IMPROVING PASSING LANE SAFETY AND EFFICIENCY IN TWO-LANE RURAL HIGHWAYS

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Abstract

The primary goal of the research presented in this thesis is to mitigate passing lane crash risks on two-lane rural highways. Medium-fidelity driving simulators are normally used to examine the potential safety and operational benefits of several measures. These measures include reducing the speed of drivers in the right lane while being passed and reducing the incidence of late, high-speed passes at the end of the passing lane. Alternatives considered in this study include a mix of explicit behavioral interventions, such as regulation (enforcing lower speed limits) and advanced warning (advisory signage upstream from and at the passing lane) as well as passive speed reduction measures such as alternative striping and pavement marking. Results from the driver simulator experiments suggest that regulatory speed reduction signs result in slower speeds for vehicles driving in the right lane. The results also show that passive speed reduction measures have little or no impact on the speed of the drivers. The research shows that the presence of surrounding traffic seems to have no impact on the effectiveness of passive speed resection alternatives. Finally, an analysis of the 2008-2012 state of Idaho reported crashes indicates that, while crash rates at the passing lane merging segments (0.5-mile downstream from the passing lane) are higher than that for the passing lane and for the two-lane highway segments, these differences are not statistically significant at the 95% confidence level.

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Dedication

I would like to thank my parents, Chuck and Sue, for all of the sacrifices they made for me over the years; it means more to me than you will ever know. Thank you also to my friends who always encouraged me to never give up and put a smile on my face during the hard times. Finally, thank you to Desiree for always supporting me and always pushing me to strive for the best.

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CHAPTER 1: INTRODUCTION

High traffic volumes and variation in vehicle speeds can lead to queues forming on two-lane rural highways. Passing lanes on these rural highways provide motorists with the opportunity to pass slower vehicles, increasing the level of service (LOS) of the highway operations. However, such passing maneuvers can be hazardous for the passing vehicle as well as for the opposing traffic. Due to wider roads and higher design quality of passing lanes, some vehicles—including large trucks and recreational vehicles—tend to increase their speed once entering a no-grade, level passing lane. This, in turn, causes motorists to pass at excessive speeds that could propagate into the merge area and increase the risk of head-on severe or sometimes fatal crashes. Additionally, crashes may occur downstream from a passing lane where the demand to pass is still high. Passing lane safety and efficiency could be significantly improved if vehicles in the right lane were induced to maintain a relatively slower speed, thus allowing more vehicles to pass in the passing lane segment without excessive speeds or reckless weaving maneuvers.

The primary goal of the research this thesis presents is to mitigate passing lane crash risks on two-lane rural highways. A medium-fidelity driving simulation was used to examine the potential safety and operational benefits of several measures aimed at reducing the speed of drivers in the right-hand lane while being passed and reducing the incidence of late, high-speed passes at the end of the passing lane zone. The driving simulator consisted of a reclaimed pick-up truck cab and large projector screens to simulate driving on a rural two-lane highway. This study considers alternatives including a mix of explicit behavioral interventions such as regulation, advanced signing, and passive speed reduction measures. Regulation is simply enforcing a lower speed limit. Advanced signing alerts drivers upstream of the passing lane about the potential to pass. Passive speed reduction measures consist of alternative striping or pavement markings that are based on a scientific understanding of human perception and driver decision making.

68 participants were involved in three driving simulator experiments to investigate various passing lane speed reduction scenarios. Participants were exposed to computer-generated scenery simulating a typical two-lane two-way rural highway environment. The first two experiments assessed driver speed and lane deviation throughout passing lanes with varying vehicle types: a vehicle towing a trailer (Experiment 1) and a sedan not towing a

trailer (Experiment 2). The purpose of these two experiments was to investigate the safety and operational efficiency of nine different speed reduction scenarios as well as that of a baseline scenario. The third experiment investigated whether the presence of traffic in passing lanes impacts how drivers respond to passive speed measures.

In addition to the driving simulator experiments, this study analyzes Idaho crash data from 2008 through 2012 in order to document the characteristics of passing lane crashes and compare them to the characteristics of crashes on other rural two-lane highway segments. Additionally, crash rates are also compared for three different highway segments: passing lane segments, merging segments, and downstream segments. The merging section is defined as the 0.5-mile segment immediately downstream of passing lanes, and the downstream segment is defined as the 0.5-mile segment following the merging segment.

Research Objectives

The research presented in this thesis has six research goal objectives:

1. Examine the effectiveness of regulatory and advisory speed reductions signs on the speed of vehicles travelling along the passing lane segment
2. Examine the effectiveness of passive speed reductions measures on the speed of vehicles travelling along the passing lane segment
3. Examine the effect of towing a trailer on lane position
4. Examine the impact of presence of traffic on the passing lane segment on the effectiveness of passing speed reduction measures
5. Document the characteristics of crashes on passing lane segments and compare them to the characteristics of crashes on two-lane highway segments
6. Compare crash rates at passing lane segments with crashes rates at merging segments and at downstream segments

Thesis Organization

This thesis is organized into six chapters. After the introduction, a comprehensive literature review is presented in Chapter 2. The literature review focuses on three main aspects of the research: passing lane safety and efficiency, effectiveness of passive speed reduction measures, and the use of driving simulator experiments in traffic-related studies. Chapter 3 documents the methodology for the driving simulator experiments. Chapter 4 presents the analysis and results of the driving simulator experiments. Chapter 5 describes a comprehensive crash analysis of reported crashes in the state of Idaho over a five-year period including a documentation of the passing lane crash characteristics and crash rate analysis. Finally, Chapter 6 discusses the research conclusions.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

This chapter describes the literature review performed over three broad sections involved with this research: passing lanes, pavement markings as passive speed reduction tools, and the use of driving simulators in highway safety and human factors research. Of note, the literature found contrasting views on whether passing lanes increase or decrease crash rates compared to other road segments.

An Overview of Passing Lanes

According to the American Association of State Highways and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets 6th Edition*, passing lanes are provided to reduce delay on long segments of highways typically six to 60 miles in length. Passing lanes implemented on rural two-lane highways provide increased traffic flow and reduce driver frustration without the cost of extensive road realignment or construction of four-lane highways (Charlton 2007). The passing lane should be installed at logical locations for the driver: on an uphill grade or where sight distance is limited (AASHTO). Passing lanes on uphill grades provide opportunities to pass heavy vehicles. Passing lanes on sections with limited sight distance, such as in rolling terrain, provide passing opportunities at a location where a driver would not be able to pass normally.

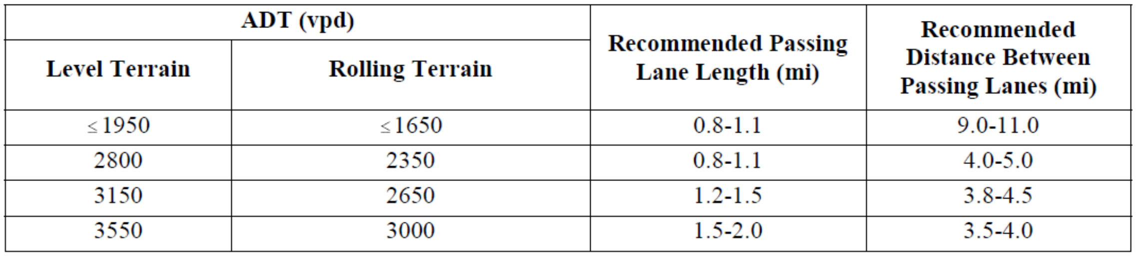
Passing lanes are added to provide more passing opportunities for motorists on conventional two-lane highways (Harwood et al. 1988). The Highway Capacity Manual 2010 (HCM) measures automobile LOS for two-lane highways as a function of either average travel speed (ATS) or percent time spent following (PTSF). Harwood et al. (1985) found that the platooning, or queuing, of vehicles was a more sensitive measure of traffic service than mean speed. They found that the percentage of vehicles in platoons decreased approximately 14% from upstream of a passing lane to within the passing lane. Intuitively, as the percentage of vehicles in platoons increases, the PTSF will also increase. Thus, by allowing more opportunities to pass, traffic operations will improve.

Passing Lane Design Considerations

Next, the design and safety analysis of passing lanes will be investigated further. Using data about the reduction in delay and cost, Harwood et al. (1985) developed a table for optimum passing lane lengths as a function of the one-way hourly flow rate. For example, the authors proposed that for a passing lane with an hourly flow rate of 200 vehicles, the optimum passing lane length is 0.50-0.75 miles. However, Harwood et al. (1985) did not consider varying terrain for its analysis.

Wooldridge et al. (2001) claim that passing lanes may be warranted on rural two-lane highways with average daily traffic (ADT) between 1,000 and 6,200 in both directions depending on terrain, cost, and LOS. Wooldridge et al. (2001) used the TWOPAS simulation model to produce the results of passing lane length and distance between passing lanes and is shown below in Table 1 below.

Table 1: Recommended Passing Lane Length and Distance between Passing Lanes



ADT (vpd)		Recommended Passing Lane Length (mi)	Recommended Distance Between Passing Lanes (mi)
Level Terrain	Rolling Terrain		
≤ 1950	≤ 1650	0.8-1.1	9.0-11.0
2800	2350	0.8-1.1	4.0-5.0
3150	2650	1.2-1.5	3.8-4.5
3550	3000	1.5-2.0	3.5-4.0

Table 1 suggests that terrain does have an effect on the recommended passing lane length and distance between passing lanes. For example, an ADT of more than 3,500 for level terrain and only an ADT of 3,000 for rolling terrain would yield the same recommended passing lane length: 1.5-2.0 miles. More than 500 fewer vehicles would warrant the same passing lane length and distance between passing lanes on rolling terrain vs. level terrain.

Heavy Vehicle Operations

Heavy vehicles, including trucks, can have an adverse effect on highway safety. A study along Interstate 84 in Idaho and Utah concluded that passenger cars have consistently higher speeds and standard deviations than trucks in ideal weather conditions (Liang et al. 1998). The study reported that the average speed for trucks and cars in ideal weather conditions was 67 mph and 63 mph, respectively, and went on to conclude that the standard deviation of passenger car speeds was also higher than trucks. Garber and Gadiraju (1998) found that crash rates increase as speed variation, or standard deviation, increases. So, with the increase of speed variation between trucks and cars, crash rates will increase.

A study conducted along five two-lane, rural highways in California (May 1991) analyzed traffic performance on passing lanes with varying flow rates, grades, and heavy vehicle percentages, including RVs. May (1991) found that as the percent grade of a passing lane increases, the average number of passes decreases. This could be contributed to vehicle performance on grades. May (1991) went on to show that of the three sites with grades exceeding 4%, the highest number of passes occurred on the site with the largest heavy vehicle percentage. Thus, drivers desire to pass the heavy vehicles in the passing lane increases with grade and percentage of heavy vehicles.

Passing Lane Safety

Some studies found that passing lanes and short, four-lane cross sections of rural highway decrease the rate of accidents compared to conventional two-lane highways. Harwood et al. (1985) found that the mean accident rate for 66 passing lane sites was approximately 1.04 accidents per million vehicle miles (MVM), whereas the mean accident rate for non-passing lanes was 1.57 accidents per MVM. Another study by Harwood et al. (1988) found that, overall, passing lanes decreased accident rates by 25% and decreased fatal accident rates by 30%. Additionally, Taylor and Jain (1991) concluded that crash rates on low, medium, and high traffic volumes passing lanes were all lower than conventional highways with low, medium, and high traffic volumes without passing lanes.

The magnitude of crash reduction that can be attributed to passing lanes varies throughout the literature. Rinde (1977) found that there was a 42% reduction in all accidents on level and rolling terrain with passing lanes compared to conventional two-lane highways with similar terrain. Harwood and St. John (1984), however, found that there was only a nine percent reduction in all accidents on level and rolling terrain with passing lanes compared to conventional two-lane highways with similar terrain. Rinde (1977) analyzed passing lanes with a total roadway width that varied from 36 feet to 44 feet. Harwood and St. John (1984), on the other hand, analyzed passing lanes with a total roadway width that varied from 40 feet to 48 feet. Based on these two studies, it can be concluded that as the roadway width increases, the effect passing lanes have on the reduction of all accidents decreases.

Not all of the studies concluded that passing lanes will reduce crash rates compared to road segments without passing lanes. Gattis et al. (2006) found that of 19 passing lane sites in Arkansas, the crash rates were usually less than the statewide average crash rate for two-lane rural roads. However, there were cases where passing lane sites actually increased the average crash rate compared to the statewide average. Gattis et al. (2006) went on to conclude that the severe injury rate was actually higher in passing lanes compared to rural two-lane highways across the state.

Pavement Markings

Road markings are physical treatments on the surface of the road that provide regulatory warning information to the driver (Castro 2009). The literature has found that pavement markings are quite effective at reducing the speed of drivers. This section will present an overview of various pavement markings that have been used to impact driver behavior.

Force Right

May (1991) studied a force right pavement marking to encourage drivers to move into the right lane at the beginning of the lane-addition taper. A force right consists of a pavement marking in the left lane of the passing lane that encourages drivers to merge right at the beginning of the passing lane. The study found that before the pavement marking was implemented, 80% of vehicles entered directly into the left, passing lane; however, after the force right pavement marking was installed, 80% of vehicles remained in the basic, right lane.

Chevrons

According to *Public Innovation Aboard*, converging chevron pavement markings were installed on the Yodogawa Bridge in Japan. Over a six-month period before the chevrons were installed, there were 10 accidents on the bridge, including two fatalities. However, in the same time period after the installation of the chevrons, there were no accidents involving injuries reported. Overall, chevron pavement markings may reduce crashes 25% to 50% (Griffin and Reinhardt 1995). Griffin and Reinhardt (1995) go on to say that the high cost of chevron installation—$90,000—may be offset by the six-year service life and drastic reduction in crashes.

Transverse Bar

Denton was one of the first to study the effect of transverse bar pavement markings pattern (Griffin and Reinhardt 1995). Denton (1971) found that mean and 85th percentile speed were reduced more than 20% after installation of transverse bar pavements markings on a high-speed approach to a roundabout. Agent (1980) found an average speed reduction of more than 12 mph along a high-speed horizontal curve, and the percentage of drivers exceeding the speed limit decreased by 50%.

The most extensive study on transverse line pavement markings and its effect on crash reductions was performed by Helliar-Symons in 1981 (Griffin and Reinhardt 1995). Helliar-Symons (1981) found that the total crashes were reduced by approximately five percent.

The effectiveness of the transverse line pavement markings varied throughout the research. Havell (1983) found that the markings were effective for many months. However, Marony and Dewar (1987) found that the effectiveness of the markings would deteriorate within a few days or weeks. Additionally, Enuston (1972) found that transverse bars had no effect on speed. Even if the effectiveness of the markings is not long term, the low cost of installation—$4,000—and service life of five years may make the transverse bars attractive for some agencies (Griffin and Reinhardt 1995).

The Use of Driving Simulators in Highway Research

A study by Kemeny and Panerai (2003) found that the use of driving simulators in research is expanding rapidly. While saving time and money, driving simulators can study road and traffic safety without subjecting the public to dangerous situations.

Godley et al. (2000) used logarithmically decreasing transverse markings to study driving behavior in a simulator. The researchers found an average speed reduction of almost six mph when using the logarithmically decreasing transverse markings on a high-speed approach to a rural intersection. Charlton (2007) used three desktop computers of a low-fidelity driving simulator to model driving behavior throughout passing lanes. The data from the simulation showed that speeds were within 10% of field conditions. Additionally, Charlton (2007) concluded that a continuity line—similar to a force right pavement marking—reliably moved drivers into the basic lane.

CHAPTER 3: DRIVING SIMULATOR METHODOLOGY

This chapter describes the methodology behind the driving simulator used to test the various passing lane scenarios. First, a background section explains the general concept of the research. Then, the 10 passing lane scenarios are described. Next, the driving simulator is reviewed. Then, each experiment is described with the goals for each clearly defined. Finally, the output data are discussed, including the data used for these analyses.

Background

To evaluate the efficacy of the various passing zone scenarios on driving behavior, a sample of participants were tested using a driving simulation of a two-lane rural highway through the Alaskan countryside. The first goal of the simulation was to familiarize participants with the responsiveness of the driver simulator. Participants were exposed to a 50-mile track. Additionally, participants had the opportunity to get familiar with the simulator for approximately five minutes before any data collection began. This would allow the test subjects to become accustomed with the sensitivity of the acceleration pedal, brake pedal, and steering wheel so that more accurate data were collected during the actual testing procedure.

The second goal of the simulation was to analyze the effects of various passing lane scenarios on two types of drivers: those towing an RV or trailer and those driving a sedan not towing a trailer. Experiment 1 examined drivers towing a RV, while Experiment 2 examined sedan, non-towing, drivers. Different traffic scenarios were developed for these two categories of drivers and slightly different instructions were provided in order to implicitly induce the trailer-towing drivers to use the right lane of passing zones to let vehicles pass and the non-towing drivers to use the left hand lane and attempt to pass slower traffic.

Participants were treated in accordance with a University-approved protocol governing the use of human subjects in research. Appendix G contains the letter from the University of Idaho Office of Research Assurances Institutional Research Board approving the study on human subjects for the driving simulator.

Passing Lane Scenarios

10 different passing lane scenarios were developed to test driver behavior: one control and nine tests. The nine scenarios consisted of various pavement markings, signage, or external posts on the side of the road. Each passing lane scenario had a minimum of five signs that remained constant—the description of each is listed below.

The passing lane was divided into three sections. Section one was the portion of the passing lane with 660 foot lane-addition taper forming. Section two was the one-mile, two-lane portion of the passing lane. Finally, section three was the portion of the passing lane with a 660 foot lane-reduction taper.

In advance of each passing lane scenario, two regulatory signs were shown to provide drivers information about the passing lane. The first sign, a R4-6b from the Manual on Uniform Traffic Control Devices (MUTCD) is shown in Figure 1 below and placed 0.5 miles in advance of the passing lane. The second sign, a R4-16 from the MUTCD, shown in Figure 2 below, was placed at the beginning of the lane-addition taper.

Figure 1: R4-6b Sign
(Source: MUTCD 2009)

Figure 2: R4-16 Sign
(Source: MUTCD 2009)

At the end of each passing scenario, at least two warning signs were shown to provide drivers information about the lane-reduction taper. The first sign, a W9-1 from the MUTCD, is shown in Figure 3 below. A warning sign was placed at the beginning of the lane-reduction taper. The second and third signs, either a W9-2 and/or W4-2R from the MUTCD, are shown in Figures 4 and 5 below.

Figure 3: W9-1 Sign
(Source: MUTCD 2009)

Figure 4: W9-2 Sign
(Source: MUTCD 2009)

Figure 5: W4-2 Sign
(Source: MUTCD 2009)

Two signs were positioned for the opposing lane of traffic. Although drivers were not specifically exposed to these signs, they were included in the simulation. The first sign, a modified R4-1, was placed at the end of the lane-reduction taper for the opposing direction of traffic. The second sign, a modified W6-3 sign, was placed at the midpoint of the passing lane section for the opposing lane of traffic. Both of these signs are not standard MUTCD signs and are therefore designated as “modified.” The standard R4-1 MUTCD sign reads “*DO NOT PASS*,” whereas the sign used in the simulation reads *“DO NOT PASS WHEN OPPOSING TRAFFIC.”* The standard W6-3 MUTCD sign only has two arrows: one for each direction of travel, whereas the sign in the simulation has three arrows: two arrows to represent the flow of traffic in the two-lane passing section and one arrow to represent the flow of traffic in the opposing-lane section.

A schematic for each of the 10 passing lane sections is shown below in Figures 6 through 15. The section after the passing lane figures describes each passing lane scenario in greater detail. If pavement markings were present on a passing lane scenario, they were only included in the right lane of section two. Additionally, it should be noted that none of the figures have their geometry to scale.

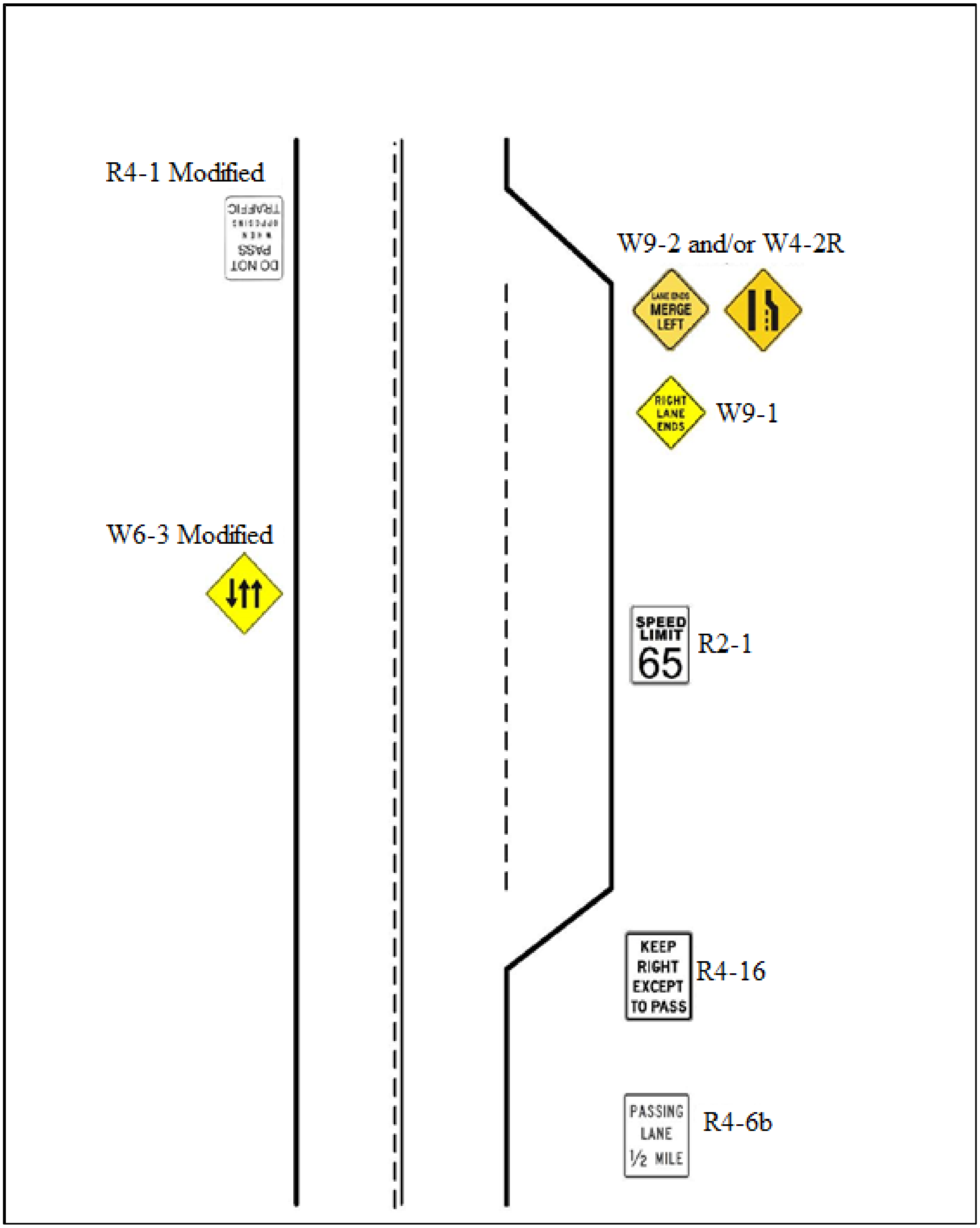


Figure 6: Scenario 0 (Baseline)

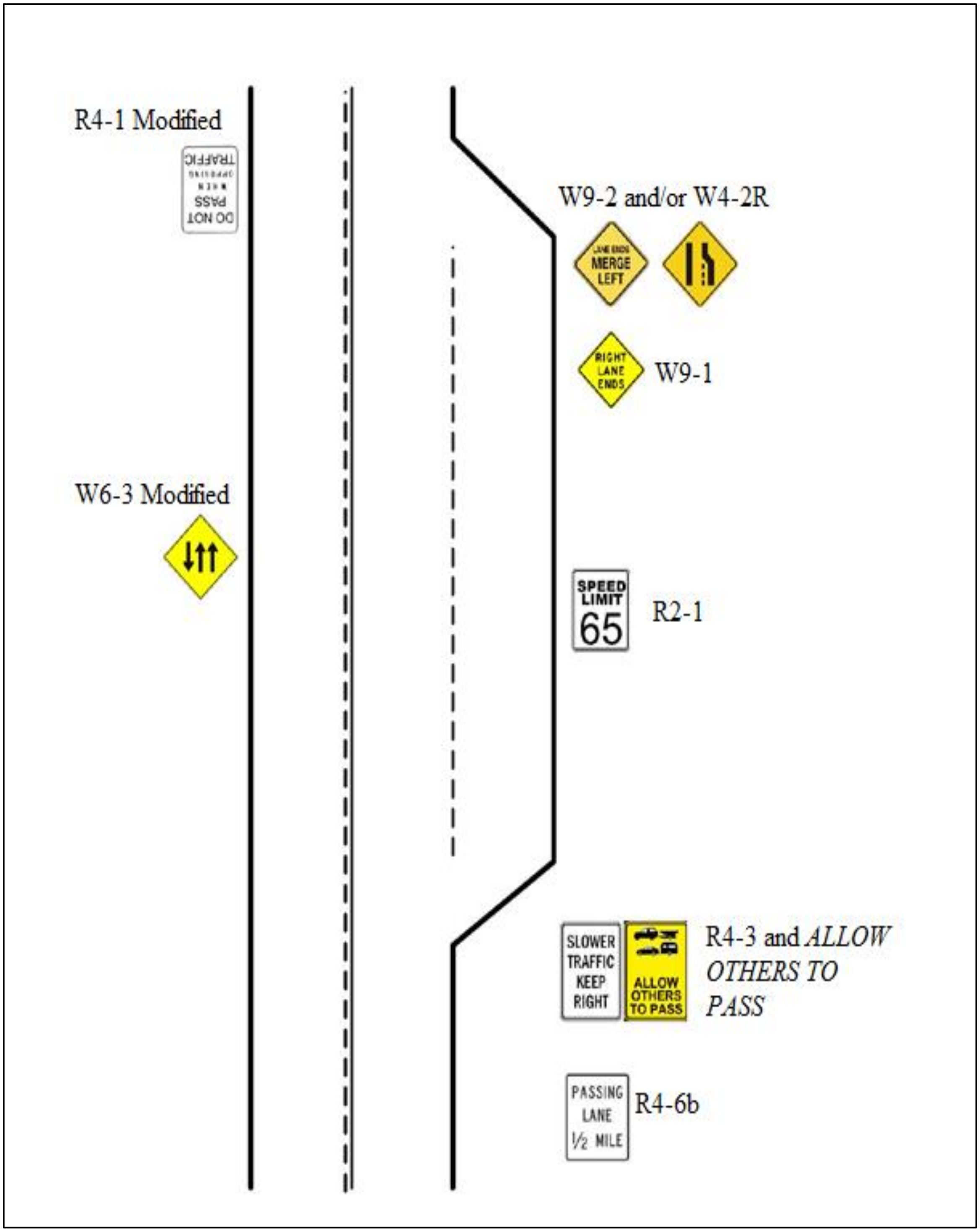


Figure 7: Scenario 1 (Advisory)

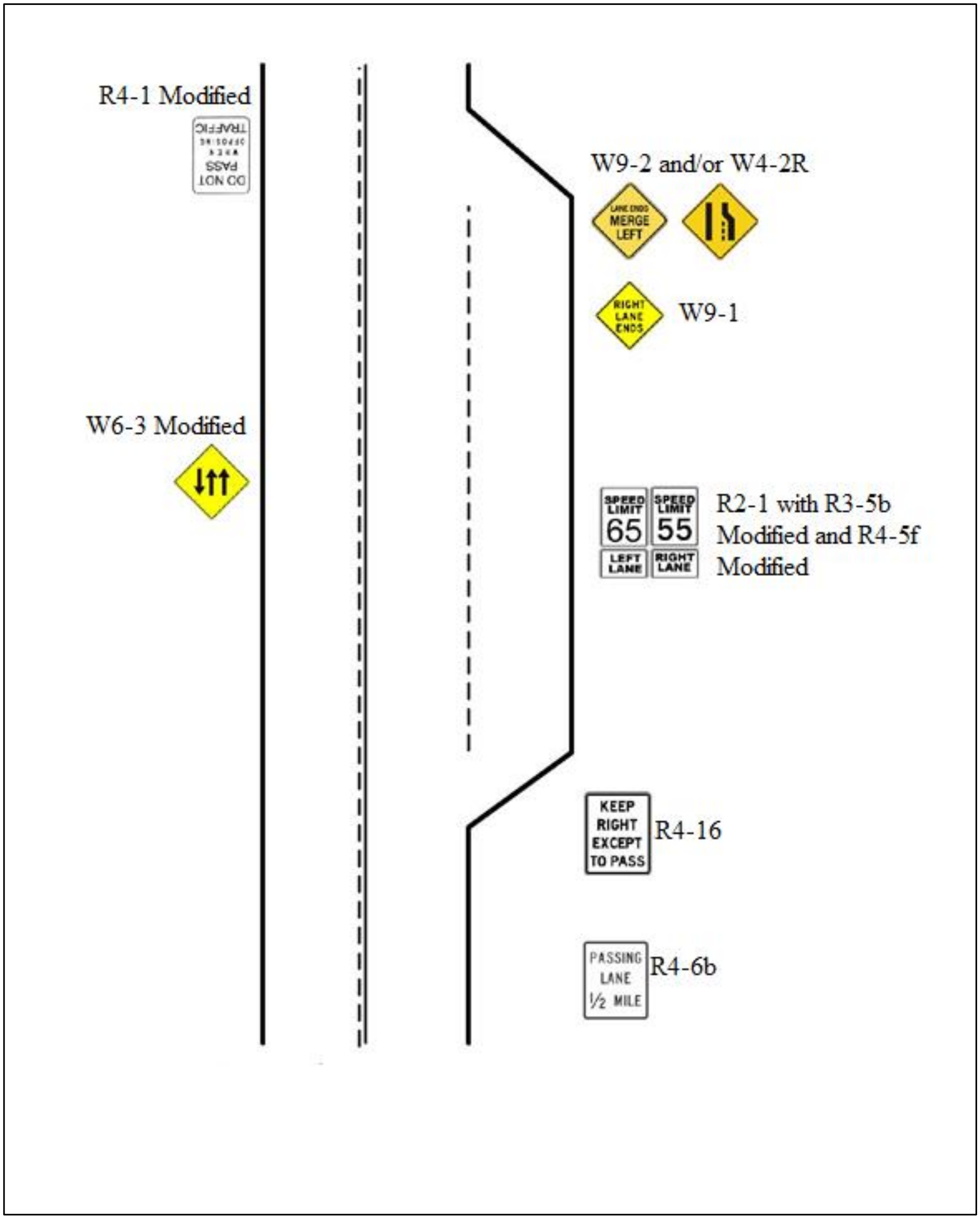


Figure 8: Scenario 2 (Regulatory)

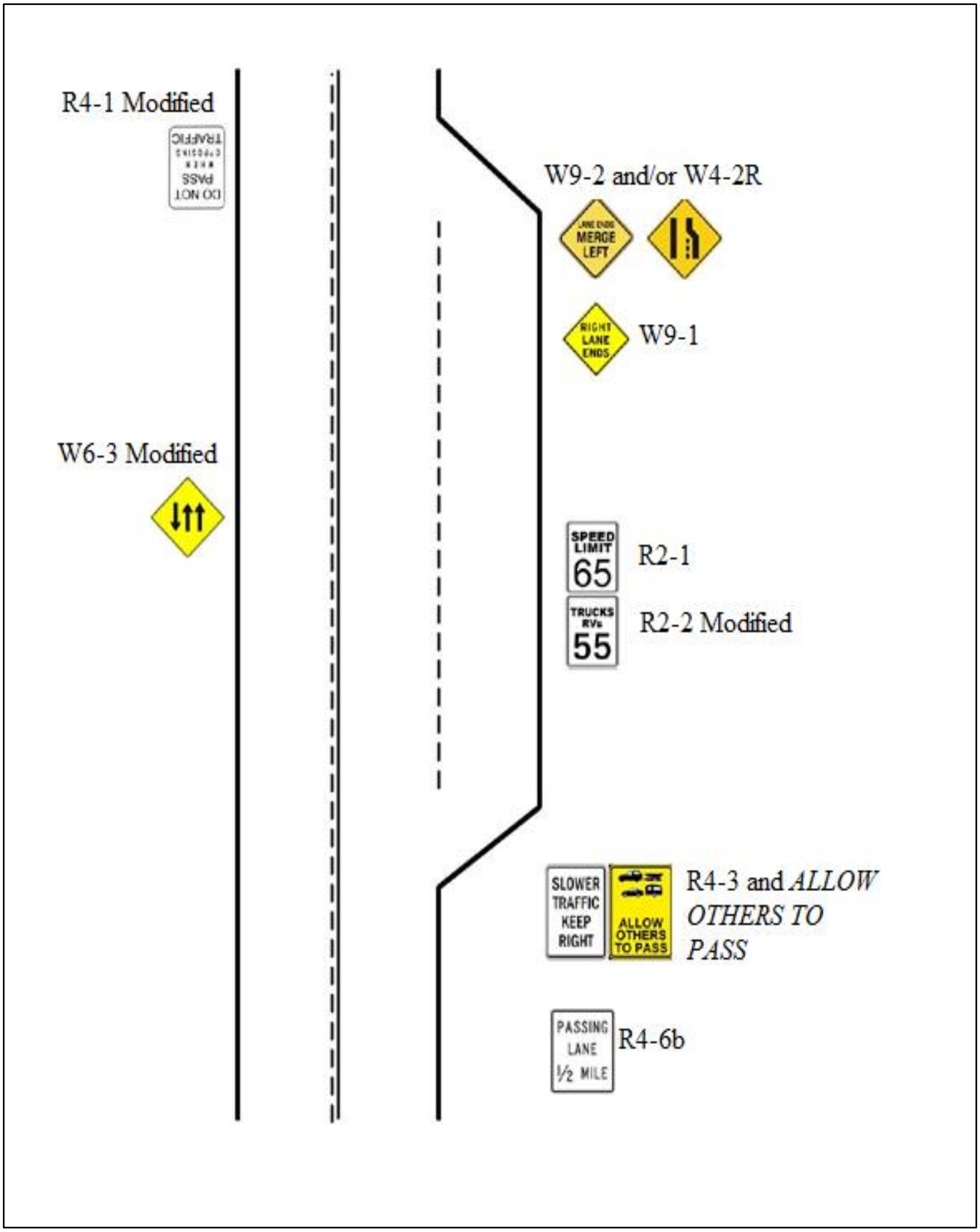


Figure 9: Scenario 3 (Regulatory plus Advisory)

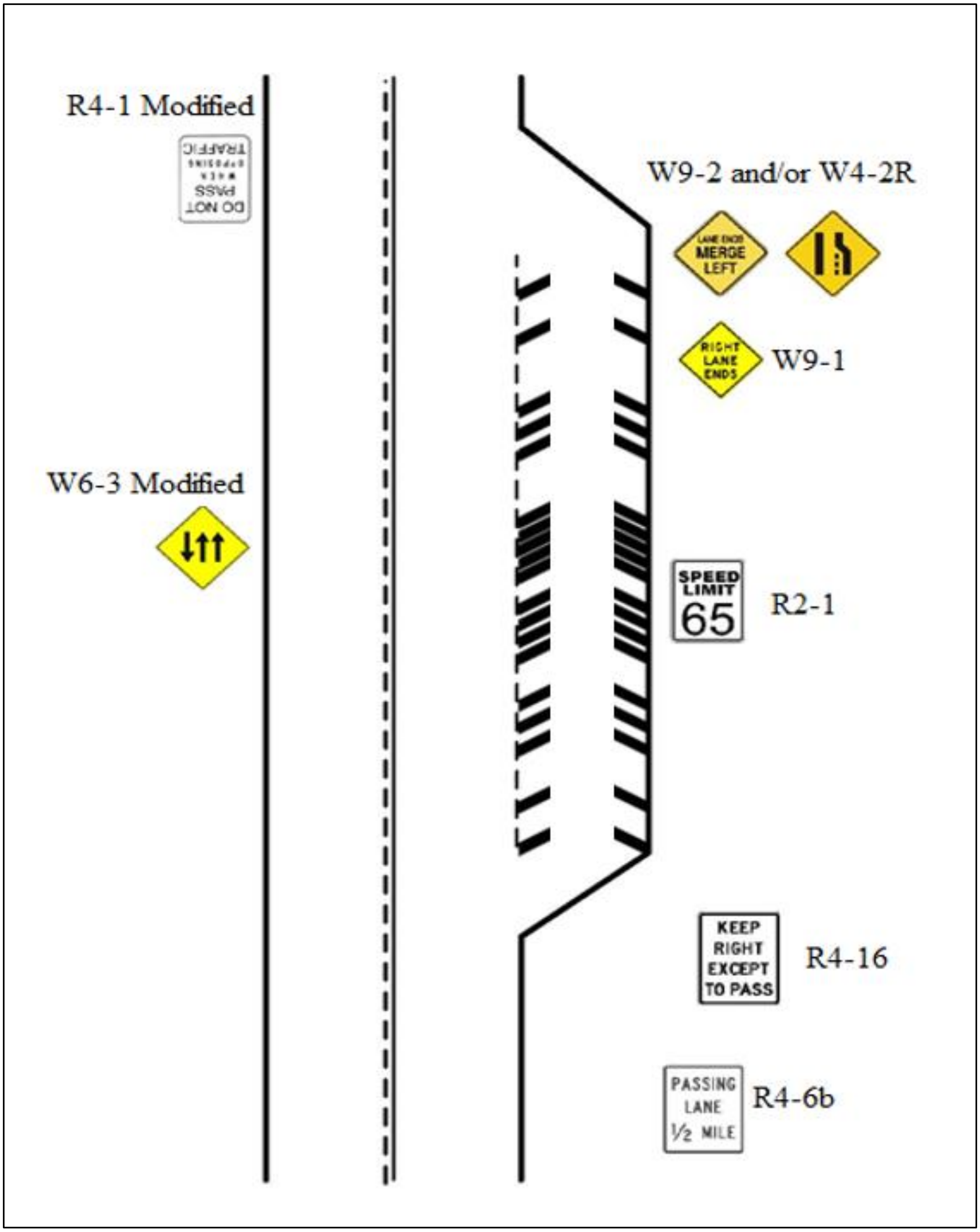


Figure 10: Scenario 4 (Chevrons)

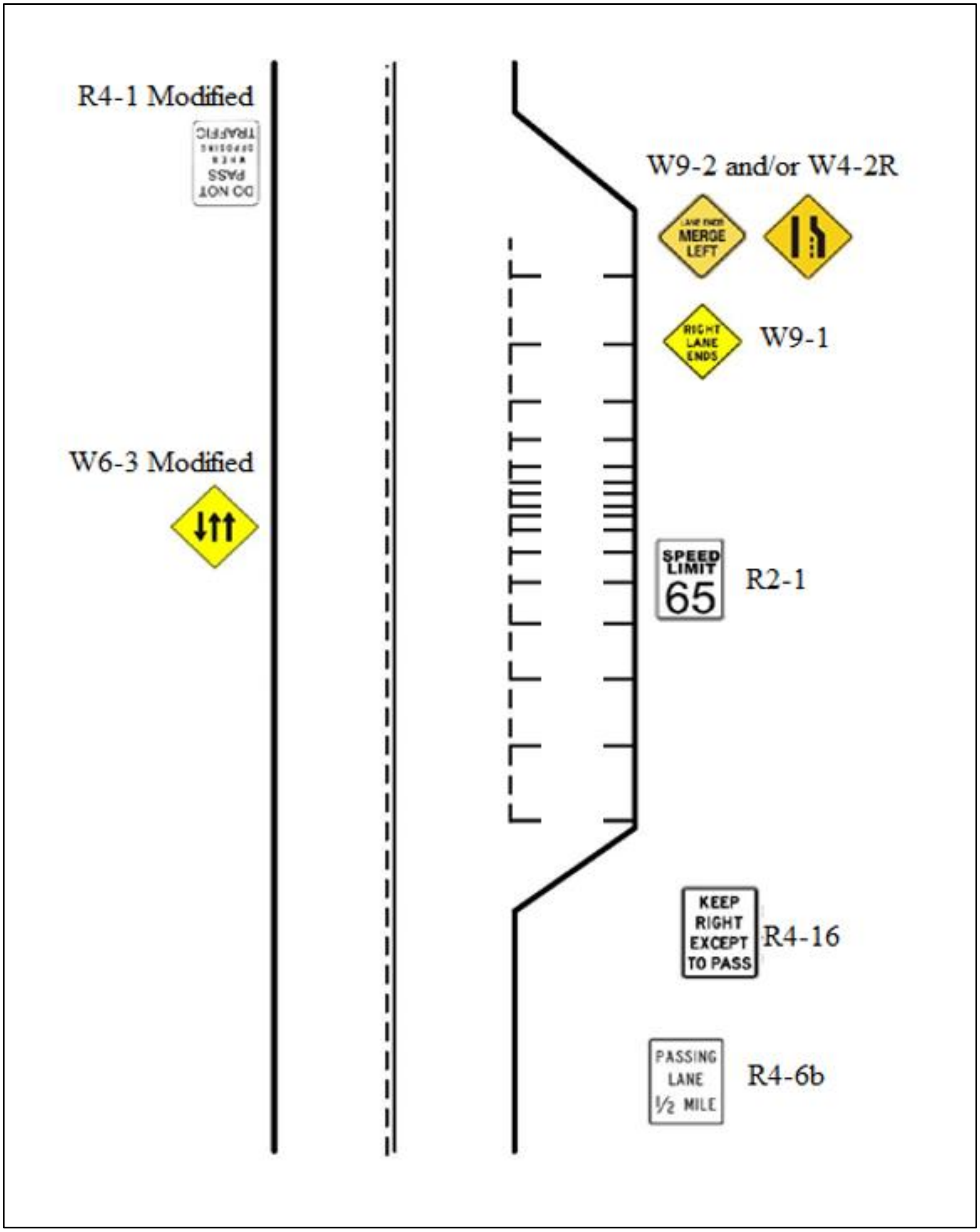


Figure 11: Scenario 5 (Lines)

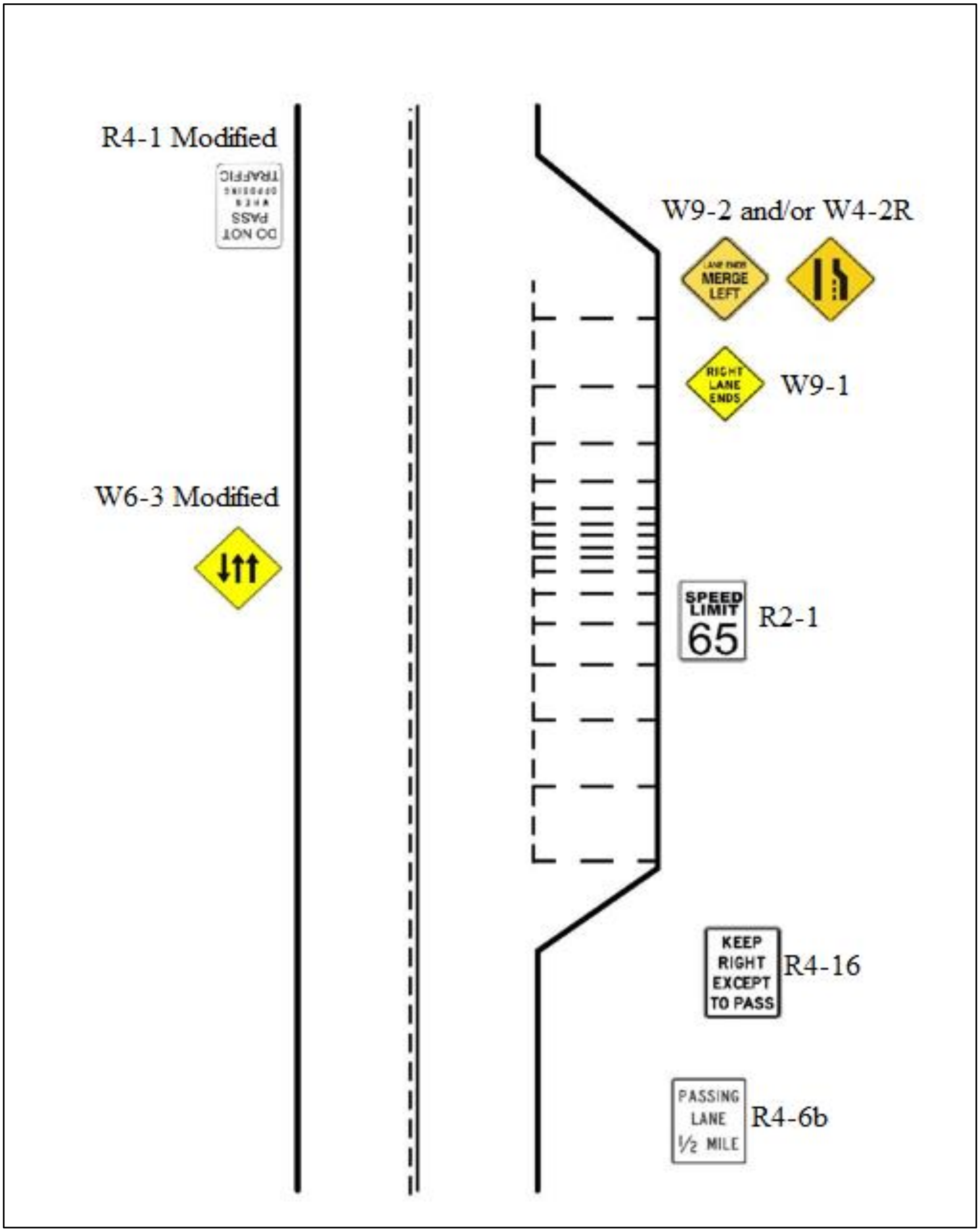


Figure 12: Scenario 6 (Lines without Middle)

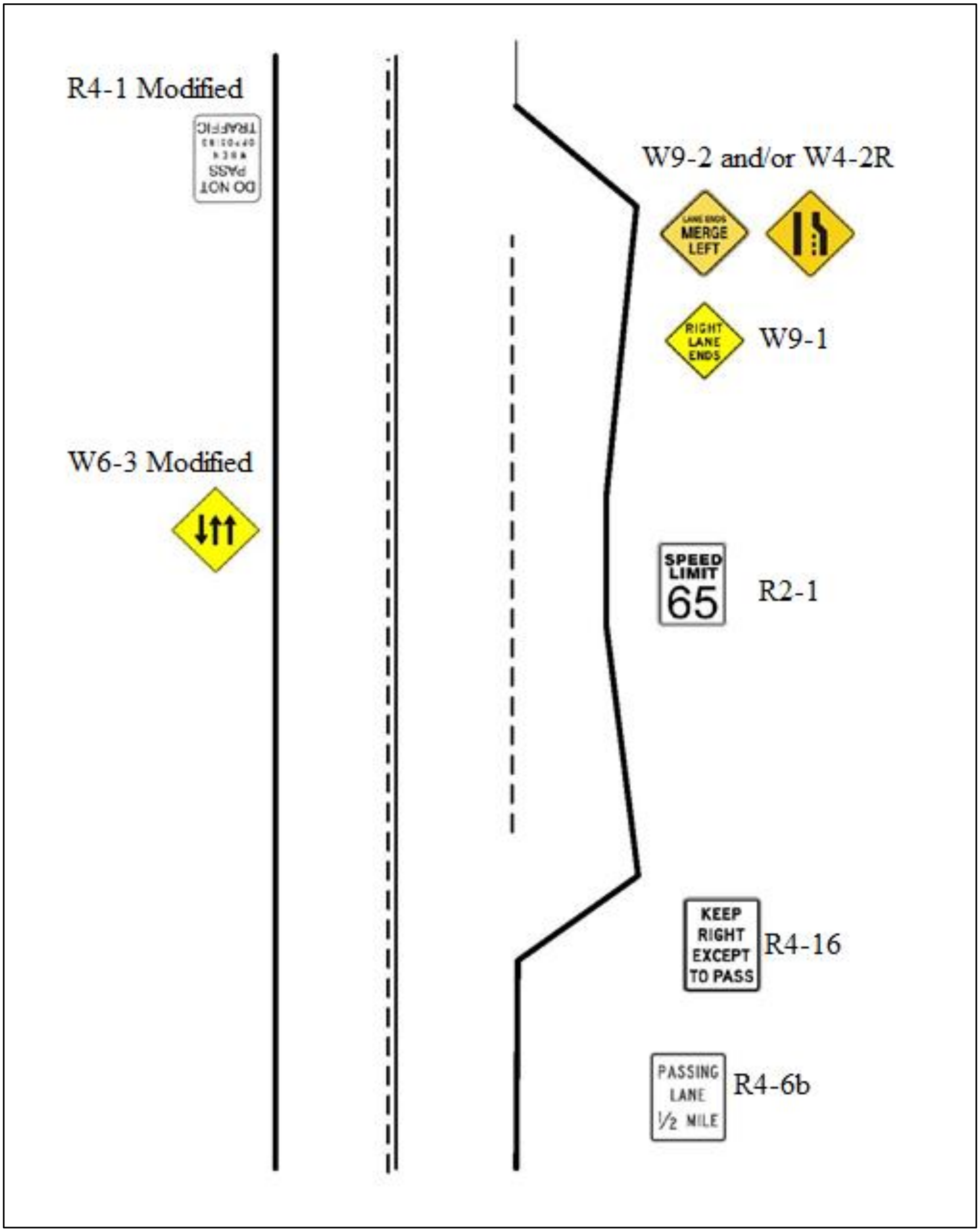


Figure 13: Scenario 7 (Narrowing)

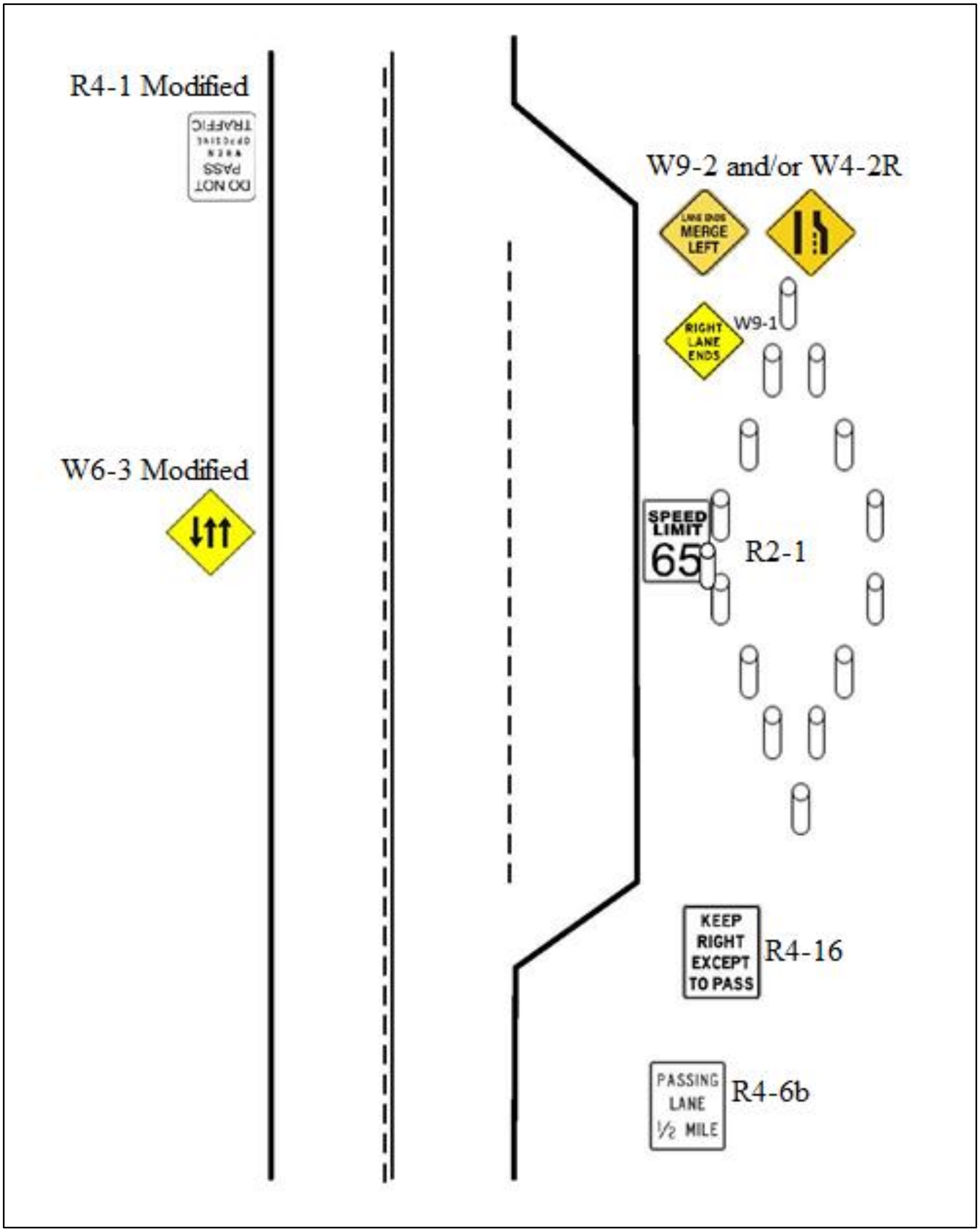


Figure 14: Scenario 8 (Parallax)

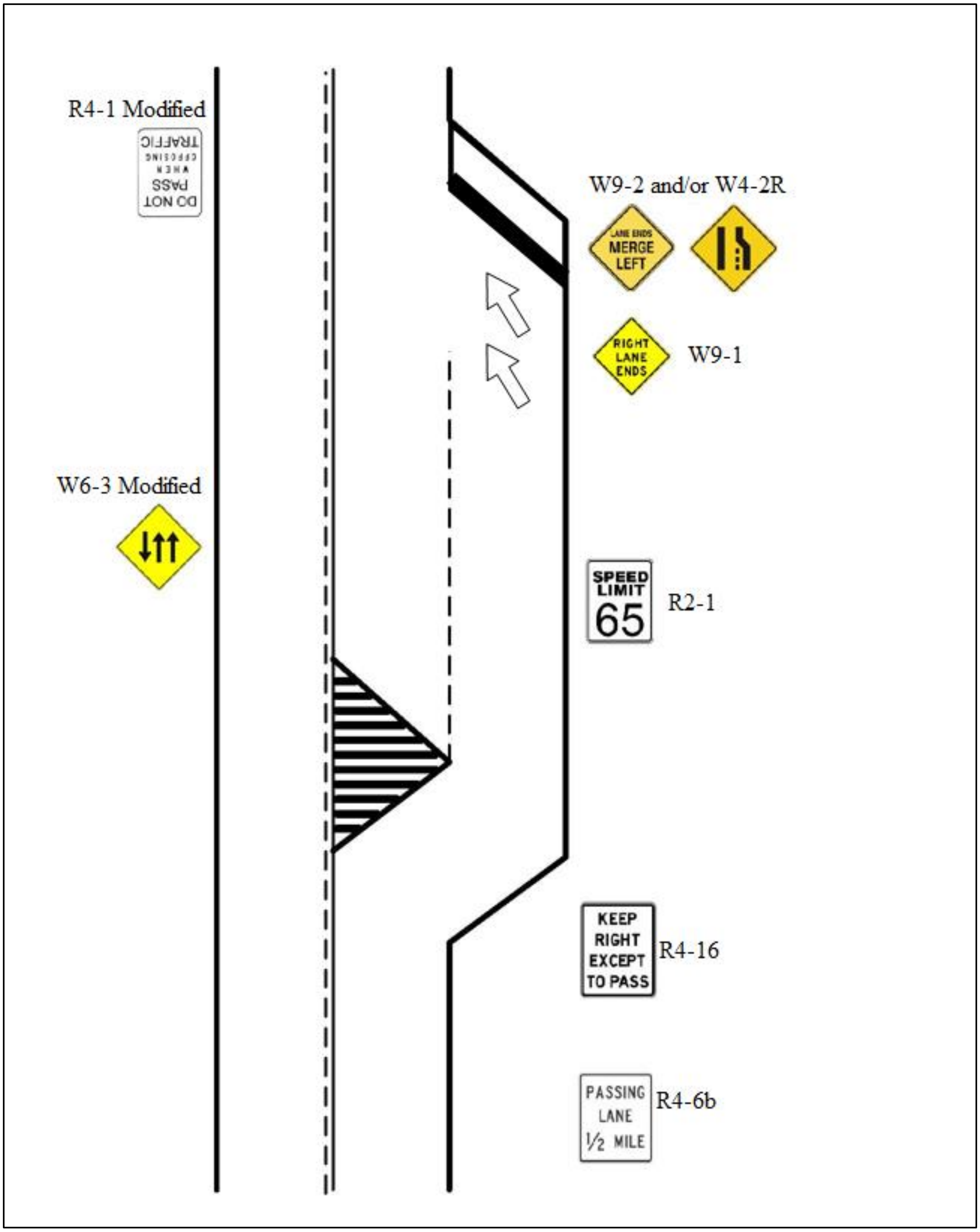


Figure 15: Scenario 9 (Force Right/Neutral Zone)

Scenario 0 (Baseline)

This scenario simulated what the default conditions of a passing lane are. All of the other passing lane treatments were compared to this baseline.

Scenario 1 (Advisory)

This scenario was identical to the baseline except for the implementation of an added advisory sign “ALLOW OTHERS TO PASS” to the existing R4-3 sign.

Scenario 2 (Regulatory)

This scenario was identical to the baseline except the speed limits for each lane were set at 65 mph for the left lane and 55 mph for the right lane and signed accordingly.

Scenario 3 (Regulatory plus Advisory)

This scenario was identical to Scenario 1 except for the implementation of an added speed limit of 55 mph for trucks and RVs with the existing speed limit sign of 65 mph.

Scenario 4 (Chevrons)

This scenario was identical to the baseline except for partial chevron markings added to the pavement. The chevron markings consisted of a group of approximately six inch-wide, white lines spaced two inches apart. The spacing between the groups was reduced by a factor of 0.988 over 0.25 miles until the spacing reached 26.8 feet between the 38th and 39th chevron group. Then, the spacing remained constant at 26.8 feet between each chevron group for 0.5 miles. Finally, the spacing increased over the last 0.25 miles at a factor of 1.012 until reaching 42 feet for the last five chevron groups. The spacing of the chevron groups was selected to be logarithmically increasing or decreasing over the initial 0.25 mile section or final 0.25 mile section.

Scenario 5 (Lines)

This scenario was identical to Scenario 4 except instead of chevrons, white lines were added to the pavement. The white lines, however, did not extend across the entire lane width. Instead, the lines would extend two feet from the lane edges into the lane, leaving an eight-foot gap in the middle of the lane. The spacing of the lines was identical to the spacing described for the chevrons in Scenario 4.

Scenario 6 (Lines without Middle)

This scenario was identical to Scenario 5 except an additional line was added in the center of the pavement. Each line was divided into six segments: a two-foot painted white line, a three-foot space, a two-foot painted white line, a three-foot space, and a two-foot painted white line.

Scenario 7 (Narrowing)

This scenario was identical to the baseline except the right-lane width varied throughout the passing lane section. The right lane started at 12 feet in width at the beginning of section two. Then, it decreased linearly over 0.25 miles to 10 feet. Next, the right lane stayed fixed at 10 feet in width for the middle 0.5 miles. Finally, the right lane increased linearly to 12 feet over the last 0.25 miles.

Scenario 8 (Parallax)

This scenario was identical to the baseline except 10-foot tall, yellow posts were installed off of the side of the road and spaced to create a parallax effect. The posts were four inches in diameter and spaced exactly like the chevrons in Scenario 4.

Scenario 9 (Force Right/Neutral Zone)

This scenario was identical to the baseline except a pavement marking was placed in the left lane at the beginning of the passing lane section that encouraged drivers to move to the right lane first. Also, two left pavement arrows were placed near the end of section two in order to encourage drivers to merge sooner. Additionally, a rumble strip extended at an angle across the pavement was installed in advance of the lane ending to further alert drivers to move merge left.

The Driving Simulator

The same driving simulator was used for all three experiments. A seven-video channel National Advanced Driving Simulator (NADS) MiniSim rendered the simulations and collected the behavioral data of the participants. Participants drove the simulations from a truck cab based on a 2001 Chevrolet S10 pick-up truck. The cab of the truck was positioned so 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 horizontal by 1050 pixels vertical.

Screens were also installed to simulate a participant looking behind them in the side mirrors and rear-view mirror. Eight-inch liquid crystal display (LCD) screens, each with a spatial resolution of 800 pixels horizontal by 600 pixels vertical, were mounted to the left and right side rearview 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 horizontal by 720 pixels vertical resolution—the refresh rate of this screen was also 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 horizontal by 800 pixels vertical. This display screen was mounted in place of the normal mechanical analog instrument cluster of 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 displays. This video adapter also rendered the dashboard and right side-mirror displays. A GeForce GTX660TI video adapter rendered the left side-mirror and center rearview mirror displays. Finally, 4.1-channel audio system used the four speakers mounted in the cab doors and a sub-woofer mounted behind the driver's seat to produce automobile and road noise.

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 16 below shows an overhead view of the truck cab with the three main projection screens and right-side mirror display. The left-side mirror display, rear-view mirror display, and dashboard instrument display are not visible in the figure.

Figure 16: Cab with Projected Screens

Experiment 1 Description

The goal of Experiment 1 was to encourage trailer-towing drivers to transition to the right lane of a passing lane section and reduce their speed so other vehicles could pass them in the left lane. This section describes the procedure, simulated traffic, and participant information for Experiment 1.

Procedure

Participants were treated in accordance with a University-approved protocol governing the use of human subjects in research. Prior to participation, all participants were read a general description of the study, warned of the risks involved, and asked to sign a consent form. The only tangible risk for these experiments was motion sickness encountered while driving in the simulator. Next, the instructions listed in Appendix A were read to participants. These instructions emphasized that participants should imagine themselves driving on a rural Alaskan highway and that they should act normally in obeying traffic laws and driving etiquette.

To ensure all participants had a firm understanding of the signs that were displayed in this experiment, participants were given a multiple choice sign quiz shown in Appendix B. The quiz included questions on familiar signs as well as new signs developed for the experiments. If any questions were missed, the correct response was explained to participants to ensure understanding before proceeding on to the next sign.

Following the sign quiz, participants were given a five-minute test drive on a rural two-lane stretch of road with horizontal and vertical curves in order to familiarize themselves with the simulator and the sensitivity of the controls. Once participants were comfortable with the controls, the experiment began. At approximately half way through the track, a message appeared on the main screen informing the participant to pull off on the shoulder for a break. During this break, participants were asked to exit the simulator and walk around for a few minutes to stretch their legs. Participants then completed the last 25 miles of the track. After the simulation was completed, participants were asked a number of debriefing questions aimed to assess the immersive quality of the simulation. For example, drivers were asked about their degree of fatigue or motion sickness experienced during the experiment, whether participants noticed our experimental manipulations, and what hypotheses they may have formed as to the nature of the experiment. Following these questions, participants were informed about the details of the study.

Simulated Traffic

Traffic in the participants’ direction of travel was specifically designed to induce a feeling of following traffic pressure. In each highway segment between passing lane sections, a new set of nine vehicles was created out of view both ahead and behind the participant’s vehicle. Two leading vehicles were scripted to maintain a speed of 45 mph until the participant's vehicle caught up to them, at which time they increased their speed to maintain gaps of 600 feet and 1000 feet in front of the participant’s vehicle. These gaps were small enough to induce a feeling of driving in traffic, but also far enough ahead that the trailer-towing drivers would not feel pressured to try to pass. The seven following vehicles were scripted to induce pressure on our trailer-towing drivers to allow them to pass. These vehicles were scripted to drive at moderately high speeds to catch up to the participant's vehicle, at which time they maintained gaps of only 100 feet between vehicles. Thus, the seventh vehicle followed the participant's vehicle at a distance of 700 feet. Once the participant reached a passing zone and pulled into the right-hand lane, the following vehicles accelerated to 74 mph to pass. To discourage participants from driving too fast, a simulated police siren sounded whenever their speed exceeded 75 mph.

Participant Information

A total of 33 participants with valid driver's licenses were tested for this experiment. Three participants failed to complete the experiment due to motion sickness; their data were excluded from the analysis. Participants included 20 students from the University of Idaho, and the remaining 10 participants were recruited using an online advertisement and were compensated $30. All participants wore corrective lenses if they were required to wear them while driving. Participants had an average age of 29.7, ranging from age 18 to 62, with an average of 14.4 years of driving experience. Additionally, 57% of participants had previous experience pulling a trailer.

Experiment 2 Description

The goal of Experiment 2 was to document any differences in driver behavior between trailer-towing drivers and non-trailer-towing drivers.

Procedure

Again, participants were treated in accordance with a University-approved protocol governing the use of human subjects in research. The same protocol used in Experiment 1: participants were read the instructions, given a quiz over the various signs used in the simulation, and were able to familiarize themselves with the simulator and track for a few minutes prior to data collection. If any questions were answered incorrectly on the sign quiz, the correct response was explained to participants to ensure understanding before proceeding on to the next sign.

Participants were instructed to imagine they were heading home from a recreational weekend in the Alaskan countryside and—perhaps most importantly—that they were in a hurry to get home. Additionally, participants were instructed to obey traffic regulations, advisories, and etiquette in a manner they normally would while driving in a hurry. The full instructions for Experiment 2 are listed in Appendix C.

Simulated Traffic

The traffic in Experiment 2 was designed differently than that of Experiment 1. Traffic in the participant's direction of travel was specifically designed to induce pressure for participants to pass other vehicles. In each section between passing lane sections, a new set of nine vehicles was created out of view both ahead and behind the participant's vehicle. Seven leading vehicles were scripted to appear ahead of the participant's vehicle and drive 45 mph until the participant caught up to them. Then, the vehicles maintained a specific distance headway of 100 feet between each of the leading vehicles and 200 feet from the participant. Thus, the first of the leading vehicles was 800 feet from the participant, and the seventh of the leading vehicles—the last in the leading vehicle platoon—was only 200 feet from the participant. At the start of each passing zone, the leading vehicles turned on their right-turn signals and pulled into the right-hand lane. Additionally, the vehicles maintained a constant speed of 65 mph, regardless of passing zone scenario or the participants' behavior. The two following cars were scripted to maintain distance headways of 600 feet and 1000 feet behind the participant's vehicle until it exited the passing zone, at which point these vehicles pulled to the side of the highway. Again, to discourage participants from driving extremely fast, simulated police sirens sounded whenever their speed exceeded 85 mph.

Participant Information

Fewer participants were available for Experiment 2; as a result, only 23 participants with valid driver's licenses were tested for this experiment. Three participants failed to complete the experiment due to motion sickness and were excluded from the analysis. Participants included 14 students from the University of Idaho, and the remaining six participants were recruited an online advertisement and compensated $30. All participants wore corrective lenses if they were required to wear them while driving. Participants had an average age of 25.1 years, ranging from age 19 to 47, with an average of 9.2 years of driving experience.

Experiment 1 and Experiment 2 Common Inputs

This section describes the inputs that were identical for both experiments including the simulated track layout, passing lane order, and wind effect.

Simulated Track Layout

Participants drove a simulated 50-mile track representing a two-lane rural highway with 10 passing lane sections sporadically distributed every three to four miles. The passing lane sections consisted of a straight, flat roadway; there were no horizontal or vertical curves. The road between the sections included horizontal and vertical curves, as well as flat sections. For each passing section, there were 0.125-mile lane-addition and lane-reduction tapers at the beginning and end of the passing lane, respectively. A white-dashed skip line separated the one-mile, two-lane passing section. A solid yellow with yellow skip line was used for the median striping; opposing vehicles were allowed to pass if there was an available gap in the left passing lane. However, vehicles in the left passing lane could not pass on the left.

Passing Lane Order

Each participant encountered each of the 10 of the scenarios exactly once throughout the simulated track. However, the order of the passing lane scenario varied between participants. A unique counter-balanced order was developed so that each scenario occurred just as often in each place of the order and preceded and followed every other scenario an equal number of times. Table 2 below shows the order of the passing lane scenarios presented to each participant. For example, Scenario 1 only followed Scenario 0 only once, and Scenario 1 preceded Scenario 2 only once. From Table 2, it can be seen that participants 1, 11, and 21 all started with the Baseline Scenario and drove Scenario 1 as their second passing lane segment.

Table 2: Order of Passing Lane Scenario by Participant

Participant	Order of Passing Lane Scenario Presentation (Left to Right)									
1, 11, 21	0	1	9	2	8	3	7	4	6	5
2, 12, 22	1	2	0	3	9	4	8	5	7	6
3, 13, 23	2	3	1	4	0	5	9	6	8	7
4, 14, 24	3	4	2	5	1	6	0	7	9	8
5, 15, 25	4	5	3	6	2	7	1	8	0	9
6, 16, 26	5	6	4	7	3	8	2	9	1	0
7, 17, 27	6	7	5	8	4	9	3	0	2	1
8, 18, 28	7	8	6	9	5	0	4	1	3	2
9, 19, 29	8	9	7	0	6	1	5	2	4	3
10, 20, 30	9	0	8	1	7	2	6	3	5	4

Wind Effect

Each passing zone also included a pseudo-random headwind or tailwind disturbance profile to induce participants to make accelerator pedal movements in order to maintain constant speed. The wind disturbances profiles were defined by five separate velocities: a strong head-wind of 100 mph, a head-wind of 50 mph, no wind, a tail-wind of 50 mph, and strong tail-wind of 100 mph. Each of the five velocities were introduced twice in a pseudo-random order for 0.1-mile segments through section two.

While the magnitude of the disturbances defined in the Minisim software may seem extreme, their effect in accelerating the vehicle was actually very modest. In the absence of accelerator or brake inputs, these disturbances changed the vehicle speed by a maximum of four mph. Furthermore, because the wind disturbances always summed to zero within a passing section, the cumulative effect of each disturbance on the mean vehicle speed in a passing zone was minor. The order of the wind disturbances were balanced across the 10 passing sections such that each wind velocity profile was paired with each passing lane scenario an equal number of times.

Experiment 3 Description

The goal of Experiment 3 was to investigate the effect on the speed of drivers towing an RV with passive speed measures with and without traffic.

Procedure

Prior to participation, all participants were read a general description of the study, warned of the risks involved, and asked to sign a consent form. The only tangible risk for these experiments was motion sickness encountered while driving in the simulator. Because this experiment simulated drivers towing a trailer, the same instructions as Experiment 1 were read to participants and are shown in Appendix A.

Again, participants were given a sign quiz to make sure they were familiar with all of the signs throughout the simulation. If any questions were missed, the correct response was explained to participants to ensure understanding before proceeding on to the next sign.

Experiment 3 was unique from Experiment 1 and Experiment 2 in that there were only five passing lane scenarios tested with traffic and without traffic:

- Baseline
- Regulatory
- Chevrons
- Lines
- Narrowing

The length of the simulated track was the same as the previous experiments; however, the numbering convention of the passing lane scenarios that participants encountered the passing lane scenarios had to be changed to accommodate only five scenarios with traffic and without traffic. The same unique counter-balanced order of the passing lane scenarios was used as Experiment 1 and Experiment 2, shown in Table 2 above. Instead, the order of the passing lane scenario corresponded to one of the five passive speed measures with traffic and without traffic. Table 3 below lists the passing lane scenario numbers. For example, Scenario 0 would have the driver encountering the Baseline Scenario with traffic; whereas Scenario 8 would have the driver encountering the Lines Scenario without traffic.

The same procedures in Experiment 1 and Experiment 2 were utilized in Experiment 3. Participants were allowed to become familiar with the driving simulator before data were collected, given a break at the half-way point, and briefed on the purpose of the research after completing the simulation.

Table 3: Passing Lane Scenario Numbering, Experiment 3

Scenario	**Traffic**	
	On	**Off**
Baseline	0	5
Regulatory	1	6
Chevrons	2	7
Lines	3	8
Narrowing	4	9

Simulated Traffic

For passing lane scenarios with traffic present, the other vehicles were scripted exactly like Experiment 1. Thus, there were seven vehicles following the driver and two vehicles in front of the driver. For passing lane scenarios without traffic, all of the vehicles were removed so that the driver would not see a vehicle in front of, behind, or opposing them throughout the passing lane section.

Participant Information

Due to a limited number of willing participants, only 12 participants with valid driver's licenses were tested for this experiment. Data from two of the participants were not used because the participants remained in the left lane throughout the passing lane sections without traffic. Because the purpose of this experiment was to analyze how vehicle speeds are affected by passive pavement markings while towing a trailer, which are only in the right lane, their data were removed from the analysis. The additional two participants were instructed to stay in the right lane throughout the passing lane sections. All of the participants were University of Idaho students, and the average age of the participants was 27.8, ranging from age 18 to 37.

Data Collection

The following data were collected for each participant during the passing lane sections throughout Experiment 1, Experiment 2, and Experiment 3:

- Lane deviation
- Speed
- Steering wheel angle

- Accelerator position

Lane deviation is the average position in the lane. A value of 12 represents that the vehicle remained center in the left lane throughout the passing lane sections. A value of 0 represents that the vehicle remained center in the right lane throughout the passing lane sections. The speed of vehicles was calculated in mph. The steering wheel angle represented the number of degrees from the center that the steering wheel position is in. Thus, a value of 10 means that the steering wheel is 10 degrees to the right of the center. The accelerator position is a function of how compressed the accelerator is. For example, a value of 0 means that the accelerator pedal is not being pressed; however, a value of 1.0 means that the accelerator pedal is being pressed at its maximum. The values between 0 and 1.0 vary linearly based on how compressed the pedal is.

For Experiment 1 and Experiment 2, only the speed and lane deviation were investigated. The lane deviation will be used to see if drivers move to the right lane or not in each experiment. The speed will be able to assess how effective each of the passing lane scenarios area. For Experiment 3, only the speed will be investigated. The lane deviation is not necessary to analyze the data because drivers will remain in the right lane throughout the scenarios.

CHAPTER 4: DRIVING SIMULATOR RESULTS

Experiment 1

The two main factors analyzed for this experiment were lane control and speed control. The goal of the experiment was to encourage the participants pulling a trailer to move into the right lane and reduce their speed so that faster vehicles could pass them. Participants were not strictly told to move into the right lane during a passing zone. By doing this, the treatments could be assessed as to how effective they were on driver behavior.

Lane Choice

Again, the purpose of Experiment 1 was to encourage drivers to move to the right lane so vehicles could pass using the left lane of the passing lane, but drivers were told to "observe normal driving etiquette."

Figure 17 below shows the lane deviation for drivers across the Baseline Scenario. The y-axis shows the position in the lane; 12 feet represents the center of the left lane, and 0 feet represents the center of the right lane. The x-axis shows the vehicle's position throughout the passing lane section. The first 660 feet is the lane-addition taper, section one. The two-lane passing lane extends from 660 feet to 5940 feet, section two. The final 660 feet is the lane-reduction taper, section three. Figure 17 suggests that the majority of drivers move directly into the right lane at the beginning of the passing lane. The plot shows the lane deviation for each of the participants in grey and the average lane deviation for all of the participants in black.

Welch's robust test was used to determine if the means and standard deviations of the 10 passing lane scenarios were statistically equivalent. If Welch's test showed statistically reliable differences among the 10 means or standard deviations, the Games-Howell procedure was used to identify the pairs of means or standard deviations that differed reliably from one another. The Games-Howell procedure forms a pooled variance estimate for each individual pairwise comparison while adjusting for familywise error. Thus, there is not a significant reduction in confidence of the results. A Type I error probability of $\alpha = .05$ was used as the decision criterion for statistical reliability.

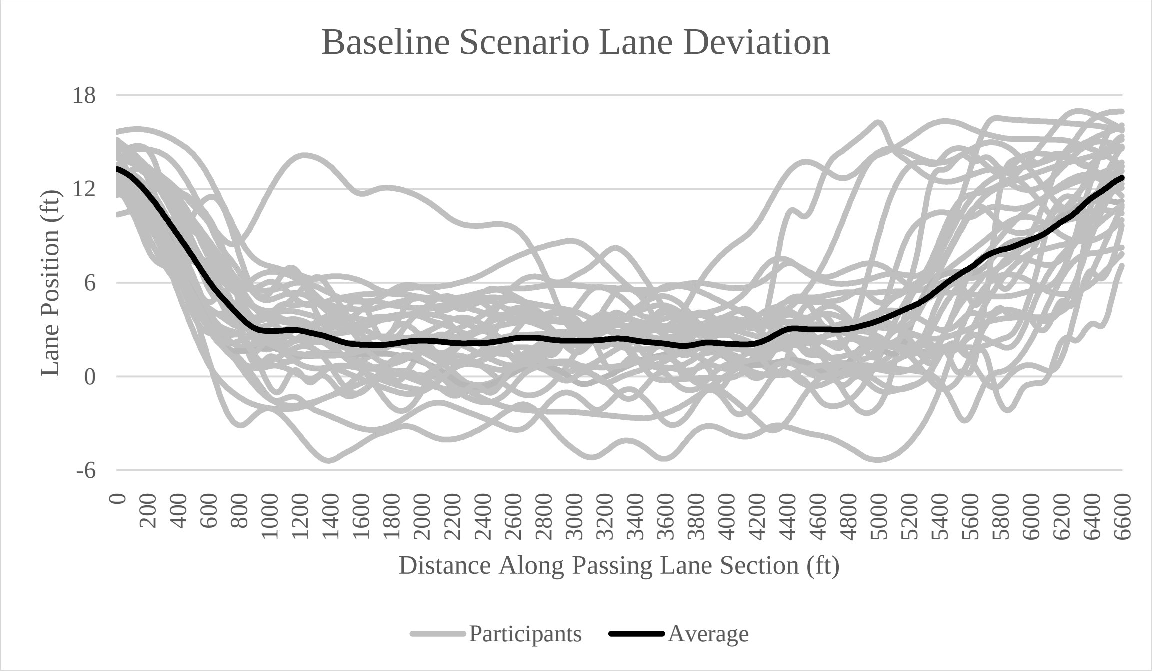


Figure 17: Baseline Lane Deviation, Experiment 1

In fact, there was an effect of scenario on the proportion of time spent in the right lane [W'(9, 117.902) = 2.10, $p < 0.05$]. There was a reliable difference in the average time spent in the right lane between passing lane scenarios. Overall, drivers occupied the right lane of the passing lane section more than 90% of the time. Appendix D shows all of the statistical tests for Experiment 1.

Because Welch's test indicated a reliable difference in the average time spent in the right lane, the Games-Howell procedure was used to identify exactly which pair of scenarios showed a reliable difference. The proportion of time spent in the right lane was reliably different between the Chevron Scenario (m = 94.3%), the Regulatory Scenario (m = 87.2%), and the Regulatory plus Advisory Scenario (m = 87.9%). Figures 18, 19, and 20 below show the lane deviation the Chevron Scenario, Regulatory Scenario, and Regulatory plus Advisory Scenario, respectively.

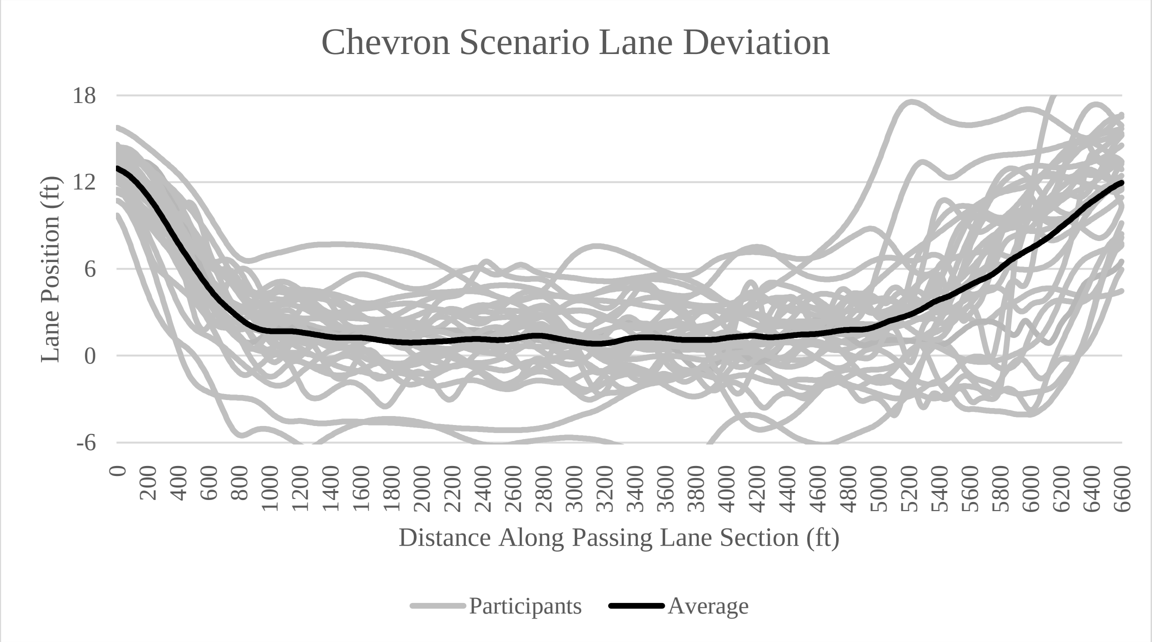


Figure 18: Chevron Scenario Lane Deviation, Experiment 1

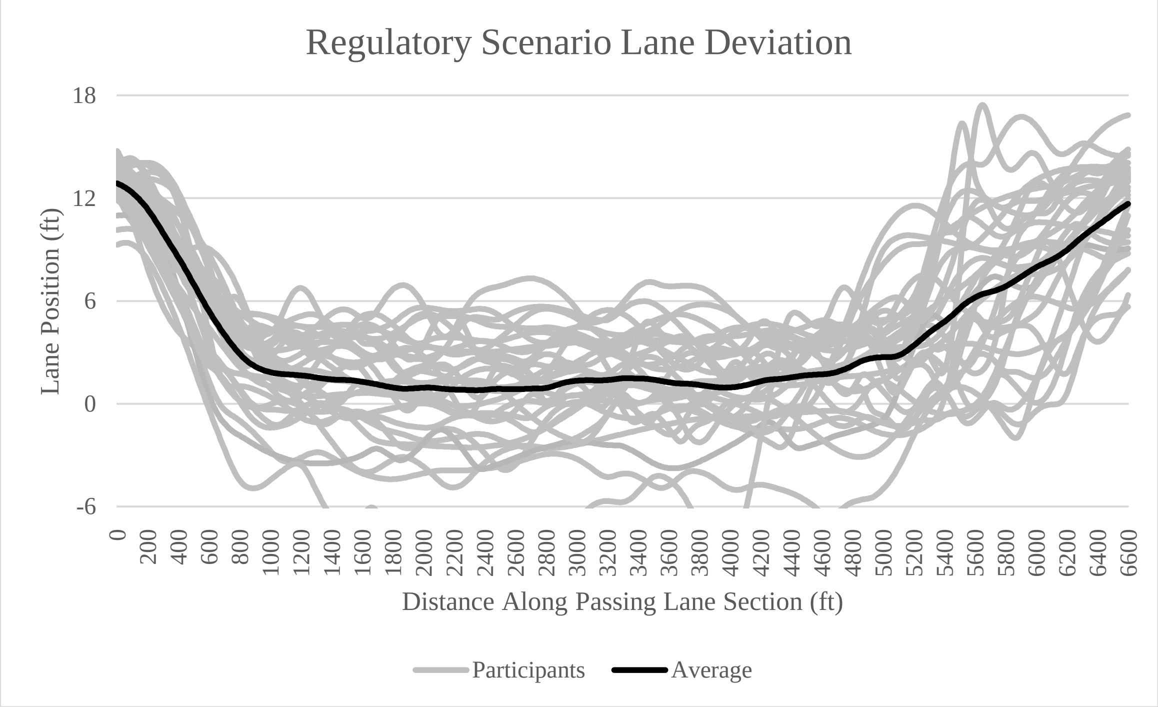


Figure 19: Regulatory Scenario Lane Deviation, Experiment 1

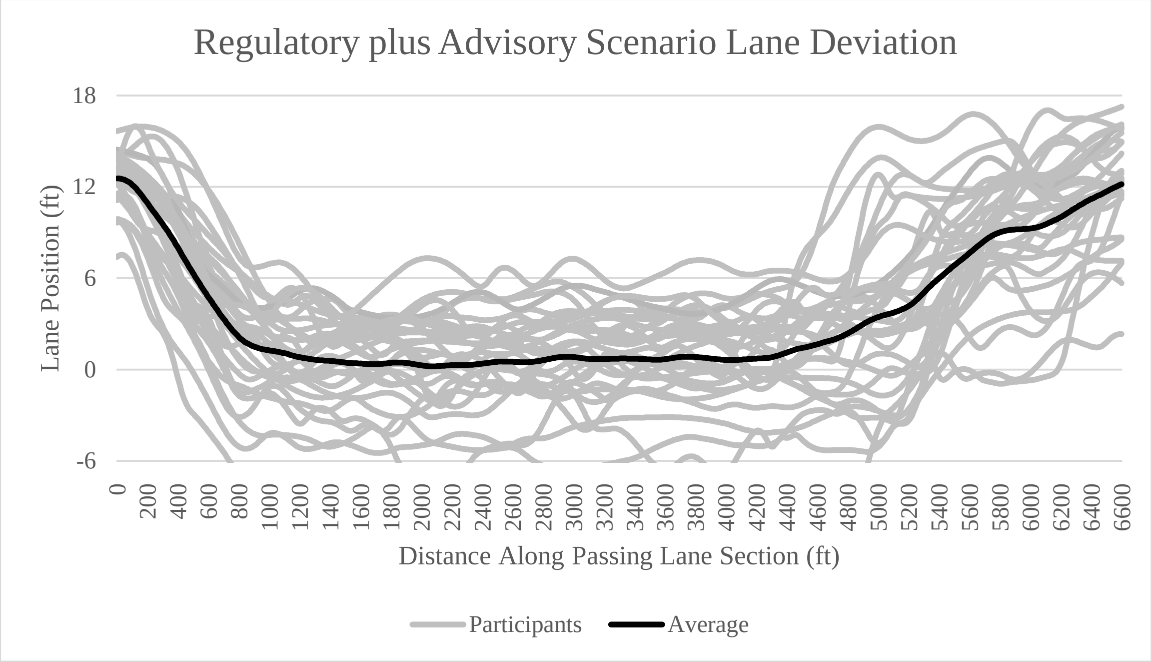


Figure 20: Regulatory plus Advisory Lane Deviation, Experiment 1

Force Right and Neutral Zone Scenario

The Force Right/Neutral Zone Scenario contained a knurled roadway marking at the neutral zone and a rumble strip at the end of the passing zone to assist drivers to merge back to the left lane. A Welch test on lane deviation at the end of the two-lane passing lane yielded marginally-reliable results [W'(9, 118.097) = 1.68, $p > 0.05$]. To provide a more direct test, an unequal variance t-test on lane position was used to compare the Baseline Scenario to the Force Right/Neutral Zone Scenario. This suggests that the neutral zone condition does have some impact on moving drivers back to the left lane. Drivers were on average approximately three feet closer to the left lane with the Force Right Scenario compared to Baseline [t(57.9) = 2.22, $p < 0.05$]. When a comparison of vehicle speeds at the end of the passing lane segment are assessed between the Baseline and Force Right/Neural Zone Scenarios, the difference is not reliable [t(57.8) = 0.77, $p > 0.05$]. In sum, the Force Right/Neutral Zone Scenario had little effect on driver behavior in this study. Figure 21 below shows the lane deviation of the Force Right/Neutral Zone Scenario.

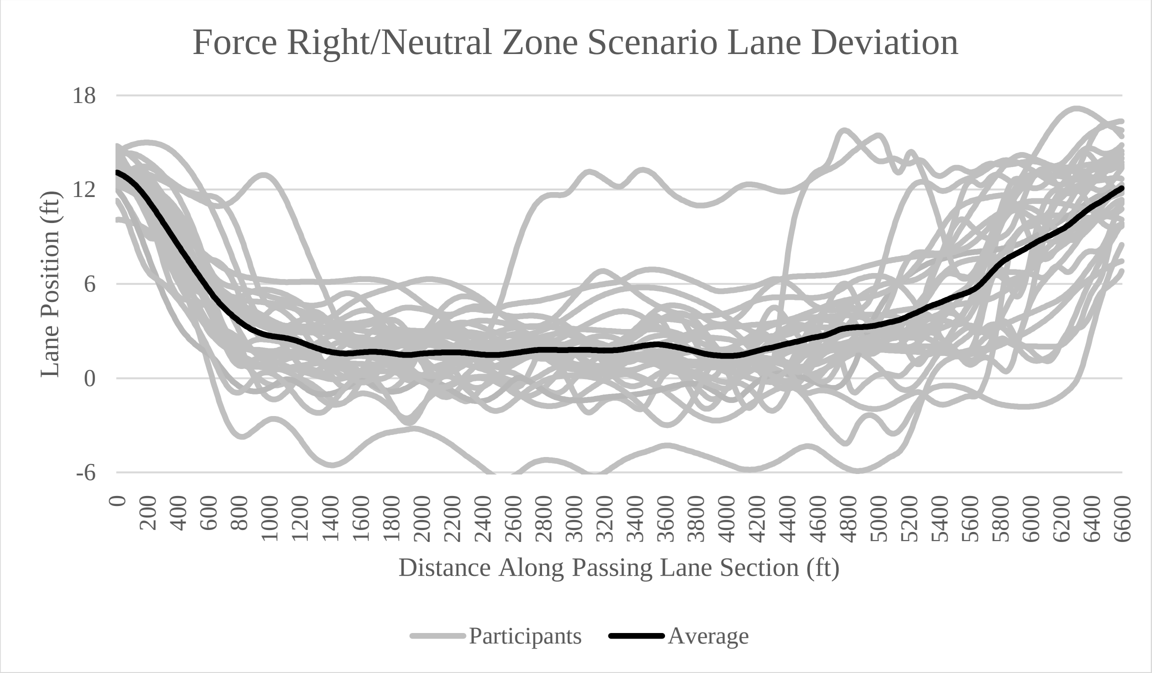


Figure 21: Force Right/Neutral Zone Lane Deviation, Experiment 1

Mean Vehicle Speed

The speeds of the vehicles through each of the passing lane treatments were recorded to see which passing lane scenario reduced the speed the most compared to the base case. Figure 22 below shows the average speeds for each of the passing lane scenarios compared with the Baseline Scenario. The average speeds were calculated using all of the participants over the one-mile passing lane section. The average Baseline Scenario speed for all of the participants was 59.9 mph. The Regulatory and Regulatory plus Advisory Scenarios reduced the speed the greatest amount of the scenarios with average speeds of 53.4 mph and 54.2 mph, respectively.

Welch's test was performed on the mean vehicle speeds of the passing lane scenarios and yielded reliable results [W'(9, 117.956) = 6.00, $p < 0.001$]. Next, the Games-Howell procedure was run to identify which pair of passing lane scenarios exhibited reliable differences. The Games-Howell procedure found that the Regulatory Scenario was reliably different from every other passing lane scenario except the Regulatory plus Advisory Scenario. The procedure also found that the Regulatory plus Advisory Scenario is reliably different from the following scenarios: Baseline, Narrowing, and Lines without Middle.

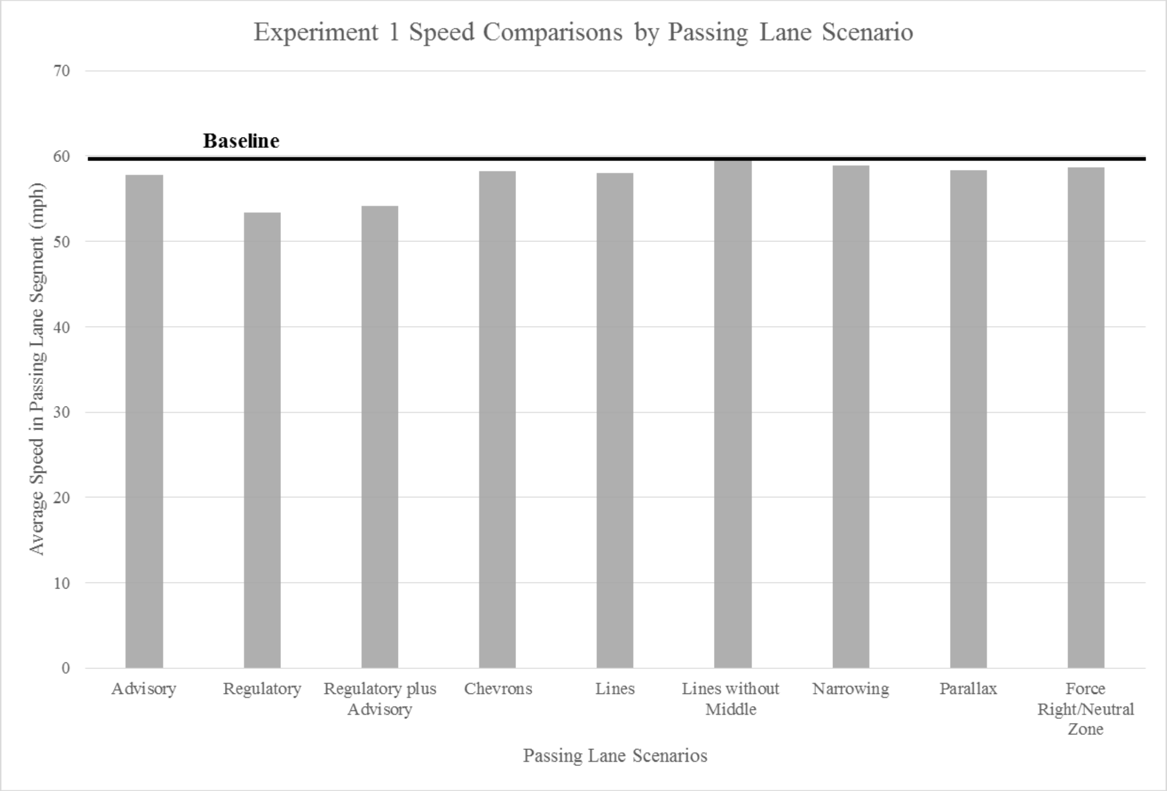


Figure 22: Mean Vehicle Speeds over Passing Lane Scenarios, Experiment 1

The vehicle speeds were analyzed using within-subject confidence intervals pioneered by Loftus and Masson (1994). Essentially, each participant's average speed was measured and compared to their own baseline instead of the average baseline of all the participants. Figure 23 below shows the results of the analysis with 95% confidence interval bars. The shaded area represents the 95% confidence interval of the Baseline Scenario. Means with error bars that fall outside of the light gray band are considered reliably different from the Baseline Scenario, and means whose error bars do not overlap are considered reliably different from one another.

According to this analysis, six of the nine scenarios reliably reduced the average vehicle speed over the one-mile, full two-lane segment of the passing zone:

- Advisory reduced speed by 2.1 mph
- Regulatory reduced speed by 6.5 mph
- Regulatory plus Advisory reduced speed by 5.7 mph
- Chevrons reduced speed by 1.6 mph

- Transverse Lines reduced speed by 1.8 mph
- Parallax reduced speed by 1.5 mph

Clearly, the Regulatory and Regulatory plus Advisory treatments have the greatest effect on vehicle speeds in the passing lane. However, scenarios including regulatory elements have the largest effect on reducing the speed of our participants, but the use of chevrons, transverse lines, or parallax should also be expected to have a reliable—though smaller—effect on speed control.

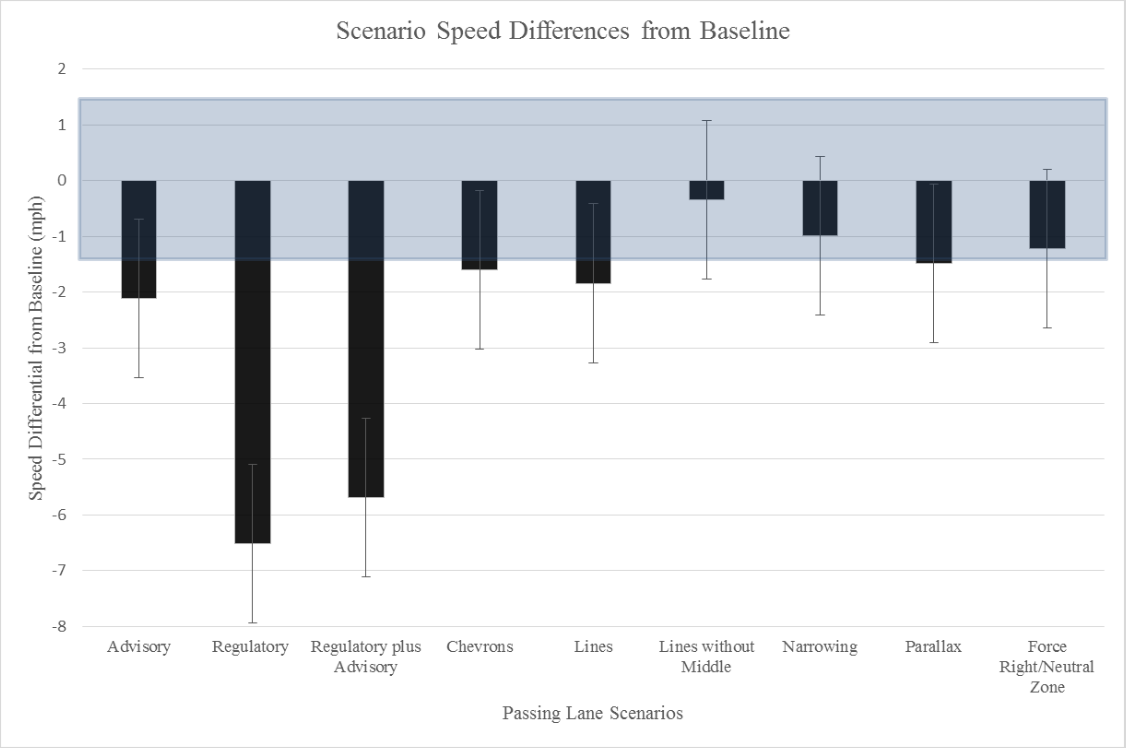


Figure 23: Within Subject Speed Differences from Baseline, Experiment 1

Standard Deviation Vehicle Speeds

The standard deviation of vehicles speeds throughout the one-mile passing lane section was calculated to note the variation of speeds in each scenario. Figure 24 below shows the standard deviation of each passing lane scenario compared to the Baseline Scenario. Each passing lane scenario is represented by a bar with a corresponding standard deviation on the y-axis. The standard deviation of speeds throughout the passing lane scenarios was fairly consistent. As a result, the standard deviations were not reliably different from one another [W'(9, 117.894) = 0.55, p > 0.05].

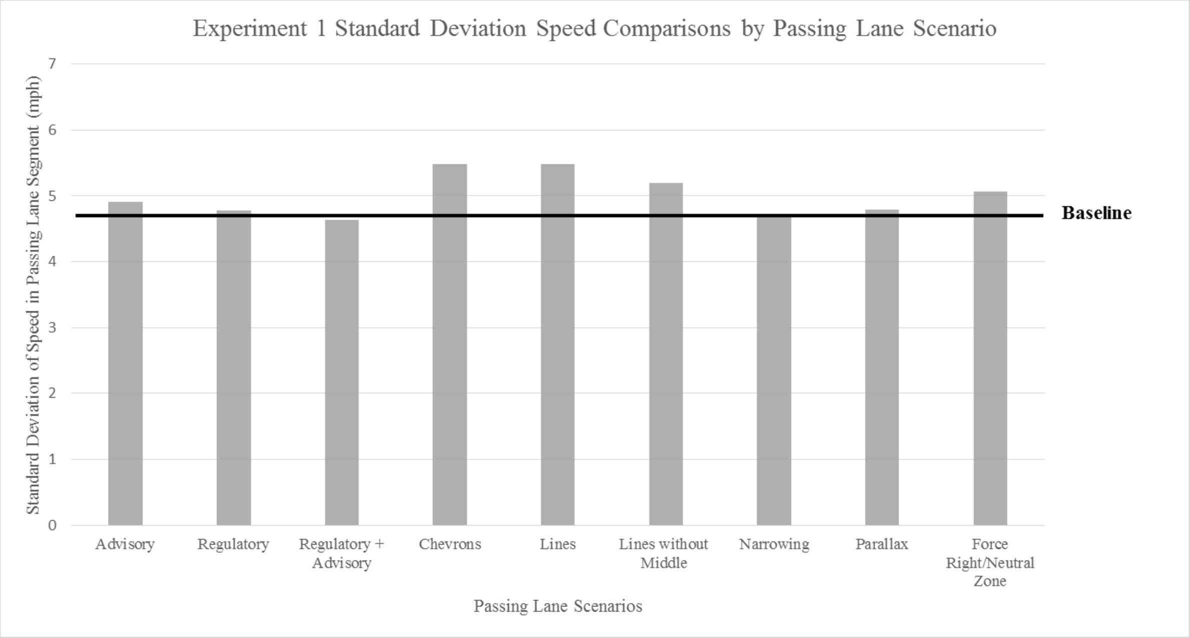


Figure 24: Standard Deviation Vehicle Speeds, Experiment 1

Conclusion

Experiment 1, with vehicles towing a trailer, showed that most of the participants drove in the right lane of the passing lane, allowing the following vehicles to pass. The Games-Howell method found that that Regulatory and Regulatory plus Advisory Scenarios are the most effective in reducing vehicle speeds of all participants. However, the within-subject analysis suggested that other scenarios may be effective in reducing driver speed in a passing lane compared to the Baseline. There were no significant trends in standard deviation of vehicle speeds.

Experiment 2

The main goal for this experiment was to investigate whether driver behavior changed when participants were not towing a trailer and instead drove a sedan. Drivers were not told which lane to use in the passing lane sections; however, an urgency to get home was expressed in the directions prior to the start of the experiment. The lane choice and speed of vehicles were investigated to see if there were any noticeable differences from Experiment 1.

Lane Choice

Based on the lane deviations of all the participants over all of the scenarios, drivers were in the left lane more than 81% by distance, and there was no reliable difference in the percentage of distance in the left lane [W’(9, 77.301) = 0.65, $p > 0.05$]. Predictably, there were no reliable differences observed on mean lane deviation in the two-lane passing lane section [W’(9, 77.35) = 0.73, $p > 0.05$]. Appendix E includes all of the statistical tests for Experiment 2.

Figure 25 below shows the lane deviation for the Baseline Scenario. Again, the y-axis shows the position in the lane; 12 feet represents the center of the left lane, and 0 feet represents the center of the right lane. The x-axis shows the vehicle’s position throughout the passing lane. The first 660 feet is the lane-addition taper. The two-lane passing lane extends from 660 feet to 5940 feet, and the final 660 feet is the lane-reduction taper. The plot shows the lane deviation for each of the participants in grey and the average lane deviation for all of the participants in black.

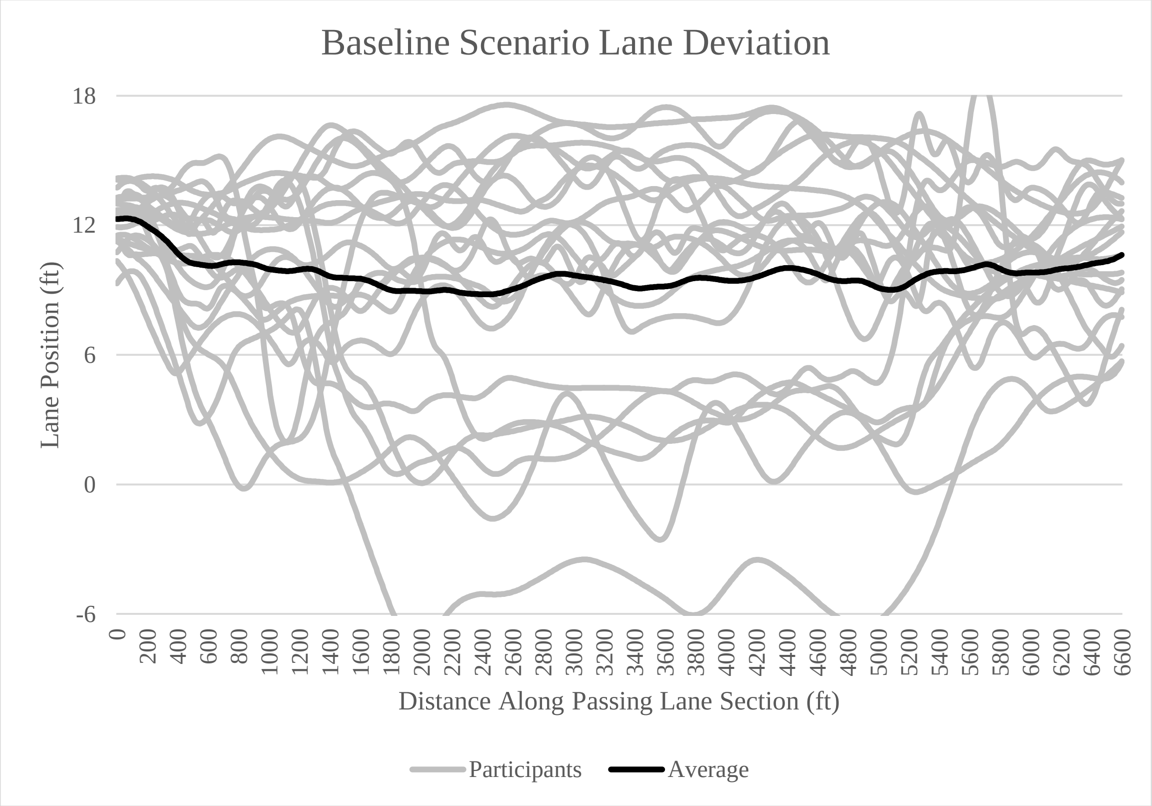


Figure 25: Baseline Lane Deviation, Experiment 2

Figure 25 suggests that the majority of drivers remain in the left lane. This is a large contrast to Experiment 1 where most drivers pulling a trailer moved into and remained in the right lane.

Force Right and Neutral Zone Scenario

The Force Right/Neutral Zone Scenario incorporated a knurled force right pavement marking at the beginning of the passing lane. When lane deviation at the beginning of the two-lane passing lane segment is examined, a reliable effect is observed [W'(9, 77.084) =3.16, $p < 0.01$]. Next, the Games-Howell procedure was run to find exactly which scenarios were reliably different from one another. The Force Right/Neutral Zone Scenario is reliably different from the Regulatory, Regulatory plus Advisory, and Narrowing Scenarios. This difference is clearly seen in the ANOVA table: the lane deviation for the Force Right/Neutral Zone Scenario is 6.1 feet, whereas the Regulatory plus Advisory Scenario is 12.1 feet. Thus, drivers in the Regulatory plus Advisory Scenario were on average directly in the middle of the left lane, and drivers for the Force Right/Neutral Zone Scenario were, on average, six feet closer to the right lane at the start of the two-lane passing lane segment.

The effect of the force right marking is apparent in Figure 26 below. The majority of participants drive into the right lane near 660 feet. However, 25% of the participants did not abide by the pavement marking and drove directly into the left lane, circled in Figure 26 below. This is similar to the study conducted by May (1991) which found that 20% of participants did not abide by the force right pavement marking.

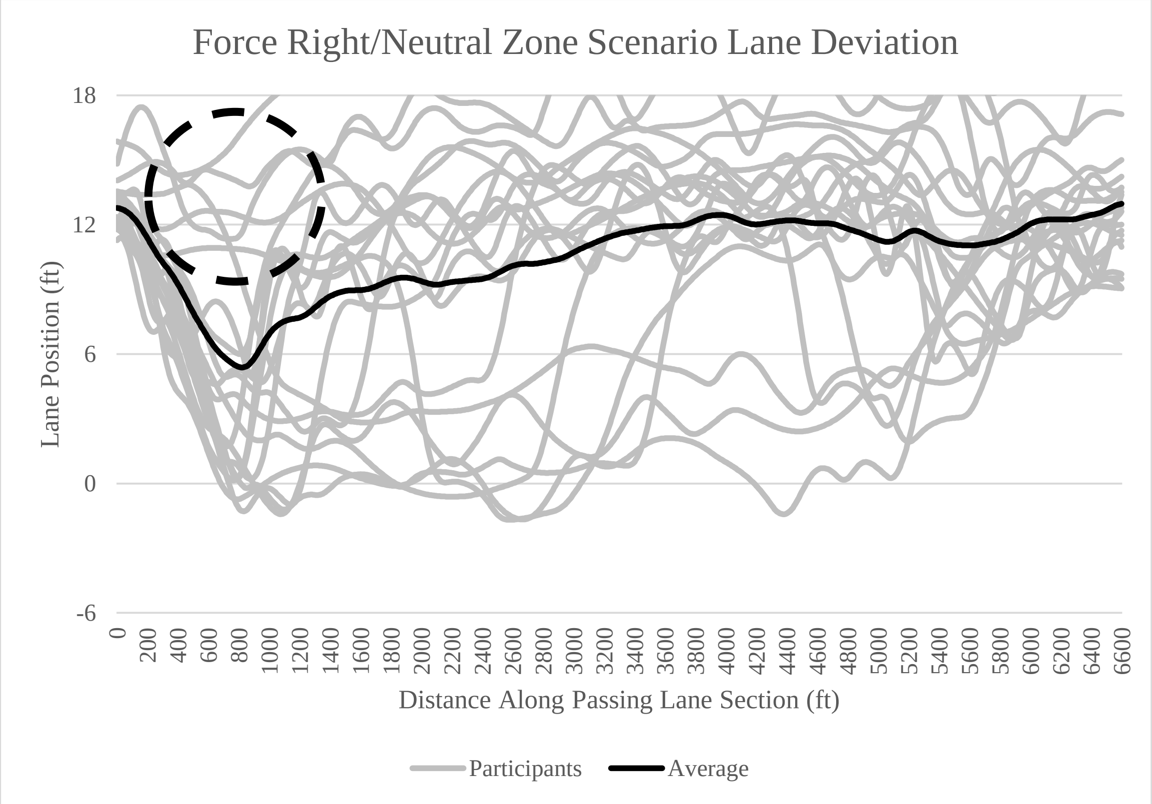


Figure 26: Force Right/Neutral Zone Scenario Lane Deviation, Experiment 2

Mean Vehicle Speed

The speeds of the vehicles through each of the passing lane treatments were recorded to see which passing lane scenario reduced the speed the most in comparison with the Baseline Scenario. Figure 27 below shows the average speeds for each of the passing lane scenarios compared to the Baseline Scenario. The average speeds were calculated using all of the participants over the one-mile passing lane section. The average baseline speed for all of the participants was 68.5 mph. None of the passing lane treatments reduced the average speed of drivers throughout the passing lane section compared to the baseline. In fact, none the scenarios were deemed reliably different from one another by Welch's test [W'(9, 77.294) = 0.42, $p > 0.05$]. There are minor differences in the speed of vehicles over each treatment. However, practically speaking, the differences appear insignificant in relation to the overall variability.

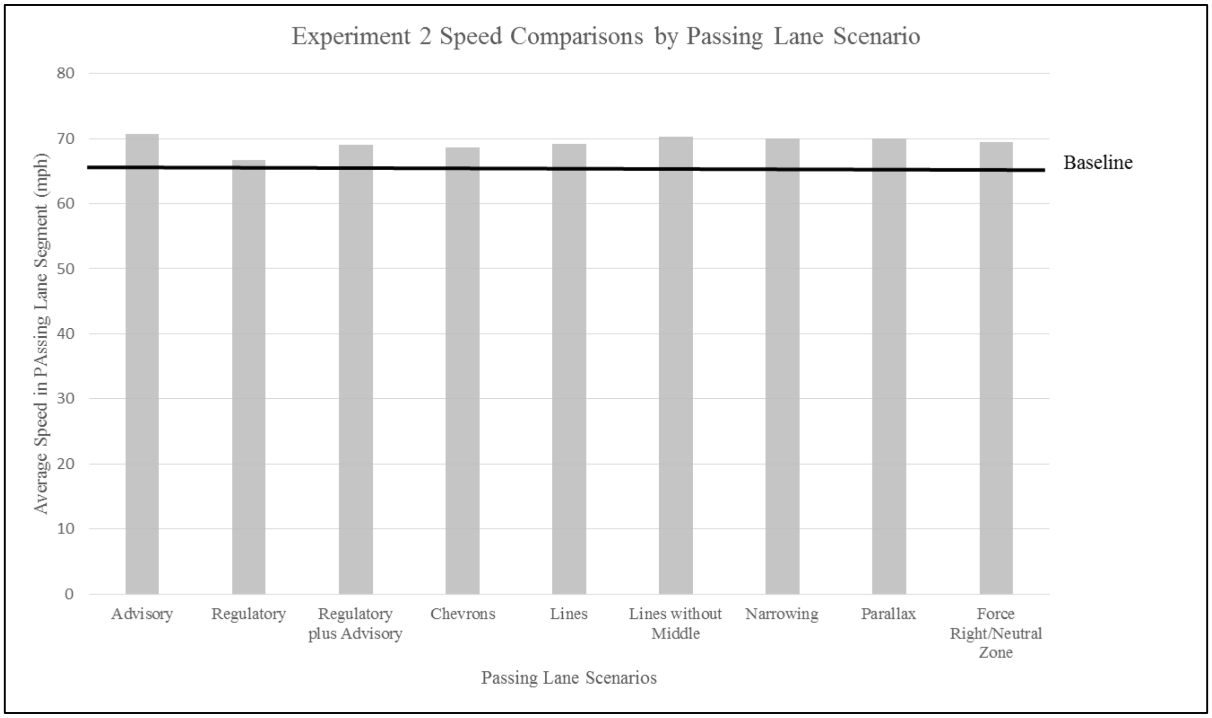


Figure 27: Average Vehicle Speeds over Passing Lane Treatments, Experiment 2

Again, the vehicle speeds were analyzed using within-subject confidence intervals. Figure 28 below shows the results of the analysis. The shaded area represents the 95% confidence interval of the Baseline Scenario. Means with error bars that fall outside of the shaded area are considered reliably different from Baseline Scenario, and means whose error bars do not overlap are considered reliably different from one another. According to this analysis, none of the scenarios reliably reduced the speed of drivers compared to the Baseline Scenario or each of the scenarios.

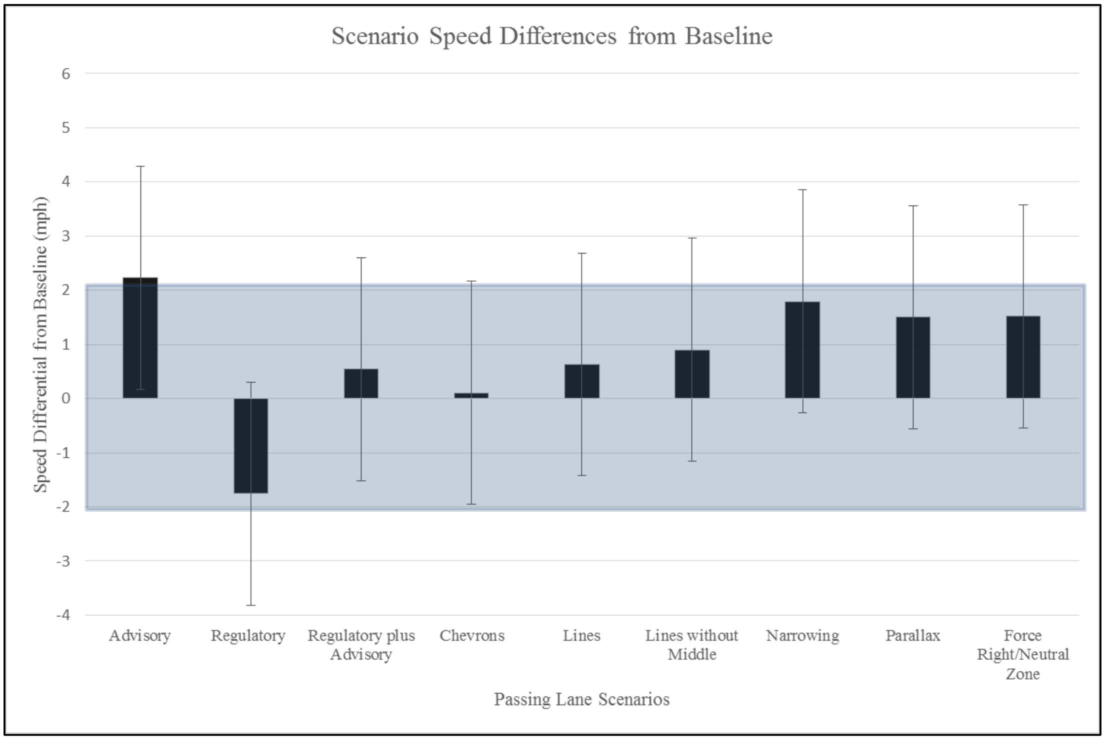


Figure 28: Within Subject Speed Differences from Baseline, Experiment 2

Standard Deviation Vehicle Speed

The standard deviation of vehicles speeds throughout section two was calculated to note the variation of speeds in each scenario. Figure 29 below shows the standard deviation of vehicle speeds for each passing lane scenario in comparison with the Baseline Scenario. A bar with a corresponding standard deviation value on the y-axis represents each passing lane scenario.

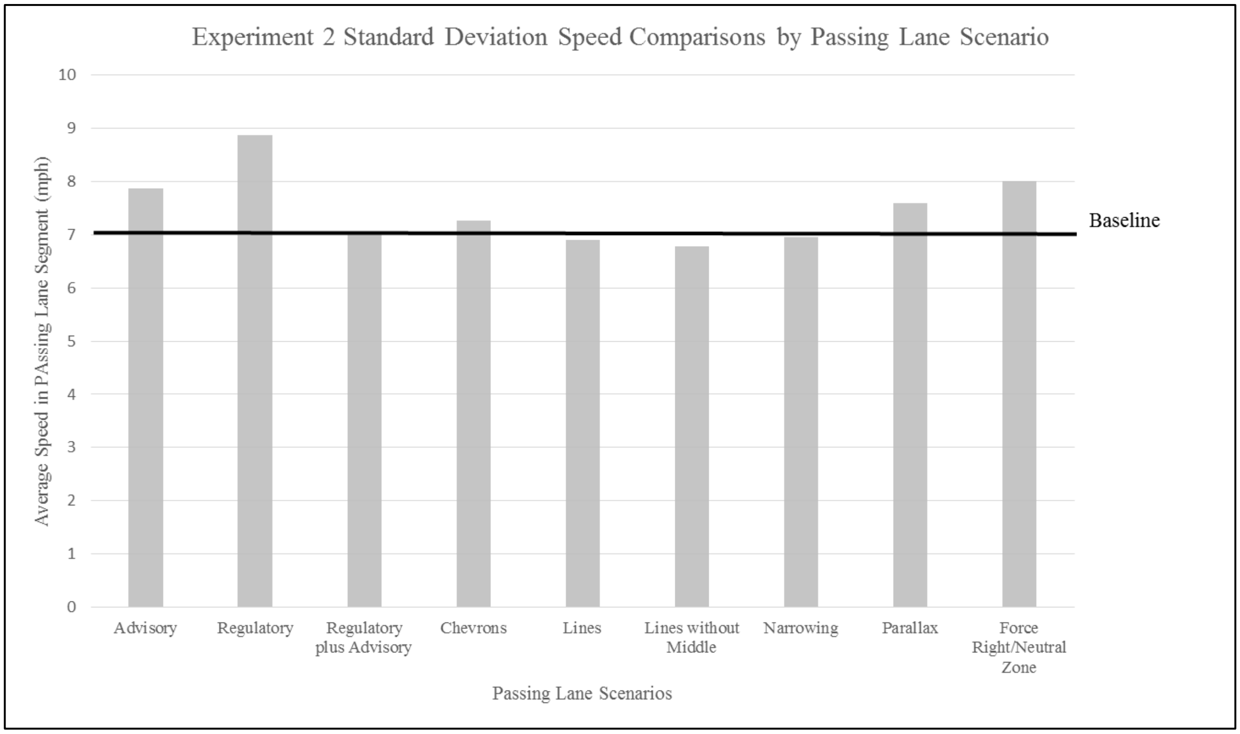


Figure 29: Standard Deviation Vehicle Speeds, Experiment 2

Overall, the standard deviations for Experiment 2 were fairly similar to the Baseline Scenario. There were no reliably different standard deviations of the 10 scenarios [W'(9, 77.318) = 0.78, p > 0.05]. However, a two sample t-test assuming unequal variances was performed on the average standard deviations for each of the scenarios for Experiment 1 and Experiment 2, and there was a reliable difference in the standard deviations [t(13) = 10.59, p < 0.001]. Thus, drivers in Experiment 2 have more variability in driving through the passing lane sections than Experiment 1. Furthermore, there was more variability in driver behavior when participants were driving a sedan rather than pulling a trailer.

Conclusion

Overall, drivers not towing a trailer in Experiment 2 drove faster compared to drivers towing a trailer in Experiment 1. Additionally, the majority of the time, drivers remained in the left lane of the passing lane section. There was not a significant difference in vehicle speeds between scenarios throughout the one-mile passing lane section. In fact, all of the average vehicle speeds for the passing lane scenarios were greater than the Baseline Scenario. The Force Right/Neutral Zone Scenario seemed to have a significant effect on moving drivers to the right lane at the lane-addition taper. There was no difference in the standard deviations of drivers in Experiment 2. However, there was a difference in the standard deviations of Experiment 2 when compared to Experiment 1. Thus, drivers in Experiment 2 exhibited more variability.

Experiment 3

The main goal for this experiment was to investigate whether drivers reduced their speed in the passing lane section based on traffic and passive speed measures. A series of statistical tests were performed on the data to determine the within-subject effects of the collected data. Generally, the speed of vehicles was determined to be the most effective measure of the passing lane scenarios with and without traffic. Because the passive markings only applied to drivers in the right lane, lane deviation was not evaluated for this experiment.

Omnibus ANOVA

Three of the traffic by section by scenario Omnibus ANOVA tests indicated a reliable difference between subjects with $\alpha = 0.05$: the standard deviation of pedal position, mean vehicle speed, and standard deviation of vehicle speed. First, the standard deviation of pedal position had a traffic main effect, section main effect, and traffic by section main. Next, the mean vehicle speed had a scenario main effect, section main effect, scenario by section main effect, and traffic by section main effect. However, a traffic main effect was reliable at $\alpha = 0.10$ for the mean speed. Similar to Experiment 1 and Experiment 2, the Regulatory scenario had the largest effect on the mean vehicle speed. Finally, the standard deviation of vehicle speed had a traffic main effect and section main effect. The traffic by section by scenario OmniBus ANOVA did not indicate a reliable difference between subjects with $\alpha = 0.05$ for the remaining three tested dependent variables: mean pedal position, mean steering wheel position, and standard deviation steering wheel position. Next, ANOVAs were run to see if there was an effect based strictly on traffic or strictly by section.

No Traffic, All Section, ANOVA

Four of the no traffic, all section, two-way ANOVA tests indicated a reliable difference between subjects with $\alpha = 0.05$: the mean pedal position, the standard deviation of pedal position, mean vehicle speed, and standard deviation of vehicle speed. First, the mean pedal position had a section main effect. Then, the standard deviation of pedal position had a section main effect. Next, the mean vehicle speed had a scenario main effect and section main effect. Finally, the standard deviation of vehicle speed had a section main effect. The no traffic, all section, two-way ANOVA did not indicate a reliable difference between subjects with $\alpha = 0.05$ for the remaining two tested dependent variables: mean steering wheel position and standard deviation of steering wheel position.

Traffic, All Section, ANOVA

Three of the traffic, all section, two-way ANOVA tests indicated a reliable difference between subjects with $\alpha = 0.05$: the standard deviation of pedal position, mean vehicle speed, and standard deviation of vehicle speed. First, the standard deviation of pedal position had a section main effect. Next, the mean vehicle speed had a section main effect and section by scenario main effect. Finally, the standard deviation of vehicle speed had a section main effect. The traffic, all section, two-way ANOVA did not indicate a reliable difference between subjects with $\alpha = 0.05$ for the remaining three tested dependent variables: mean pedal position, mean steering wheel position, and standard deviation of steering wheel position.

Welch Tests

Welch t-tests of means were performed on the one-mile passing lane section only with traffic and without traffic. None of the dependent variables—pedal position, steering wheel position, or speed—yielded reliable differences with $\alpha = 0.05$. Thus, when driving with traffic or without traffic, there was not a reliable difference in the average speed of vehicles in comparison with the Baseline Scenario. Appendix F includes the statistical results of Experiment 3.

Discussion

Figure 30 below shows the speed differential compared to the baseline without traffic. Figure 31 shows the speed differential compared to the baseline with traffic compared to the baseline over the passing lane section. The error bars represent a 95% confidence interval, and the shaded area represents the 95% confidence interval of the

Baseline Scenario. The dark column for each scenario represents the mean speed differential of drivers compared to the Baseline Scenario.

Although all of the passive speed measures reduce the mean vehicle speed in comparison with the Baseline Scenario, the reduction in speed is negligible for most scenarios, and there are no reliable differences in speed between the passing lane scenarios. Similar to Experiment 1 and Experiment 2, the Regulatory Scenario had the greatest reduction in speed; however, according to the Welch test, none of the scenarios reliably reduced the speed of drivers compared to any of the scenarios for traffic [W’(4, 22.226) = 1.51, p > 0.05] or without traffic [W’(4, 22.209) = 1.52, p > 0.05]. Although none of the scenarios reliably reduced the speed of drivers compared to the Baseline Scenario, the Regulatory Scenario had the largest practical reduction in speed. Thus, the relatively low number of participants for this experiment—10—could be affecting the power of the statistical analysis. If more participants were sampled, the Regulatory Scenario may prove to be reliably different from one of the passive speed scenarios or the Baseline Scenario.

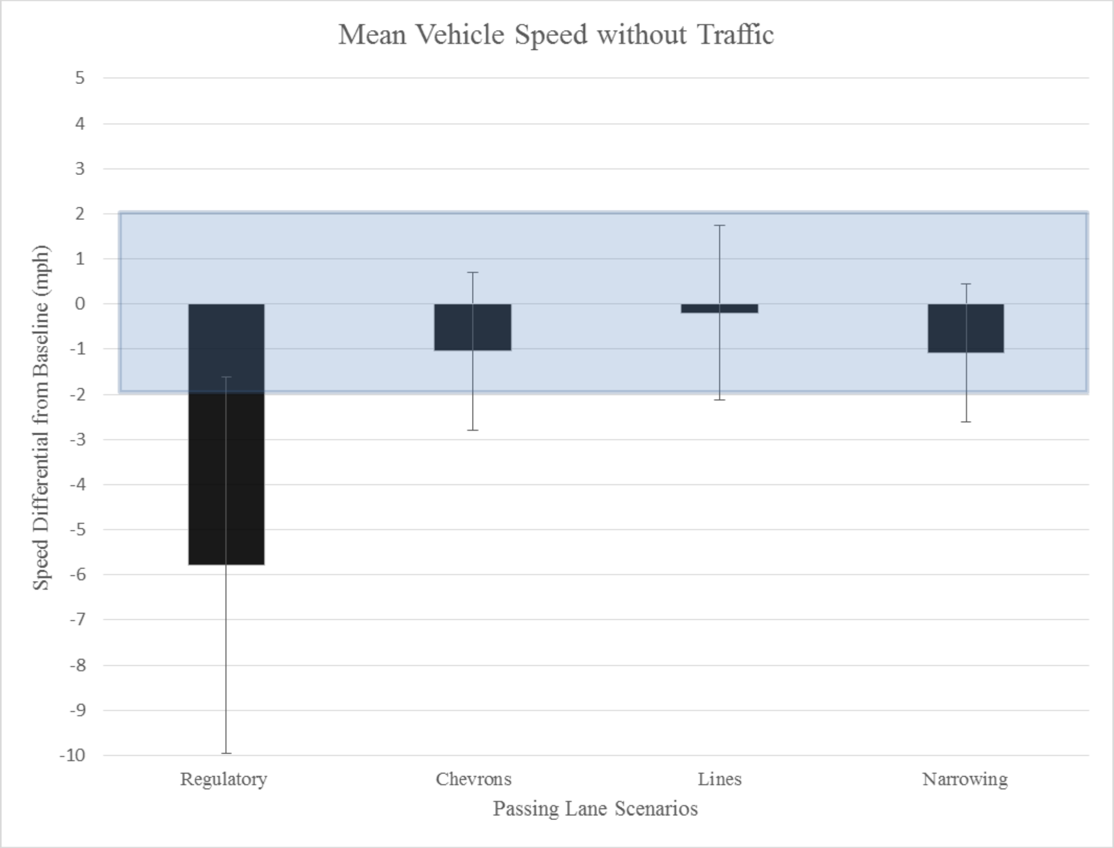


Figure 30: Mean Vehicle Speed without Traffic, Experiment 3

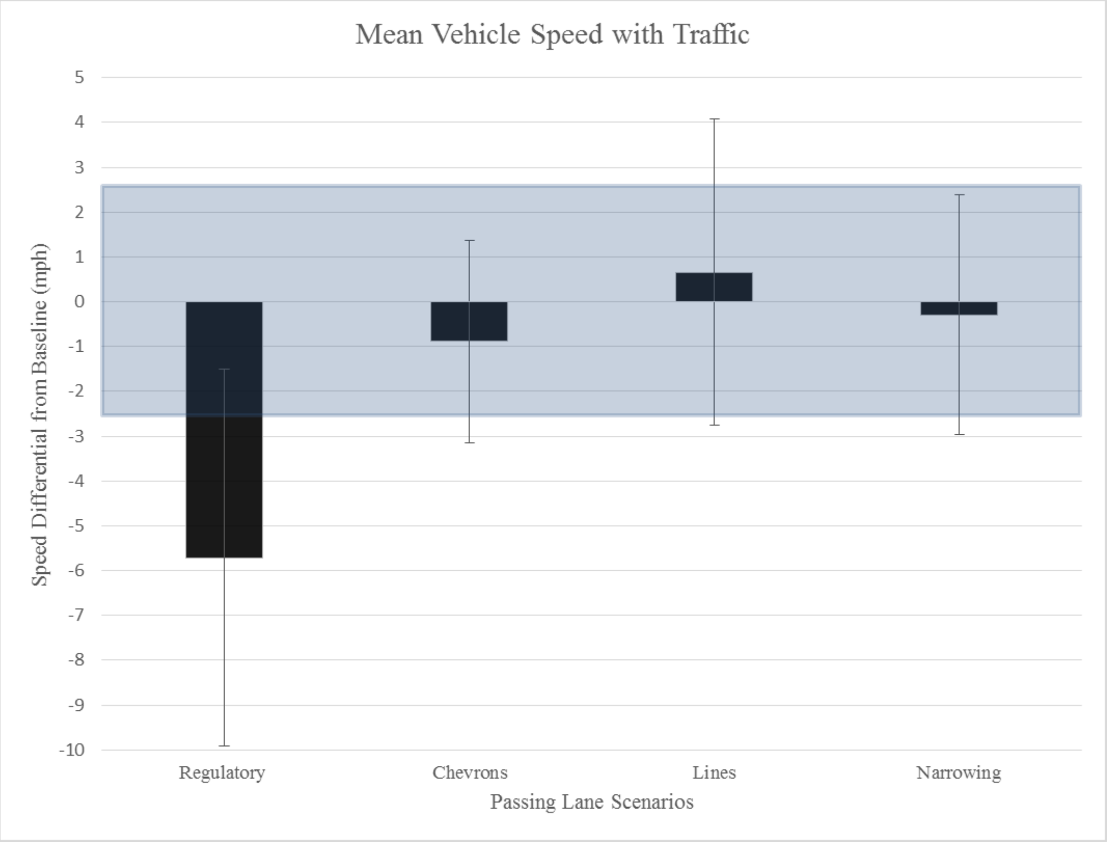


Figure 31: Mean Vehicle Speed with Traffic, Experiment 3

Figure 32 below shows the comparison of vehicle speeds across the various passing lane scenarios with traffic and without traffic. Drivers tended to drive marginally slower over the scenarios when traffic was present; however, according to a two-sample t-test assuming equal variances, there is no reliable difference between them, [$t(8) = 0.59$, $p > 0.05$].

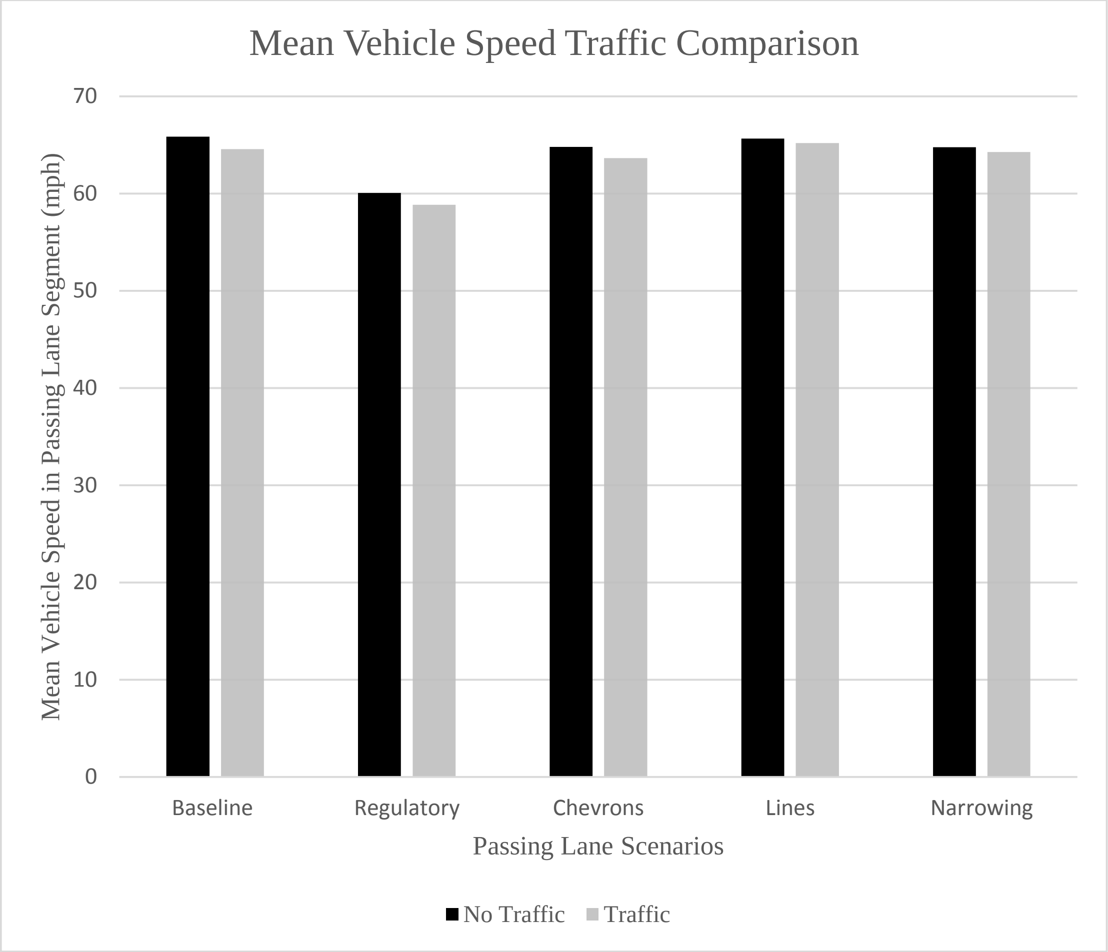


Figure 32: Mean Vehicle Speed Traffic Comparison

Figure 33 below shows the standard deviation of vehicle speeds for the passing lane scenarios with traffic and without traffic. The average standard deviations for each scenario with traffic and without traffic are not reliably different based on a two sample t-test assuming equal variances [t(8) = 1.07, p > 0.05]. Although drivers appear to exhibit more variability with traffic compared to without traffic, there is no statistically reliable difference between the two scenarios.

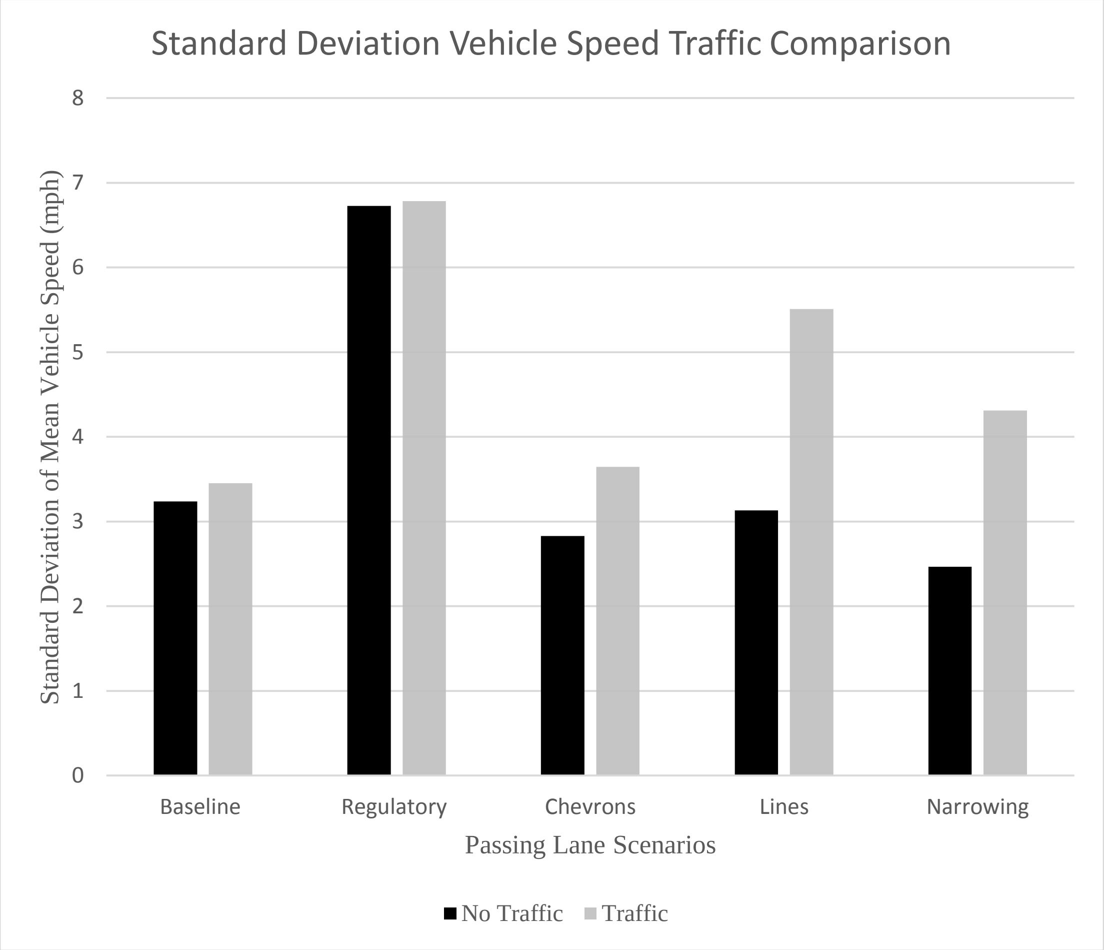


Figure 33: Standard Deviation Vehicle Speeds, Traffic Comparison

Conclusion

The OmniBus ANOVA test indicated that there were reliably different variances in pedal position standard deviation, mean vehicle speed, and standard deviation of vehicle speed over section, scenario, or traffic cases. Additional ANOVA tests were performed to compare traffic versus no traffic and section two only versus all sections in order to try and isolate the cause for the main effects in the OmniBus ANOVA. Again, this analysis found reliable differences in the pedal position and vehicle speeds over the traffic and no-traffic scenarios throughout the three sections. Finally, a Welch t-test was performed on section two with and without traffic and found no reliable difference in the mean vehicle speeds of each scenario. An additional t-test found no reliable difference in the mean and standard deviation vehicle speeds between traffic vs. no traffic condition.

Although there were no reliable differences in speed between the traffic and no-traffic conditions, the Regulatory Scenario proved to be the most effective in reducing the average speeds, which is consistent with Experiment 1 and Experiment 2. The Regulatory Scenario may not be statistically different than any of the scenarios due to the sample size being 10, which causes an issue in the relative power of the results. More participants may prove that the Regulatory Scenario is reliable different than other scenarios.

CHAPTER 5: CRASH ANALYSIS

This chapter describes an analysis of vehicle crashes that was conducted using real-world crash data from the state of Idaho. The purpose of the crash analysis was to identify situations that were common to crashes along rural, two-lane highways in Idaho.

Sources of Data

This section describes the various sources the crash analysis data were collected from.

Roadway Geometry

Roadway geometry data were obtained from the Idaho Transportation Department (ITD). These data included the following information for rural passing lanes in Idaho:

- Lane width
- Shoulder width
- Shoulder type
- Median width
- Median type
- Passing lane width
- Horizontal curves
- Vertical grades

Additionally, the beginning and ending mileposts were included for each segment. These data included roadway geometry for passing lane sections from 2003 to 2012. Because crash statistics were calculated over a five-year period from 2008 through 2012, the passing lane segments from 2008 were used to search for crash statistics. Assuming ITD would not remove any passing lane segments, this ensured that road segments with passing lanes in 2008 would theoretically have passing lanes in 2012. However, roads that had passing lanes installed after 2008 would not be included in order to ensure that the road segments are consistent throughout the analysis.

Roadway Crash Statistics

ITD’s WebCars crash analysis reporting system was used to obtain the crash statistics on the passing lane segments. Specifically, the query and report builder section of WebCars was utilized to collect the crash data from 2008 through 2012. The WebCars data were used to investigate if there are common factors for crashes in passing lanes.

Methodology

This section describes the methodology behind obtaining the crash statistics. How the roadway geometry data were analyzed is discussed first. Then, how the crash statistics were found is presented. Next, how the comparison between passing lanes and other roadway segments is discussed.

Roadway Geometry

The roadway geometry data from ITD were used in this step. First, the data were filtered by year under the passing lane width section. All of the passing lanes in the data were 12-feet wide. The data also included segment codes, beginning mileposts, and ending mileposts for all of the rural passing lane sections. That way, all of the passing lane segments in 2008 could be listed, and the specific mileposts could be input into WebCars. These passing lanes would be the sections that would be used to find crashes in WebCars. A total of 127 passing lanes were used for the analysis.

Roadway Crash Statistics

The query and report builder function was utilized in WebCars to obtain crash statistics. First, a query name was input into WebCars. The query name is how the user can specify what sort of crashes to pull from the database. For example, specific milepost ranges can be input for a specific roadway so only crashes within the specified range are reported.

For this analysis, the only two filters used were related to city limits and intersections. The data were filtered to not include crashes within city limits because the purpose of this study is to analyze passing lanes on rural highways. Thus, a crash inside of city limits would most likely not be in a rural setting. Then, crashes that were related to intersections were filtered out of the crash data. Again, the purpose of this research was to analyze crashes that could be attributed to the passing lane and not the intersection.

Furthermore, no intersections were included during the driving simulation; so, it would not be accurate to include crashes that could be related to an intersection.

The next step was to input a report name and description into WebCars. This is where the user can specify what information to pull from the complete crash report. The most important data used for the crash analysis are listed below:

- Most harmful event
- Road surface condition
- Street 1
- Milepost
- Light conditions
- Serial number

Most of the types of data filtered from the crash reports are intuitive, but each is described in detail further. The "Most harmful event" is the most harmful cause for the crash listed on the accident report. Two examples of a "Most harmful event" are a rear-end collision and a collision due to a wild animal. Animal-vehicle collisions were removed from the analysis because they cannot be directly related to a certain road segment. The "Road surface condition" describes the pavement conditions at the time of the crash. Two examples of "Road surface conditions" are dry and snow. The "Street 1" is the roadway that the crash occurred on. Two examples of "Street 1" are US-95 and SH-55. The milepost was included so the data could be further filtered in Excel and using the SPSS statistical software. The "Light conditions" describes the time of the day of the crash and whether or not on-street lighting was present. Two examples of "Light conditions" are day or dark, and no street lights. Finally, the serial number was included so only unique crashes could be found. If four people were in a vehicle that crashed, then each person would have a crash entry including their age, sex, and name, among other details. Thus, by including the serial number, repeated crashes could be found so only one entry matched a singular event.

Finally, the year range for the crashes was input into WebCars, and the crash reports can be generated. The data are output in a tabular format and can be opened using Microsoft Word or Excel.

Because the output data from WebCars included all crashes that were both not within city limits and not intersection related, the crashes had to further be filtered to include only crashes that occurred within passing lanes. Using the mileposts of passing lanes provided from ITD and all of the crash data from 2008 through 2012, a SPSS script was run to filter the crashes to only include those within the passing lanes. There were a total of 486 crashes within the 127 passing lanes throughout the five-year period.

Next, each crash was assigned a unique crash number. If there was more than one occupant in the vehicle crash, each additional occupant would have a crash report filed with the same serial number as the driver. Thus, creating a unique crash number for each crash would account for the multiple reports filed for additional occupants.

Next, the total number of crashes per year per mile was calculated for the passing lane segments. The total number of crashes occurring in each of the passing lane segments was found, followed by the total number of crashes being divided by five to obtain the number of crashes per year for each passing lane section. Then, the number of crashes per year was divided by the length of the passing lane to find crashes per year per mile.

Downstream Passing Lane Comparison

Once all of the data for the passing lane segments were calculated in crashes per mile per year, another set of WebCars crash data were analyzed. The purpose of these crashes was to investigate whether or not the passing lanes contributed to a higher number of crashes immediately downstream of the passing lanes. The number of crashes 0.5 miles from the end of the passing lane segments, the merging segment, and 0.5 miles after that, the downstream segment, were compared. If the number of crashes in the merging section was similar to the downstream section, then the passing lane would not have any effect on crashes downstream. However, if the number of crashes in the merging section is significantly higher than the downstream section, then the increase in crashes can be attributed to the passing lane. It was assumed that the volume of vehicles in the passing lane propagated downstream, and no vehicles exited the roadway.

Common crashes that may occur downstream from a passing lane section include rear-end and head-on collisions. A rear-end collision would likely occur when a vehicle is travelling too fast for the road conditions after accelerating to pass vehicles in the passing lane and runs into the rear of the leading vehicle. A head-on collision would likely occur if a vehicle in the passing lane is forced to the opposite-direction lane of travel by a merging vehicle.

All Crash Comparison

Finally, a comparison between the crash characteristics in passing lanes vs. non-passing lanes was investigated to see if there were any notable differences. A Chi-Squared test was performed on the frequency of crash characteristics in passing lanes compared to non-passing lanes. Because the number of crashes in non-passing lanes was much larger than in passing lanes, only the percentage of characteristics was utilized to find the expected value of crashes. For example, if the lighting conditions for non-passing lanes were during the day for 50% of all of the crashes, then the expected value of crashes in the passing lane would be 50% of the overall crashes in passing lanes. The most harmful events, road surface conditions, sex of drivers, lighting conditions, and crash severities were compared between passing lane segments and non-passing lane segments.

Crash Characteristic Results

Using the crash reports from WebCars, the most prevalent causes and scenarios for crashes in passing lanes are discussed in this section. Additionally, the most common roadway surface conditions, lighting conditions, and crash severity are listed. There were 486 unique crashes within the passing lane segments that were not animal-vehicle related. Table 4 below shows the results of the Chi-Squared analysis and will be discussed in further detail below.

Table 4: Chi-Squared Statistical Results

Crash Characteristic	**χ^2 Calculated**	**df**	**P-Value**
Lighting Conditions	19.0	3	< 0.001
Crash Severity	8.9	4	0.064
Sex of Driver	1.1	2	0.576
Road Surface Conditions	92.9	5	< 0.001
Most Harmful Event	206.0	7	< 0.001

Figure 34 below shows the lighting conditions of crashes between passing lanes and other two-lane highway segments. From Table 4 above, it can be seen that p-value is much less than 0.05; thus, the null hypothesis is rejected—the distribution of crash severity in passing lanes is very different from the distribution of crash severity in non-passing lanes.

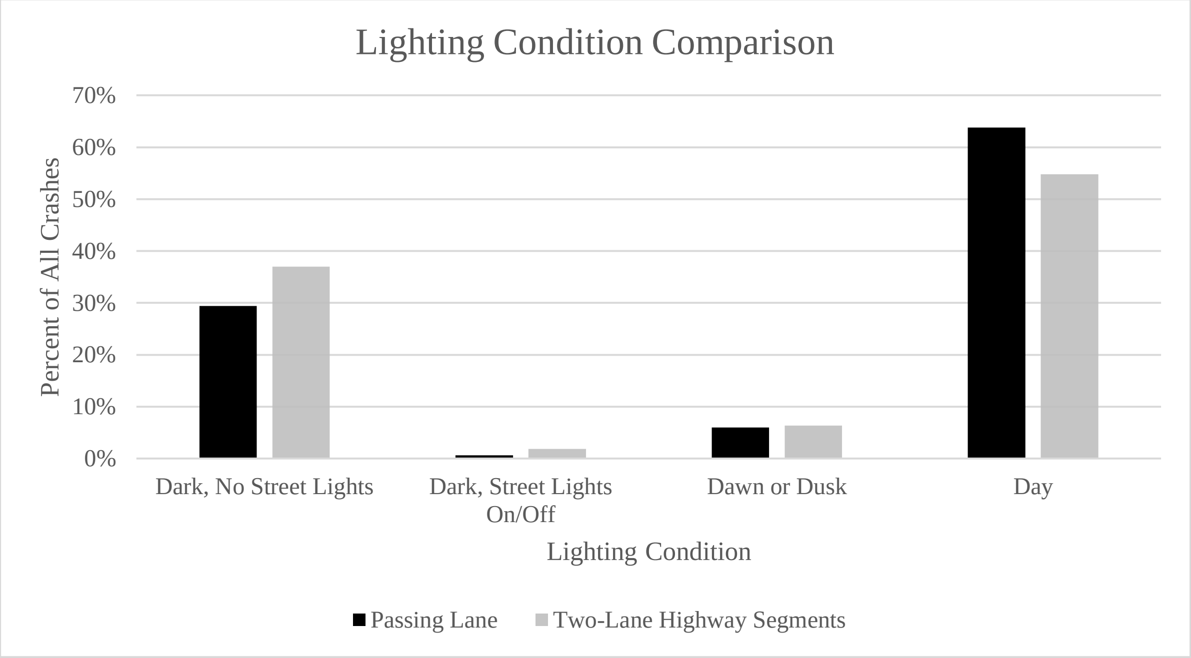


Figure 34: Crash Lighting Condition Comparison

Figure 35 below shows the crash severity between passing lanes and other two-lane highway segments. From Table 4 above, it can be seen that p-value is actually greater than 0.05. Thus, the null hypothesis fails to be rejected—the distribution of crash severity is reliably the same between passing lanes and non-passing lanes. These data suggest that passing lanes do not necessarily improve the safety of roads by reducing the frequency of certain crashes. Instead, the number of each crash type is about the same.

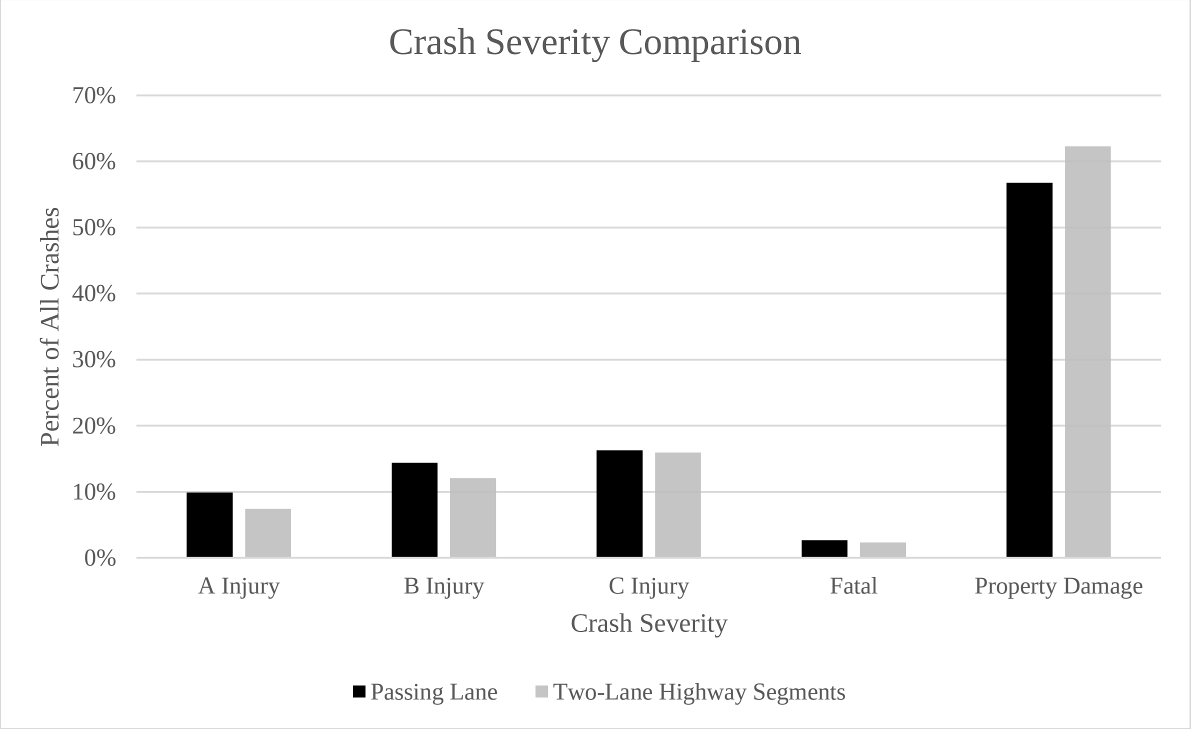


Figure 35: Crash Severity Comparison

Figure 36 below shows the sex of drivers between passing lanes and other two-lane highway segments. From Table 4 above, it can be seen that p-value is actually greater than 0.05; thus, the null hypothesis fails to be rejected—the distribution of the sex of drivers is reliably the same between passing lanes and non-passing lanes. This is logical because more men or women will not necessarily be driving on passing lanes compared to non-passing lanes.

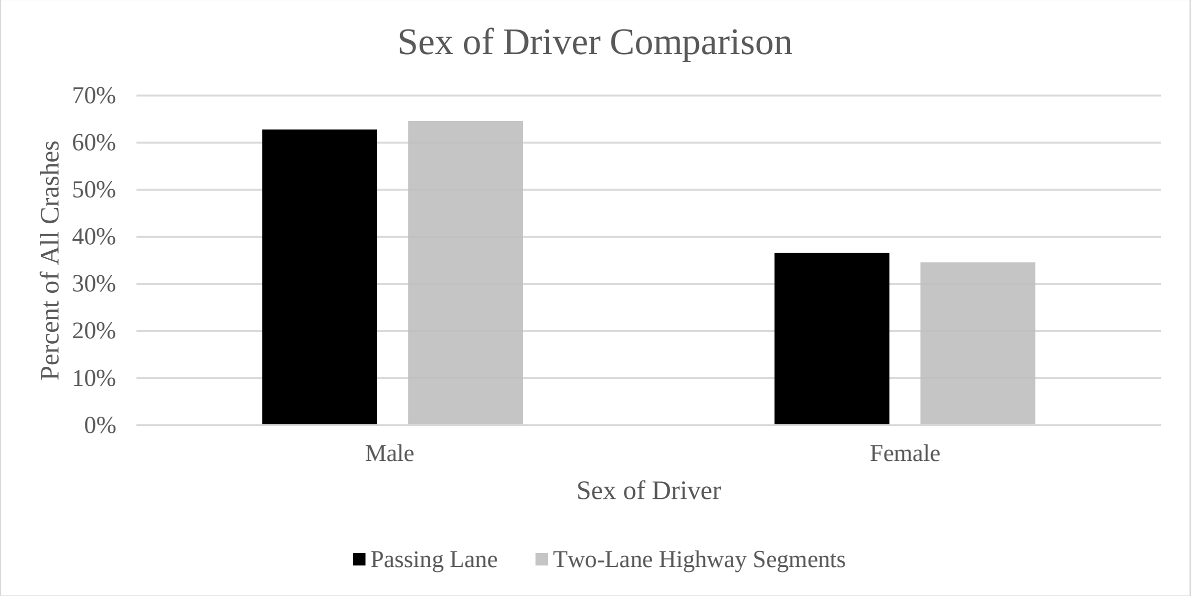


Figure 36: Crash Sex of Driver Comparison

Figure 37 below shows the crash road surface conditions between passing lanes and other two-lane highway segments. From Table 4 above, it can be seen that p-value is much less than 0.05; thus, the null hypothesis is rejected—the distribution of the road surface conditions is reliably the different between passing lanes and non-passing lanes. From Figure 37, it can be seen that crashes in ice and snow are much higher in passing lanes than other two-lane highway segments. This is logical because drivers will tend to drive faster to pass a vehicle in a passing lane, resulting in more crashes in icy or snowy conditions.

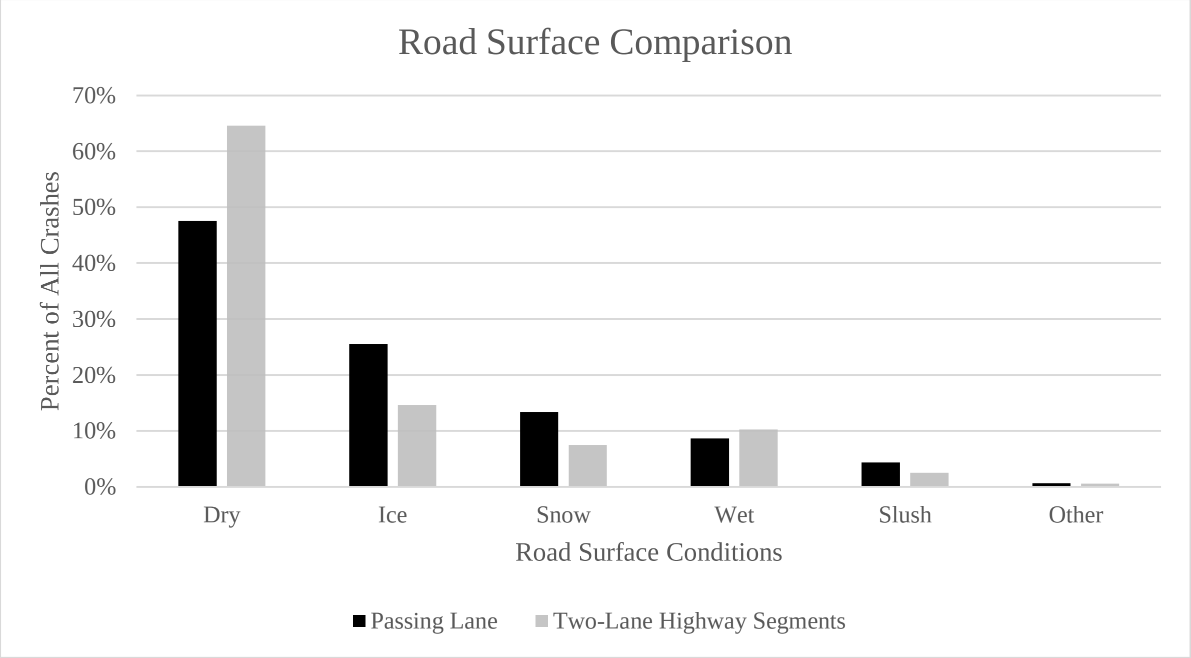


Figure 37: Crash Road Surface Condition Comparison

Figure 38 below shows the crash most harmful events between passing lanes and other two-lane highway segments. Because the p-value is much less than 0.05, the null hypothesis is rejected—the distribution of the most harmful events is reliably the different between passing lanes and non-passing lanes. The percentage of crashes that result in side swipes in the same direction are three times as likely to happen in passing lanes compared to non-passing lanes. This is logical because in passing lanes, two lanes are available for travel in one direction which means there is more of an opportunity to have a side swipe in the same direction. Additionally, the number of rear-end collisions on passing lanes is 40% less than non-passing lanes. Again, with two lanes of travel for one direction, there is less of a chance of rear ending a driver because there is an opportunity to pass. The number of head-on collisions in passing lanes is more than double that of non-passing lanes. This is logical because drivers will move to the left lane to pass a slow-moving vehicle and may drift too far into the on-coming approach lane, resulting in a head-on collision.

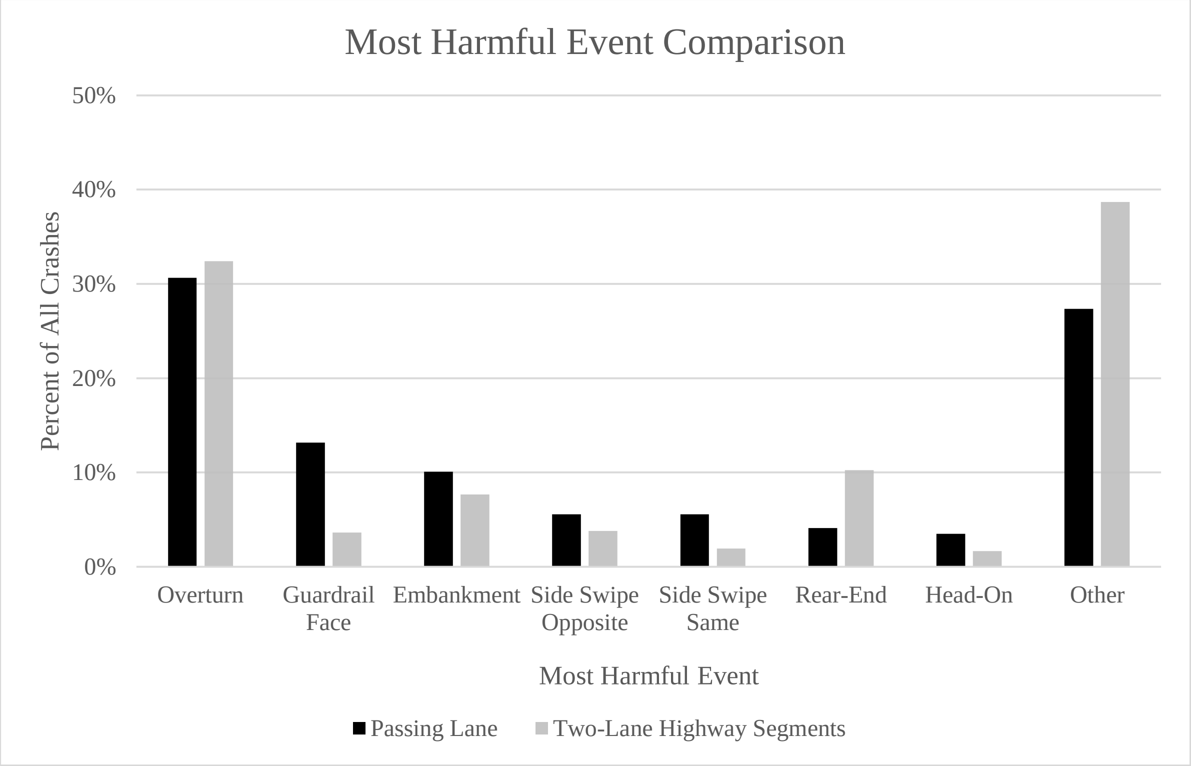


Figure 38: Most Harmful Event Comparison

Downstream Comparison Results

Because there were varying vehicular volumes throughout the analyzed passing lanes, the crashes had to be normalized to perform a statistical test. Instead of dividing the existing crash rate by the volume or calculating the number of anticipated crashes per million-vehicle-miles, the difference in crash rates were analyzed. Table 5 below shows the summary statistics of the differences in crash rates.

Table 5: Crash Rate Difference Summary Statistics

Location Difference (crash/mile/year)	Number of Crashes	Mean	Standard Deviation	Standard Error Mean
Merging - Downstream	127	0.09	0.83	0.07
Merging - Passing	127	0.05	0.92	0.08
Passing - Downstream	127	0.04	0.84	0.07

Next, a t-test was run on the difference in crash rates to see if there were any reliable differences. None of the differences in crash rates were significant using a t-test. Table 6 below shows the results of the statistical tests.

Table 6: Crash Rate Difference Statistical Results

Location	Test Statistic	Degrees of Freedom	P-value (two-tailed)
Merging - Downstream	1.20	126	0.23
Merging - Passing	0.55	126	0.58
Passing - Downstream	0.58	126	0.57

The data in Table 6 suggests that none of the comparisons produce reliable differences in crash rates. Thus, although there are differences in the mean crash rates, there are not statistically reliable differences.

Conclusion

By using ITD's WebCars crash analysis reporting system to obtain crash data on passing lanes, merging sections, downstream segments, and throughout rural, two-lane highways across the state, it became clear that there were some differences in the distribution of crash characteristics between passing lanes and non-passing lanes. Specifically, the distribution of lighting conditions, road surface conditions, and the most harmful events between passing lanes and non-passing lanes were reliably different. Next, a statistical test was run to see if there were any differences in the difference in crash rates between the passing lane section, merging section, and downstream section. Although there were differences in the mean crash rates, there were no statistically reliable differences.

CHAPTER 6: RESEARCH CONCLUSIONS

This study has presented and evaluated six hypotheses using a driving simulator and crash data from the state of Idaho. This chapter analyzes and summarizes the findings of each of the six research objectives.

Effects of Regulatory and Advisory Speed Reduction Measures

The effects of regulatory and advisory speed reduction measures were clearly seen with towing drivers in Experiment 1 where drivers remained in the right lane for the majority of time spent in the passing lane. The Regulatory Scenario had the largest average decrease in speed from the Baseline Scenario at 6.5 mph, whereas the Regulatory plus Advisory Scenario had the second largest average decrease in speed from the Baseline Scenario at 5.7 mph. The Regulatory Scenario and Regulatory plus Advisory Scenario did not have an effect on reducing the speed of drivers not towing a trailer in Experiment 2. However, the majority of drivers in Experiment 2 were in the left lane where the posted speed limit was 65 mph. Experiment 3 suggested that the Regulatory Scenario again had the greatest practical effect of reducing the speed of drivers. Therefore, regulatory and advisory speed reduction measures do significantly reduce the speed of drivers, but the effect was only noticeable for drivers towing a trailer in the right lane of the passing lane segment.

Effects of Passive Speed Reduction Measures

The effects of passive speed reduction measures were analyzed in each of the three experiment. From Experiment 1 when performing the within-subjects analysis, some passive speed scenarios had some reliable effect on reducing driver speed in the right lane. Specifically, the use of chevrons, transverse lines, or parallax should also be expected to have a reliable—though smaller—effect on speed control. In contrast, Experiment 2 and Experiment 3 showed no effect on speed reduction using passive speed measures.

Towing Effects on Lane Position

The effects of towing a vehicle on lane position was clearly seen when comparing Experiment 1 and Experiment 2. In Experiment 1—where vehicles were towing a trailer—participants remained in the right lane of passing lanes over 90% of the time. However, in Experiment 2—where vehicles were not towing a trailer—participants remained in the left lane of a passing lane more than 81% of the time. Thus, drivers towing a trailer generally moved to the right lane, and drivers not towing a trailer generally remained in the left lane of passing lanes.

Traffic Effects on Passive Speed Measures

The effects of passive speed reduction measures were analyzed in Experiment 3 with traffic and without traffic. The experiment found that there were no reliable differences in the speed of drivers with traffic versus the speed of drivers without traffic using the passive speed reduction measures.

Crash Characteristics of Passing Lanes versus Non-Passing Lanes

Crash characteristics within passing lanes were documented in the crash analysis and compared to non-passing lane segments. The crash analysis found that some characteristics were reliably different in passing lanes compared to non-passing lanes, but some crash characteristics were not. The lighting conditions, road surface conditions, and most harmful events were reliably different based on a Chi-Squared Test between passing lanes and non-passing lanes.

Crash Rate Comparison

Crash rates along various roadway segments were documented and compared in the crash analysis. The crash rate analysis found that—although there were practical differences in the rate of crashes—there were no statistically reliable differences in the mean crash rates between passing lanes, merging segments, and downstream segments. Passing lanes do not necessarily reduce the crash rates compared to sections downstream of the passing lane.

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Appendices

All of the appendices for this paper are included in this section. A list of all of the appendices is shown below:

- Appendix A: RV Towing Instructions
- Appendix B: Sign Quiz
- Appendix C: Non-Towing Instructions
- Appendix D: Experiment 1 Statistical Results
- Appendix E: Experiment 2 Statistical Results
- Appendix F: Experiment 3 Statistical Results
- Appendix G: Protocol Approval from Human Assurances Committee

Appendix A: RV Towing Instructions

This experiment examines how people drive on rural highways.

Your task will be to steer a simulated vehicle pulling a recreational vehicle (a trailer) 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 50 minutes which will simulate a 50 mile drive in traffic returning from a weekend in the Alaskan wilderness. 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 lanes to pass slow moving vehicles, letting faster vehicles behind you pass, etc.) just as you would if you were driving on a real rural highway pulling a recreational vehicle in traffic.

From time to time, the other vehicles in the simulation will slow and pull off on the shoulder. When this occurs, you should maintain a safe distance, stay in your lane, and accelerate back up to your cruising speed once the lane is clear.

Do you have any questions?

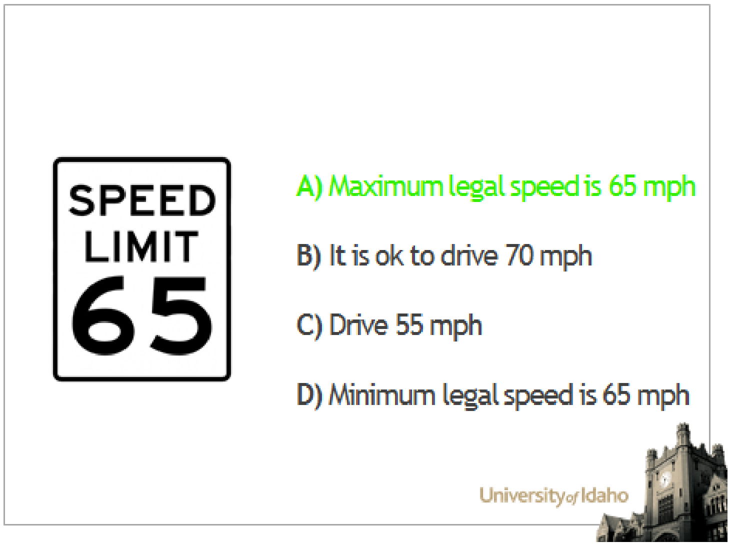
Now please explain to me, in your own words, what you will be doing in this study.

After approximately 25 miles, a message will appear on the screen asking you to pull over in front of a row of orange barrels 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.

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?

Appendix B: Sign Quiz

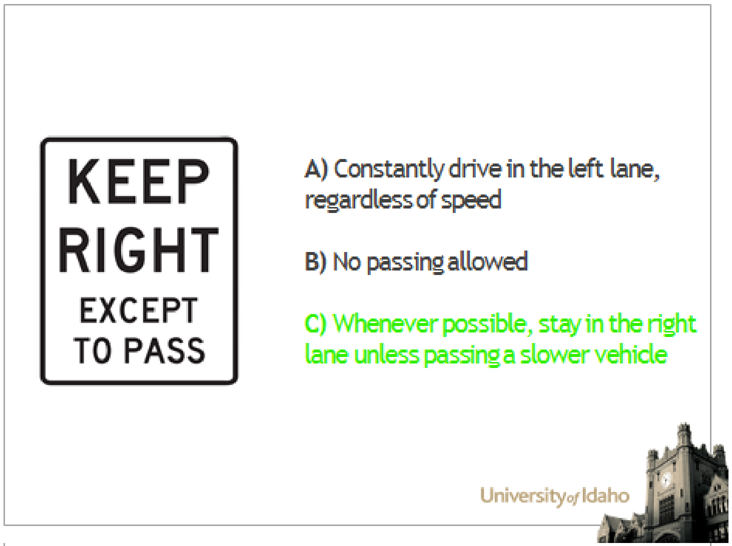


A) Maximum legal speed is 65 mph

B) It is ok to drive 70 mph

C) Drive 55 mph

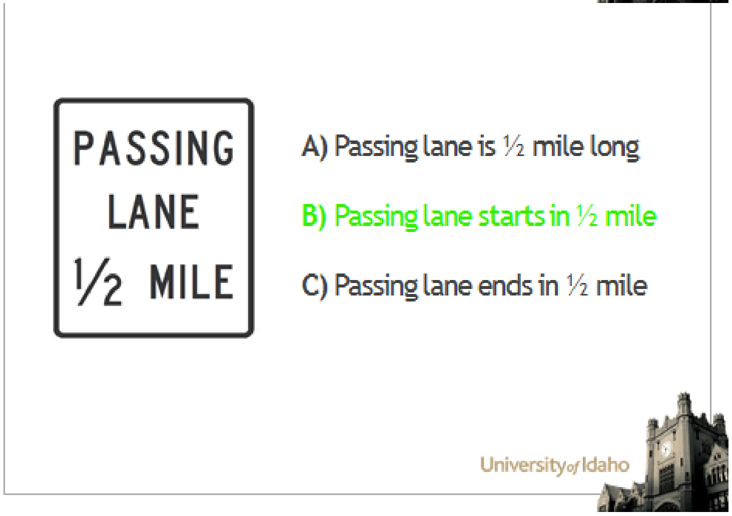
D) Minimum legal speed is 65 mph



A) Constantly drive in the left lane, regardless of speed

B) No passing allowed

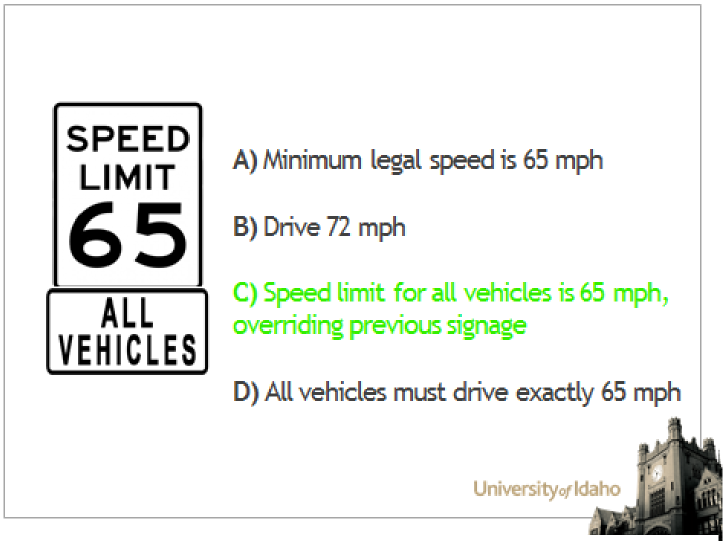
C) Whenever possible, stay in the right lane unless passing a slower vehicle



A) Passing lane is ½ mile long

B) Passing lane starts in ½ mile

C) Passing lane ends in ½ mile

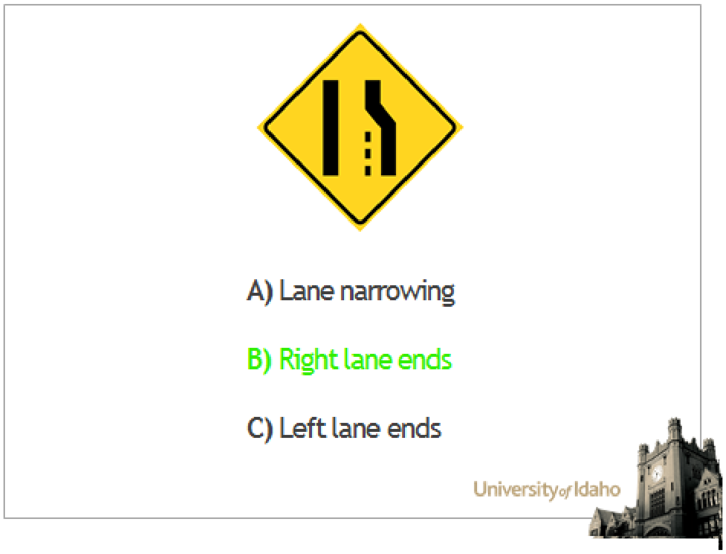


A) Minimum legal speed is 65 mph

B) Drive 72 mph

C) Speed limit for all vehicles is 65 mph, overriding previous signage

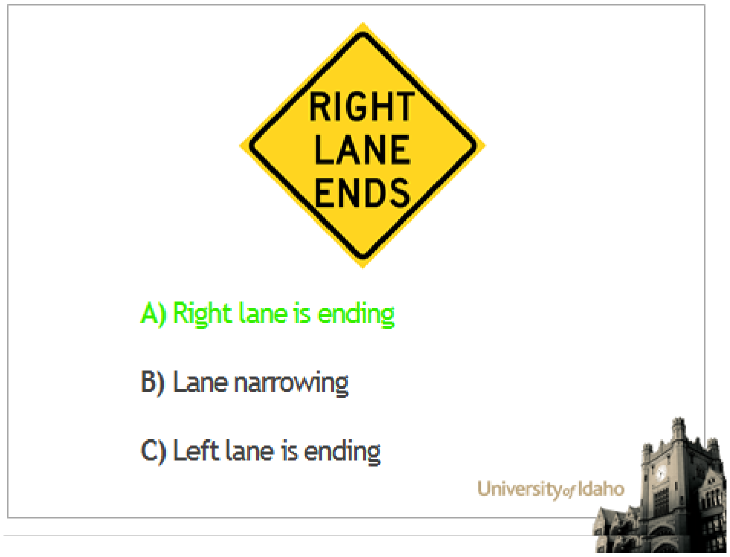
D) All vehicles must drive exactly 65 mph



A) Lane narrowing

B) Right lane ends

C) Left lane ends



A) Right lane is ending

B) Lane narrowing

C) Left lane is ending

Appendix C: Non-Towing Instructions

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 50 minutes which will simulate a 50 mile drive in traffic returning from a weekend in the Alaskan wilderness. 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 lanes to pass slow moving vehicles, letting faster vehicles behind you pass, etc.) just as you would if you were driving on a real rural highway in traffic, and in a hurry to get home. Also during this drive, you are only allowed to pass a car if there is another open lane to pass in (Passing Lane). You cannot pass someone by going into the oncoming lane (2 lane highway), even if the road markings allow you to pass (ex. dotted line), because this can cause our simulation to crash.

From time to time, the other vehicles in the simulation will slow and pull off on the shoulder. When this occurs, you should maintain a safe distance, stay in your lane, and accelerate back up to your cruising speed once the lane is clear.

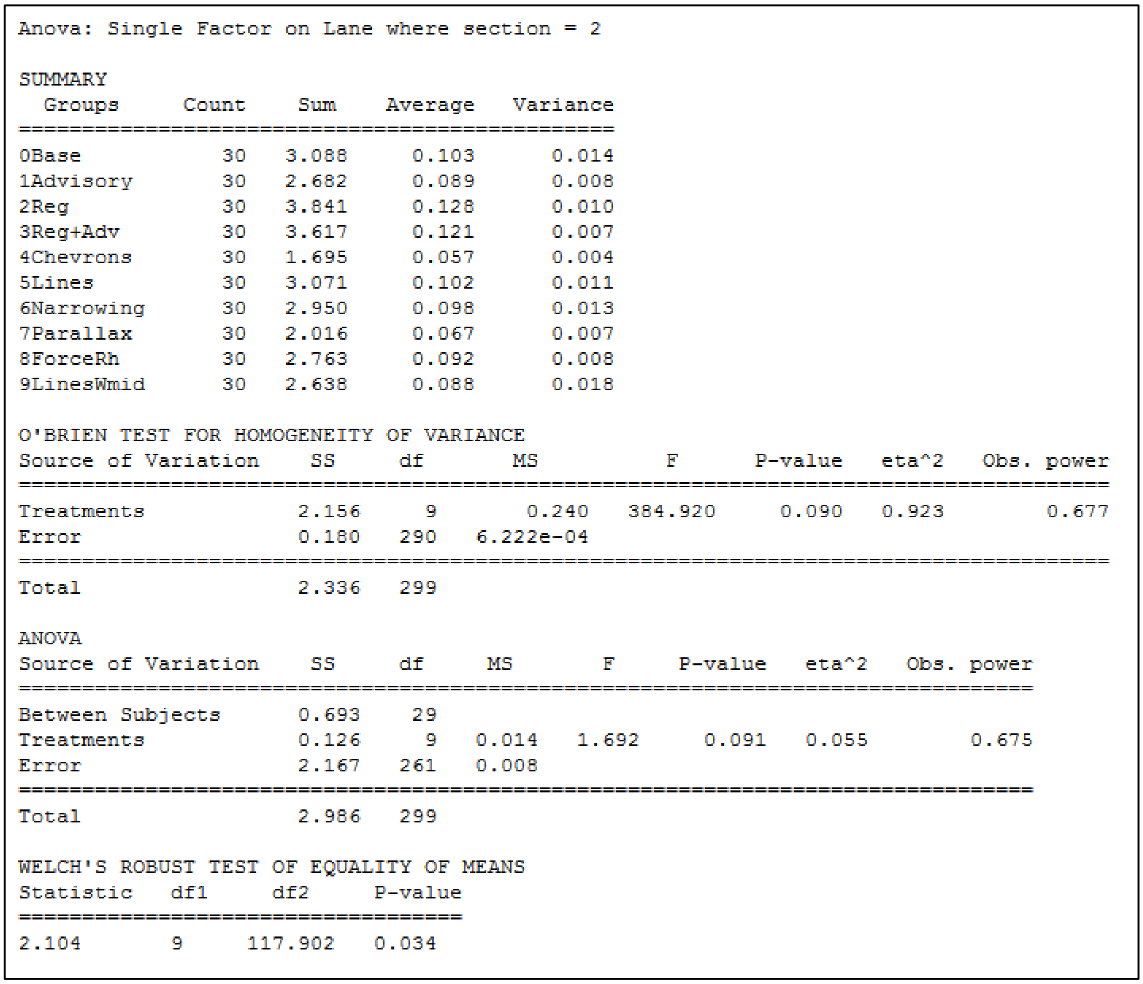
Do you have any questions?

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 in front of a row of orange barrels 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. 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.”

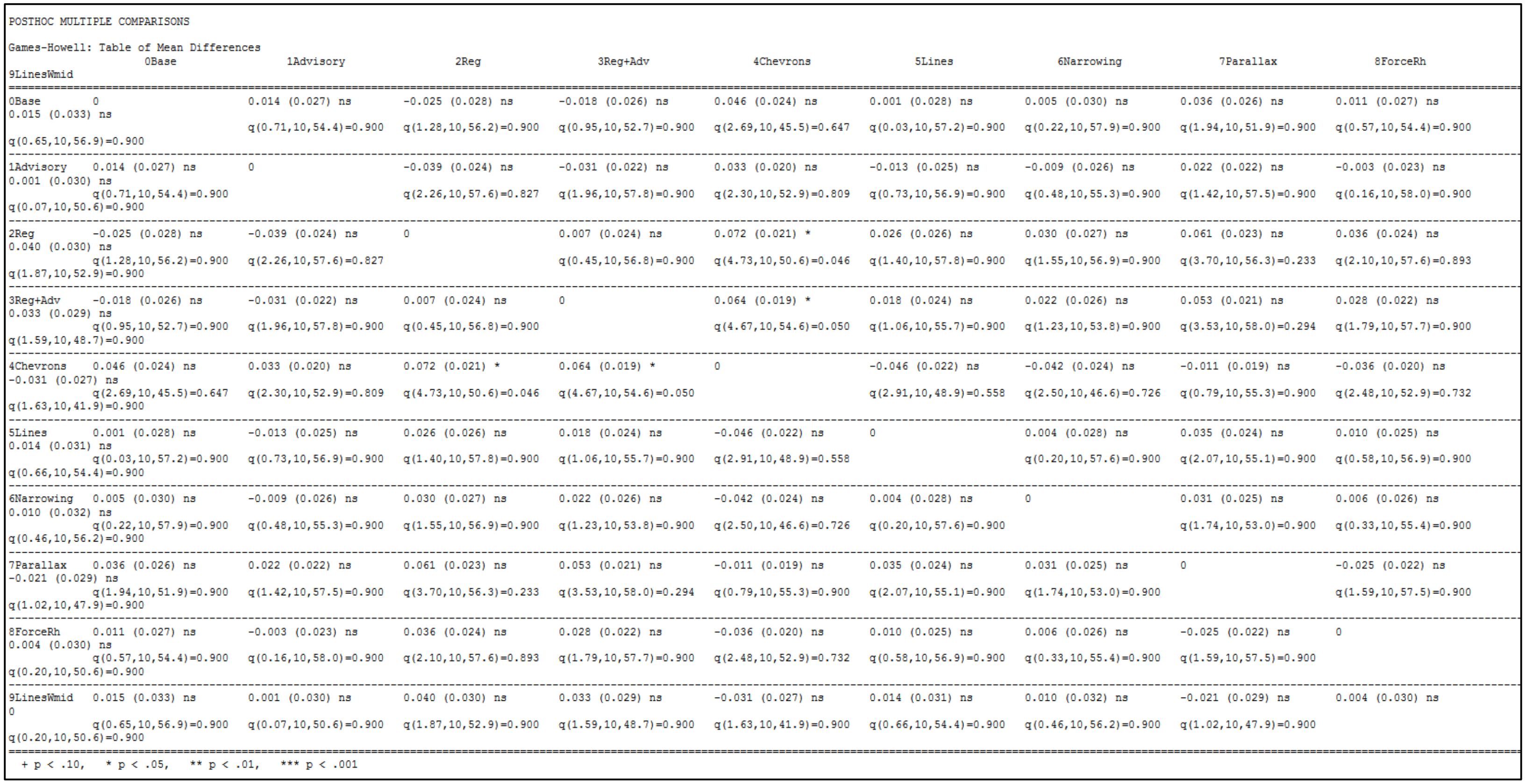
Do you have any questions?

Appendix D: Experiment 1 Statistical Results



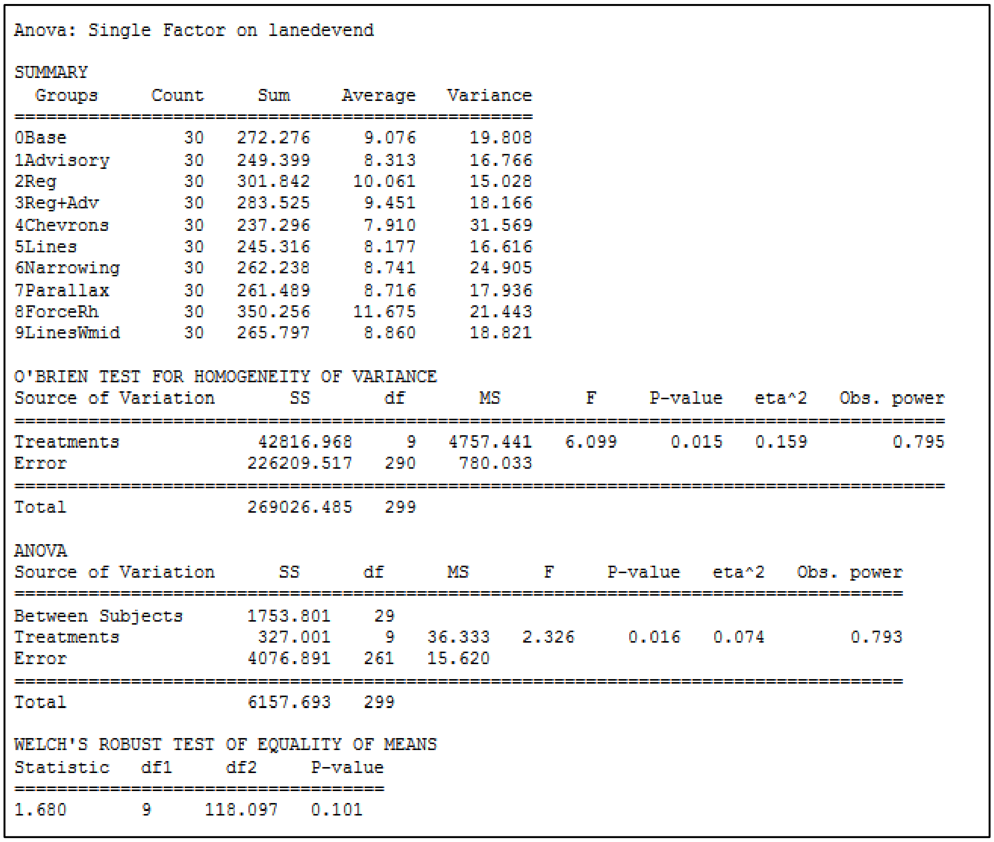
```
Anova: Single Factor on Lane where section = 2

SUMMARY
  Groups     Count    Sum    Average   Variance
===============================================
0Base          30   3.088     0.103      0.014
1Advisory      30   2.682     0.089      0.008
2Reg           30   3.841     0.128      0.010
3Reg+Adv       30   3.617     0.121      0.007
4Chevrons      30   1.695     0.057      0.004
5Lines         30   3.071     0.102      0.011
6Narrowing     30   2.950     0.098      0.013
7Parallax      30   2.016     0.067      0.007
8ForceRh       30   2.763     0.092      0.008
9LinesWmid     30   2.638     0.088      0.018

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation    SS      df       MS          F       P-value   eta^2   Obs. power
========================================================================================
Treatments           2.156      9       0.240    384.920     0.090    0.923        0.677
Error                0.180    290   6.222e-04
========================================================================================
Total                2.336    299

ANOVA
Source of Variation    SS      df     MS       F      P-value   eta^2   Obs. power
==================================================================================
Between Subjects     0.693     29
Treatments           0.126      9   0.014   1.692     0.091   0.055        0.675
Error                2.167    261   0.008
==================================================================================
Total                2.986    299

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic   df1     df2      P-value
===================================
2.104       9     117.902   0.034
```

Figure 39: ANOVA Proportion of Time Spent in Left Lane, Experiment 1



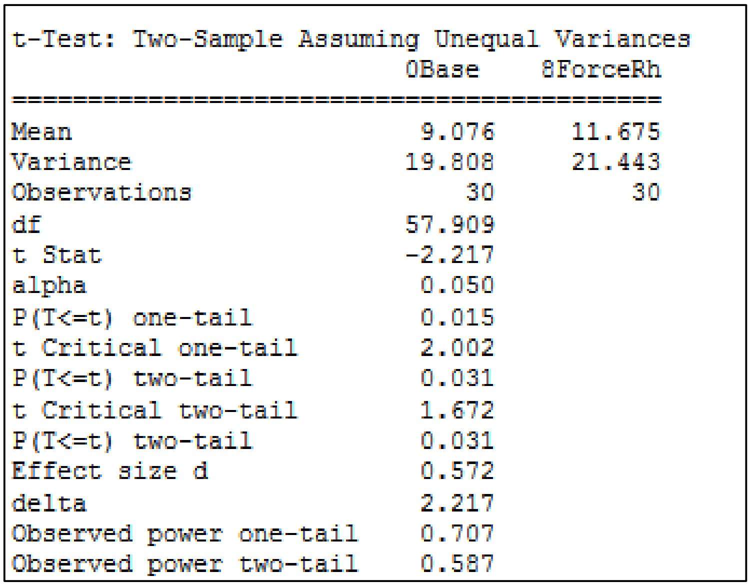
```
POSTHOC MULTIPLE COMPARISONS

Games-Howell: Table of Mean Differences
                   0Base               1Advisory              2Reg              3Reg+Adv             4Chevrons               5Lines              6Narrowing             7Parallax              8ForceRh
9LinesWmid
================================================================================================================================================================================================================
0Base        0                     0.014 (0.027) ns      -0.025 (0.028) ns     -0.018 (0.026) ns     0.046 (0.024) ns      0.001 (0.028) ns      0.005 (0.030) ns      0.036 (0.026) ns      0.011 (0.027) ns
0.015 (0.033) ns
                                   q(0.71,10,54.4)=0.900 q(1.28,10,56.2)=0.900 q(0.95,10,52.7)=0.900 q(2.69,10,45.5)=0.647 q(0.03,10,57.2)=0.900 q(0.22,10,57.9)=0.900 q(1.94,10,51.9)=0.900 q(0.57,10,54.4)=0.900
q(0.65,10,56.9)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
1Advisory    0.014 (0.027) ns      0                     -0.039 (0.024) ns     -0.031 (0.022) ns     0.033 (0.020) ns      -0.013 (0.025) ns     -0.009 (0.026) ns     0.022 (0.022) ns      -0.003 (0.023) ns
0.001 (0.030) ns
             q(0.71,10,54.4)=0.900                       q(2.26,10,57.6)=0.827 q(1.96,10,57.8)=0.900 q(2.30,10,52.9)=0.809 q(0.73,10,56.9)=0.900 q(0.48,10,55.3)=0.900 q(1.42,10,57.5)=0.900 q(0.16,10,58.0)=0.900
q(0.07,10,50.6)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
2Reg         -0.025 (0.028) ns     -0.039 (0.024) ns     0                     0.007 (0.024) ns      0.072 (0.021) *       0.026 (0.026) ns      0.030 (0.027) ns      0.061 (0.023) ns      0.036 (0.024) ns
0.040 (0.030) ns
             q(1.28,10,56.2)=0.900 q(2.26,10,57.6)=0.827                       q(0.45,10,56.8)=0.900 q(4.73,10,50.6)=0.046 q(1.40,10,57.8)=0.900 q(1.55,10,56.9)=0.900 q(3.70,10,56.3)=0.233 q(2.10,10,57.6)=0.893
q(1.87,10,52.9)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
3Reg+Adv     -0.018 (0.026) ns     -0.031 (0.022) ns     0.007 (0.024) ns      0                     0.064 (0.019) *       0.018 (0.024) ns      0.022 (0.026) ns      0.053 (0.021) ns      0.028 (0.022) ns
0.033 (0.029) ns
             q(0.95,10,52.7)=0.900 q(1.96,10,57.8)=0.900 q(0.45,10,56.8)=0.900                       q(4.67,10,54.6)=0.050 q(1.06,10,55.7)=0.900 q(1.23,10,53.8)=0.900 q(3.53,10,58.0)=0.294 q(1.79,10,57.7)=0.900
q(1.59,10,48.7)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
4Chevrons    0.046 (0.024) ns      0.033 (0.020) ns      0.072 (0.021) *       0.064 (0.019) *       0                     -0.046 (0.022) ns     -0.042 (0.024) ns     -0.011 (0.019) ns     -0.036 (0.020) ns
-0.031 (0.027) ns
             q(2.69,10,45.5)=0.647 q(2.30,10,52.9)=0.809 q(4.73,10,50.6)=0.046 q(4.67,10,54.6)=0.050                       q(2.91,10,48.9)=0.558 q(2.50,10,46.6)=0.726 q(0.79,10,55.3)=0.900 q(2.48,10,52.9)=0.732
q(1.63,10,41.9)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
5Lines       0.001 (0.028) ns      -0.013 (0.025) ns     0.026 (0.026) ns      0.018 (0.024) ns      -0.046 (0.022) ns     0                     0.004 (0.028) ns      0.035 (0.024) ns      0.010 (0.025) ns
0.014 (0.031) ns
             q(0.03,10,57.2)=0.900 q(0.73,10,56.9)=0.900 q(1.40,10,57.8)=0.900 q(1.06,10,55.7)=0.900 q(2.91,10,48.9)=0.558                       q(0.20,10,57.6)=0.900 q(2.07,10,55.1)=0.900 q(0.58,10,56.9)=0.900
q(0.66,10,54.4)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
6Narrowing   0.005 (0.030) ns      -0.009 (0.026) ns     0.030 (0.027) ns      0.022 (0.026) ns      -0.042 (0.024) ns     0.004 (0.028) ns      0                     0.031 (0.025) ns      0.006 (0.026) ns
0.010 (0.032) ns
             q(0.22,10,57.9)=0.900 q(0.48,10,55.3)=0.900 q(1.55,10,56.9)=0.900 q(1.23,10,53.8)=0.900 q(2.50,10,46.6)=0.726 q(0.20,10,57.6)=0.900                       q(1.74,10,53.0)=0.900 q(0.33,10,55.4)=0.900
q(0.46,10,56.2)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
7Parallax    0.036 (0.026) ns      0.022 (0.022) ns      0.061 (0.023) ns      0.053 (0.021) ns      -0.011 (0.019) ns     0.035 (0.024) ns      0.031 (0.025) ns      0                     -0.025 (0.022) ns
-0.021 (0.029) ns
             q(1.94,10,51.9)=0.900 q(1.42,10,57.5)=0.900 q(3.70,10,56.3)=0.233 q(3.53,10,58.0)=0.294 q(0.79,10,55.3)=0.900 q(2.07,10,55.1)=0.900 q(1.74,10,53.0)=0.900                       q(1.59,10,57.5)=0.900
q(1.02,10,47.9)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
8ForceRh     0.011 (0.027) ns      -0.003 (0.023) ns     0.036 (0.024) ns      0.028 (0.022) ns      -0.036 (0.020) ns     0.010 (0.025) ns      0.006 (0.026) ns      -0.025 (0.022) ns     0
0.004 (0.030) ns
             q(0.57,10,54.4)=0.900 q(0.16,10,58.0)=0.900 q(2.10,10,57.6)=0.893 q(1.79,10,57.7)=0.900 q(2.48,10,52.9)=0.732 q(0.58,10,56.9)=0.900 q(0.33,10,55.4)=0.900 q(1.59,10,57.5)=0.900
q(0.20,10,50.6)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
9LinesWmid   0.015 (0.033) ns      0.001 (0.030) ns      0.040 (0.030) ns      0.033 (0.029) ns      -0.031 (0.027) ns     0.014 (0.031) ns      0.010 (0.032) ns      -0.021 (0.029) ns     0.004 (0.030) ns
0
             q(0.65,10,56.9)=0.900 q(0.07,10,50.6)=0.900 q(1.87,10,52.9)=0.900 q(1.59,10,48.7)=0.900 q(1.63,10,41.9)=0.900 q(0.66,10,54.4)=0.900 q(0.46,10,56.2)=0.900 q(1.02,10,47.9)=0.900
q(0.20,10,50.6)=0.900
================================================================================================================================================================================================================
  + p < .10,   * p < .05,   ** p < .01,   *** p < .001
```

Figure 40: Proportion of Time Spent in Right Lane, Experiment 1



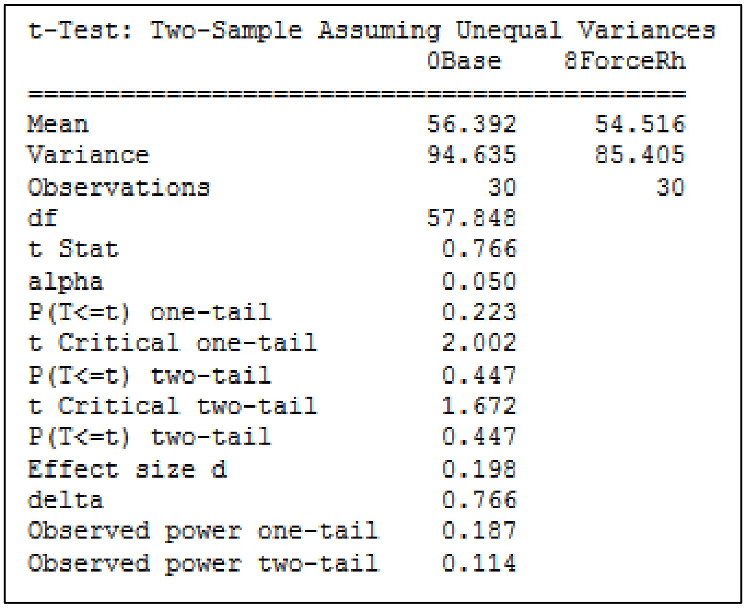
```
Anova: Single Factor on lanedevend

SUMMARY
  Groups      Count      Sum     Average   Variance
===================================================
0Base            30   272.276      9.076     19.808
1Advisory        30   249.399      8.313     16.766
2Reg             30   301.842     10.061     15.028
3Reg+Adv         30   283.525      9.451     18.166
4Chevrons        30   237.296      7.910     31.569
5Lines           30   245.316      8.177     16.616
6Narrowing       30   262.238      8.741     24.905
7Parallax        30   261.489      8.716     17.936
8ForceRh         30   350.256     11.675     21.443
9LinesWmid       30   265.797      8.860     18.821

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation        SS        df       MS        F     P-value   eta^2   Obs. power
==========================================================================================
Treatments             42816.968      9   4757.441   6.099     0.015   0.159        0.795
Error                 226209.517    290    780.033
==========================================================================================
Total                 269026.485    299

ANOVA
Source of Variation      SS       df      MS       F     P-value   eta^2   Obs. power
=====================================================================================
Between Subjects      1753.801    29
Treatments             327.001     9   36.333   2.326     0.016   0.074        0.793
Error                 4076.891   261   15.620
=====================================================================================
Total                 6157.693   299

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic   df1     df2      P-value
====================================
1.680       9     118.097   0.101
```

Figure 41: ANOVA Lane Deviation at the end of Section 2, Experiment 1



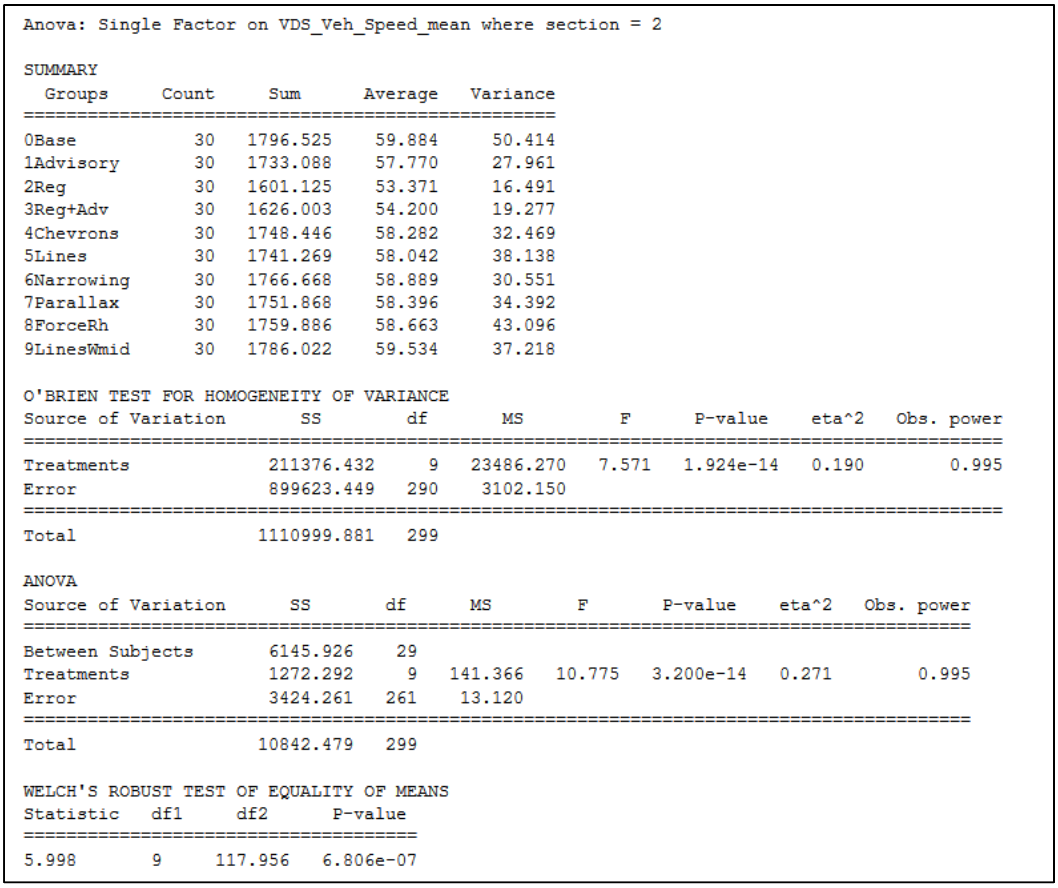
```
t-Test: Two-Sample Assuming Unequal Variances
                               0Base    8ForceRh
===========================================
Mean                           9.076      11.675
Variance                      19.808      21.443
Observations                      30          30
df                            57.909
t Stat                        -2.217
alpha                          0.050
P(T<=t) one-tail               0.015
t Critical one-tail            2.002
P(T<=t) two-tail               0.031
t Critical two-tail            1.672
P(T<=t) two-tail               0.031
Effect size d                  0.572
delta                          2.217
Observed power one-tail        0.707
Observed power two-tail        0.587
```

Figure 42: Baseline vs. Force Right/Neutral Zone t-test Lane Position, Experiment 1



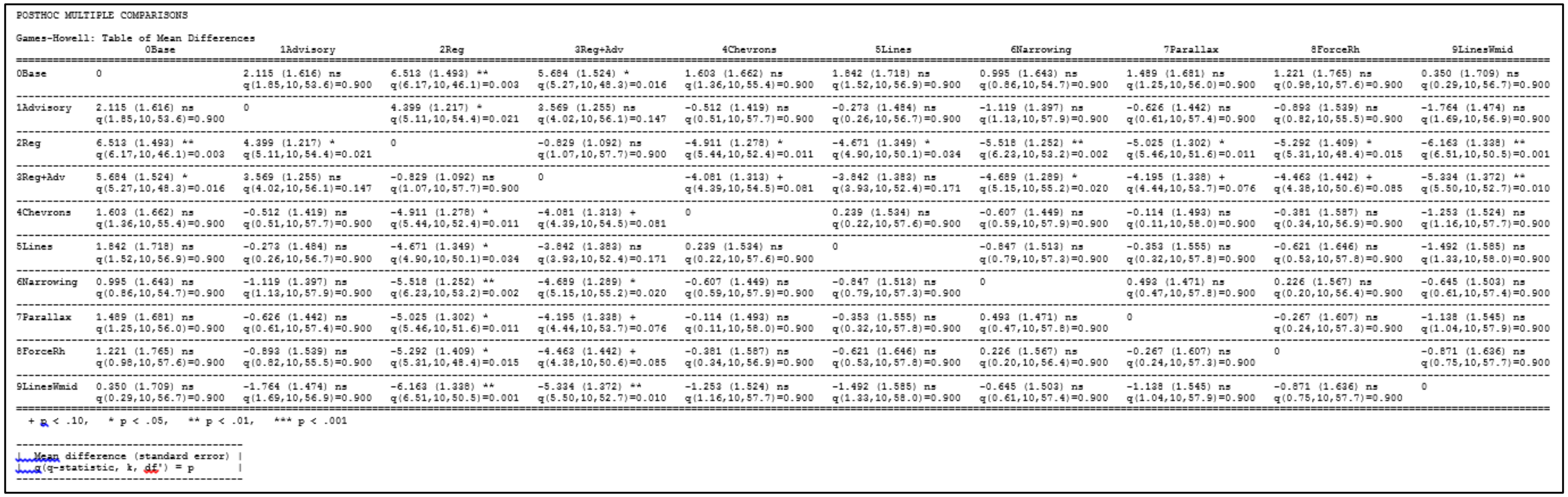
```
t-Test: Two-Sample Assuming Unequal Variances
                          0Base    8ForceRh
===========================================
Mean                      56.392     54.516
Variance                  94.635     85.405
Observations                  30         30
df                        57.848
t Stat                     0.766
alpha                      0.050
P(T<=t) one-tail           0.223
t Critical one-tail        2.002
P(T<=t) two-tail           0.447
t Critical two-tail        1.672
P(T<=t) two-tail           0.447
Effect size d              0.198
delta                      0.766
Observed power one-tail    0.187
Observed power two-tail    0.114
```

Figure 43: Baseline vs. Force Right/Neutral Zone t-test Speed, Experiment 1



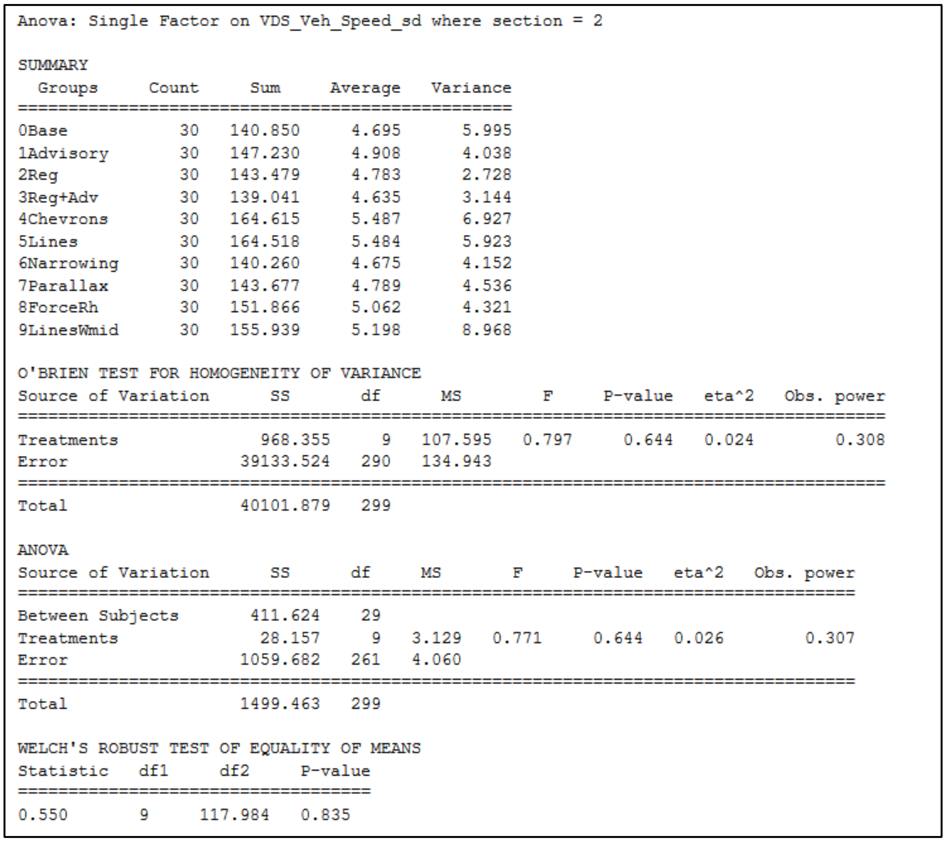
```
Anova: Single Factor on VDS_Veh_Speed_mean where section = 2

SUMMARY
  Groups      Count     Sum       Average   Variance
==================================================
0Base           30   1796.525    59.884    50.414
1Advisory       30   1733.088    57.770    27.961
2Reg            30   1601.125    53.371    16.491
3Reg+Adv        30   1626.003    54.200    19.277
4Chevrons       30   1748.446    58.282    32.469
5Lines          30   1741.269    58.042    38.138
6Narrowing      30   1766.668    58.889    30.551
7Parallax       30   1751.868    58.396    34.392
8ForceRh        30   1759.886    58.663    43.096
9LinesWmid      30   1786.022    59.534    37.218

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation       SS        df        MS          F       P-value     eta^2   Obs. power
=============================================================================================
Treatments             211376.432     9   23486.270   7.571   1.924e-14   0.190          0.995
Error                  899623.449   290    3102.150
=============================================================================================
Total                 1110999.881   299

ANOVA
Source of Variation       SS        df       MS         F        P-value     eta^2   Obs. power
==========================================================================================
Between Subjects       6145.926     29
Treatments             1272.292      9   141.366   10.775   3.200e-14   0.271          0.995
Error                  3424.261    261    13.120
==========================================================================================
Total                 10842.479    299

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic   df1     df2       P-value
=====================================
5.998        9     117.956    6.806e-07
```

Figure 44: ANOVA Mean Vehicle Speed Section 2, Experiment 1



```
POSTHOC MULTIPLE COMPARISONS

Games-Howell: Table of Mean Differences
                0Base                   1Advisory               2Reg                    3Reg+Adv                4Chevrons               5Lines                  6Narrowing              7Parallax               8ForceRh                9LinesWmid
==========================================================================================================================================================================================================================================================
0Base      0                       2.115 (1.616) ns        6.513 (1.493) **        5.684 (1.524) *         1.603 (1.662) ns        1.842 (1.718) ns        0.995 (1.643) ns        1.489 (1.681) ns        1.221 (1.765) ns        0.350 (1.709) ns
                                   q(1.85,10,53.6)=0.900   q(6.17,10,46.1)=0.003   q(5.27,10,48.3)=0.016   q(1.36,10,55.4)=0.900   q(1.52,10,56.9)=0.900   q(0.86,10,54.7)=0.900   q(1.25,10,56.0)=0.900   q(0.98,10,57.6)=0.900   q(0.29,10,56.7)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
1Advisory  2.115 (1.616) ns        0                       4.399 (1.217) *         3.569 (1.255) ns        -0.512 (1.419) ns       -0.273 (1.484) ns       -1.119 (1.397) ns       -0.626 (1.442) ns       -0.893 (1.539) ns       -1.764 (1.474) ns
           q(1.85,10,53.6)=0.900                           q(5.11,10,54.4)=0.021   q(4.02,10,56.1)=0.147   q(0.51,10,57.7)=0.900   q(0.26,10,56.7)=0.900   q(1.13,10,57.9)=0.900   q(0.61,10,57.4)=0.900   q(0.82,10,55.5)=0.900   q(1.69,10,56.9)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
2Reg       6.513 (1.493) **        4.399 (1.217) *         0                       -0.829 (1.092) ns       -4.911 (1.278) *        -4.671 (1.349) *        -5.518 (1.252) **       -5.025 (1.302) *        -5.292 (1.409) *        -6.163 (1.338) **
           q(6.17,10,46.1)=0.003   q(5.11,10,54.4)=0.021                           q(1.07,10,57.7)=0.900   q(5.44,10,52.4)=0.011   q(4.90,10,50.1)=0.034   q(6.23,10,53.2)=0.002   q(5.46,10,51.6)=0.011   q(5.31,10,48.4)=0.015   q(6.51,10,50.5)=0.001
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
3Reg+Adv   5.684 (1.524) *         3.569 (1.255) ns        -0.829 (1.092) ns       0                       -4.081 (1.313) +        -3.842 (1.383) ns       -4.689 (1.289) *        -4.195 (1.338) +        -4.463 (1.442) +        -5.334 (1.372) **
           q(5.27,10,48.3)=0.016   q(4.02,10,56.1)=0.147   q(1.07,10,57.7)=0.900                           q(4.39,10,54.5)=0.081   q(3.93,10,52.4)=0.171   q(5.15,10,55.2)=0.020   q(4.44,10,53.7)=0.076   q(4.38,10,50.6)=0.085   q(5.50,10,52.7)=0.010
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
4Chevrons  1.603 (1.662) ns        -0.512 (1.419) ns       -4.911 (1.278) *        -4.081 (1.313) +        0                       0.239 (1.534) ns        -0.607 (1.449) ns       -0.114 (1.493) ns       -0.381 (1.587) ns       -1.253 (1.524) ns
           q(1.36,10,55.4)=0.900   q(0.51,10,57.7)=0.900   q(5.44,10,52.4)=0.011   q(4.39,10,54.5)=0.081                           q(0.22,10,57.6)=0.900   q(0.59,10,57.9)=0.900   q(0.11,10,58.0)=0.900   q(0.34,10,56.9)=0.900   q(1.16,10,57.7)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
5Lines     1.842 (1.718) ns        -0.273 (1.484) ns       -4.671 (1.349) *        -3.842 (1.383) ns       0.239 (1.534) ns        0                       -0.847 (1.513) ns       -0.353 (1.555) ns       -0.621 (1.646) ns       -1.492 (1.585) ns
           q(1.52,10,56.9)=0.900   q(0.26,10,56.7)=0.900   q(4.90,10,50.1)=0.034   q(3.93,10,52.4)=0.171   q(0.22,10,57.6)=0.900                           q(0.79,10,57.3)=0.900   q(0.32,10,57.8)=0.900   q(0.53,10,57.8)=0.900   q(1.33,10,58.0)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
6Narrowing 0.995 (1.643) ns        -1.119 (1.397) ns       -5.518 (1.252) **       -4.689 (1.289) *        -0.607 (1.449) ns       -0.847 (1.513) ns       0                       0.493 (1.471) ns        0.226 (1.567) ns        -0.645 (1.503) ns
           q(0.86,10,54.7)=0.900   q(1.13,10,57.9)=0.900   q(6.23,10,53.2)=0.002   q(5.15,10,55.2)=0.020   q(0.59,10,57.9)=0.900   q(0.79,10,57.3)=0.900                           q(0.47,10,57.8)=0.900   q(0.20,10,56.4)=0.900   q(0.61,10,57.4)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
7Parallax  1.489 (1.681) ns        -0.626 (1.442) ns       -5.025 (1.302) *        -4.195 (1.338) +        -0.114 (1.493) ns       -0.353 (1.555) ns       0.493 (1.471) ns        0                       -0.267 (1.607) ns       -1.138 (1.545) ns
           q(1.25,10,56.0)=0.900   q(0.61,10,57.4)=0.900   q(5.46,10,51.6)=0.011   q(4.44,10,53.7)=0.076   q(0.11,10,58.0)=0.900   q(0.32,10,57.8)=0.900   q(0.47,10,57.8)=0.900                           q(0.24,10,57.3)=0.900   q(1.04,10,57.9)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
8ForceRh   1.221 (1.765) ns        -0.893 (1.539) ns       -5.292 (1.409) *        -4.463 (1.442) +        -0.381 (1.587) ns       -0.621 (1.646) ns       0.226 (1.567) ns        -0.267 (1.607) ns       0                       -0.871 (1.636) ns
           q(0.98,10,57.6)=0.900   q(0.82,10,55.5)=0.900   q(5.31,10,48.4)=0.015   q(4.38,10,50.6)=0.085   q(0.34,10,56.9)=0.900   q(0.53,10,57.8)=0.900   q(0.20,10,56.4)=0.900   q(0.24,10,57.3)=0.900                           q(0.75,10,57.7)=0.900
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
9LinesWmid 0.350 (1.709) ns        -1.764 (1.474) ns       -6.163 (1.338) **       -5.334 (1.372) **       -1.253 (1.524) ns       -1.492 (1.585) ns       -0.645 (1.503) ns       -1.138 (1.545) ns       -0.871 (1.636) ns       0
           q(0.29,10,56.7)=0.900   q(1.69,10,56.9)=0.900   q(6.51,10,50.5)=0.001   q(5.50,10,52.7)=0.010   q(1.16,10,57.7)=0.900   q(1.33,10,58.0)=0.900   q(0.61,10,57.4)=0.900   q(1.04,10,57.9)=0.900   q(0.75,10,57.7)=0.900
==========================================================================================================================================================================================================================================================
  + p < .10,    * p < .05,    ** p < .01,    *** p < .001

--------------------------------------
| Mean difference (standard error) |
| q(q-statistic, k, df') = p       |
--------------------------------------
```

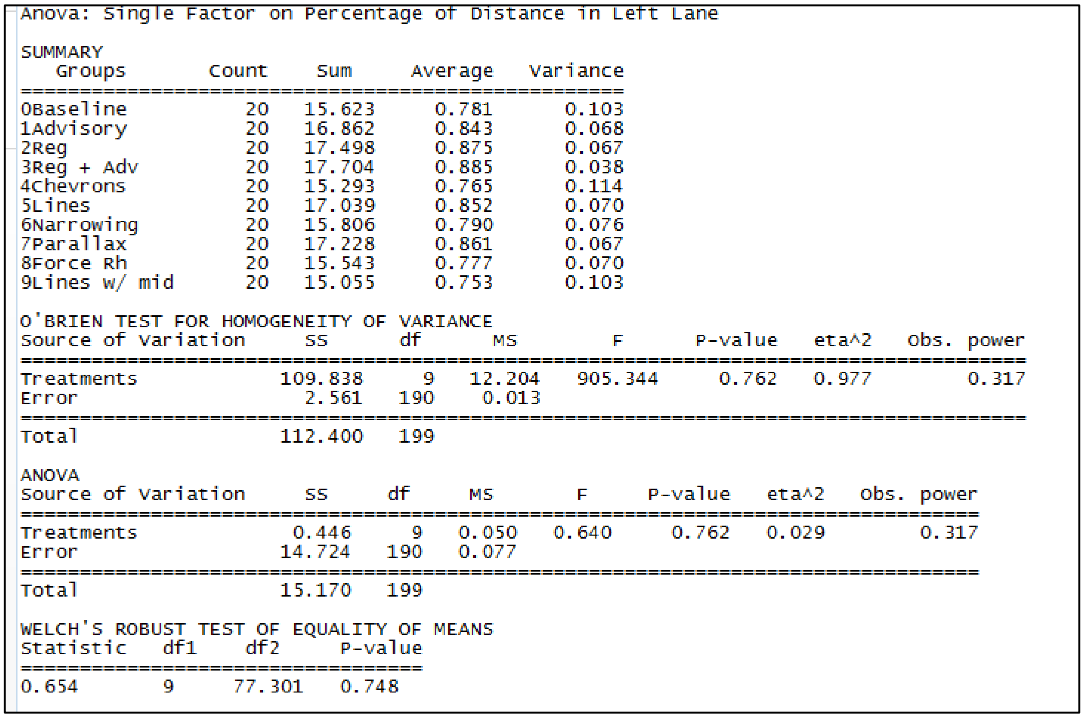
Figure 45: Games-Howell Procedure, Mean Vehicle Speed Section 2, Experiment 1



```
Anova: Single Factor on VDS_Veh_Speed_sd where section = 2

SUMMARY
  Groups     Count     Sum     Average   Variance
=================================================
0Base           30   140.850     4.695      5.995
1Advisory       30   147.230     4.908      4.038
2Reg            30   143.479     4.783      2.728
3Reg+Adv        30   139.041     4.635      3.144
4Chevrons       30   164.615     5.487      6.927
5Lines          30   164.518     5.484      5.923
6Narrowing      30   140.260     4.675      4.152
7Parallax       30   143.677     4.789      4.536
8ForceRh        30   151.866     5.062      4.321
9LinesWmid      30   155.939     5.198      8.968

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation      SS       df      MS        F     P-value   eta^2   Obs. power
======================================================================================
Treatments              968.355     9   107.595   0.797     0.644   0.024        0.308
Error                 39133.524   290   134.943
======================================================================================
Total                 40101.879   299

ANOVA
Source of Variation      SS      df     MS       F     P-value   eta^2   Obs. power
===================================================================================
Between Subjects       411.624    29
Treatments              28.157     9   3.129   0.771     0.644   0.026        0.307
Error                 1059.682   261   4.060
===================================================================================
Total                 1499.463   299

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic   df1     df2     P-value
===================================
0.550       9     117.984   0.835
```

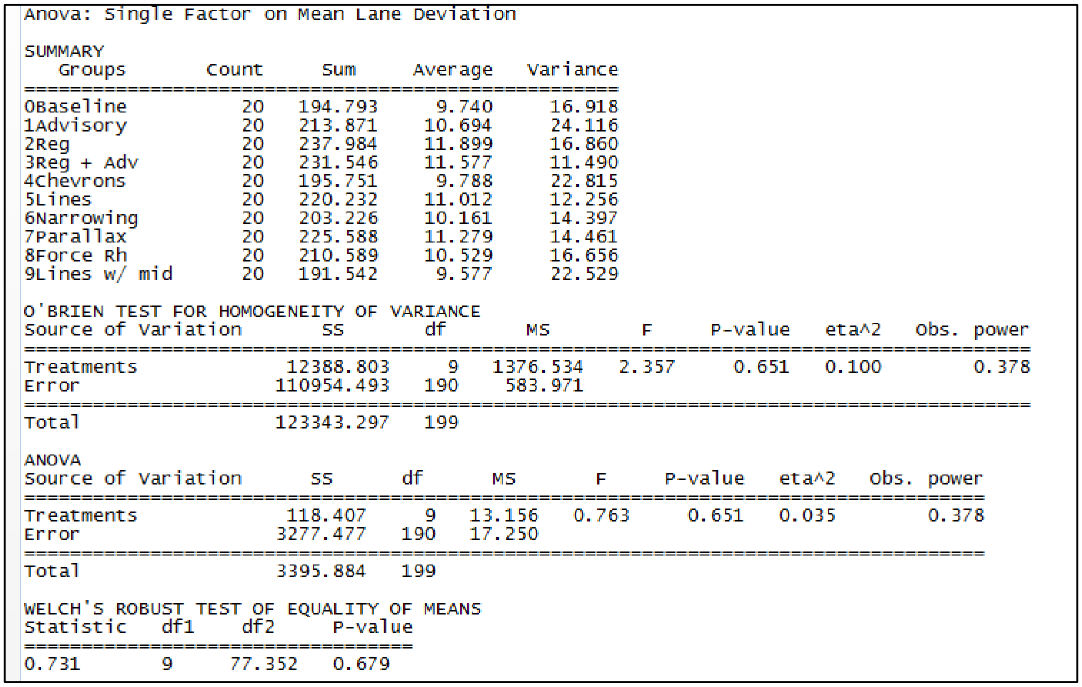
Figure 46: ANOVA Standard Deviation Vehicle Speed Section 2, Experiment 1

Appendix E: Experiment 2 Statistical Results



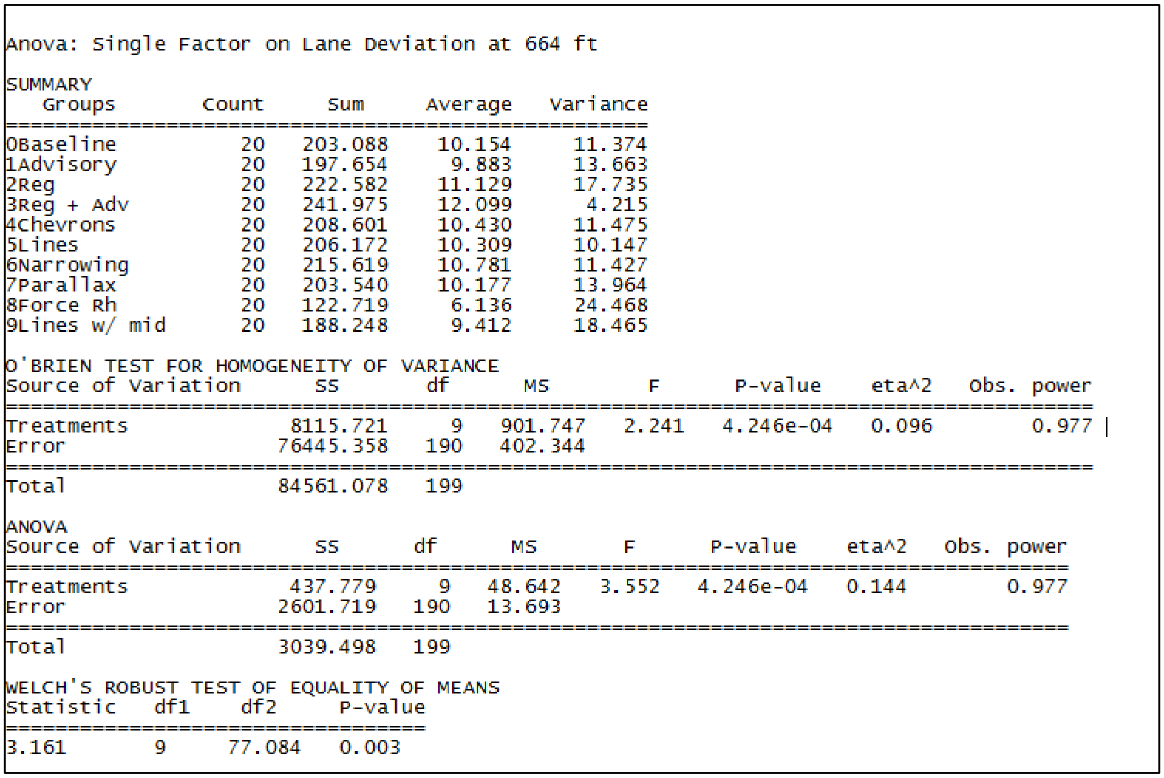
```
Anova: Single Factor on Percentage of Distance in Left Lane

SUMMARY
   Groups       Count    Sum     Average    Variance
====================================================
0Baseline         20   15.623     0.781      0.103
1Advisory         20   16.862     0.843      0.068
2Reg              20   17.498     0.875      0.067
3Reg + Adv        20   17.704     0.885      0.038
4Chevrons         20   15.293     0.765      0.114
5Lines            20   17.039     0.852      0.070
6Narrowing        20   15.806     0.790      0.076
7Parallax         20   17.228     0.861      0.067
8Force Rh         20   15.543     0.777      0.070
9Lines w/ mid     20   15.055     0.753      0.103

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation      SS      df      MS        F       P-value    eta^2    Obs. power
=========================================================================================
Treatments             109.838     9   12.204   905.344      0.762    0.977         0.317
Error                    2.561   190    0.013
=========================================================================================
Total                  112.400   199

ANOVA
Source of Variation      SS      df     MS       F      P-value    eta^2    Obs. power
=====================================================================================
Treatments               0.446     9   0.050   0.640      0.762    0.029         0.317
Error                   14.724   190   0.077
=====================================================================================
Total                   15.170   199

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic    df1    df2      P-value
==================================
0.654        9     77.301    0.748
```

Figure 47: ANOVA Percentage of Distance in Left Lane, Experiment 2



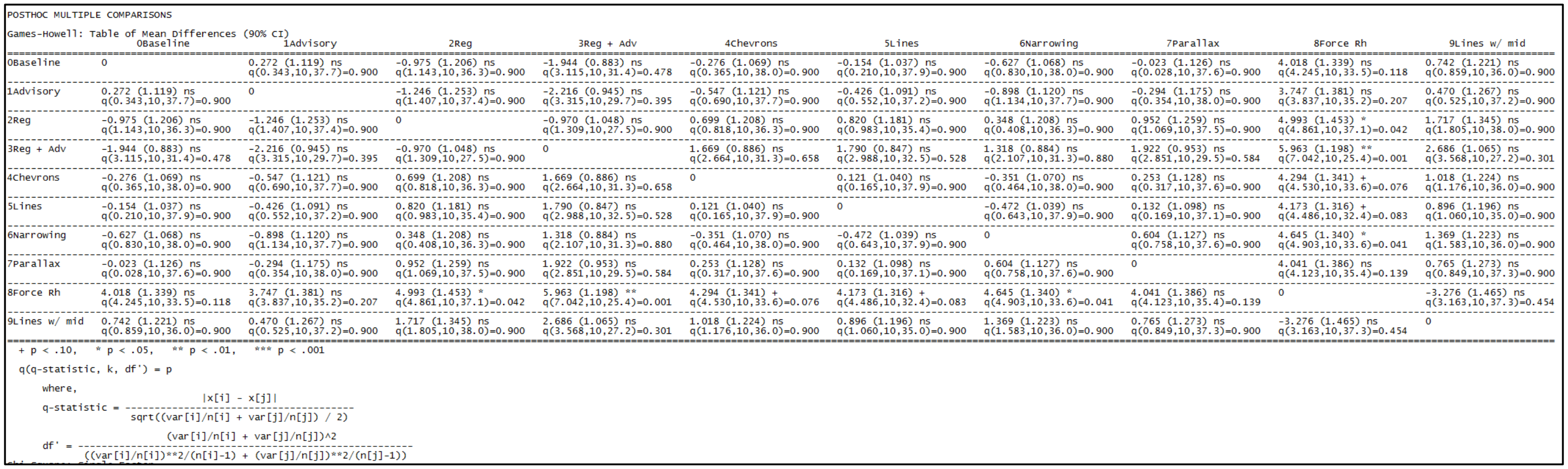
```
Anova: Single Factor on Mean Lane Deviation

SUMMARY
   Groups       Count     Sum      Average    Variance
======================================================
0Baseline         20    194.793     9.740     16.918
1Advisory         20    213.871    10.694     24.116
2Reg              20    237.984    11.899     16.860
3Reg + Adv        20    231.546    11.577     11.490
4Chevrons         20    195.751     9.788     22.815
5Lines            20    220.232    11.012     12.256
6Narrowing        20    203.226    10.161     14.397
7Parallax         20    225.588    11.279     14.461
8Force Rh         20    210.589    10.529     16.656
9Lines w/ mid     20    191.542     9.577     22.529

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation         SS        df        MS        F      P-value    eta^2    Obs. power
===============================================================================================
Treatments               12388.803     9   1376.534   2.357      0.651    0.100         0.378
Error                   110954.493   190    583.971
===============================================================================================
Total                   123343.297   199

ANOVA
Source of Variation       SS       df      MS       F      P-value    eta^2    Obs. power
=========================================================================================
Treatments               118.407     9   13.156   0.763      0.651    0.035         0.378
Error                   3277.477   190   17.250
=========================================================================================
Total                   3395.884   199

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic    df1    df2      P-value
==================================
0.731        9     77.352    0.679
```

Figure 48: ANOVA Mean Lane Deviation, Experiment 2



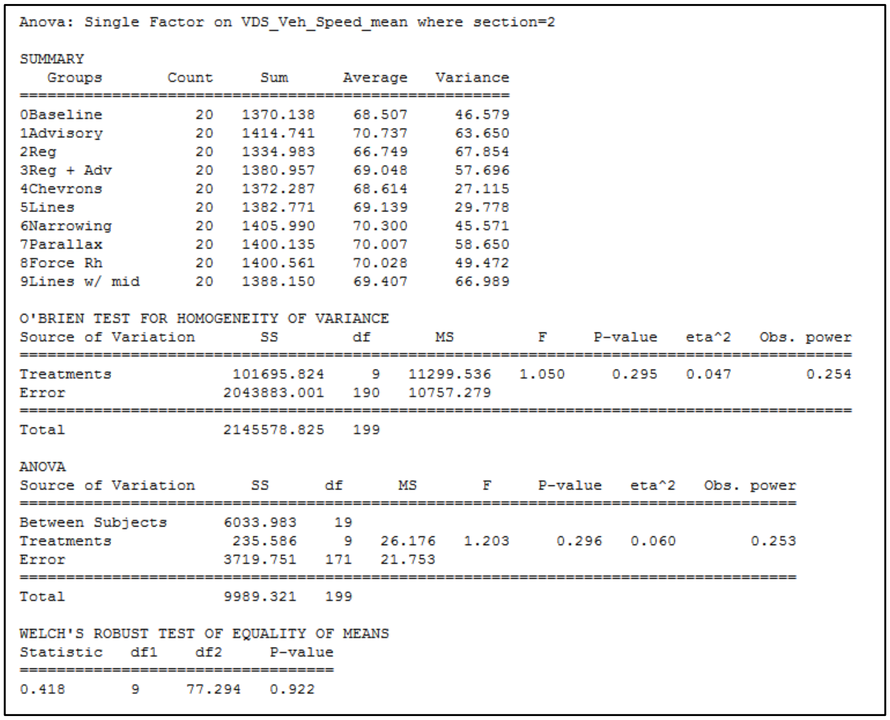
```
Anova: Single Factor on Lane Deviation at 664 ft

SUMMARY
   Groups       Count      Sum      Average   Variance
====================================================
0Baseline          20   203.088    10.154     11.374
1Advisory          20   197.654     9.883     13.663
2Reg               20   222.582    11.129     17.735
3Reg + Adv         20   241.975    12.099      4.215
4Chevrons          20   208.601    10.430     11.475
5Lines             20   206.172    10.309     10.147
6Narrowing         20   215.619    10.781     11.427
7Parallax          20   203.540    10.177     13.964
8Force Rh          20   122.719     6.136     24.468
9Lines w/ mid      20   188.248     9.412     18.465

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation      SS        df       MS         F       P-value     eta^2    Obs. power
=========================================================================================
Treatments             8115.721     9   901.747    2.241    4.246e-04    0.096         0.977 |
Error                 76445.358   190   402.344
=========================================================================================
Total                 84561.078   199

ANOVA
Source of Variation      SS       df       MS         F       P-value     eta^2    Obs. power
=======================================================================================
Treatments             437.779     9    48.642    3.552    4.246e-04    0.144         0.977
Error                 2601.719   190    13.693
=======================================================================================
Total                 3039.498   199

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic    df1     df2      P-value
==================================
3.161        9     77.084    0.003
```

Figure 49: ANOVA Lane Deviation at Beginning of Section 2, Experiment 2



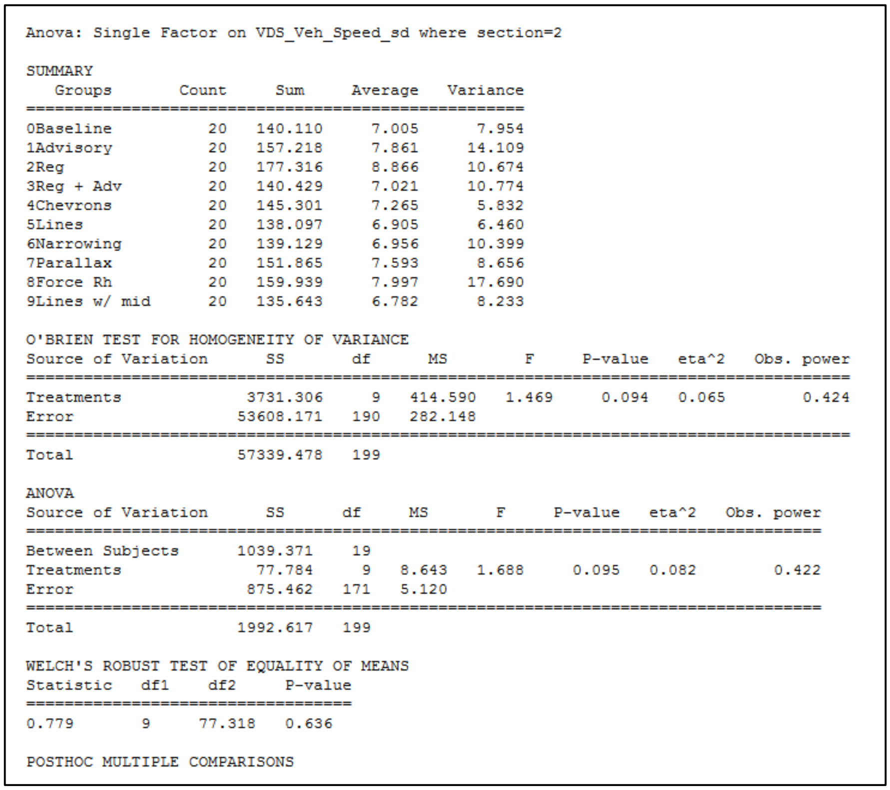
```
POSTHOC MULTIPLE COMPARISONS

Games-Howell: Table of Mean Differences (90% CI)
                     0Baseline               1Advisory                 2Reg                3Reg + Adv              4Chevrons                5Lines                6Narrowing               7Parallax               8Force Rh              9Lines w/ mid
==============================================================================================================================================================================================================================================================
0Baseline     0                       0.272 (1.119) ns        -0.975 (1.206) ns       -1.944 (0.883) ns       -0.276 (1.069) ns       -0.154 (1.037) ns       -0.627 (1.068) ns       -0.023 (1.126) ns       4.018 (1.339) ns        0.742 (1.221) ns
                                      q(0.343,10,37.7)=0.900  q(1.143,10,36.3)=0.900  q(3.115,10,31.4)=0.478  q(0.365,10,38.0)=0.900  q(0.210,10,37.9)=0.900  q(0.830,10,38.0)=0.900  q(0.028,10,37.6)=0.900  q(4.245,10,33.5)=0.118  q(0.859,10,36.0)=0.900
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
1Advisory     0.272 (1.119) ns        0                       -1.246 (1.253) ns       -2.216 (0.945) ns       -0.547 (1.121) ns       -0.426 (1.091) ns       -0.898 (1.120) ns       -0.294 (1.175) ns       3.747 (1.381) ns        0.470 (1.267) ns
              q(0.343,10,37.7)=0.900                          q(1.407,10,37.4)=0.900  q(3.315,10,29.7)=0.395  q(0.690,10,37.7)=0.900  q(0.552,10,37.2)=0.900  q(1.134,10,37.7)=0.900  q(0.354,10,38.0)=0.900  q(3.837,10,35.2)=0.207  q(0.525,10,37.2)=0.900
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
2Reg          -0.975 (1.206) ns       -1.246 (1.253) ns       0                       -0.970 (1.048) ns       0.699 (1.208) ns        0.820 (1.181) ns        0.348 (1.208) ns        0.952 (1.259) ns        4.993 (1.453) *         1.717 (1.345) ns
              q(1.143,10,36.3)=0.900  q(1.407,10,37.4)=0.900                          q(1.309,10,27.5)=0.900  q(0.818,10,36.3)=0.900  q(0.983,10,35.4)=0.900  q(0.408,10,36.3)=0.900  q(1.069,10,37.5)=0.900  q(4.861,10,37.1)=0.042  q(1.805,10,38.0)=0.900
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
3Reg + Adv    -1.944 (0.883) ns       -2.216 (0.945) ns       -0.970 (1.048) ns       0                       1.669 (0.886) ns        1.790 (0.847) ns        1.318 (0.884) ns        1.922 (0.953) ns        5.963 (1.198) **        2.686 (1.065) ns
              q(3.115,10,31.4)=0.478  q(3.315,10,29.7)=0.395  q(1.309,10,27.5)=0.900                          q(2.664,10,31.3)=0.658  q(2.988,10,32.5)=0.528  q(2.107,10,31.3)=0.880  q(2.851,10,29.5)=0.584  q(7.042,10,25.4)=0.001  q(3.568,10,27.2)=0.301
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
4Chevrons     -0.276 (1.069) ns       -0.547 (1.121) ns       0.699 (1.208) ns        1.669 (0.886) ns        0                       0.121 (1.040) ns        -0.351 (1.070) ns       0.253 (1.128) ns        4.294 (1.341) +         1.018 (1.224) ns
              q(0.365,10,38.0)=0.900  q(0.690,10,37.7)=0.900  q(0.818,10,36.3)=0.900  q(2.664,10,31.3)=0.658                          q(0.165,10,37.9)=0.900  q(0.464,10,38.0)=0.900  q(0.317,10,37.6)=0.900  q(4.530,10,33.6)=0.076  q(1.176,10,36.0)=0.900
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
5Lines        -0.154 (1.037) ns       -0.426 (1.091) ns       0.820 (1.181) ns        1.790 (0.847) ns        0.121 (1.040) ns        0                       -0.472 (1.039) ns       0.132 (1.098) ns        4.173 (1.316) +         0.896 (1.196) ns
              q(0.210,10,37.9)=0.900  q(0.552,10,37.2)=0.900  q(0.983,10,35.4)=0.900  q(2.988,10,32.5)=0.528  q(0.165,10,37.9)=0.900                          q(0.643,10,37.9)=0.900  q(0.169,10,37.1)=0.900  q(4.486,10,32.4)=0.083  q(1.060,10,35.0)=0.900
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
6Narrowing    -0.627 (1.068) ns       -0.898 (1.120) ns       0.348 (1.208) ns        1.318 (0.884) ns        -0.351 (1.070) ns       -0.472 (1.039) ns       0                       0.604 (1.127) ns        4.645 (1.340) *         1.369 (1.223) ns
              q(0.830,10,38.0)=0.900  q(1.134,10,37.7)=0.900  q(0.408,10,36.3)=0.900  q(2.107,10,31.3)=0.880  q(0.464,10,38.0)=0.900  q(0.643,10,37.9)=0.900                          q(0.758,10,37.6)=0.900  q(4.903,10,33.6)=0.041  q(1.583,10,36.0)=0.900
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
7Parallax     -0.023 (1.126) ns       -0.294 (1.175) ns       0.952 (1.259) ns        1.922 (0.953) ns        0.253 (1.128) ns        0.132 (1.098) ns        0.604 (1.127) ns        0                       4.041 (1.386) ns        0.765 (1.273) ns
              q(0.028,10,37.6)=0.900  q(0.354,10,38.0)=0.900  q(1.069,10,37.5)=0.900  q(2.851,10,29.5)=0.584  q(0.317,10,37.6)=0.900  q(0.169,10,37.1)=0.900  q(0.758,10,37.6)=0.900                          q(4.123,10,35.4)=0.139  q(0.849,10,37.3)=0.900
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
8Force Rh     4.018 (1.339) ns        3.747 (1.381) ns        4.993 (1.453) *         5.963 (1.198) **        4.294 (1.341) +         4.173 (1.316) +         4.645 (1.340) *         4.041 (1.386) ns        0                       -3.276 (1.465) ns
              q(4.245,10,33.5)=0.118  q(3.837,10,35.2)=0.207  q(4.861,10,37.1)=0.042  q(7.042,10,25.4)=0.001  q(4.530,10,33.6)=0.076  q(4.486,10,32.4)=0.083  q(4.903,10,33.6)=0.041  q(4.123,10,35.4)=0.139                          q(3.163,10,37.3)=0.454
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
9Lines w/ mid 0.742 (1.221) ns        0.470 (1.267) ns        1.717 (1.345) ns        2.686 (1.065) ns        1.018 (1.224) ns        0.896 (1.196) ns        1.369 (1.223) ns        0.765 (1.273) ns        -3.276 (1.465) ns       0
              q(0.859,10,36.0)=0.900  q(0.525,10,37.2)=0.900  q(1.805,10,38.0)=0.900  q(3.568,10,27.2)=0.301  q(1.176,10,36.0)=0.900  q(1.060,10,35.0)=0.900  q(1.583,10,36.0)=0.900  q(0.849,10,37.3)=0.900  q(3.163,10,37.3)=0.454
==============================================================================================================================================================================================================================================================
  + p < .10,   * p < .05,   ** p < .01,   *** p < .001

  q(q-statistic, k, df') = p

      where,
                              |x[i] - x[j]|
      q-statistic = ---------------------------------------
                     sqrt((var[i]/n[i] + var[j]/n[j]) / 2)

                           (var[i]/n[i] + var[j]/n[j])^2
      df' = --------------------------------------------------------
               ((var[i]/n[i])**2/(n[i]-1) + (var[j]/n[j])**2/(n[j]-1))
```

Figure 50: Lane Deviation at Beginning of Section 2, Experiment 2



```
Anova: Single Factor on VDS_Veh_Speed_mean where section=2

SUMMARY
   Groups       Count      Sum      Average   Variance
=====================================================
0Baseline         20   1370.138    68.507     46.579
1Advisory         20   1414.741    70.737     63.650
2Reg              20   1334.983    66.749     67.854
3Reg + Adv        20   1380.957    69.048     57.696
4Chevrons         20   1372.287    68.614     27.115
5Lines            20   1382.771    69.139     29.778
6Narrowing        20   1405.990    70.300     45.571
7Parallax         20   1400.135    70.007     58.650
8Force Rh         20   1400.561    70.028     49.472
9Lines w/ mid     20   1388.150    69.407     66.989

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation        SS         df       MS          F      P-value   eta^2   Obs. power
=========================================================================================
Treatments             101695.824     9   11299.536   1.050      0.295   0.047         0.254
Error                 2043883.001   190   10757.279
=========================================================================================
Total                 2145578.825   199

ANOVA
Source of Variation       SS       df      MS        F      P-value   eta^2   Obs. power
===============================================================================
Between Subjects      6033.983    19
Treatments             235.586     9   26.176   1.203      0.296   0.060         0.253
Error                 3719.751   171   21.753
===============================================================================
Total                 9989.321   199

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic   df1    df2     P-value
==================================
0.418       9     77.294   0.922
```

Figure 51: Mean Vehicle Speed Section 2, Experiment 2



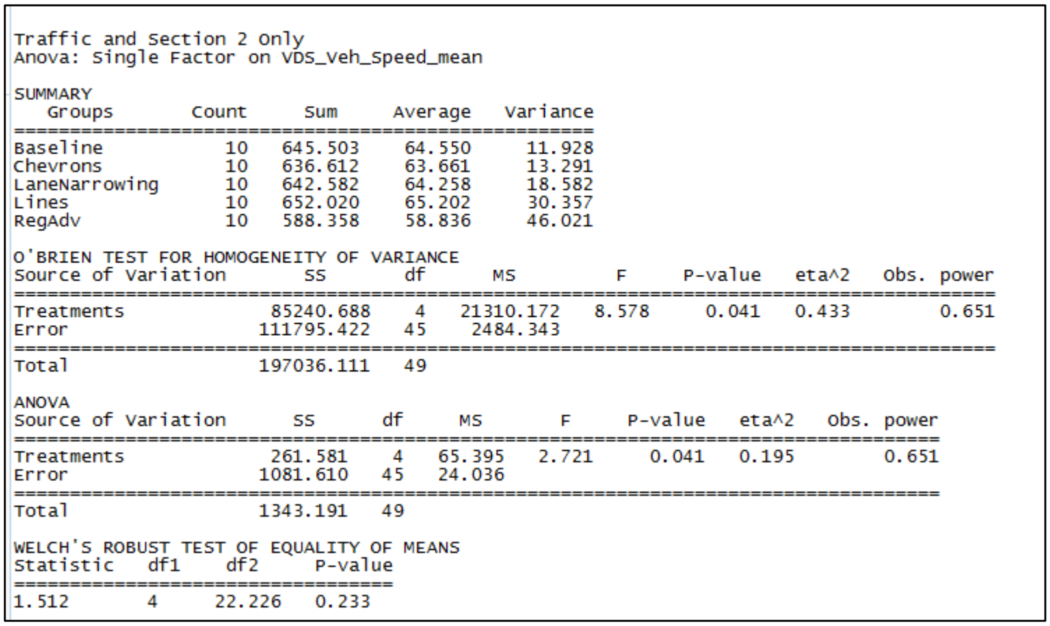
```
Anova: Single Factor on VDS_Veh_Speed_sd where section=2

SUMMARY
   Groups       Count      Sum      Average   Variance
=====================================================
0Baseline         20   140.110      7.005      7.954
1Advisory         20   157.218      7.861     14.109
2Reg              20   177.316      8.866     10.674
3Reg + Adv        20   140.429      7.021     10.774
4Chevrons         20   145.301      7.265      5.832
5Lines            20   138.097      6.905      6.460
6Narrowing        20   139.129      6.956     10.399
7Parallax         20   151.865      7.593      8.656
8Force Rh         20   159.939      7.997     17.690
9Lines w/ mid     20   135.643      6.782      8.233

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation       SS        df       MS         F      P-value   eta^2   Obs. power
=====================================================================================
Treatments             3731.306      9    414.590   1.469      0.094   0.065         0.424
Error                 53608.171    190    282.148
=====================================================================================
Total                 57339.478    199

ANOVA
Source of Variation       SS       df      MS        F      P-value   eta^2   Obs. power
==================================================================================
Between Subjects      1039.371    19
Treatments              77.784     9    8.643   1.688      0.095   0.082         0.422
Error                  875.462   171    5.120
==================================================================================
Total                 1992.617   199

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic   df1    df2     P-value
==================================
0.779       9     77.318   0.636

POSTHOC MULTIPLE COMPARISONS
```

Figure 52: ANOVA Standard Deviation Vehicle Speed Section 2, Experiment 2

Table 7: Two-Sample t-test Assuming Unequal Variances for Standard Deviation

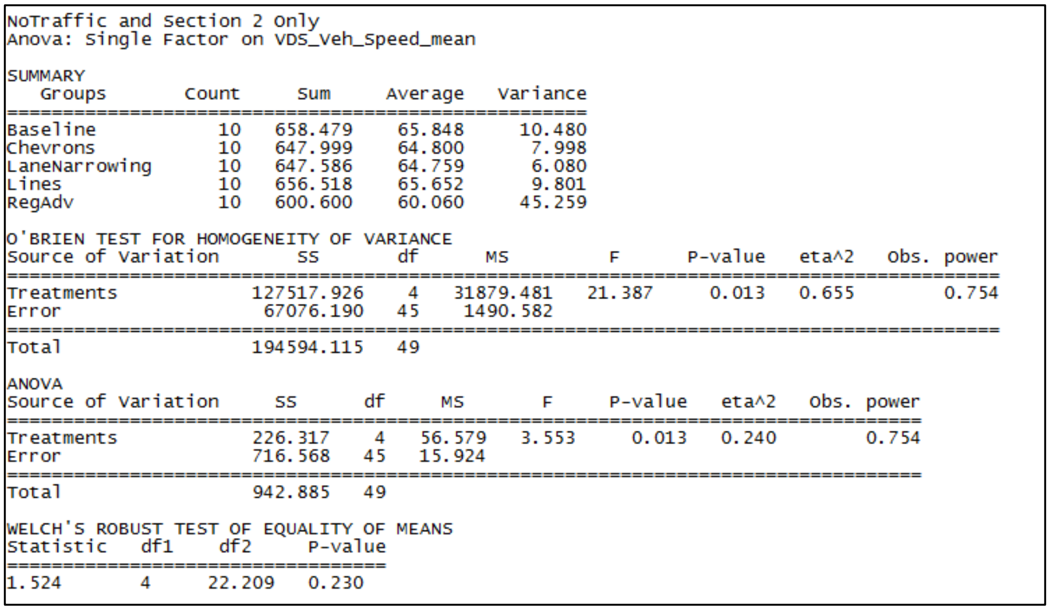
Object	Experiment 1	Experiment 2
Mean	4.97	7.43
Variance	0.10	0.43
Observations	10	10
Pearson Correlation	-0.04	
Hypothesized Mean Difference	0	
df	13	
t Stat	-10.59	
P(T<=t) one-tail	0.000000005	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.0000001	
t Critical two-tail	2.16	

Appendix F: Experiment 3 Statistical Results



```
Traffic and Section 2 Only
Anova: Single Factor on VDS_Veh_Speed_mean

SUMMARY
   Groups        Count      Sum      Average    Variance
====================================================
Baseline           10    645.503     64.550     11.928
Chevrons           10    636.612     63.661     13.291
LaneNarrowing      10    642.582     64.258     18.582
Lines              10    652.020     65.202     30.357
RegAdv             10    588.358     58.836     46.021

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation        SS         df       MS          F       P-value    eta^2    Obs. power
=================================================================================================
Treatments              85240.688     4    21310.172    8.578      0.041     0.433         0.651
Error                  111795.422     45    2484.343
=================================================================================================
Total                  197036.111     49

ANOVA
Source of Variation       SS       df      MS        F      P-value    eta^2    Obs. power
==========================================================================================
Treatments              261.581     4    65.395    2.721     0.041     0.195         0.651
Error                  1081.610     45   24.036
==========================================================================================
Total                  1343.191     49

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic    df1     df2      P-value
==================================
1.512         4     22.226    0.233
```

Figure 53: Mean Vehicle Speed Section 2 with Traffic, Experiment 3



```
NoTraffic and Section 2 Only
Anova: Single Factor on VDS_Veh_Speed_mean

SUMMARY
   Groups        Count      Sum      Average    Variance
====================================================
Baseline           10    658.479     65.848     10.480
Chevrons           10    647.999     64.800      7.998
LaneNarrowing      10    647.586     64.759      6.080
Lines              10    656.518     65.652      9.801
RegAdv             10    600.600     60.060     45.259

O'BRIEN TEST FOR HOMOGENEITY OF VARIANCE
Source of Variation        SS         df       MS          F       P-value    eta^2    Obs. power
=================================================================================================
Treatments             127517.926     4    31879.481   21.387      0.013     0.655         0.754
Error                   67076.190     45    1490.582
=================================================================================================
Total                  194594.115     49

ANOVA
Source of Variation       SS       df      MS        F      P-value    eta^2    Obs. power
==========================================================================================
Treatments              226.317     4    56.579    3.553     0.013     0.240         0.754
Error                   716.568     45   15.924
==========================================================================================
Total                   942.885     49

WELCH'S ROBUST TEST OF EQUALITY OF MEANS
Statistic    df1     df2      P-value
==================================
1.524         4     22.209    0.230
```

Figure 54: Mean Vehicle Speed Section 2 without Traffic, Experiment 3

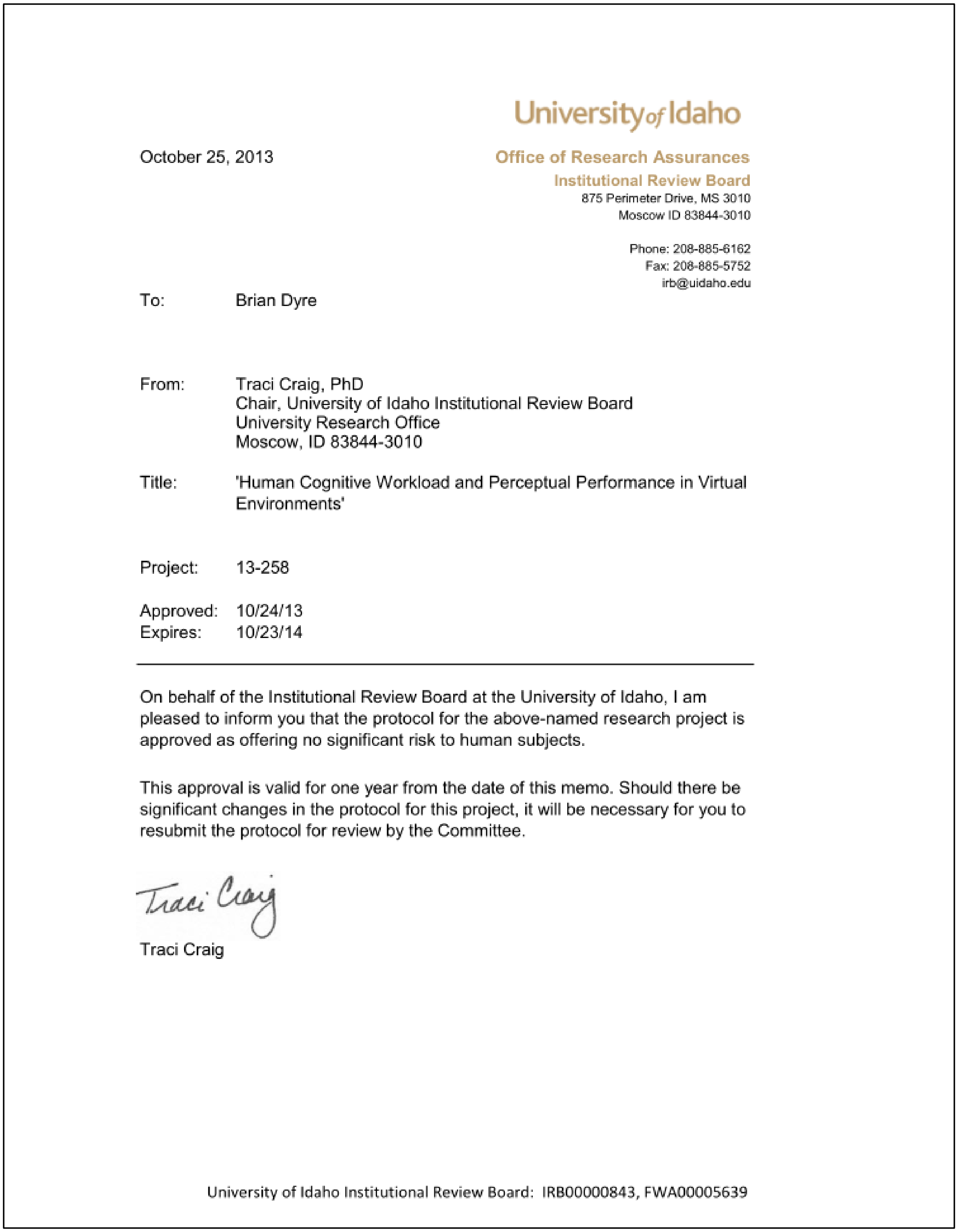
Table 8: Two-Sample t-test Standard Deviation Speed, Traffic Comparison

	No Traffic	*Traffic*
Mean	3.68	4.74
Variance	3.00	1.95
Observations	5.00	5.00
Pooled Variance	2.47	
Hypothesized Mean Difference	0.00	
df	8.00	
t Stat	-1.07	
P(T<=t) one-tail	0.16	
t Critical one-tail	1.86	
P(T<=t) two-tail	0.32	
t Critical two-tail	2.31	

Table 9: Two-Sample t-test Mean Speed, Traffic Comparison

Object	No Traffic	Traffic
Mean	64.22	63.30
Variance	5.66	6.54
Observations	5.00	5.00
Pooled Variance	6.10	
Hypothesized Mean Difference	0.00	
df	8.00	
t Stat	0.59	
P(T<=t) one-tail	0.29	
t Critical one-tail	1.86	
P(T<=t) two-tail	0.57	
t Critical two-tail	2.31	

Appendix G: Protocol Approval from Human Assurances Committee



University of Idaho

Office of Research Assurances
Institutional Review Board
875 Perimeter Drive, MS 3010
Moscow ID 83844-3010

Phone: 208-885-6162
Fax: 208-885-5752
irb@uidaho.edu

October 25, 2013

To: Brian Dyre

From: Traci Craig, PhD
Chair, University of Idaho Institutional Review Board
University Research Office
Moscow, ID 83844-3010

Title: 'Human Cognitive Workload and Perceptual Performance in Virtual Environments'

Project: 13-258

Approved: 10/24/13
Expires: 10/23/14

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the protocol for the above-named research project is approved as offering no significant risk to human subjects.

This approval is valid for one year from the date of this memo. Should there be significant changes in the protocol for this project, it will be necessary for you to resubmit the protocol for review by the Committee.

Traci Craig

Traci Craig

University of Idaho Institutional Review Board: IRB00000843, FWA00005639