EFFECTS OF HORIZONTAL CURVE ON DRIVER'S PASSING MANEUVER ALONG TWO-LANE RURAL HIGHWAYS

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by

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Passing maneuvers by drivers on rural two-lane highways consist of many potential crash risks. These maneuvers by drivers are made up of complex decisions such as: judging the speed of the approaching vehicle, interpreting the speed of the oncoming vehicle, and managing travel speed and location while in the opposing lane. When this passing maneuver is influenced by roadway geometric conditions such as horizontal curvature, passing decisions become more complicated as sight distance may be restricted, increasing potential crash risks.

This research conducted a laboratory experiment evaluating effects of horizontal curvatures on passing maneuvers. A driving simulator at the University of Idaho was used to develop a virtual scenario of three real-world highway sections in Alaska which currently experience high crash rates. Twenty-four participant drivers were tested using this virtual scenario. The passing maneuvers were affected by radius of the curve, with more passes occurring as the curve radius increases. However, the results suggest that passing maneuvers on left-hand orientation curves and right-hand orientation curves were not significantly different along these simulated real-world sections.

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DEDICATION

I dedicate this achievement to my parents Gopal and Niru, for all of the sacrifices they made for me to help me reach here. To my brother, Purvag, sister-in-law, Ushma, and my wife, Pruthvi for supporting me throughout the process. I thank them immensely because without them I would not be here and all of them have been my best cheerleaders.

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CHAPTER 1: INTRODUCTION

On rural two-lane roadways, the passing maneuver occurs when one vehicle overtakes a slower-moving vehicle by occupying the lane used by opposing traffic for some period of time. For this passing maneuver to be accomplished, the driver of the faster vehicle must be able to see a sufficient distance ahead such that the driver can make an informed and safe decision about whether or not there is enough time and distance to complete the passing maneuver without affecting the oncoming vehicle or the vehicle being passed. Since the passing maneuver requires both a transition into the opposing lane and then a return to the original lane of travel, additional sight distance is needed when compared with stopping sight distance. Hence, the passing maneuver on two-lane rural highway is believed to be one of the most complex tasks by a driver and has a significant effect on both safety and capacity.

The Federal Highway Administration (FHWA) has reported that 25% of all fatal crashes occurring on two-lane rural highways are associated with horizontal curves. This percentage is three times higher than the average crash rate of other highway systems such as interstates and multilane highways in the United States [1]. Fatal Analysis Reporting System (FARS) statistics reported that 18% of head-on collisions occurred on the two-lane rural highway system. FARS also indicated that 23% of all head-on crashes on two-lane rural highways occurred when a driver was negotiating a horizontal curve [2]. A two-lane rural roadway segment with limited opportunities for drivers to execute passing maneuvers, due to limited gaps between oncoming vehicles, causes a reduction in capacity and level of service, which also raises the safety concerns for drivers wishing to make a passing movement. This safety concern increases on two-lane rural highways which have varying geometric configuration (i.e., horizontal curves, vertical curves, compound curves or some type of combination).

The main objective of this research was to isolate and determine the effect of horizontal curvature on passing maneuvers along rural two-lane highways in Alaska. For this purpose, three highway sections, specifically the Seward Highway from milepost (M.P.) 108 to 113, Parks Highway M.P. 154 to 160 and Sterling Highway M.P. 145.5 to 150.5 were selected since safety concerns had previously been documented.

This study was conducted in a virtual driving environment, commonly referred to as a driving simulator. A replica of the original horizontal geometry and traffic scenarios were created. Participants were hired to drive both northbound and southbound along a simulated alignment; this alignment comprised of highway sections which were randomly assigned based on the statistical experimental design of a latin square. The participant drive was followed by a questionnaire which collected socioeconomic information and asked questions about the factors that influenced passing decisions during the simulation exercise.

Research Objectives

The research presented in this thesis has two primary objectives:

1. To evaluate the effect of different combinations of horizontal curvature on passing maneuvers; and
2. To determine the probability of passing maneuvers along these real-world highway simulations.

Thesis Organization

This thesis is organized into five chapters. An introduction is presented in Chapter 1, and a comprehensive literature review is presented in Chapter 2. This literature review focuses on past research work related to this specific research topic. It also provides information about passing maneuvers on rural highways, design considerations for passing sight distance, and the evaluation of passing maneuvers in a virtual environment. Chapter 3 presents the methodology for the driving simulator experiment. Chapter 4 presents the data analyses and results of this study, and Chapter 5 discusses the research conclusions.

CHAPTER 2: LITERATURE REVIEW

The literature review focused on three broad sections involved with this research: passing maneuvers on rural two-lane highways, passing sight distance and its design considerations, and evaluating passing maneuvers in a virtual environment.

Passing Maneuvers on Rural Two-Lane Highways

Passing maneuvers are an integral part of driving on two-lane rural highways. It is a complex task which has a significant impact on safety, capacity, and level of service. The passing maneuver on two-lane rural highways is accomplished by the faster vehicle occupying the lane used by opposing traffic for some period of time and then returning to the traveling lane after passing the slower vehicle. For a pass to be accomplished without any interference from an opposing vehicle, the passing driver needs to see a sufficient distance ahead so that the driver can make an informed and safe decision about whether or not there is enough distance and time to initiate and complete a passing maneuver without impeding the oncoming vehicle or the vehicle being overtaken.

The following assumptions as described in AASHTO are made concerning the behavior of drivers when assessing operational efficiency of passing maneuvers [3] [4]:

1. The passed vehicle travels at a uniform speed;
2. The passing vehicle has reduces the speed (to less than desired) and trails the overtaken vehicle as it enters a passing area;
3. The driver spends some amount of time to perceive the clear passing area and to initiate the passing maneuver, i.e., a delayed start;
4. The passing vehicle accelerates during the maneuver, occupies the left lane at a speed 12 miles per hour (mph) higher than the vehicle being overtaken;
5. The perception-reaction time of a driver deciding to abort a pass and the headway between passing and passed vehicles during an aborted pass are one second; and

6. The vehicle returns to its lane with suitable clearance length between it and an oncoming vehicle in the opposing lane with a minimum clearance time of one second between the passing and opposed vehicles.

Table 1 shows the minimum values for Passing Sight Distance (PSD) which are based on field observations [5] and two theoretical models for sight distance. The first theoretical model by Glennon assumes that the critical position occurs where the passing sight distance to complete the maneuver is equal to the sight distance needed to abort the maneuver [3]. The second theoretical model by Hassan assumes that the critical position occurs either based on the Glennon model assumption or where the passing and passed vehicles are abreast [4] and PSD is the sum of the following four distances [6]:

$$PSD = d_1 + d_2 + d_3 + d_4 \quad [1]$$

where,

d_1 = distance traveled during perception and reaction time and initial acceleration to the point of encroachment on the left lane;

d_2 = distance traveled while the passing vehicle occupies the left lane;

d_3 = distance between the passing vehicle and opposing vehicle at the end of the passing maneuver; and

d_4 = distance traveled by an opposing vehicle for two-thirds of the time the passing vehicle occupies the left lane or 2/3 of d_2.

Figure 1 illustrates the components of PSD based on AASHTO and as presented in NCHRP Report 605 [5].

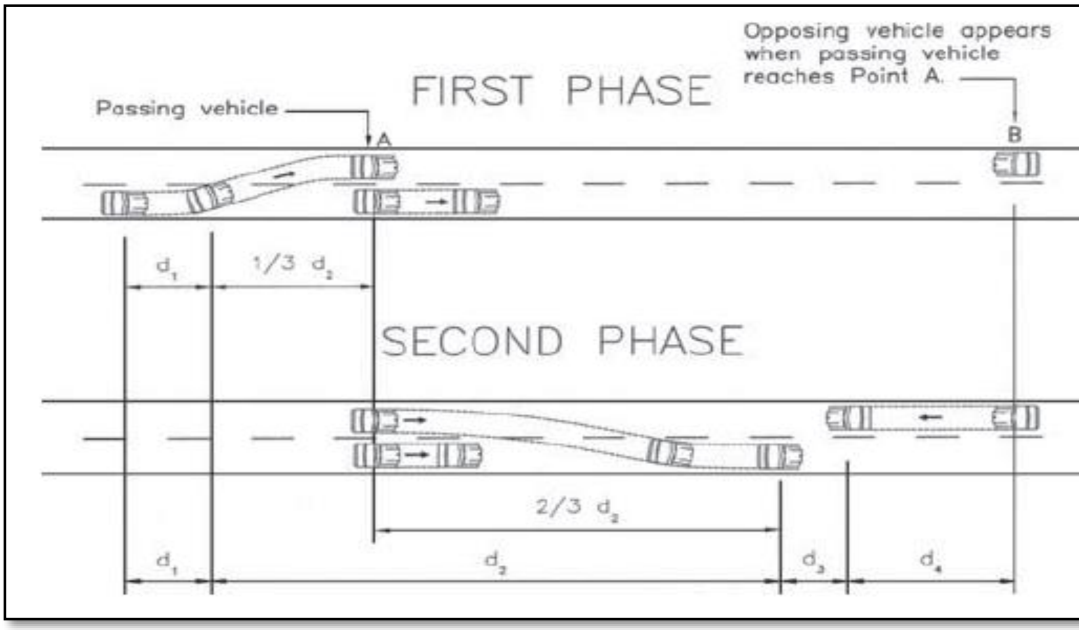

Figure 1 Elements of Passing Maneuvers on Two-Lane Highways [5]

Table 1 Passing Sight Distance for Design of Two-Lane Highways (AASHTO)

Design Speed (mph)	Assumed Speeds (mph)		Passing Sight Distance (ft.)
	Passed Vehicles	Passing Vehicles	
20	8	20	400
25	13	25	450
30	18	30	500
35	23	35	550
40	28	40	600
45	33	45	700
50	38	50	800
55	43	55	900
60	48	60	1000
65	53	65	1100
70	58	70	1200
75	63	75	1300
80	68	80	1400

To evaluate the passing process on two-lane rural highways, Abishai developed models to quantify the major components of the passing process, evaluated time parameters of passing process, and compared the results to AASHTO standards [6]. It was found that reaction time and safety margin were smaller from the field data than the AASHTO standard while travel distance was longer in the field, but these differences essentially canceled out each other to match the total distance as mentioned in the AASHTO standards. Another finding from the research was that there was no acceleration by the driver until moving into the opposite lane, and accelerative passing occurred in the opposing lane which contradicted AASHTO's assumption of passing at a constant speed [7]. In a separate research study based in Spain, it was determined that the type and speed of the passed vehicle and length of the passing zone had the strongest influence on time and distance of the passing process. It was concluded that when the speed limit was higher the total time required to complete the passing maneuver comparably increased. [8].

In an attempt to validate AASHTO's passing sight distance model with real-time data, Paul carried out data collection on a two-lane highway in Texas and collected data for 105 single-vehicle passes. It was deduced that the passing sight distance speeds mentioned in AASHTO were adequate, but Paul's results indicated that the AASHTO model would not be validated if the overtaken vehicle speed was 60 or 65 mph [9].

Passing maneuvers are determined by a driver's behavior and driving technique. Understanding this behavior in the real-world environment can be key to overall safety and capacity of two-lane highways. To understand human behavior in passing maneuvers, Carlos conducted a study to predict the influence of age, gender, and delay on overtaking dynamics. More than 200 passing maneuvers were recorded using an instrumented passenger car, and the results showed that young males (18 to 24 years of age) have an overtaking time that is one second less than any other age and gender groups, while their speed during passing maneuvers are 4 kilometers per hour higher. [10].

Passing Sight Distance Design Considerations

Passing sight distance determines the passing zone and no passing zones on rural two-lane highways. These zones are determined based on standards described in the Manual on Uniform Traffic Control Devices (MUTCD) [11]. Passing zones are established where there is sight distance greater than the prescribed limits in the MUTCD. For example, as per MUTCD guidelines for a rural two-lane highway having a posted speed limit of 55 mph or an 85th percentile speed of 55 mph (whichever is greater), the sight distance required for passing is 900 feet. This means that if the sight distance drops below 900 feet due to any obstruction it would mark the start of the no-passing zone. Table 2 shows current design values for minimum passing zone length in the MUTCD.

Table 2 Minimum Passing Sight Distances for No-Passing Zone Markings (MUTCD)

85th-Percentile or Posted or Statutory Speed Limit (mph)	Minimum Passing Sight Distance (ft.)
30	500
35	550
40	600
45	700
50	800
55	900
60	1000
65	1100
70	1200

Since 1940, several models have been developed to determine minimum passing zone requirements which resulted in the development of manuals and associated criteria, but several types of research have been carried out regarding the comparison of the models presented in these manuals. In a comparison review of passing zone guidelines between the MUTCD and AASHTO, some studies have concluded reports that the current passing sight distance values in the MUTCD and AASHTO are very low. For example, the minimum length of passing zone which is 400 feet has unknown origins [12]. Another study published by the Transportation Research Board concluded similar results that the reason for selection of passing sight values in the MUTCD are not known. However, AASHTO has taken into consideration several assumptions with regard to passing maneuvers, driver safety and measurement on sections with regular traffic flows for their models [4]. A large percentage of drivers can be represented by AASHTO's passing sight distance model and it is based on the "delayed beginning and hurried return" assumption which means that the passing car accelerates into the left lane with a speed of 12 mph or higher than that of the overtaken car. Polus indicated that the AASHTO sight distance model is adequate for car-car passing as the values are a little higher than required but for a car passing a truck the values were not sufficient [7]. Recent research comparing field data and passing sight distance criteria from AASHTO and MUTCD found that the values mentioned in these documents are consistent with field data collected from the states of Missouri, Pennsylvania, and Texas, and use of current standards are recommended for marking no-passing zones [13].

Evaluating Passing Maneuvers in a Virtual Environment

In the real world, changing a driver's ability to pass by re-marking passing zones based on engineering judgement, time of day or different season is not realistic. However, driving simulation can help us to evaluate according to the research needs. Using a driving simulator, the virtual environment can be created to replicate the original highway and test a driver under various conditions. The driving simulator can generate data about many driving parameters such as lane position and acceleration-deceleration and this data can be analyzed for research. Several studies have shown that data obtained from a driving simulator is a reliable source and similar to data that could be collected from the field. Moreover, these data could be used to assess a driver's behavior and passing maneuvers (15**,** 16**,** 17**,** 18).

Haneen studied gap perception of different driver groups on two-lane rural highways. He concluded that parents, female drivers and older age drivers (30+ years old) perceive that the gap in the opposing lane is less than it actually is, so the gap acceptance ratio is less for these driver groups compared with the non-parent driver, male drivers, and young drivers [14]. A study on a similar group of drivers deduced that females and older age drivers take a passing duration that is 33% higher than the suggested value by AASHTO which leads them toward riskier passing maneuvers and an increased chance of a head-on collision while making passing maneuvers [15].

A study for deriving the tendency of a driver to pass another vehicle revealed that mental load is the prime contributor for passing maneuvers [16]. This conclusion can be supported by the explanation in AASHTO that drivers need to process visual information like geometric information, car speed, weather, and visibility. Increased amounts of information processed by a driver requires more time to make a decision and if there is an error in one or more details processed by the driver then the driver must terminate the passing movement, if possible, or the likelihood of a single or multiple vehicle crash will inherently increase.

A study of driver perception hypothesis, where the perception of three different types of curves, namely flat horizontal curves, horizontal curves with vertical sag, and horizontal curve with vertical crest, by the driver was studied by measuring the change in speed and lateral position. The results indicated that there is no significant reduction in speed and no major change in lateral position for flat horizontal curves and horizontal curves with vertical sag while the horizontal curve with vertical crest produces speed reduction and change in lateral position. From the results, it was concluded that the horizontal sag curves are safer than horizontal crest curves as driver perception on sag horizontal curves exhibits similar results with flat horizontal curves, whereas crest horizontal curves resemble sharper curve [17].

A safety evaluation study was carried out by Bella to evaluate the risk of collision with respect to traffic volumes. The time to collision was analyzed for rear-end collisions, and it implied that as the traffic volume increased the risk of rear-end collisions increased. Further, the detailed analysis concluded that geometry does not have any effect on the risk of rear-end collision, hence whether it is a straight section or a curvy road the amount of traffic is the key factor influencing time to collision on two-lane highways [18].

In an effort to evaluate the effects of the presence of a shoulder and guardrail on vehicle speed and position on horizontal curves, the study revealed that the speed of the vehicle is greatly influenced by horizontal curves while the lateral position is affected by the presence of shoulder and guardrail [19].

This literature review did not find any previous research related to either passing maneuvers on horizontal curvature or the assessment of passing maneuvers of a real-world alignment in a virtual environment.

CHAPTER 3: DRIVING SIMULATOR METHODOLOGY

This chapter provides the methodology that was used to test the different scenarios for this research. First, the background section describes the general concept of the research. Second, the driving simulator functions and its operations are presented. Third, scenario development composed of a general summary, simulated traffic, and experimental design are explained. Finally, the procedures for data collection are discussed.

Background

To determine the effect of horizontal curvature on passing maneuvers, twenty-four participants were tested on a driving simulation environment that replicated three sections of two-lane rural highway in the State of Alaska. Each participant was exposed to a combination of three real-world highway sections and a straight section totaling approximately 48 miles in length. All participants conducted one session, driving for about 55 to 60 minutes during the session. Every participant was given a five to ten-minute break halfway during each session. Each participant experienced the same traffic but the highway sections were presented in different orders. After the participants had concluded their session, they responded to questions from the debriefing form related to the study.

Driving Simulator

The driving simulator used for all experiments was comprised of a seven-video channel. National Advanced Driving Simulator (NADS) Minisim rendered the simulations and collected the behavioral data of the participants. Simulation participants drove from a truck cab of a 2001 Chevrolet S10 pick-up truck. The cab of the truck was positioned so that the driver’s eyes were located at the projected eye-point of the simulated environment.

Three Canon REALiS SX800 projectors formed the front view of the environment on three white screens arranged as three sides of an octagon whose center was coincident with the projected eye-point of the simulation. The three screens provided a field of view of approximately 135 degrees horizontally and 34 degrees vertically. The three main screens had a refresh rate of 60 Hertz and a spatial resolution of 4200 pixels x 1050 pixels.

The screens were also installed to simulate a participant looking behind them in the side view mirrors and center rear-view mirror. Eight-inch liquid crystal display (LCD) screens, each with a spatial resolution of 800 pixels x 600 pixels, were mounted to the left and right side view mirror housings of the S10 cab. The rear-view mirror of the cab reflected the view out the rear window of the cab, which had images projected on a 65-inch plasma screen with 1280 pixels x 720 pixels with a refresh rate of 60 Hertz.

The last of the video channels was installed to display the dashboard instrument cluster including tachometer, speedometer, engine temperature gauge, gear selection, and fuel gauge. The screen consisted of a 10-inch LCD with a resolution of 1280 pixels x 800 pixels. This display screen was mounted in place of the normal mechanical analog instrument cluster in the S10 truck cab.

The seven screen displays were rendered by the NADS Minisim software running under the Windows 7 operating system on a single graphics workstation. The computer contained a six-core Intel Core I7 processor running at 3.9 GHz, 32 GB of RAM, and two NVidia video display adapters. Additionally, a GeForce GTX680 routed through a Matrox T2G-D3D-IF controlled the three main screens. This video adapter also rendered the dashboard and right side mirrors. A GeForce GTX660TI video adapter rendered the left side-mirror and interior rear-view mirror displays. Finally, a 4.1-channel audio system used four speakers mounted in the cab doors and a subwoofer mounted behind the driver’s seat to produce automobile and road noise.

Figure 2 and Figure 3 show an overhead view of the truck cab with the three main projection screens, projectors, left-side mirror display, rear-view screen location and 7-screen display rendered by NADS Minisim Software which shows all of the screen participant views during the simulation. The right-side mirror display, rear-view mirror display, and dashboard instrument display are not displayed in the figures.

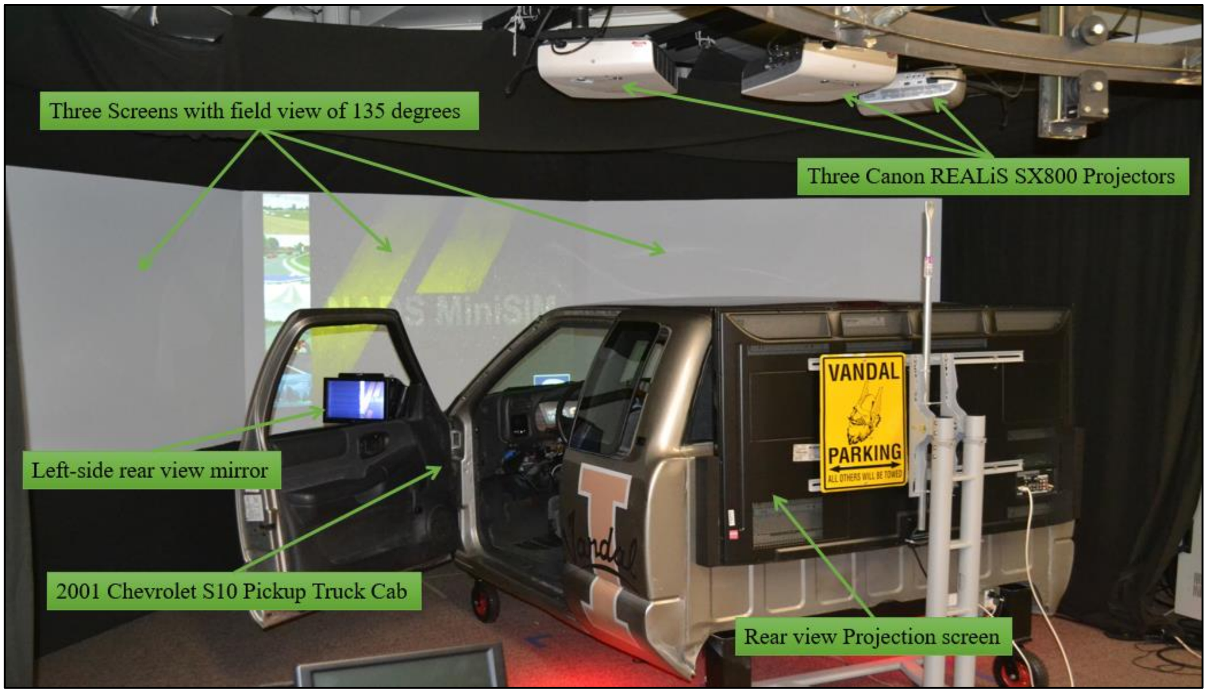

Figure 2 Driving simulator description

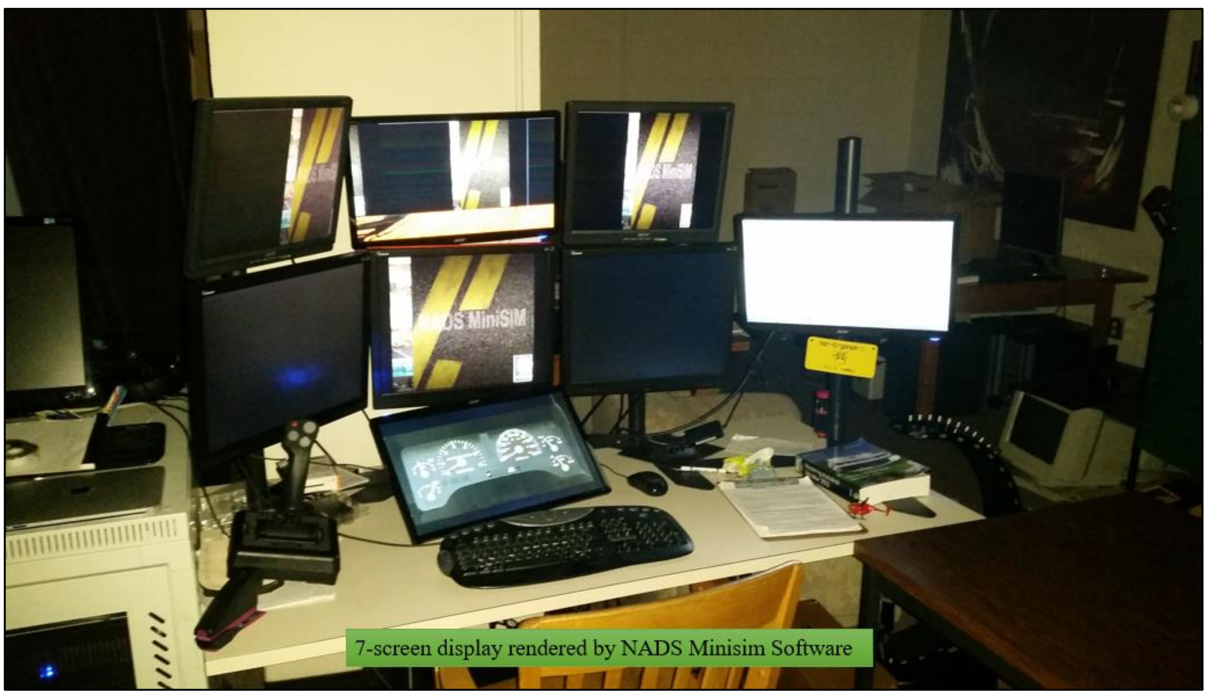

Figure 3 Display for driving simulator

Scenario Development

General Summary

To develop the required scenarios for each participant, seven software applications were used along with the simulator program to test these scenarios. Every scenario was composed of multiple tiles that displayed the appropriate roadway geometries and the surrounding environment. These roadway geometries were composed of straight and horizontal curved segments which represented three real-world alignments of the Alaskan highway system as well as a straight section of about four miles. The sections from the Alaskan highway system were: Seward Highway (M.P. 108 to M.P. 113), Parks Highway (M.P. 154 to M.P. 160) and Sterling Highway (M.P. 145.5 to M.P. 150.5).

The roadway geometry was composed of a 24-foot paved roadway, a 6-foot paved shoulder, a 6-foot gravel shoulder, edgelines, and centerline. The surrounding environment consisted of a pleasant summer day appearance and replicated, as close as possible, the real world highway section. The graphics displayed included cliffs and water for Seward Highway and forest, rolling highways, and mountains for the Parks and Sterling Highways. For this specific study, some adjustments were made to the roadway geometry; there were no no-passing zones regardless of sight distance (i.e., dashed centerline stripe throughout) and the terrain was flat to isolate the analysis of roadway horizontal curvature.

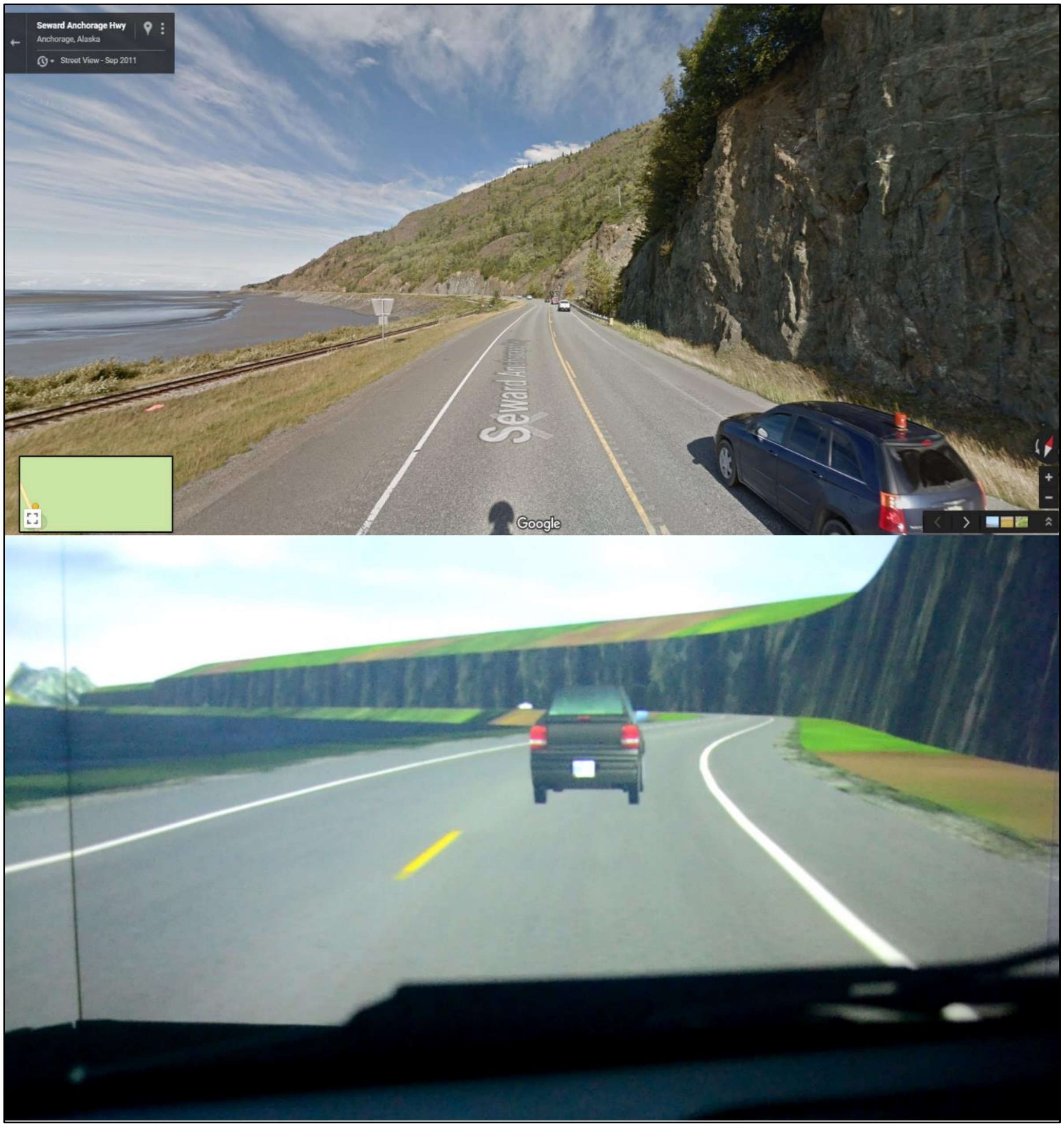

Figure 4 Seward Highway comparison: actual highway vs. simulation highway

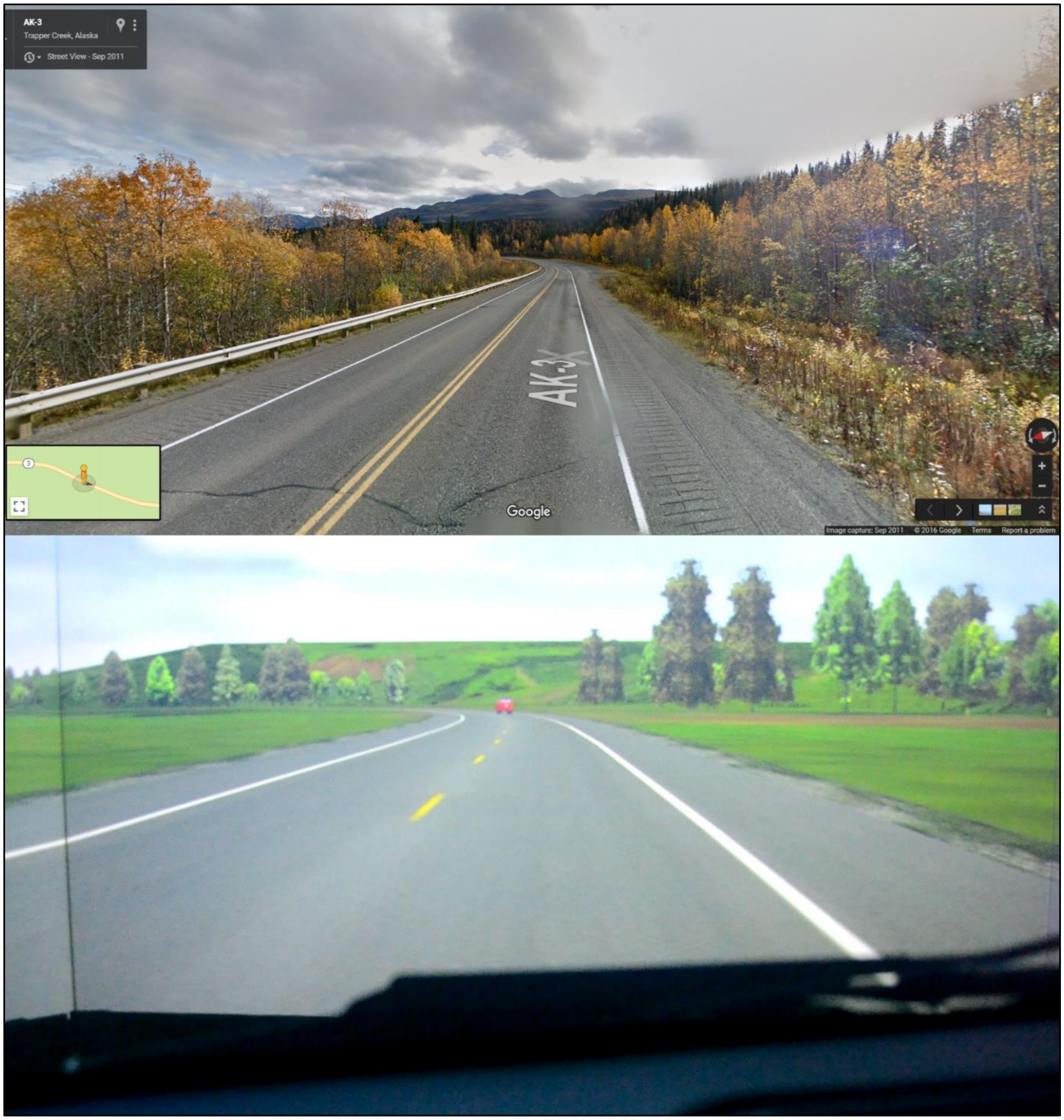

Figure 5 Parks Highway comparison: actual highway vs. simulation highway

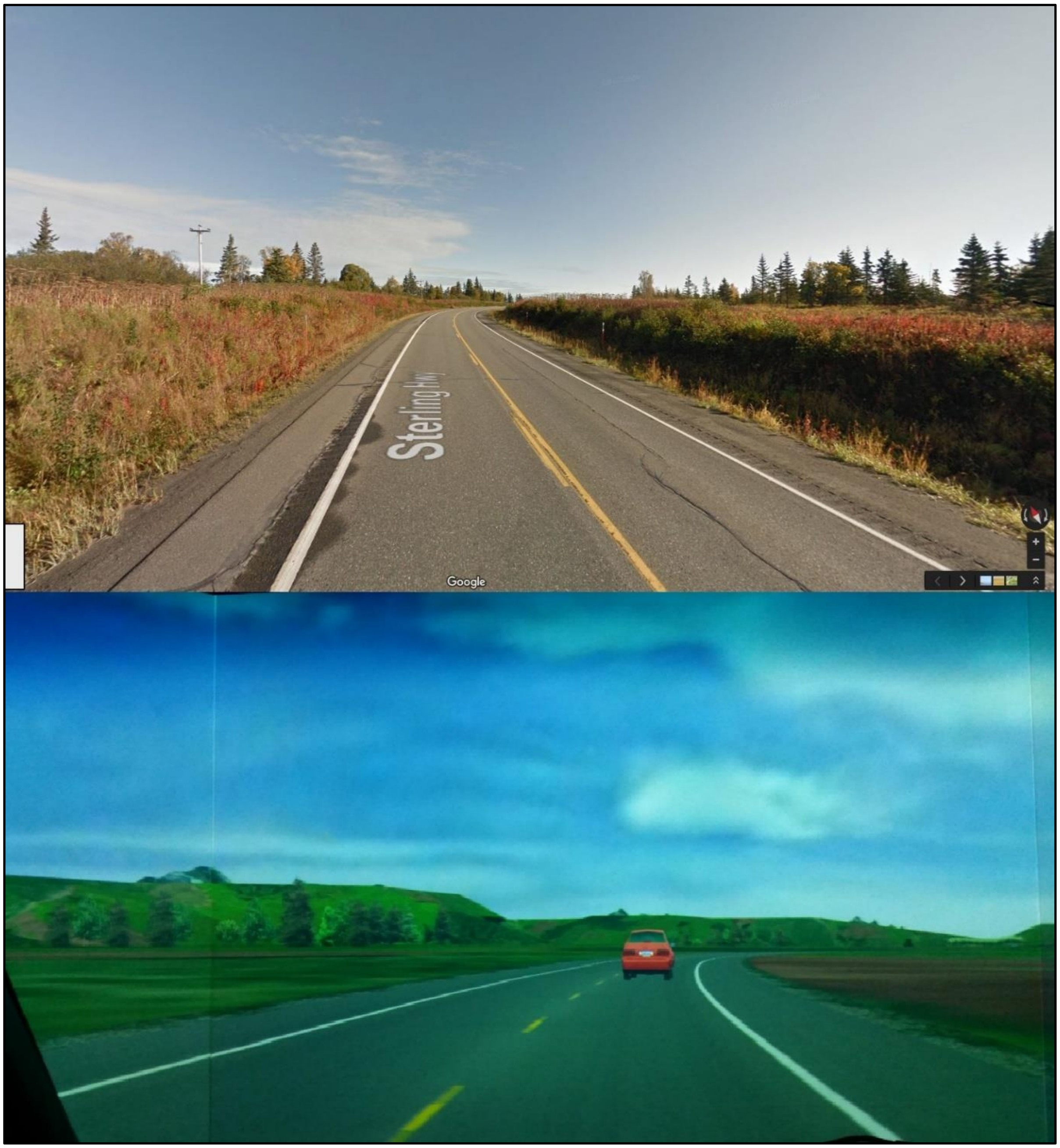

Figure 6 Sterling Highway comparison: actual highway vs. simulation highway

The ESRI ArcGIS program was used to load and crop the highway centerlines provided by the Alaska Department of Transportation [20]. Autodesk Civil 3D was used to create a roadway based on the centerlines and then exported to Autodesk 3ds Max Design. The 3ds Max Design program was used to make the tiles which consisted of the roadway, surrounding environments, and roadway markings. Following 3ds Max Design, the tiles were exported to Tile Mosaic Tool (TMT), which was used to join multiple tiles together to create the appropriate roadway simulation tracks, known also as scenarios. Lastly, output files from TMT were exported to the Interactive Scenario Authoring Tool (ISAT). In ISAT, vehicles, speed limit signs, and triggers (data collection points) were added to each scenario track. Finally, these scenarios were trial tested to make certain that everything looked appropriate with the right adjustments and appearances needed for this study. A total of four trial tests were conducted and confirmed prior to the start of the actual data collection process.

Simulated Traffic

The simulated traffic needed to be condition-specific to encourage passing by each participant along the selected roadway section. Traffic was simulated in the travel lane as well as in the opposing lane. The same lane traffic had a gap of a ¼ mile which provided sufficient time and distance for a driver to initiate and complete a passing maneuver. The opposing lane traffic had a gap of ½ mile. This ½ mile gap has been proven to encourage passing on two-lane rural highways as shown in previous research [21].

Experimental Design

To evaluate the passing decision-making of drivers on horizontal curves with varying geometric conditions, a sample of 24 participants were hired, and each drove for about an hour in the simulator. Participants drove through combinations of four different tracks, once driving northbound, taking a break of five to ten minutes, and then driving southbound. Each segment consisted of 5 to 7-mile sections of Seward Highway, Parks Highway, Sterling Highway and a straight section to assess passing decisions of participants. The straight section was included as a control segment. Each drive was followed by a questionnaire which collected a participant's personal perspective about their type of driving (aggressive or passive) and socioeconomic information such as age, gender, and years of driving experience.

The statistical experimental design of a latin square was carried out to control variation in the experiment. In a latin square design treatment, the sections were randomly assigned to rows and columns in such a way that each treatment occurred once. Table 3 shows the experimental design built for this study.

Table 3 Experimental Design

TRACK ORDER	TILE ORDER								
TRACK 1	1	2	3	4	Break	5	6	7	8
TRACK 2	2	1	4	3	Break	6	5	8	7
TRACK 3	3	4	2	1	Break	7	8	6	5
TRACK 4	4	3	1	2	Break	8	7	5	6

The tracks were a combination of various geometry to avoid the bias of data towards one highway section in the experiment. Each track was driven by six participants. The track was coded as follows: 1 = Seward Highway Northbound, 2 = Parks Highway Northbound, 3 = Sterling Highway Northbound, 4 = straight section Northbound, 5 = Seward Highway Southbound, 6 = Parks Highway Southbound, 7 = Sterling Highway Southbound, and 8 = straight section Southbound. Each track was approximately 48 miles in length. Figure 7 shows a sample of the different track combinations prepared according to the experimental design in the northbound direction. Figure 7 also shows the centerline of the highway for each highway section. Similar track combinations were created for the southbound sections.

Data Collection

Data were collected from participants as they drove through the simulation. A Suzo-Happ model 95-0800-10k USB Game Controller Interface (UGCI) connected the steering wheel, gear selector, turn signals, and brake and accelerator pedals to the Minisim. The original S10 steering wheel provided 540 degrees of steering range and was self-centering. Additionally, the original S10 brake and throttle controls provided haptic displacement feedback similar to a normal automobile. Finally, a center console housed an automatic gear selector from a 2001 Honda Civic to provide participants with a standard interface for gear selection. Figure 8 shows the control of the driving simulator.

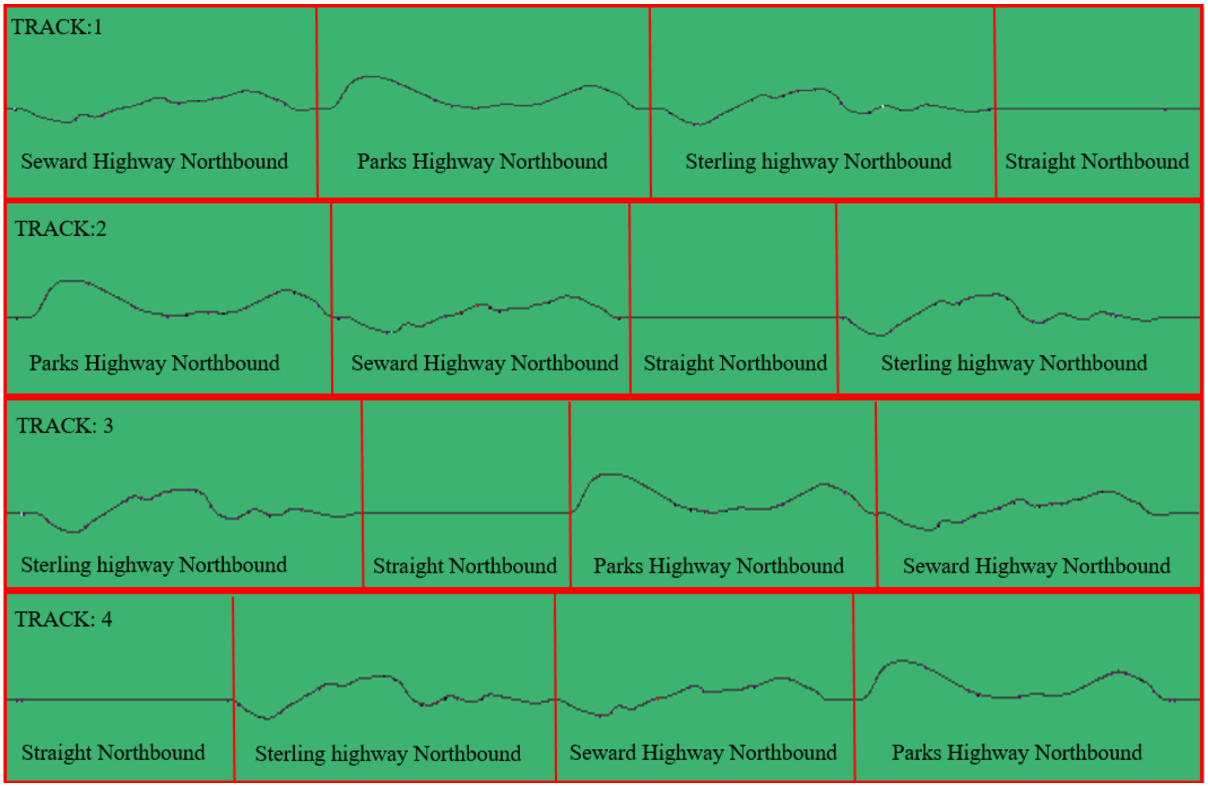

Figure 7 Track combinations Northbound

The total number of data collection points in the study independently represented the left-hand curves, right-hand curves, and straight section in each track. Table 4 shows the information regarding each data collection point for each track. As shown in Table 4, each highway geometry had a different combination of curved and straight sections. Parks Highway had horizontal curves ranging from 1910 feet to 5730 feet with an average radius of 4229 feet. Seward Highway featured horizontal curves ranging from 996 feet to 4585 feet with an average radius of 1628 feet and Sterling Highway had horizontal curves ranging from 1146 feet to 1910 feet with an average radius of 1554 feet. A detailed table presenting the radius and orientation of all data collection points can be found in Appendix A.

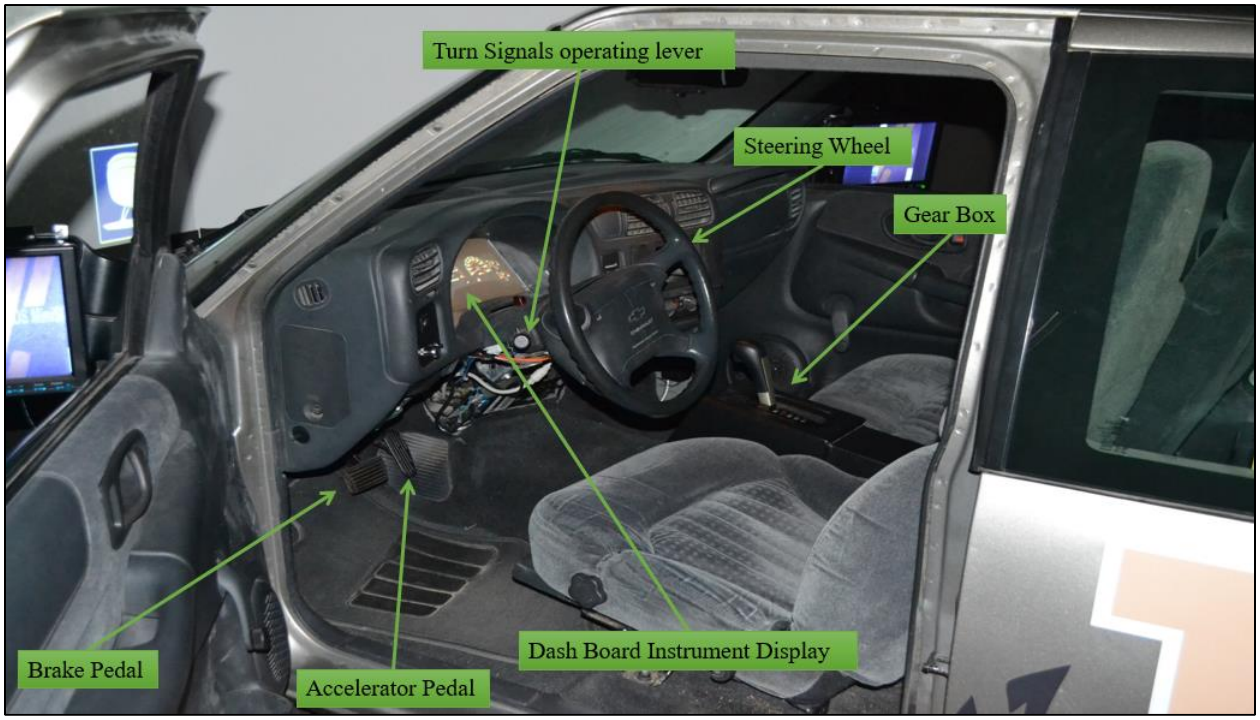

Figure 8 Driving Simulator Control Panel

Twenty-four participants with unrestricted valid driver's licenses were tested. All the participants were recruited from the community through advertising flyers posted in public places such as grocery shops, shopping centers and on craigslist. The advertisement indicated that participants were needed immediately for a driving simulator study. Participants needed to be 18 years of age or older for this study, and were paid $20 per hour. Additional details of the advertisement are shown in Appendix B.

Participants recruited for the study were handled in accordance with the University of Idaho's Institutional Review Board (IRB) protocol governing the use of human subjects in research. Before starting, participants were given a consent form to read, agree to its contents, and sign. The consent form explained that a simulated virtual environment was going to be presented and there was risk of simulator sickness associated with the study. It stated that their task was to control their movement in the virtual world using input devices like a steering wheel and brake and gas pedals. It also mentioned that their participation was going to require one session of approximately sixty minutes, and they could withdraw from the study at any time without penalty. The form also stated that the data they provided would be kept anonymous. More details about the content of the consent form are provided in Appendix B.

Table 4 Data Collection Points

Highway	Geometry			Total
	Left	Right	Straight	
Parks North	4	3	5	**12**
Parks South	3	4	5	**12**
Seward North	6	3	5	**14**
Seward South	3	6	5	**14**
Sterling North	5	7	5	**17**
Sterling South	7	5	5	**17**
Straight North	0	0	1	**1**
Straight South	0	0	1	**1**
Total	**28**	**28**	**32**	**88**

Participants were also asked to fill out a W-9 form. This was done in order for the National Institute for Advanced Transportation Technology (NIATT) to pay the participants for their time and participation.

A general description of the study was read to all drivers prior to participation. The general description pointed out that the participants' goal was to keep their vehicle centered in their lane and to travel at an appropriate speed, just as they would in everyday driving. In the description, it was also emphasized that they would drive the vehicle as if they were in a hurry to get home from a long weekend trip. The instructions did not indicate that the participant had to pass other vehicles so as to not compromise the objective to the study. A copy of the instruction of the study is provided in Appendix B.

To ensure all participants had a firm understanding of the study procedures and to make themselves familiar with the control of the driving simulator, participants were given a five to ten-minute test drive on a rural two-lane highway composed of straight and curved horizontal segments. Participants were asked to enter the vehicle and adjust the rear view mirror and driver's seat to their preference. After the completion of their test drive, the participants were asked to remain in their seat while the experiment simulation was uploaded. The participants were again reminded that the steering wheel needed to be centered. After about 25 minutes of driving, a message appeared on the screen asking the participant to pull over to the shoulder for a break. During the break, participants were asked to get out of the vehicle to walk around and stretch their legs for a couple of minutes.

Once the participants felt like they could continue with the experiment, they returned to the vehicle and completed the last half of the track. At the end of the experiment a "Please pull over, thank you for your time!" message was provided to each participant letting them know that the experiment had ended. After making sure the participant had pulled over and parked the vehicle, the researcher proceeded to stop the simulation. The researcher then stored the experiment data and saved it into the appropriate folder for analysis. After the participants had completed their session, they were asked to answer a debriefing form that was provided by the researcher. Participants were asked about their age, gender, years of driving experience, if they noticed anything unusual about the simulation and what affected their driving behavior. The debriefing form is provided in Appendix B. Following these questions, the purpose of the study was informed to the participants and the researcher answered any questions that the participants had about the study. The participant was subsequently compensated for his or her time.

CHAPTER 4: DATA ANALYSES AND RESULTS

In this chapter, the output data and initial analyses are provided first, followed by the participant information and passing maneuver analyses. In the passing maneuver analysis, the effects of geometry on a driver's passing maneuver were assessed by using an analysis of variance statistical test to determine the difference in means between passing maneuvers in different data collection zones and the effect of curve radius on a driver's passing probability. The effect of gender and parental status on passing maneuvers was assessed last.

Output Data and Analysis

All the participants drove for about fifty minutes in the driving simulator and the session recorded about 1.5 gigabytes of data which was stored in a data acquisition (.daq) format. These data contained all the microscopic information related to car movement in a specific geometry and other data related to car mechanics. Data related to car movement in a specific geometry consisted of speed, lane position, car heading direction, distance from the vehicle ahead, and distance from the vehicle behind. Car mechanics data included steering wheel angle, accelerator position, brake pedal position, engine rotation per minute, and gear position. All .daq files were converted into a hierarchical data format (hdf5) for analysis purposes. However, only required data needed for this research were extracted from the hdf5 files. It should also be noted that the analysis was conducted on data from 21 out of the total 24 participants as some technical issues were encountered when converting the .daq files.

The main objective of this research was to identify the number of passing maneuvers on a given horizontal geometry. For this purpose, a relative headway variable was used to assess passing maneuvers from the driving simulator data. Relative headway is often referred to as headway in a general context and is measured in feet. A headway can be defined as a gap or distance between two vehicles in the same lane [22]. Relative headway recorded in the driving simulator was either a positive or negative number. If the headway was positive, it indicated that the driver's vehicle was behind a vehicle to be passed; a negative headway indicated that the driver had completed a passing maneuver.

An algorithm was written using an IPython interface to read the data files and count the number of passes by each participant based on the concept of critical position in passing maneuvers. Critical position in passing maneuvers can be defined as a point during the passing maneuver where vehicles are abreast and the driver of the passing vehicle cannot abort the passing maneuver [6]. Hence, the critical position in the simulation occurred when the relative headway changed from positive to negative. An assumption for counting passes was made; if the driver reached the critical position, he or she was assumed to have completed the passing maneuver.

Figure 9 shows a graphical representation of the total number of the passes obtained for each highway section. In this figure the following abbreviations are defined as follows: CS = control segment, NB = northbound, SB = southbound, EB = eastbound, and WB = westbound.

As discussed in Chapter 3, the surrounding environment included cliffs and water for Seward Highway and forest, rolling highways, and mountains for the Parks and Sterling Highways. In Figure 9, it can be seen that drivers on the Parks and Sterling sections completed more passes than on the Seward Highway. This could be attributed to the surrounding environment. Also, the Parks Highway had the highest average radius of 4229 feet among the three geometries, while Sterling Highway had the lowest average radius of 1554 feet and Seward Highway had an average radius of 1628 feet. Evaluating the total number of passes on left-hand curves, right-hand curves, and on straight sections shows that straight sections had the most number of driver passes. When comparing northbound with southbound travel direction, it can be observed that the number of passes was higher on left-hand curves as compared to right-hand curves in the northbound direction, while the number of passes was generally higher on right-hand curves in the southbound direction.

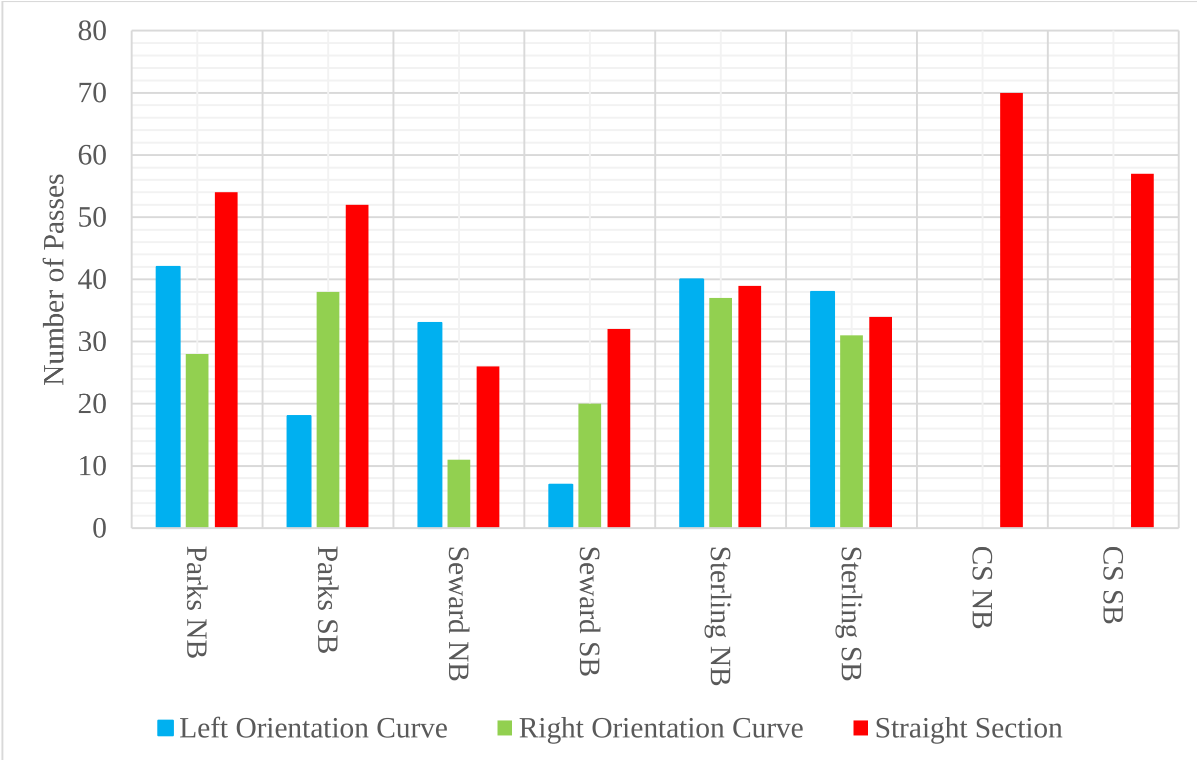

Figure 9 Total Passes Count on Each Geometry (Raw Data)

Participant Information

Twenty-one participants were analyzed. Participant age ranged from 19 to 59 years old with a mean of 29.4 years old and a median age of 25.6 years old. Figure 10 shows the age distribution of the participant and Table 5 shows the descriptive statistics for participant age.

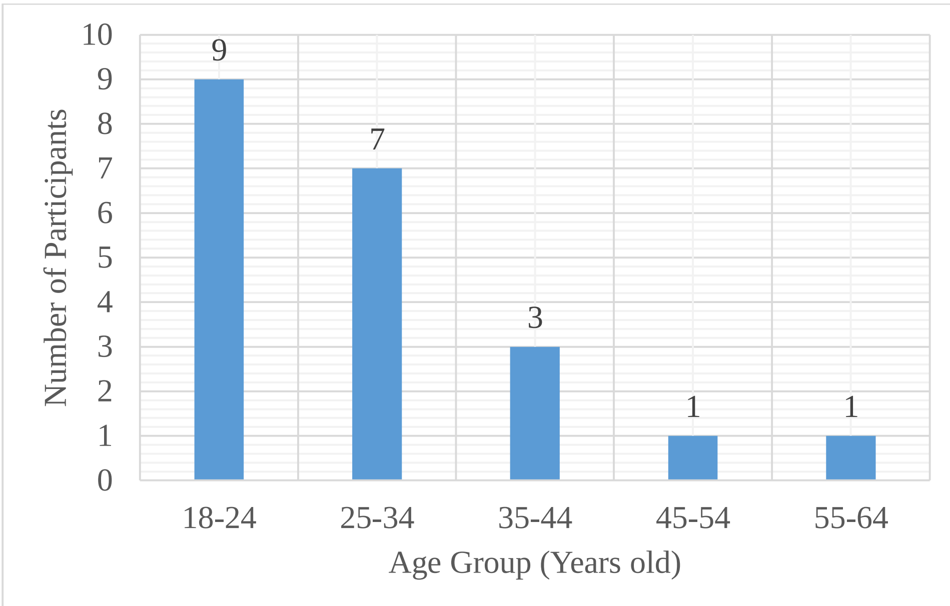

Figure 10 Participant's Age Distribution

Table 5 Descriptive Statistics for Age

Mean	29.4
Median	26.0
Standard Deviation	11.0
Minimum	19.0
Maximum	59.0

Participant driving experience ranged from 2 to 40 years with a mean driving experience of 12.7 years and a median of 8.0 years. Figure 11 shows the driving experience distribution of participants and Table 6 shows the descriptive statistics for years of driving experience.

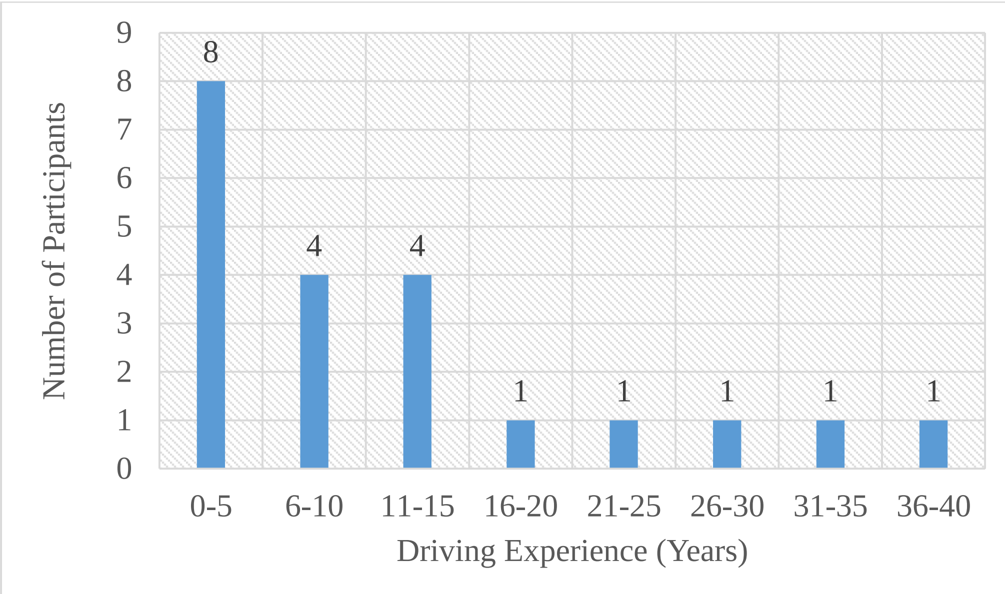

Figure 11 Participant's Driving Experience Distribution

Table 6 Descriptive Statistics for Driving Experience

Mean	12.7
Median	8.0
Standard Deviation	10.6
Minimum	2.0
Maximum	40.0

Figure 12 shows the gender distribution of the participants with respect to marital status. Out of the 21 individuals, there were a total of 16 males (76%) and 5 females (24%). Based on marital status, males represented 78.6% of single people and 71.4% of married couples.

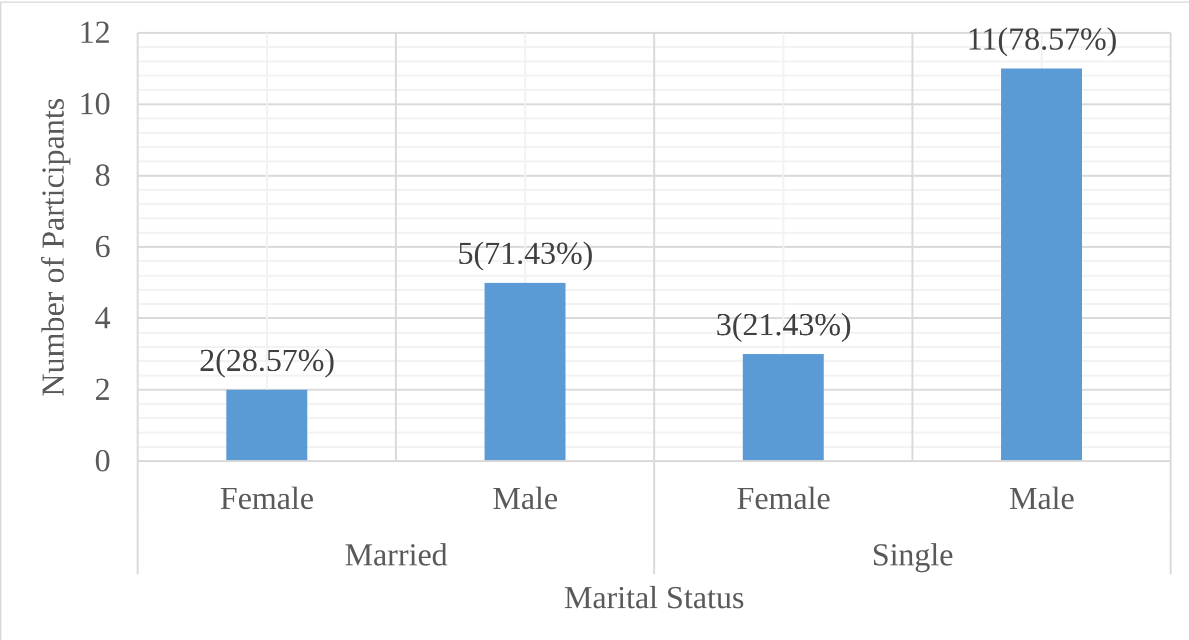

Figure 12 Participant Demographics (Gender and Marital Status)

Passing Maneuver Analysis

Passing maneuvers were analyzed with respect to the number of passes completed on different geometries, which included left-hand orientation curves, right-hand orientation curves, and straight sections. The passing probability was derived as a representation of passing maneuvers in the simulation. Passing probability was calculated based on the average number of passing maneuvers completed.

Probability of Passing Maneuvers

Passing probabilities were computed for each data collection zone along the real-world highway sections of Seward, Parks, and Sterling. Appendix C shows the passing probabilities for each data collection zone. The calculated passing probabilities were georeferenced to the real-world highway section using ESRI ArcMap. Figures 13, 14 and 15 show the passing probability maps. For example, a passing probability of 0-10% indicates that 0 to 2 out of 21 drivers completed a passing maneuver.

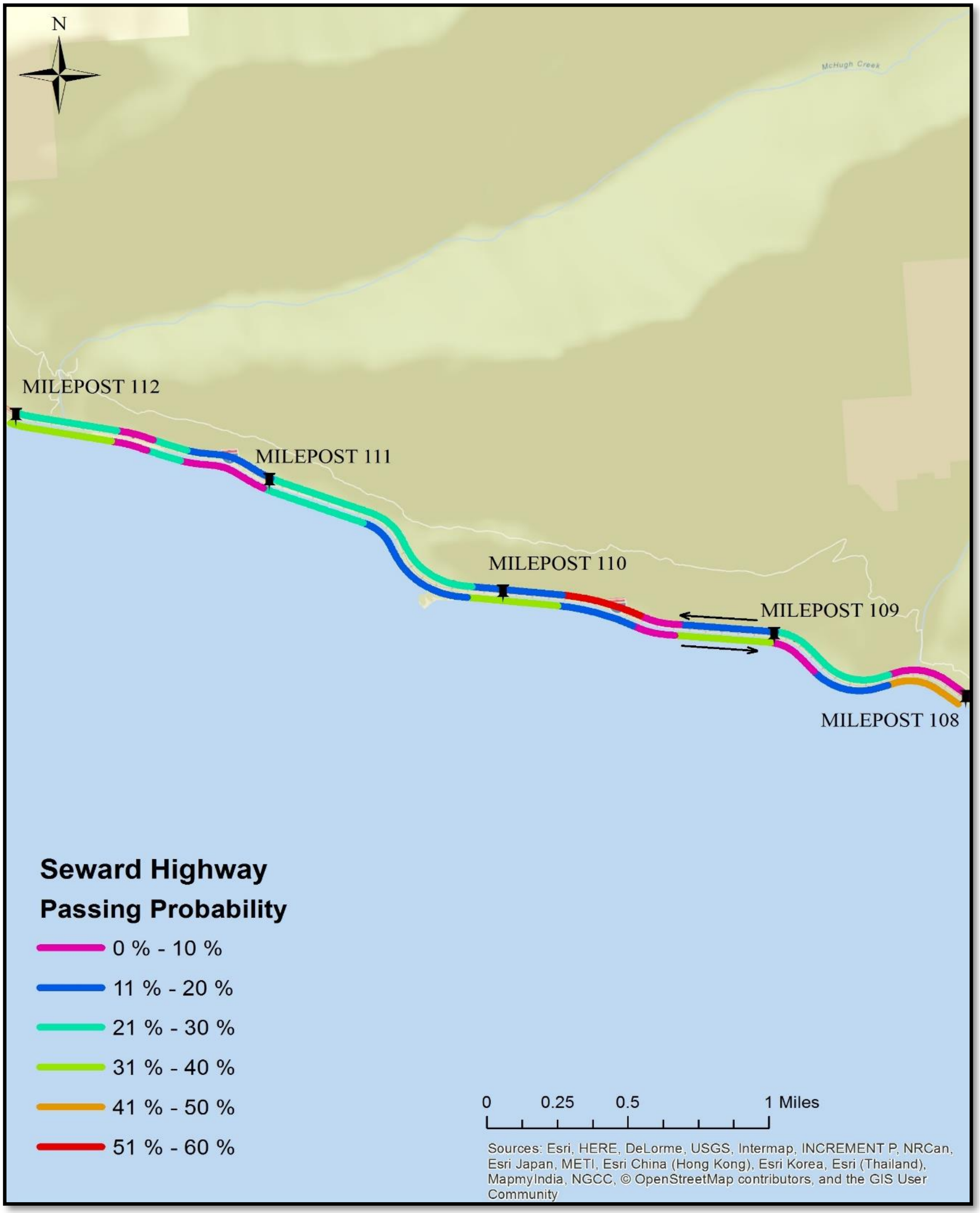

Figure 13 Seward Highway Passing Probability Map

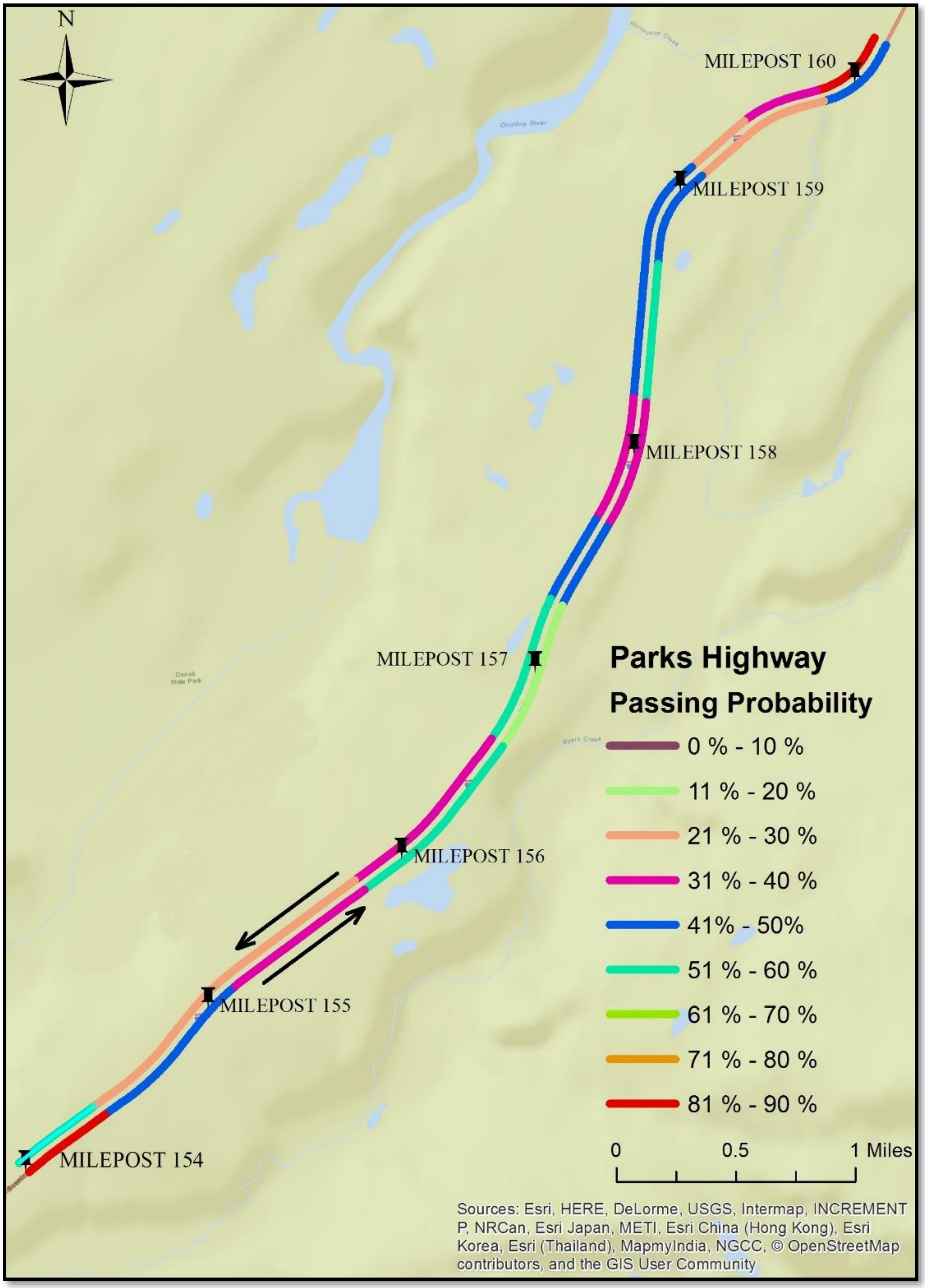

Figure 14 Parks Highway Passing Probability Map

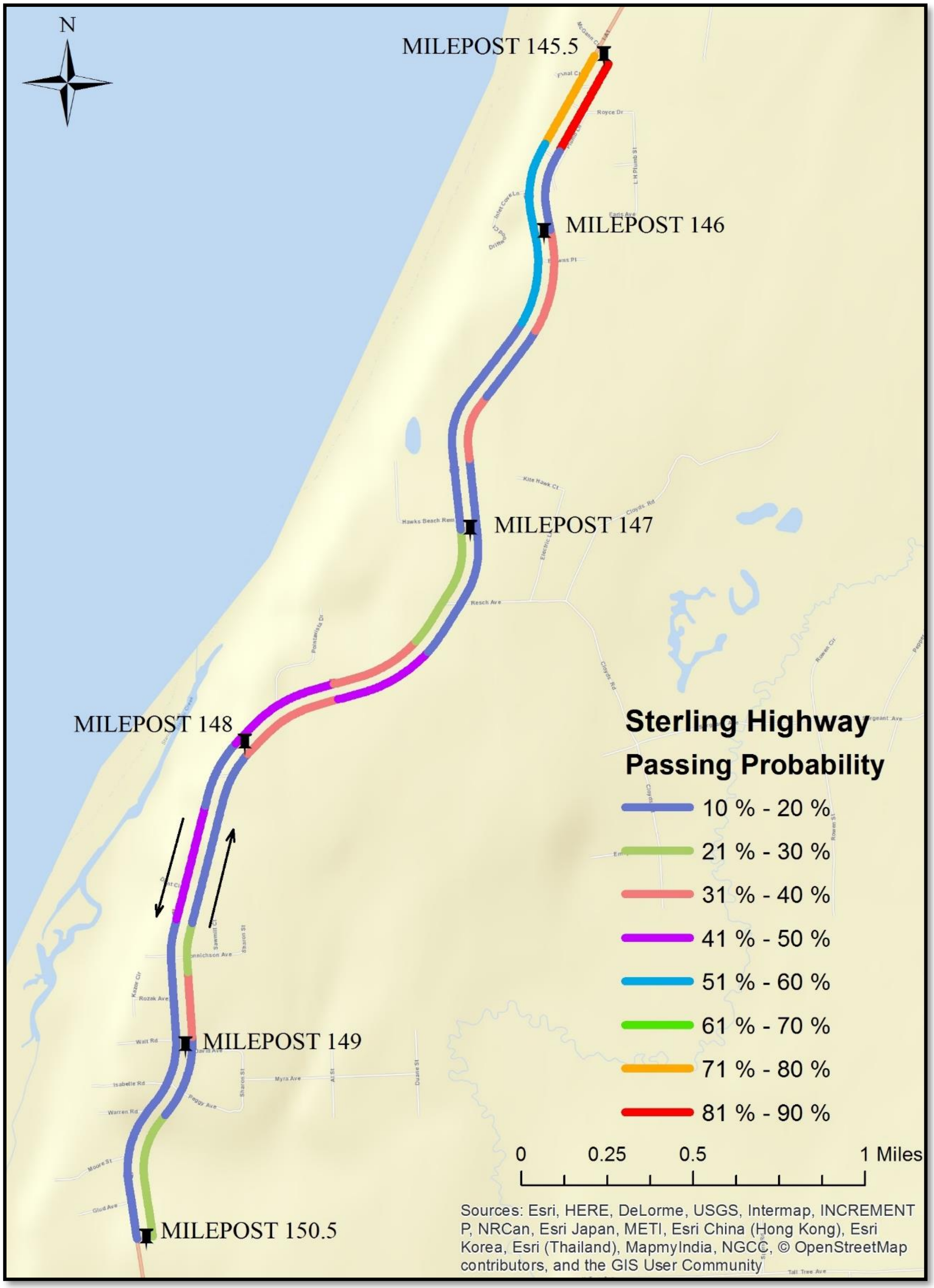

Figure 15 Sterling Highway Passing Probability Map

Effect of Geometry on Passing Maneuvers

Figure 16 shows a plot of passing probabilities on left-hand orientation curves, right-hand orientation curves and straight sections with respect to each highway. Figure 16 suggests that the passing probability on Parks Highway was about 25% higher as compared to Seward Highway and about 15% higher than that of Sterling Highway. The passing probability was also higher on straight sections as compared to left-hand and right-hand curves for most of the geometries. When comparing northbound and southbound travel direction, it can be observed that the passing probability was higher on left-hand curves as compared to right-hand curves in the northbound direction, while the passing probability was higher on right-hand curves as compared to left-hand curves in the southbound direction. A left-hand curve in the northbound direction is a right-hand curve in the southbound direction so passing maneuvers were undertaken on curves with a certain radius irrespective of orientation. A detailed table on passing probabilities on curves with each radius is provided in Appendix C.

To assess these passing probabilities in further detail, a one-way ANOVA was used to determine if there was any significant difference between the passing probabilities of different geometries with respect to their curve orientations. Tables 7, 8 and 9 show the comparisons made between left-hand curve orientation, right-hand curve orientation and the straight sections of the three roadway geometries. The respective statistical analyses is shown in Appendix D. These results were concluded based on a 95% confidence interval.

Statistical comparisons were made between:

1. left-hand curve vs. right-hand curve,
2. left-hand curve vs. straight section,
3. right-hand curve vs. straight section

These comparisons were completed for each direction (northbound and southbound) and for each geometry (Seward Highway, Parks Highway, and Sterling Highway).

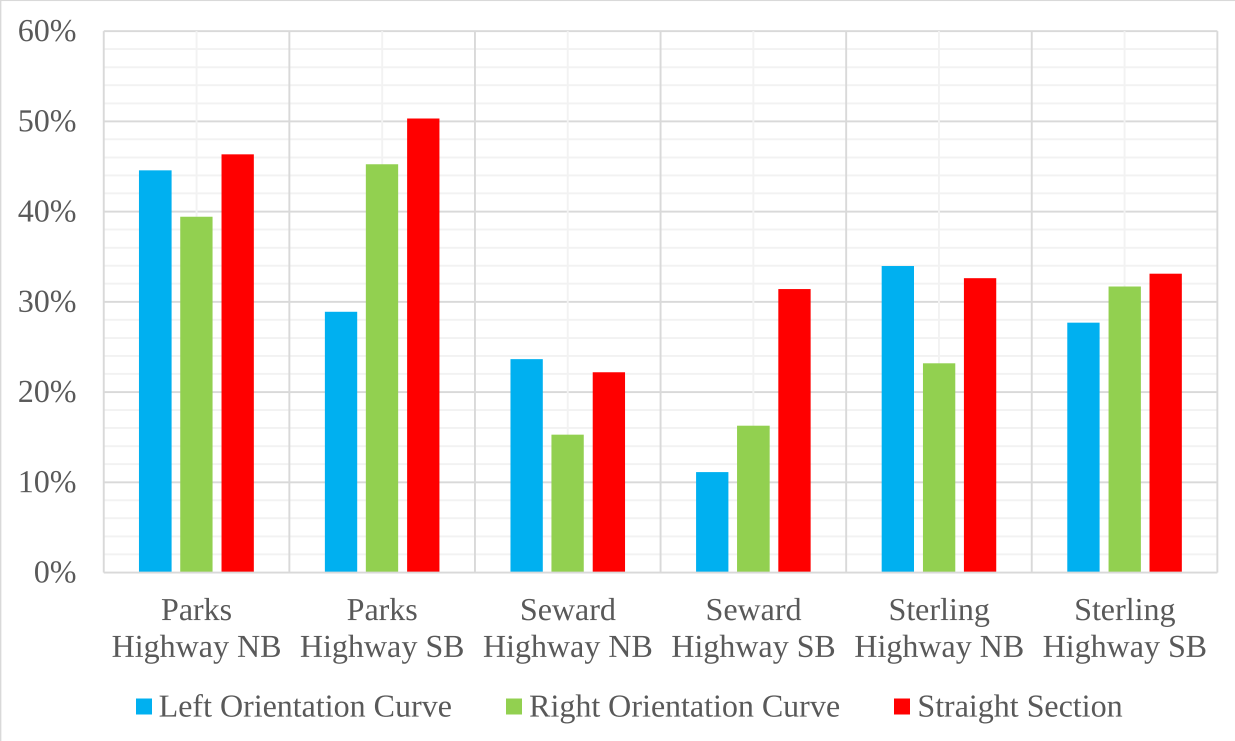

Figure 16 Passing Probability for Each Geometry

In Table 7, it can be observed that there was no difference in the means of the passing probabilities along the Seward Highway in the northbound direction. In the southbound direction, only the straight section and left-hand curve comparison had a significant difference in means which indicates that the straight section had more passing probability than the left-hand curve section. These results suggest that while traveling southbound on Seward Highway, sight distance may have been affected by the presence of the cliff on the left side of the highway. On the other hand, the presence of the cliff on the right side while traveling northbound did not have a significant impact on passing.

Table 7 Seward Highway: ANOVA Results Summary

Direction	**Alignment**	**Left**	**Right**
Northbound	**Left**	-	-
	Right	Same	-
	Straight	Same	Same
Southbound	**Left**	-	-
	Right	Same	-
	Straight	*Different (Straight has more passes)*	Same

In Table 8, it can be observed that there was no difference in means for the passing probabilities on the Parks Highway in either the northbound or southbound direction. This suggests that passing probabilities for Parks Highway in either direction was the same. A change in the direction of travel did not significantly affect a driver's passing maneuvers.

Table 8 Parks Highway: ANOVA Results Summary

Direction	Alignment	Left	Right
Northbound	**Left**	-	-
	Right	Same	-
	Straight	Same	Same
Southbound	**Left**	-	-
	Right	Same	-
	Straight	Same	Same

Table 9 shows that the Sterling Highway geometry yielded results similar to the Parks Highway.

Table 9 Sterling Highway: ANOVA Results Summary

Direction	Alignment	Left	Right
Northbound	**Left**	-	-
	Right	Same	-
	Straight	Same	Same
Southbound	**Left**	-	-
	Right	Same	-
	Straight	Same	Same

Table 10 shows the comparison between the four geometries, i.e., Seward Highway, Parks Highway, Sterling Highway and the straight control section. Their respective statistical analyses are shown in Appendix D.

In the comparison of straight section with the Parks, Seward, and Sterling Highways, it can be observed in Table 10 that passing probabilities were significantly different. The passing probability was higher on the straight section as compared to the other three geometries. This suggests, not surprisingly, that drivers were more likely to pass on a highway with a straight alignment than on an alignment with a curvilinear alignment (alignment with a combination of horizontal left-hand and right-hand curves).

In the comparison of Parks Highway vs. Seward Highway, it was deduced that passing probabilities on Parks Highway were significantly higher than that of Seward Highway. This could be caused by the combined effect of different horizontal curvature radii and the surrounding environment. Parks Highway had an average radius 4229 feet with a surrounding environment of forest and rolling hills and no sight distance obstructions. On the other hand, Seward Highway had an average radius of 1628 feet for its horizontal curvatures with a surrounding environment of cliff and water. This implies that passing probabilities were higher when the curvature was more gradual and sight distance was not obstructed.

Table 10 Geometry Comparison: ANOVA Results Summary

Geometry	**Parks Highway**	**Seward Highway**	**Sterling Highway**
Parks Highway	-		
Seward Highway	*Different (Parks has more Passes)*	-	
Sterling Highway	*Different (Parks has more Passes)*	*Different (Sterling has more Passes)*	-
Straight Section	*Different (Straight has more Passes)*	*Different (Straight has more Passes)*	*Different (Straight has more Passes)*

When comparing Sterling Highway with Parks Highway, it was deduced that the passing probability was higher on Parks Highway. Sterling Highway had an average radius of 1554 feet for its horizontal curvatures and a surrounding environment of forest and rolling hills with no sight distance obstructions. This suggests that passing probability was higher on the Parks Highway which had a wider radius as compared to Sterling Highway. When comparing Sterling Highway with Seward Highway, it was concluded that passing probability was significantly different from each other as the Sterling Highway had a higher passing probability than Seward Highway. The average radius along the Sterling Highway was less than the average radius of the Seward Highway. However Sterling Highway had a higher passing probability. This implies that passing maneuvers were likely affected by the presence of the cliff and water on Seward Highway which resulted in a lower passing maneuver probability as compared to the Sterling and Parks Highways.

The above discussion suggested that horizontal curve radius was one of the likely factors affecting passing maneuvers by drivers. To further assess, a scatter plot of the curve radii and associated passing probability was developed and is shown in Figure 17.

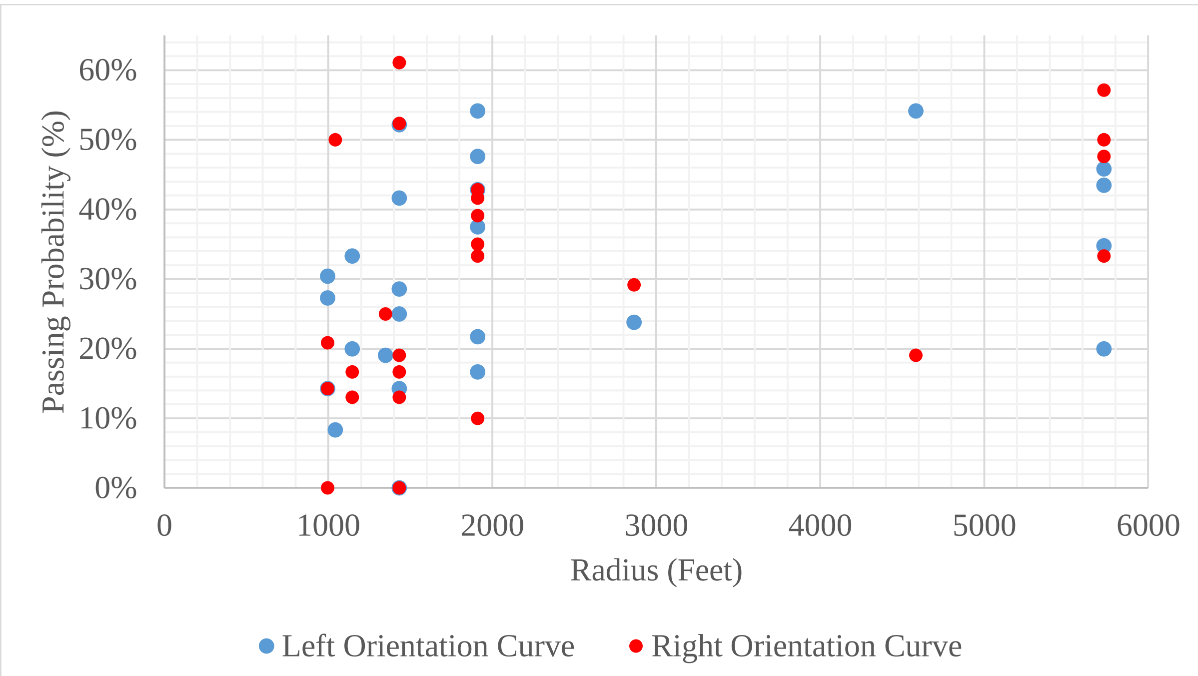

Figure 17 Effect of Curve Radius on Passing Probability

In Figure 17, the blue-colored data points indicate passing probability on a left-hand curve and the red-colored data points indicate passing probability on a right-hand curve of a specific radius. For example, there were two curves (one left-hand and one right-hand) with a radius of 2865 feet and their respective passing probabilities were 29% and 24%. A detailed table representing the passing probability on each curve for a specific radius is shown in Appendix C. The radius of curves on the real-world alignments ranged from 996 feet to 5730 feet, and from Figure 17 it is apparent that the radius is broadly separated into two groups with ranges of 996 feet to 2865 feet and 4584 feet to 5730 feet. There were no curves with radius in the range of 2866 feet to 4583 feet. Hence, the curves were divided into two groups to test the difference in means between them. The groups consisted of radius less than and more than 3000 feet.

A one-way ANOVA was used to test the difference in means between the two groups. The results showed that the p-value (0.021) was less than the 0.05 significance level. Looking at the F-statistic, the F-value (5.697) is also greater than F-critical (4.047), which indicated that there was a significant difference between the radius groups. It was deduced that curves with a radius of more than 3000 feet have a greater likelihood of driver passing than the curves with a radius of less than 3000 feet. Respective statistical analysis is shown in Appendix D.

Effect of Driver's Demographics on Passing Maneuvers

The gender and marital status of drivers was compared to the average number of passing maneuvers to assess how these variables affected passes on left-hand curves, right-hand curves, and straight sections. Figure 18 shows the comparison of gender and marital status based on the average number of passes.

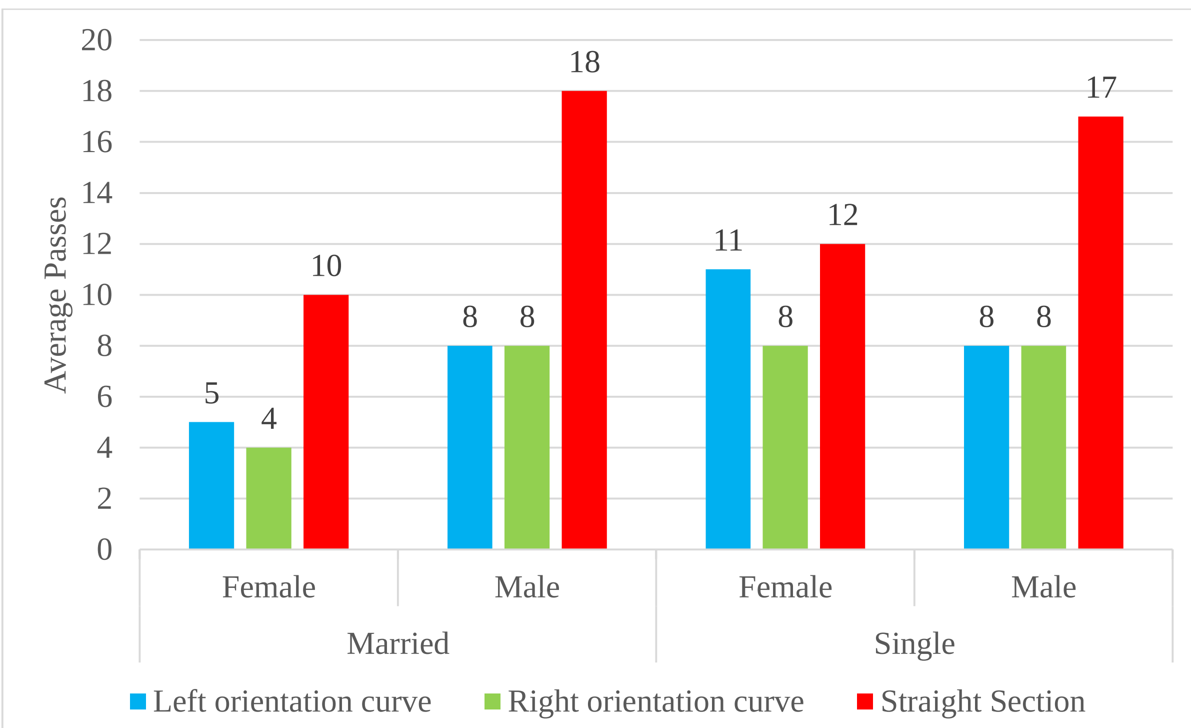

Figure 18 Participant Demographics vs. Number of Passes

It can be observed that average passes by the male driver are higher compared to female drivers on straight sections regardless of marital status. The figure also shows that single female drivers pass 50% more than married female drivers which suggests that females tend to be more conservative drivers after marriage. On the other hand, average passes for the male driver remained the same before and after marriage.

A one-way ANOVA was used to test the difference in means between gender and marital status. The comparison was made on a macroscopic level between male vs. female and married vs. single at a confidence level of 95%. It was found that neither male vs female (P-value = 0.132) nor married vs single (P-value = 0.378) had a difference in means. This suggests that there was no significant passing behavior difference between those population subsets. As there was no significant difference found, further analysis was not conducted.

CHAPTER 5: RESEARCH CONCLUSIONS

This study presented and evaluated the effects of horizontal curvature on passing maneuvers along real-world, rural, two-lane highways in Alaska using a driving simulator. This chapter summarizes the results and discusses the research findings.

Effect of Geometry on Passing Maneuvers

The effects of geometry on passing maneuvers were evident, with the Parks Highway having the highest passing probability followed by Sterling Highway and Seward Highway. Left-hand orientation curves, right-hand orientation curves and straight sections did not have a significant difference in the passing probability on Parks and Sterling Highway. For the Seward Highway, which had a surrounding environment of cliff on one side and water on the other side, a significant difference in passing probability between left-hand orientation curves and straight sections was determined. The sight distance was largely affected when travelling in the southbound direction (cliff on the left side) so left-hand orientation curves had a lower passing probability.

This study deduced that when drivers had opportunities to pass on either a straight section or curvilinear geometry, drivers were more likely to initiate passing maneuvers on straight sections. The passing probability decreased from Parks Highway to Sterling Highway to Seward Highway. Parks Highway had an average radius of 4229 feet, Sterling Highway had an average radius of 1554 feet, and Seward Highway had an average radius of 1628 feet. Parks Highway had the highest average radius and had the highest passing probability. However, Sterling Highway had the lowest average radius and had a passing probability higher than Seward Highway. The surrounding environment on Seward Highway likely had an effect on passing probability resulting into fewer passing maneuvers.

Curves having radius of more than 3000 feet has a higher driver passing probability when compared to curves with a radius of less than 3000 feet. This suggests that it was likely that the passing probability increases with increasing radius of the curve.

Effect of Driver's Demographics on Passing Maneuvers

The results implied that females tended to be more conservative drivers after marriage while male drivers remained the same before and after marriage. However, the statistical analysis showed that a driver's gender (male vs female) and marital status (married vs single) did not have any significant difference in passing probability, hence there was no evidence of effect of gender or marital status on passing probability.

Future Research

This research was designed to test horizontal alignment, as the goal was to determine if the driver initiated a passing maneuver on a specific geometry or not. Real-world alignments also have vertical curvature so this represents one natural area of further expansion of this study. Future research could also incorporate more roadside environment (which could obstruct driver's sight distance on curves) such as trees, houses, and rolling hills near the roadway. Other roadside environments that could be included which obstruct sight distance to a lesser degree are guardrail and vegetation. Rumble strips which are now typically encountered on real-world, two-lane highways could also be factor that can be included in a future study. Last but not least, driver eye-movement could be tracked in a simulated environment which could be helpful to determine where the driver focuses his or her attention when making a passing maneuver.

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APPENDICES

Appendix A

The table below shows detailed information on each of the data collection zones that participants faced. The Epoch # is the point identification number used during data analyses. A radius or length equaling zero indicates that the particular curve or section information was not listed in the as-builts provided.

Epoch #	Geometry	Turn	Radius/Length (ft.)	Length of Curve (ft.)
0	Seward North	Left	1041.74	993.91
1	Seward North	Right	996.45	1127.88
2	Seward North	Left	996.45	734.76
3	Seward North	Straight	1961.22	0.00
4	Seward North	Right	1432.39	515.47
5	Seward North	Left	4583.66	1569.02
6	Seward North	Straight	1824.05	0.00
7	Seward North	Right	1348.16	1306.60
8	Seward North	Left	996.45	770.49
9	Seward North	Straight	0.00	0.00
10	Seward North	Left	0.00	0.00
11	Seward North	Straight	0.00	0.00
12	Seward North	Left	0.00	0.00
13	Seward North	Straight	0.00	0.00
14	Park North	Straight	0.00	0.00
15	Park North	Left	5729.59	1571.70
16	Park North	Straight	1542.30	0.00
17	Park North	Left	5729.73	2016.70
18	Park North	Right	5729.45	1296.70
19	Park North	Straight	1575.80	0.00
20	Park North	Left	5729.53	2568.30
21	Park North	Straight	3684.80	0.00

22	Park North	Right	1909.83	1458.90
23	Park North	Straight	1744.50	0.00
24	Park North	Right	2864.67	1332.50
25	Park North	Left	1909.83	1587.80
26	Sterling North	Right	0.00	0.00
27	Sterling North	Left	1432.50	557.50
28	Sterling North	Straight	4021.10	0.00
29	Sterling North	Right	1432.50	1028.30
30	Sterling North	Left	1910.00	1650.20
31	Sterling North	Straight	1131.50	0.00
32	Sterling North	Right	1146.00	870.70
33	Sterling North	Straight	1454.00	0.00
34	Sterling North	Right	1146.00	754.20
35	Sterling North	Right	1910.00	1420.00
36	Sterling North	Left	1910.00	997.20
37	Sterling North	Left	1910.00	1011.10
38	Sterling North	Straight	2176.70	0.00
39	Sterling North	Right	1432.50	446.00
40	Sterling North	Straight	1204.00	0.00
41	Sterling North	Left	1432.50	1060.60
42	Sterling North	Right	1432.50	1180.00
43	Straight North	Straight	20300.00	0.00
44	Seward South	Straight	0.00	0.00
45	Seward South	Right	0.00	0.00
46	Seward South	Straight	0.00	0.00
47	Seward South	Right	0.00	0.00
48	Seward South	Straight	0.00	0.00
49	Seward South	Right	996.45	770.49
50	Seward South	Left	1348.16	1306.60
51	Seward South	Straight	1824.05	0.00

52	Seward South	Right	4583.66	1569.02
53	Seward South	Left	1432.39	515.47
54	Seward South	Straight	1961.22	0.00
55	Seward South	Right	996.45	734.76
56	Seward South	Left	996.45	1127.88
57	Seward South	Right	1041.74	993.91
58	Park South	Right	1909.83	1587.80
59	Park South	Left	2864.67	1332.50
60	Park South	Straight	1744.50	0.00
61	Park South	Left	1909.83	1458.90
62	Park South	Straight	3684.80	0.00
63	Park South	Right	5729.53	2568.30
64	Park South	Straight	1575.80	0.00
65	Park South	Left	5729.45	1296.70
66	Park South	Right	5729.73	2016.70
67	Park South	Straight	1542.30	0.00
68	Park South	Right	5729.59	1571.70
69	Park South	Straight	0.00	0.00
70	Sterling South	Left	1432.50	1180.00
71	Sterling South	Right	1432.50	1060.60
72	Sterling South	Straight	1204.00	0.00
73	Sterling South	Left	1432.50	446.00
74	Sterling South	Straight	2176.70	0.00
75	Sterling South	Right	1910.00	1011.10
76	Sterling South	Right	1910.00	997.20
77	Sterling South	Left	1910.00	1420.00
78	Sterling South	Left	1146.00	754.20
79	Sterling South	Straight	1454.40	0.00
80	Sterling South	Left	1146.00	870.70
81	Sterling South	Straight	1131.50	0.00

82	Sterling South	Right	1910.00	1650.20
83	Sterling South	Left	1432.50	1028.30
84	Sterling South	Straight	4021.10	0.00
85	Sterling South	Right	1432.50	557.50
86	Sterling South	Left	0.00	0.00
87	Straight South	Straight	23150.00	0.00

Appendix B

This appendix contains: the advertisement used to recruit participants, participant consent form and study instructions.

Advertisement Driving Study

ADVERTISEMENT – DRIVING STUDY

uihumanfactors@gmail.com

The University of Idaho IRB Approved

Participants needed IMMEDIATELY for Driving Simulator Study

One session for about 90 minutes

Requirements:

Participants must be 18 or older, have a valid Driver's License, and have at least 20/30 UNCORRECTED vision. If your vision is corrected to at least 20/30, please bring either glasses or wear contacts.

CAUTION: If you are prone to Motion Sickness/Nausea this study is not recommended.

Please contact at uihumanfactors@gmail.com ASAP. If you are, have any questions or are interested, and meet the requirements above.

The study pays up to a total of $30.

Consent Form

CONSENT FORM
Idaho Visual Performance Laboratory
Department of Psychology and Communication Studies
College of Liberal Arts and Social Sciences
University of Idaho

The University of Idaho Institutional Review Board has approved this project.

During this experiment you will be presented a simulated virtual environment. Various parameters of the environment will be manipulated to examine the processes underlying vision and decision making. The experimental tasks will require you control your movement in the virtual world using input devices like a steering wheel and brake/gas pedals.

Your participation will help increase knowledge of visual processes underlying locomotion and aid in the design of visual displays used in transportation. Subsequent to your participation the purpose and methods of the study will be described to you and any questions you have about the study will be answered. It is our sincere hope that you will learn something interesting about your visual system from this debriefing.

We believe the risks in this study are minimal, however displays simulating movement through virtual environments may on rare occasion cause motion sickness or eye fatigue. If at any time during the experiment you feel any discomfort, eye fatigue, dizziness, headache or nausea, please let the experimenter know immediately so that you can prevent these symptoms from becoming more intense. We endeavor to design our virtual environments to minimize eye fatigue and motion sickness. We also schedule periodic breaks to further reduce the occurrence of these risks. As a result, these risks are generally avoided, but it is important for you to inform us immediately if they do occur. At such time we will immediately terminate the experiment and provide you with a comfortable place to rest. If your discomfort is mild and passes quickly you will be given the opportunity to continue the experiment if you so desire. Any new information developed during the course of this research which might affect your willingness to continue participation will be provided as soon as it is available.

Your participation will require 1 session of approximately 90 minutes. You may withdraw from this study at any time without penalty. If you do wish to withdraw, simply inform the experimenter; you will receive full compensation for your time spent in the experiment up to that point. However, please be aware that your data will have the greatest scientific value if you complete the experiment in its entirety.

The data you provide will be kept anonymous. There will be absolutely no link between your identity and your particular set of data.

If you have further questions or issues please contact:

Dr. Brian P. Dyre
Department of Psychology and Communications Studies
University of Idaho
(208) 885-6927
bdyre@uidaho.edu

I have reviewed this consent form and understand and agree to its contents.

Participant Name ______________________________
Date of Birth ______________________________
Signature ______________________________
Date ______________________________

Experimenter Name______________________________
Signature______________________________
Date ______________________________

Thank you for your participation.

Driving Study Instructions

Driving Study Instructions
Instructions

Please Ask If they have participated in any other driving study.
If they say yes, please inform them there will no correlation with that study. This simulation will be totally independent.

This experiment examines how people drive on rural highways.

Your task will be to steer a simulated vehicle over a road through a simulation of the Alaskan countryside. Your goal is to keep your vehicle centered in your lane and moving at an appropriate speed, just as you would in everyday driving. Just like with any car, to turn right you move the top of the steering wheel to the right. To turn left you move the top of the steering wheel to the left. To accelerate you press the gas pedal. To slow down, you press the brake pedal. Turn signals operate just like in a real vehicle.

In this experiment you will go through 1 trial lasting approximately 60 minutes which will simulate a 50 mile drive returning from a weekend long trip. there will be vehicles ahead and behind you as well as in the oncoming lane. You should pay careful attention to other vehicles, road signs, speed limits, etc. and use normal driving etiquette (obeying speed limits, using turn signals, using passing zones to pass other vehicles etc.) just as you would if you were driving on a real rural highway, and **in a hurry to get home from weekend long trip.**

Do you have any questions?

Now please explain to me, in your own words, what you will be doing in this study.

After approximately 25 miles, a message will appear on the screen asking you to pull over and take a break. At this time, we want you to park the car on the shoulder, placing the transmission in “Park” and exit the vehicle so that you can get up, walk around, and stretch your legs for a minute.

Upon entering the vehicle, please adjust the center rear view mirror and seat to your preference (the side mirrors do not adjust). To begin each trial you will need to depress the brake pedal to release the transmission lock and shift the gear shift into “D” or “drive.”

Do you have any questions?

First of all you will go through a test drive lasting approximately 5-10 mins. The test drive is meant for you to get confortable with the controls of the car. Feel free to ask questions after the test drive if you have any. Make sure the steering wheel is centered before the simulation starts.

Just drive normal as in real driving and in a hurry to get home from weekend long trip.

Debriefing Form

A debriefing form was set up for post data collection questions on the Google form platform. The snapshots below show some of the questions asked to the participants. All of the answers were noted when a participant responded.

AKDOT Passing Zone Study Phase-1 Debriefing Form

Section:1 Participant's Driving History

In some questions "other" option is provided please ask participant to elaborate their answer and type it in other section.

1.1 Types of roadway Driven(Approx % of time driven)

	Less than 20%	20% - 40%	40% - 60%	60% - 80%	80% +	None
Interstates/Freeways	○	○	○	○	○	○
City Roads	○	○	○	○	○	○
Town Roads	○	○	○	○	○	○
Rural Highways	○	○	○	○	○	○
Others	○	○	○	○	○	○

1.2 How would you describe your real-life driving Style ?

- ☐ Careful
- ☐ Defensive
- ☐ Passive
- ☐ Aggresive
- ☐ NASCAR: Racing
- ☐ Downright Mean
- ☐ Other: ____

1.3 Types of Vehicles Driven have you driven on two-lane rural highway

- [ ] Sedan
- [ ] SUV
- [ ] Minivan
- [ ] Pickup
- [ ] Van
- [ ] Commercial
- [ ] Motorcycles
- [ ] Other: ____________

Section:2 Simulation

In some questions "other" option is provided please ask participant to elaborate their answer and type it in other section.

2.1 Did the simulation make you feel as if you were driving through a three-dimensional Environment?

- [ ] Yes
- [ ] No
- [ ] Other: ____________

2.2 Did you notice anything unusual about the simulated environment ?

- [ ] Yes
- [ ] No
- [ ] Other: ____________

Section:3 Vehicles in Simulation

3.1 In terms of other vehicles in the simulation study, what influenced your driving ? (Please ask to elaborate and note it down in other section)

- [ ] Speed of Vehicles in front of you
- [ ] Number of cars travelling Ahead of you
- [ ] Amount of Traffic in opposing Lane
- [ ] Vehicle travelling behind you
- [ ] None of the above
- [ ] Other: ____________

3.2 Did these vehicles affected your decision to pass ? (ask why? and note it down in others check box)

- [ ] Yes
- [ ] No
- [ ] Other: ____________

Section:4 Simulation Layout

4.1 In terms of simulated environment layout in study, what influenced your driving and decision to pass other vehicle? (ask why? and note it down in others check box)

- [ ] Left Direction Curve
- [ ] Right Direction Curve
- [ ] Straight roads
- [ ] Trees/Forests
- [ ] Rolling hills
- [ ] Mountains
- [ ] Cliff
- [ ] Water/Lake/Sea
- [ ] None
- [ ] Other: ____________

4.2 while driving on rural highways in real-life how often do you pass other vehicle ? (ask why? and note it down in others check box)

Your answer ____________

Personal Information

Gender

- ○ Male
- ○ Female
- ○ Other: ________

Age

Your answer ________

Years of Driving Experience

Your answer ________

Martial Status

Your answer ________

Parent

Your answer ________

Appendix C

The table below shows passing probability for each of the data collection zones. A passing probability of 8% indicates that there was a probability that about 2 out of 21 total drivers were likely to adopt the passing maneuvers.

Epoch #	Geometry	Turn	Radius/Length (feet)	Probability of Passing
0	Seward North	Left	1041.7	8%
1	Seward North	Right	996.5	21%
2	Seward North	Left	996.5	30%
3	Seward North	Straight	1961.2	18%
4	Seward North	Right	1432.4	0%
5	Seward North	Left	4583.7	54%
6	Seward North	Straight	1824.1	13%
7	Seward North	Right	1348.2	25%
8	Seward North	Left	996.5	27%
9	Seward North	Straight	0.0	26%
10	Seward North	Left	0.0	17%
11	Seward North	Straight	0.0	25%
12	Seward North	Left	0.0	4%
13	Seward North	Straight	0.0	29%
14	Park North	Straight	0.0	88%
15	Park North	Left	5729.6	35%
16	Park North	Straight	1542.3	26%
17	Park North	Left	5729.7	43%
18	Park North	Right	5729.5	50%
19	Park North	Straight	1575.8	38%
20	Park North	Left	5729.5	46%
21	Park North	Straight	3684.8	55%
22	Park North	Right	1909.8	39%
23	Park North	Straight	1744.5	26%

24	Park North	Right	2864.7	29%
25	Park North	Left	1909.8	54%
26	Sterling North	Right	0.0	9%
27	Sterling North	Left	1432.5	42%
28	Sterling North	Straight	4021.1	79%
29	Sterling North	Right	1432.5	13%
30	Sterling North	Left	1910.0	17%
31	Sterling North	Straight	1131.5	13%
32	Sterling North	Right	1146.0	17%
33	Sterling North	Straight	1454.0	42%
34	Sterling North	Right	1146.0	13%
35	Sterling North	Right	1910.0	42%
36	Sterling North	Left	1910.0	38%
37	Sterling North	Left	1910.0	22%
38	Sterling North	Straight	2176.7	13%
39	Sterling North	Right	1432.5	17%
40	Sterling North	Straight	1204.0	17%
41	Sterling North	Left	1432.5	52%
42	Sterling North	Right	1432.5	52%
43	Seward South	Straight	0.0	32%
44	Seward South	Right	0.0	5%
45	Seward South	Straight	0.0	24%
46	Seward South	Right	0.0	10%
47	Seward South	Straight	0.0	29%
48	Seward South	Right	996.5	14%
49	Seward South	Left	1348.2	19%
50	Seward South	Straight	1824.1	35%
51	Seward South	Right	4583.7	19%
52	Seward South	Left	1432.4	0%
53	Seward South	Straight	1961.2	38%

54	Seward South	Right	996.5	0%
55	Seward South	Left	996.5	14%
56	Seward South	Right	1041.7	50%
57	Park South	Right	1909.8	43%
58	Park South	Left	2864.7	24%
59	Park South	Straight	1744.5	29%
60	Park South	Left	1909.8	43%
61	Park South	Straight	3684.8	57%
62	Park South	Right	5729.5	33%
63	Park South	Straight	1575.8	48%
64	Park South	Left	5729.5	20%
65	Park South	Right	5729.7	57%
66	Park South	Straight	1542.3	33%
67	Park South	Right	5729.6	48%
68	Park South	Straight	0.0	85%
69	Sterling South	Left	1432.5	25%
70	Sterling South	Right	1432.5	19%
71	Sterling South	Straight	1204.0	35%
72	Sterling South	Left	1432.5	29%
73	Sterling South	Straight	2176.7	20%
74	Sterling South	Right	1910.0	10%
75	Sterling South	Right	1910.0	35%
76	Sterling South	Left	1910.0	48%
77	Sterling South	Left	1146.0	20%
78	Sterling South	Straight	1454.4	14%
79	Sterling South	Left	1146.0	33%
80	Sterling South	Straight	1131.5	11%
81	Sterling South	Right	1910.0	33%
82	Sterling South	Left	1432.5	14%
83	Sterling South	Straight	4021.1	86%

84	Sterling South	Right	1432.5	61%
85	Sterling South	Left	0.0	25%

Appendix D

Following are the results for ANOVA comparisons discussed in Chapter 4.

Seward Highway: Northbound ANOVA Comparison Results

Seward Highway Northbound Anova: Single Factor (Left-hand Curve vs. Right-hand Curve)

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Left	6	1.4195	0.2366	0.0327
Right	3	0.4583	0.1528	0.0179

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0140	1.0000	0.0140	0.4927	0.5054	5.5914
Within Groups	0.1996	7.0000	0.0285			
Total	0.2136	8.0000				

Seward Highway Northbound Anova: Single Factor (Straight Section vs. Right-hand Curve)

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Right	3	0.4583	0.1528	0.0179
Straight	5	1.1094	0.2219	0.0045

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0090	1.0000	0.0090	0.9936	0.3573	5.9874
Within Groups	0.0541	6.0000	0.0090			
Total	0.0630	7.0000				

Seward Highway Northbound Anova: Single Factor (Left-hand Curve vs. Straight Section)

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Left	6	1.4195	0.2366	0.0327
Straight	5	1.1094	0.2219	0.0045

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0006	1.0000	0.0006	0.0292	0.8681	5.1174
Within Groups	0.1818	9.0000	0.0202			
Total	0.1824	10.0000				

Seward Highway: Southbound ANOVA Comparison Results

Seward Highway Southbound Anova: Single Factor (Left-hand Curve vs. Right-hand Curve)

SUMMARY				
Groups	***Count***	***Sum***	***Average***	***Variance***
Left	3	0.3333	0.1111	0.0098
Right	6	0.9762	0.1627	0.0318

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0053	1.0000	0.0053	0.2083	0.6619	5.5914
Within Groups	0.1789	7.0000	0.0256			
Total	0.1842	8.0000				

Seward Highway Southbound Anova: Single Factor (Straight Section vs. Left-hand Curve)

SUMMARY				
Groups	***Count***	***Sum***	***Average***	***Variance***
Straight	5	1.5706	0.3141	0.0031
Left	3	0.3333	0.1111	0.0098

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0773	1.0000	0.0773	14.4894	0.0089	5.9874
Within Groups	0.0320	6.0000	0.0053			
Total	0.1093	7.0000				

Seward Highway Southbound Anova: Single Factor (Straight Section vs. Right-hand Curve)

SUMMARY				
Groups	***Count***	***Sum***	***Average***	***Variance***
Straight	5	1.5706	0.3141	0.0031
Right	6	0.9762	0.1627	0.0318

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0625	1.0000	0.0625	3.2803	0.1035	5.1174
Within Groups	0.1715	9.0000	0.0191			
Total	0.2341	10.0000				

Parks Highway: Northbound ANOVA Comparison Results

Parks Highway Northbound Anova: Single Factor (Left-hand Curve vs. Right-hand Curve)

SUMMARY				
Groups	***Count***	***Sum***	***Average***	***Variance***
Left	3	0.8667	0.2889	0.0150
Right	4	1.8095	0.4524	0.0098

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0458	1.0000	0.0458	3.8525	0.1069	6.6079
Within Groups	0.0595	5.0000	0.0119			
Total	0.1053	6.0000				

Parks Highway Northbound Anova: Single Factor (Straight Section vs. Right-hand Curve)

SUMMARY				
Groups	***Count***	***Sum***	***Average***	***Variance***
Straight	5	2.5167	0.5033	0.0505
Right	4	1.8095	0.4524	0.0098

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0058	1.0000	0.0058	0.1746	0.6886	5.5914
Within Groups	0.2313	7.0000	0.0330			
Total	0.2371	8.0000				

Parks Highway Northbound Anova: Single Factor (Left-hand Curve vs. Straight Section)

SUMMARY				
Groups	***Count***	***Sum***	***Average***	***Variance***
Left	3	0.8667	0.2889	0.0150
Straight	5	2.5167	0.5033	0.0505

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0862	1.0000	0.0862	2.2319	0.1858	5.9874
Within Groups	0.2318	6.0000	0.0386			
Total	0.3180	7.0000				

Parks Highway: Southbound ANOVA Comparison Results

Parks Highway Southbound Anova: Single Factor (Left-hand Curve vs. Right-hand Curve)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Left	4	1.7826	0.4457	0.0064
Right	3	1.1830	0.3943	0.0109

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0045	1.0000	0.0045	0.5537	0.4903	6.6079
Within Groups	0.0408	5.0000	0.0082			
Total	0.0453	6.0000				

Parks Highway Southbound Anova: Single Factor (Left-hand Curve vs. Straight Section)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Straight	5	2.3172	0.4634	0.0665
Left	4	1.7826	0.4457	0.0064

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0007	1.0000	0.0007	0.0173	0.8992	5.5914
Within Groups	0.2851	7.0000	0.0407			
Total	0.2858	8.0000				

Parks Highway Southbound Anova: Single Factor (Straight Section vs. Right-hand Curve)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Straight	5	2.3172	0.4634	0.0665
Right	3	1.1830	0.3943	0.0109

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0090	1.0000	0.0090	0.1868	0.6807	5.9874
Within Groups	0.2877	6.0000	0.0480			
Total	0.2967	7.0000				

Sterling Highway: Northbound ANOVA Comparison Results

Sterling Highway Northbound Anova: Single Factor (Left-hand Curve vs. Right-hand Curve)

SUMMARY				
Groups	***Count***	***Sum***	***Average***	***Variance***
Left	7	1.9381	0.2769	0.0114
Right	5	1.5849	0.3170	0.0377

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0047	1.0000	0.0047	0.2140	0.6535	4.9646
Within Groups	0.2193	10.0000	0.0219			
Total	0.2240	11.0000				

Sterling Highway Northbound Anova: Single Factor (Left-hand Curve vs. Straight Section)

SUMMARY				
Groups	***Count***	***Sum***	***Average***	***Variance***
Straight	5	1.6553	0.3311	0.0952
Left	7	1.9381	0.2769	0.0114

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0086	1.0000	0.0086	0.1907	0.6716	4.9646
Within Groups	0.4490	10.0000	0.0449			
Total	0.4576	11.0000				

Sterling Highway Northbound Anova: Single Factor (Right-hand Curve vs. Straight Section)

SUMMARY				
Groups	***Count***	***Sum***	***Average***	***Variance***
Straight	5	1.6553	0.3311	0.0952
Right	5	1.5849	0.3170	0.0377

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.0005	1.0000	0.0005	0.0074	0.9334	5.3177
Within Groups	0.5317	8.0000	0.0665			
Total	0.5322	9.0000				

Sterling Highway: Southbound ANOVA Comparison Results

Sterling Highway Southbound Anova: Single Factor (Left-hand Curve vs. Right-hand Curve)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Left	5	1.6975	0.3395	0.0213
Right	7	1.6216	0.2317	0.0282

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0339	1.0000	0.0339	1.3317	0.2753	4.9646
Within Groups	0.2547	10.0000	0.0255			
Total	0.2886	11.0000				

Sterling Highway Southbound Anova: Single Factor (Left-hand Curve vs. Straight Section)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Straight	5	1.6304	0.3261	0.0823
Left	5	1.6975	0.3395	0.0213

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0004	1.0000	0.0004	0.0087	0.9281	5.3177
Within Groups	0.4143	8.0000	0.0518			
Total	0.4148	9.0000				

Sterling Highway Southbound Anova: Single Factor (Right-hand Curve vs. Straight Section)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Straight	4	1.4638	0.3659	0.0991
Right	7	1.6216	0.2317	0.0282

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0459	1.0000	0.0459	0.8849	0.3714	5.1174
Within Groups	0.4668	9.0000	0.0519			
Total	0.5127	10.0000				

Radius of Curve ANOVA Comparison Results

Radius of Curves Anova: Single Factor (Radius <3000 feet vs Radius > 4000 feet)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
<3000	39	10.68187151	0.273894141	0.025657927
4000+	10	4.054037267	0.405403727	0.017849954

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.137652259	1	0.137652259	5.696870986	0.021071769	4.047099895
Within Groups	1.135650818	47	0.024162783			
Total	1.273303077	48				