oncoming direction, four vehicles, including a truck were individually programmed so that traffic could be controlled across all participants for each cross-section configuration. The specific order of combinations for each of five drives is shown in Table 2.

**TABLE 2: Latin Square Design to Vary Presentation Order**

<table>
<thead>
<tr>
<th>Participants/Scenario Drive</th>
<th>Sc1</th>
<th>Sc2</th>
<th>Sc3</th>
<th>Sc4</th>
<th>Sc5</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
</tr>
<tr>
<td>#2</td>
<td>E</td>
<td>A</td>
<td>D</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>#3</td>
<td>B</td>
<td>D</td>
<td>A</td>
<td>E</td>
<td>C</td>
</tr>
<tr>
<td>#4</td>
<td>C</td>
<td>E</td>
<td>B</td>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>#5</td>
<td>D</td>
<td>C</td>
<td>E</td>
<td>B</td>
<td>A</td>
</tr>
</tbody>
</table>

Data was collected continuously throughout the drive; however, five locations were selected for data comparisons. Each participant’s vehicle speed with lateral position at the five data collection check points within a scenario were compared to their speed and lateral position within a different scenario. Data collection checkpoints within the scenarios were 1. Start (located at 0.022 mile of the roadway for a length of 0.05 mile), 2. Straight (located at 0.11 mile for a length of 0.013 mile), 3. Small Left Curve (located at 0.20 mile for a length of 0.055 mile), 4. Right Curve (located 0.405 mile for a length of 0.181 mile), and 5. End (located at 0.96 mile for a length of 0.02 mile).
3.4 Participants and Procedure

Need for participants were adversities through flyers passing in and around campus area. All procedures including informed consent, payment, and participant recruitment followed Protocol ID#: 2016-2903 as approved by the Institutional Review Board (IRB) of the University of Massachusetts.

A total of twenty drivers (nine females, eleven males) participated in the experiment. Their ages ranged from 20-60 years old (mean:29.35, SD:10.91) and all had more than one year of driving experience (mean: 11.245, SD:10.99) with minimal or no prior simulator driving experience were recruited for the study. There were nine females and eleven male participants and had driving experience in United States for more than 3 year and overall participants average driving experience was 11.5 years.

Participants started by giving informed consent and then completed a pre-study questionnaire which asked for their demographics, driving history, and medical conditions which may influence their driving performance. Participants were asked to complete a pre-simulation sickness questionnaire and after completion of the drive, they were again asked to complete a post-simulation sickness questionnaire. This was to know that they were not at risk for simulator sickness. Before entering the simulator, participants were fitted with the head-mounted eye tracker. After calibration, participants were given a practice drive session to familiarize them with the driving simulator. The practice training drive included typical roadway with 12 ft two direction and 4 ft shoulder with a posted speed limit 30 mph. Prior to the driving experiment participants were instructed to drive through all the scenarios as normally as they would in their vehicle in their day to day life.
Finally, a post-study questionnaire was administered which evaluated their post exposure information about the virtual environments and their driving performance. Participants were compensated $20 for their time.

3.5 Experimental Design

As a *base* scenario 44 feet two lane roadway, consists of 14feet one directional travel lane, 8 feet shoulder was modeled using the aforementioned software tools. The second *Narrower Lane* scenario was remodeled with 12 feet one directional travel lane, 6 feet shoulder accounting to a 36 feet total roadway. In the third *bicycle lane* scenario, a 5 feet bicycle facility with 1feet buffer zone was introduced on both directions of the roadway replacing the 8 feet shoulder, it also includes 14 feet one directional travel lane to a total of 40 feet wide roadway environment. The forth *raised median scenario* comprises of 6 inches raised 6 feet median along the center of the roadway with a 14feet travel lane and 2 feet shoulder total of 44 feet roadway cross-section. The fifth *curvilinear roadway* scenario entails 44 feet roadway with 6 inches raised 6 feet median along the center of the curvilinear roadway section and with 14feet roadway with 2 feet shoulder. Moderate plantation was placed on the median to maintain the natural feel along the roadway. Within subject experimental design was used in this study. Each scenario drive took participants approximately 120 seconds to complete, and lasted roughly fifteen minutes to finish the five scenario drives. 

**Figure 5, 5.1, 5.2, 5.3, 5.4 and 5.5**, are the screen shots of five scenarios which illustrates the width and various geometric features of the modeled roadway.
FIGURE 5: Existing Burnett Road, Chicopee MA, USA: 14ft travel lane, 8 ft shoulder, no median

FIGURE 5.1: Base Scenario (Sc1): 14ft travel lane, 8ft shoulder, no median
FIGURE 5.2: Narrower Lane (Sc2): 12ft travel lane, 6ft shoulder, no median

FIGURE 5.3 Bicycle Lane (Sc3): 14ft travel lane, 5ft bike lane, 1ft buffer zone, no median and shoulder
FIGURE 5.4 Raised Median (Sc4): 14ft travel lane, 2ft shoulder, 6ft median

FIGURE 5.5: Curved Profile (Sc5): 14ft travel lane, 2ft shoulder, 6ft median
CHAPTER IV

RESULTS

The research objectives addressed the relationship between cross-sectional design elements and the effect on driver’s behavior pertaining their vehicle speed and lateral position. As discussed, the main dependent variables were speed and lateral positioning while independent measures were various geometric roadway design elements (scenarios). In this study, units of measurements used for speed is miles per hour (mph), and lateral position is represented by a unit of distance as feet (ft). Lateral position is calculated from measuring the difference between the absolute center of the vehicle from the center of the travel lane within the simulated roadway scenario. Negative lateral position values indicate that participants’ vehicle is positioned nearer to the centerline while, positive values imply that the vehicle is positioned closer to the edge line.

A between subject t-test was used to make the comparative analysis. The α level was set at 0.05 and values with a calculated p ≤ 0.05 were statistically significant. An example comparison of various geometric scenarios on various roadway geometry is shown in Table 4 and Table 6 for speed and lateral position

4.1 Speed

Evaluating the participants’ vehicle speed data to address the objectives, of various cross-sectional designed scenarios (Sc1, Sc2, Sc3, Sc4, Sc5), we looked at the mean participant speed across the scenarios along all the checkpoints. Table 3 shows the mean speeds of participants in each of the five scenarios at the five different checkpoints. For the base scenario (Sc1), with a 14 ft wide travel lane and 8 ft shoulder the mean vehicle speed was M = 29.5 mph and SD = 5.4 mph. As the
participants drove into the scenario at checkpoint 2 (straight) the mean speed increased to $M = 35.6$ mph with $SD = 8.4$ mph. At checkpoint 3 (small left curve) the mean speed was $M = 39.5$ mph with $SD = 10.0$ mph. At the checkpoint 4 (right curve), the mean speed increased to $M = 41.3$ mph with $SD = 12.2$ mph, while at the checkpoint 5 (end) of the roadway was $M = 41.6$ mph with $SD = 13.7$ mph.

**TABLE 3: Descriptive Statistics for Speed**

<table>
<thead>
<tr>
<th>Scenario / Checkpoint</th>
<th>Base Scenario (Sc1)</th>
<th>Narrower Lane (Sc2)</th>
<th>Bicycle Lane (Sc3)</th>
<th>Raised Median (Sc4)</th>
<th>Curved Profile (Sc5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Start</td>
<td>29.5 ± 5.4</td>
<td>28.7 ± 5.8</td>
<td>30.3 ± 5.0</td>
<td>28.3 ± 6.0</td>
<td>23.0 ± 5.4</td>
</tr>
<tr>
<td>2. Straight</td>
<td>35.6 ± 8.4</td>
<td>36.0 ± 6.9</td>
<td>37.0 ± 6.5</td>
<td>35.7 ± 6.9</td>
<td>25.9 ± 5.5</td>
</tr>
<tr>
<td>3. Small Left Curve</td>
<td>39.5 ± 10.0</td>
<td>39.5 ± 8.2</td>
<td>39.8 ± 8.2</td>
<td>38.7 ± 9.3</td>
<td>27.2 ± 5.2</td>
</tr>
<tr>
<td>4. Right Curve</td>
<td>41.3 ± 12.2</td>
<td>39.9 ± 8.7</td>
<td>41.3 ± 11.8</td>
<td>41.2 ± 11.9</td>
<td>27.4 ± 5.2</td>
</tr>
<tr>
<td>5. End</td>
<td>41.6 ± 13.7</td>
<td>40.9 ± 10.1</td>
<td>40.7 ± 14.8</td>
<td>41.2 ± 14.1</td>
<td>30.6 ± 5.5</td>
</tr>
</tbody>
</table>

Note: All values are Mean ± St. Dev.

Note: Bold indicate increased speed pattern from checkpoint 1 to 5

*Table 3* demonstrates clearly that the participants’ vehicle speed increased as they drove through the scenarios, irrespective of the roadway geometry. This trend seems to be constant across all the scenarios along the checkpoints. The mean participants’ vehicle speed was lower for the curved roadway profile (Sc5) (10 miles less than the mean speeds of base scenario) and participants did not tend to exceed the posted speed limit (30mph).
The mean participants’ speeds for narrower lane (Sc2) were comparatively lower than the wide lane scenarios i.e. scenario Sc1, Sc3 and Sc4 along the checkpoints 1, 2 and 4. While the speed on checkpoint 3 and 5 are almost equal. The descriptive analysis shows that the mean participants’ speed for bicycle lane scenario (Sc3) is higher at checkpoints 1, 2, 3 and 4, except at checkpoint 5, when compared with base scenario (Sc1). Interestingly, introducing a 6 ft raised median in Sc4 showed a slight change in the speed profile (slight decreased speeds) when compared to the base scenario (Sc1) across all the checkpoints of the roadway.

The paired t-test compared results between scenarios, Table 4, revealed no significant differences in speed between the base scenario (Sc1) and narrower lane (Sc2), bicycle lane (Sc3), and raised median scenarios (Sc4). This result supported the hypotheses that introducing the narrow lane, bicycle lane or a raised median would not influence the participants’ speed at any of the checkpoints along the roadway. However, there seemed to be well established significance between base scenario (Sc1) and curved roadway profile (Sc5) where p was much lower than 0.05 at all the checkpoints along the roadway.

Paired t-tests between narrower lane (Sc2) and bicycle lane scenario (Sc3) indicated some significance in participants’ mean speed at checkpoint 1 where p = 0.02. Also, at checkpoint 1, significant differences existed between the bicycle lane scenario (Sc3) and raised median scenario (Sc4) where p = 0.04.
### TABLE 4: Inferential Difference Mean Speed (mph) and Paired t-test P values

<table>
<thead>
<tr>
<th>Scene</th>
<th>Checkpoints</th>
<th>Base Scenario (Sc1)</th>
<th>Narrower Lane (Sc2)</th>
<th>Bicycle Lane (Sc3)</th>
<th>Raised Median (Sc4)</th>
<th>Curved Profile (Sc5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean (P Value)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Base Scenario (Sc1)</strong></td>
<td>1.Start</td>
<td>0.8(0.66)</td>
<td>-0.8(0.81)</td>
<td>1.2(0.77)</td>
<td>6.5(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.Straight</td>
<td>-0.4(0.70)</td>
<td>-1.5(0.30)</td>
<td>-0.2(0.89)</td>
<td>9.7(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.Small Left Curve</td>
<td>0.0(0.99)</td>
<td>-0.3(0.99)</td>
<td>0.8(0.19)</td>
<td>12.2(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.Right Curve</td>
<td>1.3(0.23)</td>
<td>0.0(0.81)</td>
<td>0.1(0.90)</td>
<td>13.9(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.End</td>
<td>0.6(0.66)</td>
<td>0.9(0.57)</td>
<td>0.4(0.66)</td>
<td>11.0(0.00)</td>
<td></td>
</tr>
<tr>
<td><strong>Narrower Lane (Sc2)</strong></td>
<td>1.Start</td>
<td></td>
<td>-1.6(0.02)</td>
<td>0.4(0.71)</td>
<td>5.8(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.Straight</td>
<td></td>
<td>-1.1(0.15)</td>
<td>0.3(0.81)</td>
<td>10.1(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.Small Left Curve</td>
<td></td>
<td>-0.3(0.74)</td>
<td>0.8(0.44)</td>
<td>12.2(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.Right Curve</td>
<td></td>
<td>-1.4(0.15)</td>
<td>-1.2(0.29)</td>
<td>12.5(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.End</td>
<td></td>
<td>0.9(0.85)</td>
<td>-0.3(0.85)</td>
<td>10.4(0.00)</td>
<td></td>
</tr>
<tr>
<td><strong>Bicycle Lane (Sc3)</strong></td>
<td>1.Start</td>
<td></td>
<td></td>
<td>2.0(0.04)</td>
<td>7.3(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.Straight</td>
<td></td>
<td></td>
<td>1.3(0.12)</td>
<td>11.1(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.Small Left Curve</td>
<td></td>
<td></td>
<td>1.1(0.22)</td>
<td>12.5(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.Right Curve</td>
<td></td>
<td></td>
<td>0.2(0.86)</td>
<td>13.99(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.End</td>
<td></td>
<td></td>
<td>-0.5(0.72)</td>
<td>10.1(0.00)</td>
<td></td>
</tr>
<tr>
<td><strong>Raised Median (Sc4)</strong></td>
<td>1.Start</td>
<td></td>
<td></td>
<td></td>
<td>5.3(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.Straight</td>
<td></td>
<td></td>
<td></td>
<td>9.8(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.Small Left Curve</td>
<td></td>
<td></td>
<td></td>
<td>11.5(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.Right Curve</td>
<td></td>
<td></td>
<td></td>
<td>13.7(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.End</td>
<td></td>
<td></td>
<td></td>
<td>10.7(0.00)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Bold indicates a significant difference based on a Paired t-test
4.2 Lateral Positioning

Drivers always try to choose a comfortable position in lane to avoid potential risks such as physical roadside barricades or moving vehicles. In terms of mean participants’ vehicle lateral positioning, the results are displayed in Table 5, within the base scenario (Sc1) participants drove further from the centerline further towards the edge line along the checkpoints (1, 2, 3 and 5) of the roadway. However, except at checkpoint 4 (right curve) participants moved towards the center line, $M = -0.9 \, \text{ft} \, SD = 0.6 \, \text{ft}$. In narrow lane scenario (Sc2), as expected, drove almost near to the center line along checkpoints except for the fifth checkpoint, where they drove towards the edge line. Similar patterns from Table 5, were observed in bicycle lane scenario (Sc3) where participants drove away from the center line (+ve) and moved towards the edge line irrespective of the checkpoint geometry. While the mean lateral position of participants’ vehicle was higher in raised median scenario (Sc4) with larger means and SD along the checkpoints 1, 2, 3, and 4, but, at the 5th checkpoint participants drove towards the center line $Mean = -1.5 \, \text{ft} \, SD = 4.3 \, \text{ft}$. For the curved profile scenario (Sc5), participants moved towards the edge line at checkpoints 1, 2, 3, and 4 except for checkpoint 5, where the participants positioned themselves towards the center line of the travel lane.

To achieve the research objectives and test the developed hypotheses, statistical paired t-test were performed between the scenarios at all the checkpoints to explore the participants’ lateral positions. Shown in Table 5, though the participants moved towards the edge line in most of the scenarios, interestingly, but there seems to be a statistical significance in terms of vehicle lateral position between the base scenario (Sc1) and narrower lane (Sc2) along all the checkpoints where $p<0.05$, indicated in Table 6. When a similar comparison was made between base scenario (Sc1) and bicycle lane scenario (Sc3) there seemed to have poor significance at checkpoints 1, 2, and 3 ($p>0.05$), while at checkpoint 4 and 5 $p<0.05$ indicated significance. A paired t-test between base
scenario (Sc1) and raised median scenario (Sc4) revealed that at all the checkpoints lateral position mean differences were not significant. But for base scenario (Sc1) and curved scenarios (Sc5) the patterns are quite different, at checkpoint 1, 2 and 4 the mean difference seemed to be poorly significant, while at checkpoint 3 and 5 p<0.05 showing great mean difference is significant.

**TABLE 5: Descriptive Statistics for Lateral Position**

Observed Mean Lane Positions for Scenarios at Checkpoints

<table>
<thead>
<tr>
<th>Scenario / Checkpoint</th>
<th>Base Scenario (Sc1)</th>
<th>Narrower Lane (Sc2)</th>
<th>Bicycle Lane (Sc3)</th>
<th>Raised Median (Sc4)</th>
<th>Curved Profile (Sc5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Start</td>
<td>1.7 ± 0.9</td>
<td>(-)1.5 ± 0.6</td>
<td>2.0 ± 0.9</td>
<td>7.2 ± 4.3</td>
<td>1.9 ± 2.7</td>
</tr>
<tr>
<td>2. Straight</td>
<td>1.9 ± 0.7</td>
<td>(-)1.4 ± 0.7</td>
<td>2.2 ± 0.9</td>
<td>8.3 ± 2.6</td>
<td>1.9 ± 2.5</td>
</tr>
<tr>
<td>3. Small Left Curve</td>
<td>2.2 ± 0.6</td>
<td>(-)0.8 ± 0.7</td>
<td>2.1 ± 0.7</td>
<td>4.9 ± 5.0</td>
<td>3.2 ± 1.7</td>
</tr>
<tr>
<td>4. Right Curve</td>
<td>(-)0.9 ± 0.6</td>
<td>(+)1.1 ± 0.6</td>
<td>2.3 ± 0.7</td>
<td>4.0 ± 2.9</td>
<td>0.4 ± 1.3</td>
</tr>
<tr>
<td>5. End</td>
<td>2.6 ± 1.2</td>
<td>0.3 ± 1.0</td>
<td>4.9 ± 0.1</td>
<td>(+)1.5 ± 4.4</td>
<td>(+)0.03 ± 4.3</td>
</tr>
</tbody>
</table>

Note: Values are Mean ± St. Dev.

Note: (-) indicates vehicle position closer to centerline.

Additional paired t-test was performed to explore the lateral position between the scenarios, shown in **Table 6** narrower lane scenario (Sc2) and bicycle lane (Sc3), raised median (Sc4) and curved profile (Sc5) scenarios. It is evidential that there is high significance along the checkpoints 1,2,3 and 4 between narrower lane scenario (Sc2) vs. bicycle lane (Sc3), raised median (Sc4) and curved profile (Sc5) with respect to participants’ mean lateral positioning, except at the checkpoint 5, where the mean differences were not significant. A paired t-test between bicycle lane (Sc3) and raised median scenario (Sc4), reveals that there is huge significance in the mean difference at all
the checkpoints, however, when compared with curved scenario (Sc5) there was no significant difference at checkpoint 1 and 2, while significant difference were observed at checkpoint 3,4, and 5. For a statistical paired t-test between the raised median (Sc4) and curved profile scenario (Sc5), the significance there seems to have a statistical significance were obtained at checkpoints 1, 2 and 4, and poorly significant at checkpoints 3 and 5. Figure 6 illustrate the individual participants speed profile in base (Sc1), narrower lane (Sc2), bicycle lane (Sc3), raised median (Sc4) and curved (Sc5) scenario. Figure 7 illustrate the individual participants lateral position in base (Sc1), narrower lane (Sc2), bicycle lane (Sc3), raised median (Sc4) and curved (Sc5) scenario.
FIGURE 6.a Participants Speed Profile Scenario 1

FIGURE 6.b Participants Speed Profile Scenario 2
FIGURE 6.c Participants Speed Profile Scenario 3

FIGURE 6.d Participants Speed Profile Scenario 4
FIGURE 6.e Participants Speed Profile Scenario 5

FIGURE 7.a Participants Lateral Position Scenario 1
FIGURE 7.b Participants Lateral Position Scenario 2

FIGURE 7.c Participants Lateral Position Scenario 3
FIGURE 7.d Participants Lateral Position Scenario 4

FIGURE 7.e Participants Lateral Position Scenario 5
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Check points</th>
<th>Base Scenario (Sc1)</th>
<th>Narrower Lane (Sc2)</th>
<th>Bicycle Lane (Sc3)</th>
<th>Raised Median (Sc4)</th>
<th>Curved Profile (Sc5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (P Value)</td>
<td>Mean (P Value)</td>
<td>Mean (P Value)</td>
<td>Mean (P Value)</td>
<td>Mean (P Value)</td>
</tr>
<tr>
<td></td>
<td>1.Start</td>
<td>3.3(0.00)</td>
<td>-0.3(0.15)</td>
<td>-3.6(0.00)</td>
<td>-0.3(0.15)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.Straight</td>
<td>3.4(0.00)</td>
<td>-0.2(0.35)</td>
<td>-4.7(0.00)</td>
<td>-0.2(0.35)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.Small Left Curve</td>
<td>3.0(0.00)</td>
<td>0.1(0.51)</td>
<td>-0.9(0.46)</td>
<td>0.1(0.51)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.Right Curve</td>
<td>0.9(0.00)</td>
<td>-2.4(0.00)</td>
<td>-2.4(0.00)</td>
<td>-2.4(0.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.End</td>
<td>2.3(0.00)</td>
<td>-2.3(0.00)</td>
<td>5.9(0.00)</td>
<td>4.4(0.00)</td>
<td></td>
</tr>
<tr>
<td>Base Scenario (Sc1)</td>
<td>1.Start</td>
<td>-3.5(0.00)</td>
<td>-6.8(0.00)</td>
<td>-1.8(0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.Straight</td>
<td>-3.6(0.00)</td>
<td>-8.0(0.00)</td>
<td>-1.7(0.02)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.Small Left Curve</td>
<td>-2.9(0.00)</td>
<td>-3.9(0.00)</td>
<td>-2.2(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.Right Curve</td>
<td>-3.4(0.00)</td>
<td>-3.3(0.00)</td>
<td>0.3(0.43)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.End</td>
<td>-4.7(0.00)</td>
<td>3.5(0.10)</td>
<td>2.1(0.06)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrower Lane (Sc2)</td>
<td>1.Start</td>
<td>-3.3(0.00)</td>
<td></td>
<td>1.7(0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.Straight</td>
<td>-4.4(0.00)</td>
<td></td>
<td>2.0(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.Small Left Curve</td>
<td>-1.0(0.40)</td>
<td></td>
<td>0.7(0.19)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.Right Curve</td>
<td>0.1(0.93)</td>
<td></td>
<td>3.6(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.End</td>
<td>8.2(0.00)</td>
<td></td>
<td>6.7(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle Lane (Sc3)</td>
<td>1.Start</td>
<td>-3.3(0.00)</td>
<td></td>
<td>1.7(0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.Straight</td>
<td>-4.4(0.00)</td>
<td></td>
<td>2.0(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.Small Left Curve</td>
<td>-1.0(0.40)</td>
<td></td>
<td>0.7(0.19)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.Right Curve</td>
<td>0.1(0.93)</td>
<td></td>
<td>3.6(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.End</td>
<td>8.2(0.00)</td>
<td></td>
<td>6.7(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raised Median (Sc4)</td>
<td>1.Start</td>
<td></td>
<td></td>
<td>5.0(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.Straight</td>
<td></td>
<td></td>
<td>6.4(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.Small Left Curve</td>
<td></td>
<td></td>
<td>1.7(0.13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.Right Curve</td>
<td></td>
<td></td>
<td>3.6(0.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.End</td>
<td></td>
<td></td>
<td>-1.5(0.32)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Bold indicates significant difference based on a Paired t-test
CHAPTER V

DISCUSSION

Results from the study show that participants’ mean speed is higher than the posted speed limit in all the scenarios except the curved roadway scenario (Sc5). The speed trends were appeared to be increasing along the checkpoints as the drivers drove into the virtual scenarios. But at starting of the checkpoint 1 across all the scenarios, the mean speed was lower than the posted speed limit. As the participants drove through the scenarios, they must have felt comfortable with driving vehicle within the lab environment and familiar with virtual scenarios must have resulted in increased speed patterns as they drove into the scenarios.

5.1 Speed and Lateral Position

The speeds shown in Figure 6a, b, c and d were not largely affected in base (Sc1), narrower lane (Sc2), bicycle lane (Sc3) and raised median (Sc4) scenarios only a few participants chose speeds above 40 mph and the rest drove at or below the posted speed limit. However, in curved scenario (Sc5) Figure 6e most of the participants’ speeds appeared to be below the posted speed limit i.e. 30mph. For all checkpoints, the extreme change was seen in participant lateral position in all the scenarios. In case of base scenario (Sc1) assessment, it appeared that participants drove closer to the edge line at checkpoint 1,2,3 and 5 but at checkpoint 4 at a curve section participants moved towards the center line. In bicycle lane scenario (Sc3) evaluation, it appeared that participants did not perceive the risk of presence of bicycle facility adjacent to the travel lane, but still tried to drive as fast as if no bicycle lane is present. The same conclusions were drawn from the study on speed and lateral position in the presence of bicycle lane (17). Unlike the narrower lane scenario (Sc2) Figure 6b, in the bicycle lane scenario (Sc3) most of the participants positioned themselves near
to the edge line. While in raised median (Sc4) Figure 7 d portraits that they positioned themselves towards the edge line, as they drove into the scenario after crossing checkpoint 4 most of the participants moved towards the centerline. Scattered positioning pattern was observed in curved scenario (Sc5), where all the participants followed same trend through the drive.

There were no significant difference in mean speeds between the base scenario (Sc1), bicycle lane (Sc3) and the raised median (Sc4). This may be due to the presence of 14 ft wider lanes in all the aforementioned scenarios which might have accounted for not having any influence in slowing the participants’ speeds. In fact, the wider lanes encouraged participants to select higher speeds, even in the presence of bicycle lanes or raised medians. Also, the low vehicle density in the oncoming lane, and no lead vehicle in travel direction, may have contributed to the higher speed selection. Likewise, no occurrence of pedestrians and cyclists and no public movement along the roadway with lesser or no distraction might have encouraged participants to drive at higher speeds and position themselves all over the travel lane. Nevertheless, there was some significance on mean participants’ speed along the checkpoints between base scenario (Sc1) and curve scenario (Sc5) even on 14 ft wide lane. This might be due to the curved roadway profile itself, which would have influenced the participants to slow down along all the checkpoints.

Figure 7 a, b, c, d and e demonstrates that at lower speeds, participants moved towards the center line, while at higher speeds they moved towards the right side of the travel lane. We can relate that, however speed has greater influence on lateral position, higher the speeds larger is the SD on lateral position, due to less control over speed most of the participants were driving away from the center line and moved towards the edge line. Wider lanes had no influence on maintaining the participants’ lateral positioning or in binding the vehicle towards the center of the lane. There was significance between the scenarios in terms of lateral positioning along the checkpoints.
5.2 Limitations

This study was undertaken on a fixed base driving simulator; the lack of motion may have played a role in the lack of differences in participant speeds as they could not physically sense their movement. However, previous literature has suggested that the absolute differences in speeds in this environment are consistent across scenarios as compared to real world driving(24). Roadway was simulated under daylight conditions and there were few driver distractions. Beyond this, moderate traffic density was used for each scenario and results may have differed with higher simulated traffic densities. In this study, a perfect correlation of speed and lateral position could not be established on a curved roadway profile based on the different curve radii along the roadway. When the participants were observed, it was evident that a few participants were driving cautiously, as if they knew that their performance was monitored by the researcher.

5.3 Future Work

It is possible that future studies can examine using plant potters instead of a painted 1 ft buffer zone on bicycle lane scenario cautioning the driver through the presence of physical object. Beyond that, adding cyclist density as a constant would be interesting while looking at drivers’ speed and lateral position profile. Instead of a 12 ft travel lane and 6 ft shoulder, looking into narrower lanes might give better results in terms of speed and lateral positioning. Also, this study can be elaborated upon and improved by looking at curved roadways without the median. Studying speed and lateral positions with the presence of pedestrian movements may yield different findings as well.
Principal Investigator: Professor Michael Knodler

Project Title: Study of Geometric Roadway Design Variations

WHAT IS THIS FORM?

This is an Informed Consent Form. It will give you information about this study so you can make an informed decision about participating.

WHO IS ELIGIBLE TO PARTICIPATE?

Individuals who are between 20 and 60 years old and have had a regular driver’s license for at least 18 months. Drivers who experience motion sickness, either in their own car as a passenger or driver, or in other modes of transport, should not participate.

WHO IS SPONSORING THIS STUDY?

The study is being sponsored by New England University Transportation Center (NEUTC), which receives research funding from the United States Department of Transportation. The research is being conducted by the Arbella Insurance Human Performance Lab housed in the College of Engineering at the University of Massachusetts.

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to evaluate the behavior of drivers going through various roadway configurations.

WHERE WILL THE STUDY TAKE PLACE AND HOW LONG WILL IT LAST?

Participants will have one session which will last approximately 35-50 minutes and include questionnaires, setting up eye tracker and simulator drives.

The study session will take place at the Human Performance Laboratory (Elab Building, Room 110) located in the College of Engineering at the University of Massachusetts in Amherst.
WHAT WILL I BE ASKED TO DO?

You will be asked to fill out one short demographic, driving history questionnaire and simulator sickness questionnaire (SSQ) before the experiment.

The experimenter will show you how to drive HPL’s full car simulator (referred to as the “RTI simulator”) in the Human Performance Laboratory (ELab, Room 110) and will give you general instructions for the drives. During the simulator drives, you should operate the controls of the simulator car just as you would those of any other car, and move through the simulated world accordingly. You should follow the speed limit and standard rules of the road and take care when braking.

Before the simulator drives begin, you will also be fitted with a head-mounted eye tracking device that helps us better understand your eye movements during the experiment. The eye tracker is essentially a pair of safety glasses with two miniature cameras mounted on it. The glasses are connected by a small cable to a video recorder. There will then be an eye tracker calibration routine that will take place. The researcher will fit the glasses on you and then ask you to look at certain objects in your field of view. The calibration process will take approximately 10 minutes.

Once the eye tracker has been calibrated, you will then sit in the RTI simulator, and be given a practice drive to become used to the eye tracking device and the driving simulator. Once you feel comfortable in the RTI simulator, you will drive the simulator through a virtual course which will take about 10 minutes in total. If at any time during the drives you feel discomfort or motion sickness, you should ask the experimenter to stop the simulation.

ARE THERE ANY RISKS OR BENEFITS ASSOCIATED WITH PARTICIPATION?

Benefits of participating in this study include potentially learning how to be a safer driver.

In terms of risks, there is a slight risk of simulator sickness when you operate the driving simulators. A small percentage of participants who drive the simulator may experience feelings of nausea or actual nausea. The experimenters work to minimize this risk, but it is still present. Because of this risk, any person who experiences motion sickness while in a real car should not participate in the experiment. If during the simulator drives, you feel discomfort or nausea, you should inform the experimenter immediately so that the simulation can be stopped. Halting the
simulation should quickly reduce the discomfort. If you do not feel better soon after the simulation is halted, we can arrange for someone to drive you home or help you seek medical care if necessary.

There are no known risks related to using the head-mounted eye tracking device.

**WHO WILL SEE THE RESULTS OF MY PERFORMANCE IN THE STUDY?**

The results of this research may be published and submitted for presentation at professional society meetings and/or used by the approved researchers for internal purposes. No participant will be identifiable from the reports nor will any participant’s name or initials be used in the reports. To maintain confidentiality of your records, the researchers will use subject codes, rather than names, to identify all data collected through the questionnaires and during your simulation drives. The data will be secured in the Human Performance Laboratory and will be only accessible by the principal investigator, Dr. Michael Knodler, and any other approved researchers for the study.

**WILL I RECEIVE ANY PAYMENT FOR TAKING PART IN THIS STUDY?**

You will be paid $20.00 total as compensation for your time and participation in the study. If participants drop out of the study due to simulator sickness or other reason, they will still receive full compensation.

**WHAT IF I HAVE A QUESTION?**

Should you have any questions about the experiment or any other matter relative to your participation in this project, or if you experience a research related injury as a result of this study, you may call the principal investigator, Professor Michael Knodler, at (413) 545-0228 or mknodler@ecs.umass.edu. If, during the study or later, you wish to discuss your participation or concerns regarding it with a person not directly involved in the research, you can talk with the University of Massachusetts-Amherst’s Human Subjects Research Administrator at (413) 545-3428 or humansubjects@ora.umass.edu. A copy of this consent form will be given to you to keep for your records.

**WHAT IF I REFUSE TO GIVE OR WITHDRAW MY PERMISSION?**

Your participation is voluntary and that you may refuse to participate or may withdraw consent and discontinue participation in the study at any time without prejudice.
WHAT IF I AM INJURED?

The University of Massachusetts at Amherst does not have a program for compensating subjects for injury or complications related to human subjects' research but the study personnel will assist you in getting treatment.

SUBJECT STATEMENT OF VOLUNTARY CONSENT

By signing below, I, the participant, confirm that the experimenter has explained to me the purpose of the research, the study procedures that I will undergo and the benefits as well as the possible risks that I may experience. Alternatives to my participation in the study have also been discussed. I have read and I understand this consent form.

__________________________
Printed name and signature of participant

__________________________
Date

EXPERIMENTER STATEMENT

By signing below, I the experimenter, indicate that the participant has read and had explained to them this study, and that he/she has signed this Informed Consent Form.

__________________________
Signature of person obtaining informed consent

__________________________
Date
PAYMENT VOUCHER

Please write legibly.

Name: ________________________________________________________________

Address: __________________________________________________________________

Phone: ___________________________ E-mail Address: _______________

I have participated in the simulator study at the Human Performance Laboratory and have been paid $ _______ dollars for my participation

Signature: ___________________________ Date: ___________________________

For Researcher’s Use only:

Researcher Name: __________________________________

Signature: ___________________________ 

Comments:
PRE-STUDY QUESTIONNAIRE

This is a strictly confidential questionnaire. Only a randomly generated participant ID number, assigned by the research administrator, will be on this questionnaire. No information reported by you here will be traced back to you personally in any way. You can skip any questions you do not feel comfortable answering.

Section 1: Demographics

Gender:  □ Male  □ Female

Date of Birth:  Month ____ / Day____ / Year _______  Age: ______

Race / Ethnicity:  □ Black / African American  □ Asian

(Check all that apply)  □ Caucasian  □ American Indian / Native Alaskan

□ Hispanic / Latino  □ Other

• Have you participated in a study at this laboratory in the past?

□ Yes  □ No

Section 2: Driving History

• Approximately how old were you when you got your driver’s license?  _____  Years

_____  Months

• About how many miles did you drive in the past week?

□ Less than 50  □ Less than 100  □ 100-200  □ 200-300  □ 300-500

□ 500 or more

• Do you usually wear glasses or contacts while driving?

□ No  □ Yes, glasses  □ Yes, contacts

• Do you ever get motion sickness symptoms while driving or riding in a car?

□ Yes  □ No

(If you respond Yes to this question, please bring it to the immediate attention of the experimenter.)

• Do you have any other restrictions on your driver’s license?
Section 3: Medical History

- Is there anything related to your background or health, including any medications, which might cause you to drive much better or worse than other drivers?
  - Yes
  - No
  
  If yes, please describe: __________________________________________

- Have you been previously diagnosed with Attention Deficit Hyperactive Disorder (ADHD/ADD) by an educational or medical professional?
  - Yes
  - No
  
  If yes, please indicate the type of symptoms you regularly experience:
  ____________________________________________________________________
  ____________________________________________________________________
  ____________________________________________________________________

- Are you currently taking medication to treat these symptoms?
  - Yes
  - No
  
  If so, what type of medication and dose?
  ____________________________________________________________________
  ____________________________________________________________________
SIMULATOR SICKNESS QUESTIONNAIRE (SSQ)

Developed by Robert S. Kennedy & colleagues under various projects.
For additional information contact: Robert S. Kennedy, RSK Assessments, Inc., 1040 Woodcock Road, Suite 227, Orlando, FL 32803 (407) 894-5090.

INFORMATION PROVIDED ON THIS QUESTIONNAIRE IS STRICTLY CONFIDENTIAL.
Your completion of this questionnaire is strictly voluntary and you can skip any questions that you do not want to answer.

Participant ID: Date:

THIS SECTION OF THE QUESTIONNAIRE IS COMPLETED BEFORE USING THE DRIVING SIMULATOR.

PRE-EXPOSURE BACKGROUND INFORMATION

1. How long has it been since your last exposure in a simulator? Days
   How long has it been since your last flight in an aircraft? Days
   How long has it been since your last voyage at sea? Days
   How long has it been since your last exposure in a virtual environment? Days

2. What other experience have you had recently in a device with unusual motion?

PRE-EXPOSURE PHYSIOLOGICAL STATUS INFORMATION

3. Are you in your usual state of fitness? (Circle one) YES / NO
   If not, please indicate the reason:

4. Have you been ill in the past week? (Circle one) YES / NO
   If "Yes", please indicate:
   a) The nature of the illness (flu, cold, etc.):
   b) Severity of the illness: Very Mild / Severe
   c) Length of illness: Hours / Days
   d) Major symptoms:
   e) Are you fully recovered? YES / NO

5. How much alcohol have you consumed during the past 24 hours?
   12 oz. cans/bottles of beer ounces’ wine ounces’ hard liquor

6. Please indicate all medications you have used in the past 24 hours. If none, check the first line:
   a) NONE
   b) Sedatives or tranquilizers
c) Aspirin, Tylenol, other analgesics

d) Antihistamines

e) Decongestants

f) Other (specify): ________

7.  
   a) How many hours of sleep did you get last night? Hours
   b) Was this amount sufficient? (Circle one) YES NO

8. Please list any other comments regarding your present physical state which might affect your performance on our test.

**BASELINE (PRE) EXPOSURE SYMPTOM CHECKLIST**

Instructions: Please fill this out BEFORE you go into the virtual environment.

Circle how much each symptom below is affecting you right now. #

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>

1. General discomfort

2. Fatigue

3. Boredom

4. Drowsiness

5. Headache

6. Eye strain

7. Difficulty focusing

8a. Salivation increased

8b. Salivation decreased

9. Sweating

10. Nausea
<table>
<thead>
<tr>
<th></th>
<th>Condition</th>
<th>None</th>
<th>Slight</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.</td>
<td>Difficulty concentrating</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>12.</td>
<td>Mental depression</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>13.</td>
<td>“Fullness of the head”</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>14.</td>
<td>Blurred Vision</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>15a.</td>
<td>Dizziness with eyes open</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>15b.</td>
<td>Dizziness with eyes closed</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>16.</td>
<td>*Vertigo</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>17.</td>
<td>**Visual flashbacks</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>18.</td>
<td>Faintness</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>19.</td>
<td>Aware of breathing</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>20.</td>
<td>***Stomach awareness</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>21.</td>
<td>Loss of appetite</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>22.</td>
<td>Increased appetite</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>23.</td>
<td>Desire to move bowels</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>24.</td>
<td>Confusion</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>25.</td>
<td>Burping</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>26.</td>
<td>Vomiting</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
</tr>
<tr>
<td>27.</td>
<td>Other</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
REFERENCE


3. Deller, J. The Influence Of Road Design Speed, Posted Speed Limits And Lane Widths on Speed Selection -Methodology For Simulator And Observational Research Study. IFME World Congress & IPWEA International Public Works Conference 7-11 June 2015, Rotorua, NZ.


23. KANELLAIDIS, G., A. Zervas, and V. Karagioules. Drivers’ Risk Perception of Road