POTENTIAL IMPACTS OF WIDER LONGITUDINAL EDGELINE PAVEMENT MARKINGS

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by

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

The goal of the research presented in this thesis was to study the safety effects of wider longitudinal edgeline pavement markings based on lane position and vehicle speed. Different marking deterioration percentages and roadway geometries on two-lane rural highways were implemented using the University of Idaho's driving simulator to examine these safety effects. Twenty-four people participated in this study, and the results from the driving simulator experiment suggest that wider longitudinal edgeline pavement markings do not provide safety benefits based on lane position but do provide a minor positive impact by slightly reducing vehicle speeds; however, the speed differential from an operational standpoint is negligible.

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DEDICATION

I dedicate this achievement to my parents Victor and Anastacia, and to my brother Kevin. I thank them immensely, because they have always been a motivation for me.

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CHAPTER 1: INTRODUCTION

In the State of Idaho, two of the largest contributors to single vehicle crashes are related to the inability of drivers to maintain appropriate lane position and inadequate vehicle speed. Vehicle speed contributed to just over 22% of single vehicle crashes in 2012, while failing to maintain lane position was the second most prevalent circumstance, contributing to just under 22% of single vehicle crashes *(1)*. Wider longitudinal edgeline pavement markings is one treatment that may provide positive effects on these two driver performances and therefore reduce single vehicle crashes, especially run-off-the-road. Hereafter, a wider longitudinal edgeline pavement marking will be referred to as “wider edgeline” and a longitudinal edgeline pavement marking will be referred to as “edgeline”. The objective of this research is to determine if the implementation of wider edgeline can improve a driver’s ability to better identify the roadway alignment and maintain appropriate lane position and vehicle speed in a two-lane rural highway setting.

For this study, three different edgeline widths (2 inch, 4 inch, and 6 inch) were implemented in a roadway simulation environment to determine how these width variations impact driver performance, especially when switching from the standard (4 inch) to a wider (6 inch) width. Along with these three edgeline width variations, the percent of edgeline deterioration for each width was also considered and consisted of 0%, 25%, 50%, and 75%. For example, an edgeline width with a 75% edgeline deterioration was almost worn out (less visible and opaque), while an edgeline width with a 0% edgeline deterioration was brand new (really visible and bright). The roadway geometry characteristic was also taken into consideration and included straight and curved horizontal segments throughout the roadway simulation environment.

As part of this driving simulator experiment, this study also included a post experiment questionnaire that each participant was required to fill out after completing their final session. This questionnaire was composed of questions regarding the participant’s experience, their driving behaviors while they experienced the different scenarios, if they noticed the variation in edgeline widths on the roadway simulation, and if the edgeline deterioration percentages affected their lane position.

Research Objectives

The research presented in this thesis has two primary objectives:

1. Determine if wider edgelines increase driver visibility of the roadway alignment of a two-lane rural highway and help drivers maintain appropriate lane position at different edgeline deterioration percentages and roadway geometries.
2. Determine if wider edgelines aid drivers to maintain adequate vehicle speed on two-lane rural highways at different edgeline deterioration percentages and roadway geometries.

Thesis Organization

This thesis is organized into five chapters. An introduction is presented in Chapter 1. A literature review is presented in Chapter 2 and focuses on past research work related to this specific research topic. It provides information about the application, impacts, and evaluation of wider edgelines along with information related to studies that have been conducted with a driving simulator on two-lane rural highways based on lane position and vehicle speed, marking retro-reflectivity, and marking service life. Chapter 3 presents the methodology for the driving simulator experiment. Chapter 4 presents the data analysis and results of this study, and Chapter 5 discusses the research conclusions.

CHAPTER 2: LITERATURE REVIEW

This chapter provides the literature review and describes the key elements that are involved with this research: application of wider edgelines, safety impacts of wider edgelines, evaluation of wider edgelines, use of a driving simulator on two-lane rural highways with an emphasis on lane position and vehicle speed, and marking retro-reflectivity and service life.

Industry Practices

Wider longitudinal pavement markings that include edgelines are very common in the Eastern United States. Most of the states located east of the Mississippi River (22 out of 26) currently use them. West of the Mississippi River, only 7 of the 24 states use them. Based on survey data collected from different state agencies, the main reason for implementing wider longitudinal pavement markings was improved visibility (identified by 57% of respondents). The second reason was as an older driver countermeasure (19%), and the third reason was crash reduction (14%) *(2)*.

Safety effects of wider edgelines on rural two-lane highways were examined in the states of Illinois, Michigan, and Kansas. The states of Michigan and Kansas increased the edgeline width from 4 inches to 6 inches during the analysis, while Illinois only increased it from 4 inches to 5 inches. Each state performed different statistical analysis on crash data that were obtained (before and after implementing wider edgelines) from the field (roadway). Even though the three states conducted different analyses, the study found that wider edgelines reduce vehicle crashes. The highest crash reduction percentage was on fatal plus injury (Kansas - 36.5%, Michigan analysis 1 - 15.4%, Michigan analysis 2 - 16.1%, and Illinois without animal collisions - 37.7%) *(3)*.

A similar study was conducted to determine how edgelines and retro-reflectivity affect older drivers on rural highways. For this study 25 participants were hired and each participant experienced the following: standard edgelines with no additional task (described later), standard edgelines with additional task, enhanced edgelines with no additional task, and enhanced edgelines with additional task. Here the enhancement in edgelines was the placement of glass beads into the painted edgelines. Even though in this research the implementation of glass beads embedded into the painted edgelines was not the main analysis purpose, the supplemental information could provide insight as to how the improvement of retro-reflectivity of the edgelines can positively benefit the lateral lane position and travel speed of older drivers. The additional task for this study was a mental arithmetic activity where participants were given a two digit number every 2 seconds and asked to separate the number and give the absolute difference between them. Each participant was asked to drive as closely as possible to 100 kilometers per hour (km/h). This study found that the participants were able to drive closer to 100 km/h with the enhanced markings, and that the standard deviations in road position were significantly lower when participants experienced the enhanced markings *(4)*.

Benefit/Cost

A study was conducted on a benefit/cost analysis method to select the most cost-effective policy that could help provide quantitative evidence of crash reductions. In this study, crash data were used to analyze the costs related to fatal and injury crashes. The method included summing the benefits from the wider edgelines minus the assumed service life of the standard edgeline and then dividing it by installation costs. The benefits for fatal and injury crashes were obtained by calculating the difference between the estimated crashes and observed crashes, and then multiplying this result by how much a fatality and injury was worth. The cost of installing 4 inch waterborne edgelines was about $0.10 per foot, while the cost for installing 6 inch waterborne edgelines was about $0.15 per foot, with a resulting difference in cost of $528 per mile. This study found that there is a strong benefit to cost ratio for fatal crashes; for every $1 invested in the installation of 6 inch edgelines an estimated benefit of $55.20 in crash cost reduction is realized *(5)*.

Marking Retro-Reflectivity

Retro-reflectivity of edgelines is measured in units of millicandelas per square meter per lux. Edgeline visibility at night is mainly a function of contrast between the edgeline and the roadway surface. Visibility is crucial in nighttime accidents, especially fatalities. Three major components play an important role in nighttime visibility: headlights, edgeline retro-reflectivity, and the driver’s visual capacities.

The retro-reflectiveness of edgelines is directly related to service life. As the wear of edgelines increases, their retro-reflectivity decreases, indicating that the marking needs to be refurbished or replaced. Edgelines should be replaced prior to the time when they no longer meet the nighttime visibility for drivers *(6)*.

The deterioration of the edgeline's retro-reflectivity is due to a number of factors including: climate/environment, plowing and snow removal (in some states), vehicle loading, edgeline material type, edgeline placement, and quality control. All of these factors affect how often the edgelines should be replaced in order to provide appropriate visibility of the roadway at night through their retro-reflectiveness. The Michigan DOT restripes 85% of their roadways on a yearly basis due to snow plowing that occurs during a large portion of the year *(7)*.

In another study, glass bead and pavement marker materials were tested in 19 states that included 85 sites. The results showed that the service life for a two-lane rural highway edgeline that experiences speeds of 45 miles per hour (mph) or greater is in the range of 3 to 5 years *(8)*, with the epoxy material (5 years) lasting longer than the profiled thermoplastic (3 years). In this study, the edgeline widths were not mentioned.

Statistical methodologies and models were developed to determine the relationship between retro-reflectivity values and marking age. The striping cost of two types of pavement marking materials, waterborne paint and thermoplastic, were considered and included labor and traffic control costs. The striping cost (1996 information) for waterborne paint was $0.06 per linear foot and $0.30 per linear foot for thermoplastic. The installation of the striping materials was performed on a one mile section of a four-lane highway (one direction) that included a yellow edge line, one solid white edge line, and one broken white center line with 10 foot line segments and 30 foot gaps. The installation cost for the waterborne paint was $317 per mile and $1,584 per mile for the thermoplastic. The application included installation cost, delay cost, crash cost, life-cycle cost analysis, and restriping scheduling. Thermoplastic is about five times more expensive than paint if only one time installation is considered. The results showed that the cost of thermoplastic material was about 3.1 times as much as the paint for low volume conditions and only about 2.0 times as expensive at high volume conditions *(9)*. These costs were mainly based on installation and delay costs, and crash cost was not included.

Effects of Alcohol

Wider edgelines help drivers under sober and alcohol impaired conditions to further identify the roadway delineation on two-lane rural highways. Sixteen male participants (students between 21 and 25 years old) drove over sections of a rural highway in northern

New Jersey that was composed of no edgelines, 4 inch, 6 inch, and 8 inch edgelines under sober and alcohol impaired conditions. Each participant drove twice, once with a zero Blood Alcohol Concentration (BAC) level and also with levels of either 0.05 or 0.08 BAC. These test drives occurred between midnight and 3:00AM with the help of police officers that controlled traffic by closing these highway sections. During this study, lateral lane position was recorded photographically every 100 feet to analyze driver performance. Wider edgelines were found to provide benefits when compared with standard width (4 inch), especially the wider 8 inch edgeline, whereas no reduction in variability occurred at some instances with the 6 inch edgeline *(10)*.

Another study was conducted to confirm if the use of edgelines and wider edgelines would really benefit drivers under normal and impaired conditions. As part of the methodology for the study, twelve male participants with driver licenses and in the age range of 21 to 55 years old were hired. Each participant completed six experimental sessions at BAC levels of 0.00%, 0.07%, and 0.12% (above the legal BAC level to drive in most states). Each participant encountered curves, obstacles, and road signs as part of their driving task. The design of the roadway simulation session was composed of different edgeline widths (none, 4 inch, and 8 inch), spot treatments, and curves. For this study an Analysis of Variance (ANOVA) was conducted. The study found that in a sober condition the wider edgelines (8 inch) were associated with greater lateral lane position error than standard edgelines (4 inch); however, neither edgeline was significantly different from the no edgeline condition *(11)*. On the other hand, participants with a high BAC level (0.12%) had greater lateral lane position error when there was no edgelines, with the error decreasing as the edgelines got wider *(11)*.

In the State of Idaho there is no previous research related to the implementation of wider longitudinal pavement markings on two-lane rural highways. Some past research only included one gender (mostly males) when a driving simulator was used; in this research study, males and females of different ages were hired. Some studies did not consider different pavement marking deterioration stages; here, four different stages of the pavement marking deteriorations were considered with regard to edgelines. Finally, oncoming traffic volumes similar to what one would encounter on a typical two-lane rural highway in the State of Idaho were incorporated into the study.

CHAPTER 3: DRIVING SIMULATOR METHODOLOGY

This chapter provides the methodology used to test the different scenarios for this research, as well as the outputs obtained. First, the background section describes the general concept of the research. Second, the scenario development is explained, which is composed of a general summary and a description of all 12 specific scenarios created. Third, information about the driving simulator is presented. Fourth, the experiment description is provided. Finally, the output data is discussed at the end of this chapter.

Background

To evaluate the safety benefits of wider edgelines at different edgeline deterioration percentages and geometries, a sample of 24 participants were tested using a driving simulation environment that replicated a two-lane rural highway in the State of Idaho. First, each participant was required to drive for about five minutes before the actual experiment scenarios commenced so that they could become familiar with the responsiveness of the driving simulator. The initial drive segment helped the participants become accustom to the sensitivity of the gas pedal, brake pedal, and steering wheel to help mitigate for data anomalies due to the driver's lack of familiarity with the driving simulator. Each participant was exposed to a 42 ½ mile roadway simulation track during each session. Within the 42 ½ mile track, 40 miles were ideally driven at speeds close to 60 mph (as shown on the regulatory speed limit signs which appeared during the experiment). One extra mile was placed at the beginning of each scenario roadway track to allow participants to reach a speed of 60 mph. An extra half mile was placed at the halfway point for participants to rest during the experiment drive. Finally, an extra mile was placed at the end of the track so that participants could come to a stop and complete the experiment. All participants conducted three sessions, driving for about 45 - 50 minutes during each session. Every participant was given about a 10 minute break halfway during each session. Each participant experienced the same pattern for all edgeline deterioration percentages in each of their three sessions. For example, a participant who experienced the 75% edgeline deterioration at the beginning of the roadway simulation track on his first session experienced the same deterioration level at the start of his or her second and third sessions. After the participants concluded their third session, they responded to questions from the debriefing form related to this study.

Scenario Development

General Summary:

To develop the appropriate scenarios for each participant, one computer program and two tools were used along with a simulator program. Every scenario was composed of multiple tiles that displayed the appropriate roadway geometries and surrounding environment. The roadway geometry was composed of the paved roadway, edgelines, gravel shoulder, and varying edgeline deterioration percentages. These roadway geometries were composed of straight and horizontal curved segments (wide and narrow curves). Figure 1 shows an example of a straight horizontal segment. Figure 2 shows an example of a wide horizontal curved segment, and Figure 3 shows an example of a narrow horizontal curved segment.

Figure 1: Driver simulation graphic - Straight horizontal segment

Figure 2: Driver simulation graphic - Wide curved horizontal segment

Figure 3: Driver simulation graphic - Narrow curved horizontal segment

According to the Highway Capacity Manual (HCM 2010), the base conditions of a two lane highway requires lane widths greater than or equal to 12 feet, shoulder widths up to 6 feet, zero no-passing zones, all passenger cars in the traffic stream, level terrain, and no impediments to through traffic *(12)*. Based on these conditions, each scenario was composed of: 12 foot lane widths, 10 foot shoulders (8 foot gravel shoulder and 2 foot paved shoulder), zero no-passing zones, level terrain, and also no impediments to through traffic. The surrounding environment was composed of trees, mountains, hills, house/building structures, and a daytime appearance. For this specific study, some adjustments were performed on the roadway geometries, specifically on the edgeline width and deterioration. According to the

Manual on Uniform Traffic Control Devices (MUTCD), the nominal (standard) edgeline is 4 inches wide *(13)*. For this study; scenarios with 2 inch, 4 inch, and 6 inch edgeline widths were included.

The development of the simulation environment featured a multi-step and multi-program approach. The 3ds MAX Design program (by Autodesk) was used to make the edgeline width and edgeline deterioration percentage adjustments (for every single tile) for all 12 study scenarios. The Tile Mosaic Tool (TMT) was used to join multiple tiles together to create the appropriate roadway simulation tracks for all scenarios. The Interactive Scenario Authoring Tool (ISAT) was used to import all scenarios and add vehicles, speed limit signs, information signs, and triggers (data collection points) to each roadway simulation track. The ISAT was created for the National Advanced Driving Simulator (NADS), which was developed by the National Highway Traffic Safety Administration *(14)*. These roadway simulation tracks were then tested (trial tests) to make certain that all scenarios looked appropriate and with the right adjustments and appearances for this study. A total of six trial tests were conducted to confirm that the scenarios were ready prior to the start of the data collection process.

Simulated Traffic:

Annual Average Daily Traffic (AADT) varies depending of the location of the two-lane rural highway. According to the Idaho Transportation Department (ITD), typical values for two lane rural highways range from 500 to 10,000 vehicles per day (veh/day) in the State of Idaho *(15)*. For example, the rural Highway 95 north of Moscow, Idaho that connects the towns of Moscow and Potlatch experienced an AADT of 6,391 in the 2014 year. In order to obtain an appropriate AADT value for the 12 scenarios, traffic survey and analysis monitoring stations of the ITD were reviewed. The ITD has six district boundaries in the State of Idaho and at least two two-lane rural highway locations within each district were identified. A sample size of 30 AADT values from the 2014 year (2013 if data for the 2014 was not provided) was reviewed. Based on these findings, an AADT of 3,200 veh/day was determined to be appropriate for all of the scenarios of this study (see Appendix A).

The following equation (Figure 4) was used to obtain the number of vehicles per hour in the oncoming lane based on the AADT previously mentioned.

$$DDHV = K \times D \times AADT$$

Figure 4: Directional design hourly volume equation

DDHV is the directional design hourly volume, K is the proportion of AADT occurring in the peak hour, and D is the proportion of peak-hour traffic in the peak direction. A K-value of 0.10 is recommended by the HCM 2010 for a rural highway *(12)*. A D-value of 0.5 assumed that the same traffic volume is experienced in both directions with the same number of vehicles per hour in each lane. A DDHV of 160 vehicles was calculated for the oncoming lane (typical two-lane rural highway traffic volume per hour on one lane in the State of Idaho). This DDHV value was used on all scenarios for this study.

Vehicle, Speed Limit and Information Sign, and Trigger Placement:

According to the HCM 2010, the State of Idaho has a default value of 12% heavy vehicles on two-lane highways *(12)*. Using this information, regular vehicles (SUVs, sedans, pickups, vans, etc.), two police vehicles, and 12% heavy vehicles (semi-trucks, dump trucks, etc.) were placed in the oncoming lane, so each driver was exposed to a total of approximately 160 vehicles in each scenario.

Figure 5 shows an example of a regular vehicle encountered by participants. Figure 6 shows an example of one of the police vehicles, and Figure 7 shows an example of a heavy vehicle.

Figure 5: Driver simulation graphic - Regular vehicle in oncoming lane

Figure 6: Driver simulation graphic - Police vehicle in oncoming lane

Figure 7: Driver simulation graphic - Semi-truck vehicle in oncoming lane

All of these vehicles were placed using the ISAT for all 12 scenarios in order to create the appropriate roadway simulation tracks with realistic traffic volumes. These oncoming vehicles were positioned as vehicles would appear on a rural highway with an oncoming approach speed of 60 mph. Based on the assumed percentage, heavy vehicles (mostly semi-trucks) were placed at an interval of every 15 regular vehicles. The experimental vehicle (subject vehicle) was placed near the start of the simulation roadway track. The subject vehicle was accompanied by a vehicle following at a distance of about 1,320 feet (one quarter mile), and also by another vehicle in front at a distance of about 1,320 feet. These distances were held constant throughout the experiment so the participant was not able to pass the vehicle in front or be passed by the vehicle behind it. This arrangement made the participants feel as if they were driving on a rural highway with a realistic traffic environment where they were exposed to vehicles in the oncoming lane and also to vehicles in front and behind them.

Two speed limit signs of 60 mph were installed for all scenarios, one at the beginning and another one about halfway through the roadway simulation track. Figure 8 shows the speed limit sign of 60 mph at the beginning of the experiment drive that each participant was asked to follow and respect as they would in real-world conditions. A similar speed limit sign was located at about halfway of the simulation track.

Figure 8: Driver simulation graphic - Speed limit sign of 60 mph

The information signs included curved caution warning signs that provided information about the approach of a curve. Figure 9 shows an example of an approach curved information sign placed before every curved segment turning right, and Figure 10 shows an example of an approach curved information sign placed before every curved segment turning left.

Figure 9: Driver simulation graphic - Right turn curved information sign

Figure 10: Driver simulation graphic - Left turn curved information sign

All participants were required to complete one session for each edgeline width. Each width scenario had 32 logs throughout the roadway simulation track on each scenario. These logs are triggers that created epics, and as previously stated, these triggers were placed using the ISAT. Figure 11 is an example of one of the tracks that was created showing the types of roadway geometries and the boundaries between the edgeline deterioration percentages (dotted lines).

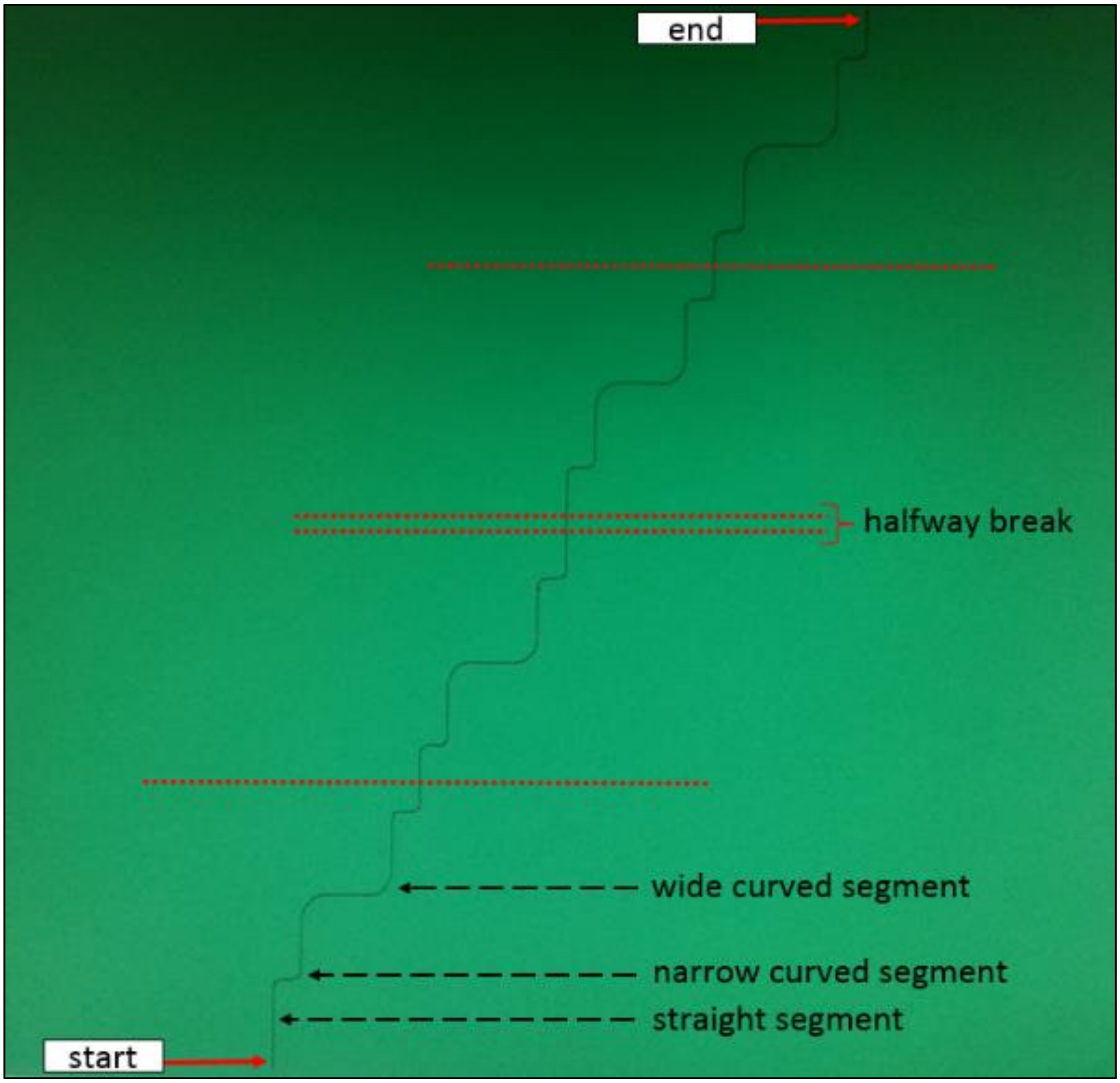

Figure 11: Graphical description of actual scenario track

There are 8 logs for each edgeline deterioration percentage, and since each scenario is composed of four different edgeline deterioration percentages, a total of 32 logs was generated from each roadway simulation track. Four logs were obtained from the triggers located on the straight segments, one log from the trigger located on the wide curved segment while turning left, one log from the trigger located on the wide curved segment while turning right, and two logs from the triggers located along the narrow curved segments for each edgeline deterioration percentage section within each scenario. The first session covered log1 – log32, the second session covered log33 – log64, and the third session covered log65 – log96. Figure 12 shows these descriptions graphically (not actual scenario tracks).

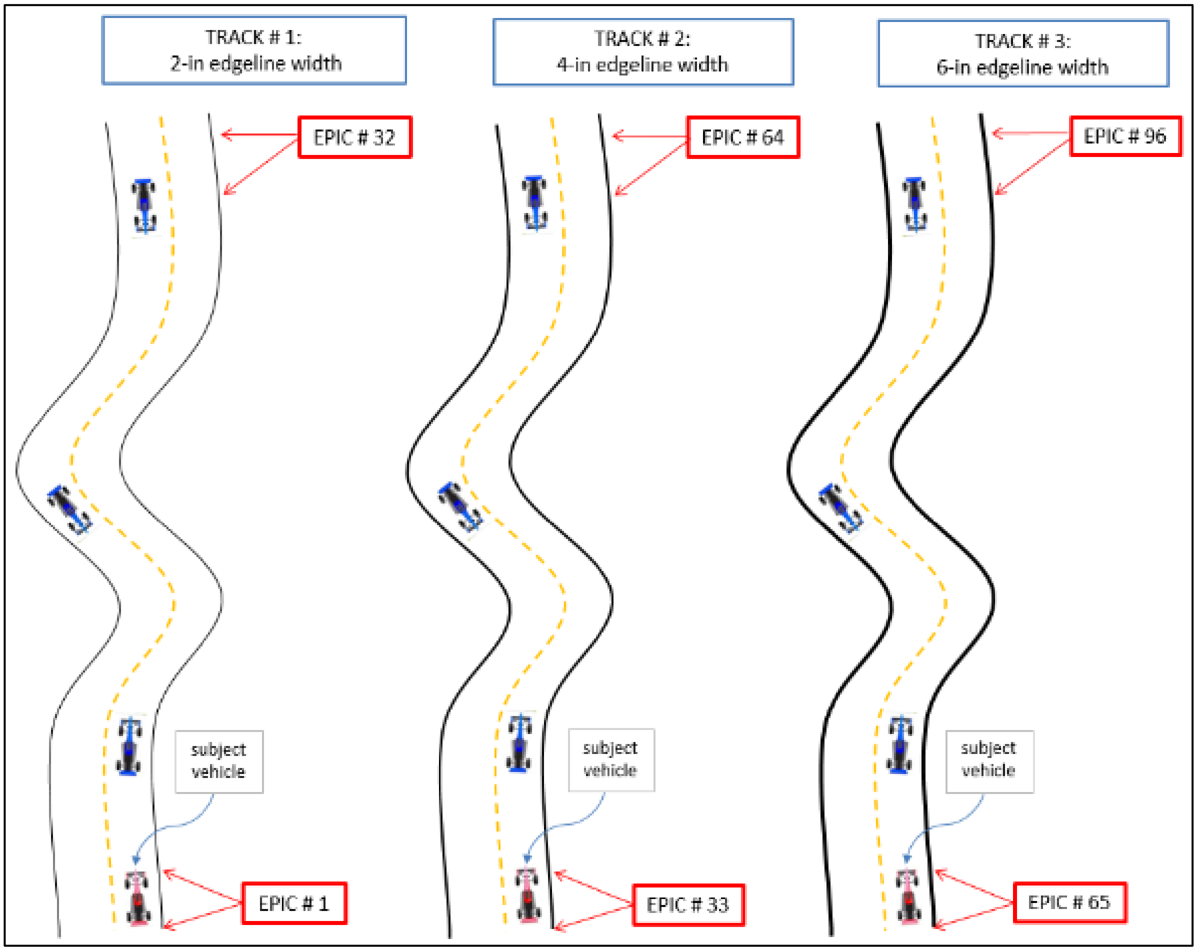

Figure 12: Graphic description of epics among scenario tracks

Each participant drove through 96 triggers during their three sessions so therefore 96 data points were collected for each of the 24 participants, resulting in a total of 2,304 data collection points. For this study, it was particularly important to keep track of the triggers, since these triggers collected the data needed for analysis purposes.

Description of All 12 Scenarios Created:

Table 1: Description of all 12 scenarios created

Scenario #	Edgeline Width (in)	Edgeline Deterioration Percentage Distribution (%)			
1	2	0	25	75	50
2	2	25	50	0	75
3	2	50	75	25	0
4	2	75	0	50	25
5	4	0	25	75	50
6	4	25	50	0	75
7	4	50	75	25	0
8	4	75	0	50	25
9	6	0	25	75	50
10	6	25	50	0	75
11	6	50	75	25	0
12	6	75	0	50	25

As Table 1 shows, scenarios 1 through 4 had the same edgeline width of 2 inches but a different distribution of edgeline deterioration percentages. Each edgeline deterioration percentage covered 10 miles out of the total 40 miles, which was followed by a switch to another deterioration level for 10 miles until all four deterioration percentages were covered in the same session. For example, scenario 1 had the 2 inch edgeline width starting with a 0% edgeline deterioration percentage for the first 10 miles, then switched to a 25% edgeline deterioration percentage for the next 10 miles and so on, until the last 10 miles where it switched to a 50% edgeline deterioration percentage. Adjustments to the edgeline width from the standard 4 inch to 2 inch did not increase the 12 foot width of the roadway lane; instead, the extra 2 inches were added to the shoulder side of the roadway environment. Scenarios 5 through 8 have the same edgeline width of 4 inches but with a different distribution of the edgeline deterioration percentages. The distribution of the edgeline deterioration percentages for scenarios 1 through 4 are the same as for scenarios 5 through 8, and 9 through 12, respectively. For scenarios 9 through 12, changes were made to the edgeline width from the standard 4 inch to 6 inch. These changes did not decrease the width of the roadway lane of 12 feet; instead, the extra 2 inches needed was taken from the shoulder side.

The following figures show the graphical representations of the 2 inch, 4 inch and 6 inch scenario sections that were created to construct the complete scenarios (composed of 4 different deterioration percentages) for this study.

Figure 13: Driver simulation graphic - 2-in edgeline with 0% deterioration

Figure 14: Driver simulation graphic - 2-in edgeline with 25% deterioration

Figure 15: Driver simulation graphic - 2-in edgeline with 50% deterioration

Figure 16: Driver simulation graphic - 2-in edgeline with 75% deterioration

Figure 17: Driver simulation graphic - 4-in edgeline with 0% deterioration

Figure 18: Driver simulation graphic - 4-in edgeline with 25% deterioration

Figure 19: Driver simulation graphic - 4-in edgeline with 50% deterioration

Figure 20: Driver simulation graphic - 4-in edgeline with 75% deterioration

Figure 21: Driver simulation graphic - 6-in edgeline with 0% deterioration

Figure 22: Driver simulation graphic - 6-in edgeline with 25% deterioration

Figure 23: Driver simulation graphic - 6-in edgeline with 50% deterioration

Figure 24: Driver simulation graphic - 6-in edgeline with 75% deterioration

Driving Simulator

To perform the driving simulation experiment, the University of Idaho's simulator lab was used. The NADS MiniSim program provided the display of the simulations and also collected and recorded the data for this study. Within the lab, a 2001 Chevrolet S10 pick-up truck cabin was used for participants to drive the three specific scenarios. The cabin was stationary and positioned in such a way that the driver's eyes were directly aimed at the roadway, similar to a real roadway environment. Figure 25 shows an overhead view of the truck cabin with the three main projection screens and the right side view mirror display.

Figure 25: Overhead view of Chevy S-10 with projected screens

Three Canon REALiS SX800 projectors displayed the simulation environment on white screens that were located next to each other and about 6 feet in front of the cab. These white screens were positioned in a way that the center of the middle screen coincided with the projected eye-point of the simulation. These screens provided a field of view of approximately 135 degrees horizontally and 34 degrees vertically. Each screen had a refresh rate of 60 Hertz with a spatial resolution of 4200 (horizontal) by 1050 (vertical) pixels, reflecting an appropriate event time accuracy per the Society of Automotive Engineers (SAE) International recommended practice. In Europe and other places, some video systems have frame rates of 50 Hertz that provide event time accuracy to the nearest 20 ms *(16)*.

Three screens were also installed in the cab to make the participants' drive more realistic, and these screens simulated the view seen by each participant looking either behind them through the rear view mirror or looking at either of the side view mirrors. A 10.4-inch liquid crystal display (LCD) touch screen with a spatial resolution of 800 (horizontal) by 600 (vertical) pixels was mounted on each side view mirror housing (left and right). A 65-inch plasma screen with a spatial resolution of 1280 (horizontal) by 720 (vertical) pixels and a refresh rate of 60 Hertz was mounted out of the rear window of the cab to reflect images from the rear view mirror.

A 10-inch LCD screen with a resolution of 1280 (horizontal) by 800 (vertical) pixels was installed to display the dashboard instrument cluster that included a tachometer, speedometer, engine temperature gauge, gear selection, and fuel gauge. This screen was mounted in place of the original mechanical analog instrument cluster of the Chevy S-10 cab.

At the corresponding workstation, seven screen displays were rendered by the NADS Minisim software. Figure 26 shows the workstation comprised of the multiple screen displays.

Figure 26: Workstation showing seven screen displays

These screens run under the Windows 7 operating system. The computer that displayed graphics on these screens contained a six-core Intel Core I7 processor running at 3.9 GHz, 32 GB of RAM, and two NVidia video display adapters. A GeForce GTX680 connected through a Matrox T2G-D3D-IF controlled the three main displays. The NVidia video adapter rendered the dashboard and right side mirror displays. The left side view mirror and center rear view mirror displays were rendered by the GeForce GTX660TI video adapter. A 4.1 channel audio system was used by the four mounted speakers located inside the cab doors and by a sub-woofer that was mounted behind the driver's seat in order to provide automobile and roadway noise.

The steering wheel, gear selector, turn signals, and brake and accelerator pedals were connected through the Suzo-Happ model 95-0800-10k USB Game Controller Interface (UGCI) to the MiniSim. The original steering wheel was self-centered, with a 540 degrees of steering range. The center console housed an automatic gear selector from a 2001 Honda Civic. Finally, the original brake pedals provided displacement similar to any normal automobile.

Experiment Description

For this research, twenty-four participants with unrestricted valid driver's licenses were tested. Every participant was recruited from the general community through an advertisement that was posted to the public online. Flyers were also placed at local commercial stores and in the downtown's public square. The advertisement stated that participants were needed immediately for a driving simulator study, and it was going to take a total of three hours spread across three 60 minute sessions within one week. Participants needed to be 18 years of age or older. The study paid $20 per hour (for each session) and included a $10 bonus for completing all three sessions. Additional details of the advertisement are shown in Appendix B.

Procedure:

All participants involved in this study were treated in accordance with the University of Idaho's protocol governing the use of human subjects in research. Before starting, participants were given a consent form to read, agree to its contents, and sign. This consent form explained that a simulated virtual environment was going to be presented. It stated that their task was to control their movement in the virtual world using input devices like a steering wheel and brake/gas pedals. It also mentioned that their participation was going to require three sessions of approximately 60 minutes, and they could withdraw from the study at any time without penalty. The form also stated that the data that they were going to provide was going to be kept anonymous. More details about the content of the consent form is provided in Appendix B.

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

A general description of the study was read to all participants prior to participation. The general description pointed out that the participants' goal was to keep their vehicle centered in their lane and to travel at an appropriate speed, just as they would in everyday driving. The description also emphasized that every participant would go through three trials lasting approximately 45 minutes, simulating a 40 mile drive on a rural highway where they were returning from a weekend camping trip in rural Idaho. Figure 27 shows the instructions of the study.

UTC Study
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 Idaho 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 3 trials lasting approximately 45 minutes which will simulate a 40 mile drive on a rural highway, where you are returning from a weekend camping trip in rural Idaho. During this drive there will be vehicles ahead of you and behind you, as well as in the oncoming lane. You should pay careful attention to other vehicles, road signs/markings, etc. and use normal driving etiquette (following speed limits, using turn signals, etc.) just as you would if you were driving on a real rural highway.

From time to time, the other vehicles in the simulation will slow down and pull off on the shoulder. When this occurs, you should maintain a safe distance, stay in your lane, and accelerate back up to 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 20 miles, a message will appear on the screen asking you to pull over onto the shoulder and take a break. At this time, we want you to park the car on the shoulder, placing the transmission in "Park" and exit the vehicle so that you can get up, walk around, and stretch your legs for a minute.

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

Do you have any questions?

Figure 27: Study instructions

To ensure all participants had a firm understanding of the study procedures, participants were given a five minute test drive on a two-lane rural highway composed of straight and curved horizontal segments. Participants were asked to get inside the vehicle and adjust their rear view mirror and driver's seat to their preference. They were also asked to center the steering wheel of the vehicle before they began their test drive. This test drive was done in order for the participants to familiarize themselves with the driver simulator and the control devices.

After the completion of their test drive, the participants were asked to remain in their seat while the researcher uploaded the experiment simulation. Again, the participants were reminded that the steering wheel needed to be centered. They were also reminded that the speed limit was 60 mph throughout the experiment track, and that after 20 minutes a message was going to appear on the screen asking them to pull over onto the shoulder for a quick break. During the break, participants were asked to get out of the vehicle to walk around and stretch their legs for at least one minute.

Once the participants felt like they could continue with the experiment, they returned to the vehicle and completed the last half of the track. At the end of the experiment the message, "Please pull over, thank you for your time!" was provided to each participant letting them know that the experiment had ended. After making sure the participant had pulled over and parked the vehicle, the researcher proceeded to stop the simulation. The researcher then stored the experiment data and saved it into the appropriate folder for analysis.

Almost the same experiment procedure was followed for the other two sessions that each participant completed as part of the study. On the second and third sessions, the participants did not have to sign any forms, but they were given the study instructions and reminded about their tasks. The participants also had to complete a test drive to familiarize themselves with the responsiveness of the simulator vehicle before they began the experiment. Participants also took quick breaks halfway through the final two sessions.

After the participants completed their third session, they were asked to answer questions from the debriefing form that was provided by the researcher. For example, participants were asked about their age, gender, years of driving experience, if they noticed anything unusual about the edgeline deteriorations and edgeline widths, and if the edgelines affected their driving behavior. More detailed information about the debriefing questions are provided in Appendix B. Following these questions, the purpose of the study was shared with the participants, and the researchers answered any questions that the participants had about the study. Each participant was then compensated for his or her time.

Participants' Session Distribution:

Every participant was assigned three different edgeline widths (2 inch, 4 inch, and 6 inch) that was composed of all four edgeline deterioration percentages. A total of three sessions were completed, one for each edgeline width.

Figure 28 shows that participants 1 through 4 experienced the 2 inch edgeline width on their first session, but each participant had a different distribution of the edgeline deterioration percentages throughout the experiment drive. Participants 1 through 4 experienced the 4 inch edgeline width on their second session, and the 6 inch edgeline width on their third session. Participants 5 through 8 experienced the 4 inch edgeline width on their first session, the 6 inch edgeline width on their second session, and the 2 inch edgeline width on their third session. The edgeline deterioration percentages varied from participant to participant but the pattern of how they were presented was the same for their first, second, and third session, and this was done to have consistency when it came to collect data. Participants 9 through 12 experienced the 6 inch edgeline width on their first session, the 2 inch edgeline width on their second session, and the 4 inch edgeline width on their third session.

Participant	Session 1				Session 2				Session 3			
#	Edgeline Width: 2"				Edgeline Width: 4"				Edgeline Width: 6"			
1	0	25	75	50	0	25	75	50	0	25	75	50
2	25	50	0	75	25	50	0	75	25	50	0	75
3	50	75	25	0	50	75	25	0	50	75	25	0
4	75	0	50	25	75	0	50	25	75	0	50	25
	Edgeline Width: 4"				Edgeline Width: 6"				Edgeline Width: 2"			
5	0	25	75	50	0	25	75	50	0	25	75	50
6	25	50	0	75	25	50	0	75	25	50	0	75
7	50	75	25	0	50	75	25	0	50	75	25	0
8	75	0	50	25	75	0	50	25	75	0	50	25
	Edgeline Width: 6"				Edgeline Width: 2"				Edgeline Width: 4"			
9	0	25	75	50	0	25	75	50	0	25	75	50
10	25	50	0	75	25	50	0	75	25	50	0	75
11	50	75	25	0	50	75	25	0	50	75	25	0
12	75	0	50	25	75	0	50	25	75	0	50	25
	Edgeline Width: 6"				Edgeline Width: 4"				Edgeline Width: 2"			
13	0	25	75	50	0	25	75	50	0	25	75	50
14	25	50	0	75	25	50	0	75	25	50	0	75
15	50	75	25	0	50	75	25	0	50	75	25	0
16	75	0	50	25	75	0	50	25	75	0	50	25
	Edgeline Width: 2"				Edgeline Width: 6"				Edgeline Width: 4"			
17	0	25	75	50	0	25	75	50	0	25	75	50
18	25	50	0	75	25	50	0	75	25	50	0	75
19	50	75	25	0	50	75	25	0	50	75	25	0
20	75	0	50	25	75	0	50	25	75	0	50	25
	Edgeline Width: 4"				Edgeline Width: 2"				Edgeline Width: 6"			
21	0	25	75	50	0	25	75	50	0	25	75	50
22	25	50	0	75	25	50	0	75	25	50	0	75
23	50	75	25	0	50	75	25	0	50	75	25	0
24	75	0	50	25	75	0	50	25	75	0	50	25

Figure 28: Participants session distribution

As shown in Figure 28, every participant was grouped in a set of four with a different edgeline deterioration percentage ordering for each person; however, they were given the same edgeline width order as previously mentioned. In this way, every set of four participants experienced unique patterns of edgeline deterioration percentages that were randomly presented in order to obtain less biased data.

Output Data

Data Collection:

A significant amount of data were collected by the MiniSim, but only the following data were of interest for this study:

Accelerator Pedal Position:

This type of data was important to include in order to determine if participants would apply different pressure at some point throughout the experiment. A wide range between minimum and maximum accelerator position values might indicate that participants behaved differently at some roadway geometries (e.g. when roadway geometry switched from curved segments to straight segments, or when they experienced big differences between the edgeline deterioration percentages, or when edgeline deterioration percentages changed from 0% to 75%). If the accelerator pedal position was almost constant throughout the experiment then that might indicate that the accelerator pedal position did not affect vehicle speed.

Steering Wheel Angle:

Steering wheel angle data were also fundamental in order to determine if steering wheel angle had any influence on lane deviation. As with the accelerator pedal position, a wide range between the minimum and maximum steering wheel angle values might indicate that participants turned abruptly at some sections of the roadway, which might help to determine the reason of these differences (e.g. switching from a straight segment into a curved segment).

Lane Deviation:

Vehicle lane position was analyzed based on lane deviation. Before participants started the experiment, the vehicle was centered on the right lane with zero lane deviation. When a vehicle moved toward the center of the two-lane rural highway, a negative lane deviation value was generated. When a vehicle moved toward the edgeline, a positive lane deviation value was generated. These lane deviation values were measured in feet.

Vehicle Speed:

Along with the lane deviation data, vehicle speed data was important to determine if there was reduction or increase in vehicle speed. Within the speed data, values fluctuated up and down as drivers reacted to the posted speed limit of 60 mph. Average vehicle speeds were recorded in miles per hour (mph).

CHAPTER 4: DATA ANALYSIS AND RESULTS

In this chapter, the participant information was analyzed first, followed by the analysis of the accelerator pedal position and steering wheel angle, lane position and vehicle speed, and debriefing survey. For the analysis of the lane position and vehicle speed, an ANOVA was used. A three way ANOVA was applied to do a general analysis of the lane position and vehicle speed, with these two driver performances as dependent variables and edgeline width, percentage of edgeline deterioration, and roadway geometry as independent variables. To make individual comparisons an ANOVA with a single factor was performed.

Participant Information

Data were collected from a total of 24 participants. Fourteen participants were males, and 10 participants were females. During the data collection process, only one participant (female) dropped out due to simulation sickness. All of the other participants were able to conclude all three sessions satisfactorily.

Regarding the age groups, 14 participants were in the range of 18 to 30 years old, 6 participants were in the range of 30 to 50 years old, and 4 participants were in the range of 50 to 70 years old.

The youngest participant was 19 years old (female), the oldest participant was 64 years old (male), and the average age among all participants was 31.58 years old. For this project balanced gender and age groups were desired but not a required condition. The average number of years driving among all participants was 15.17 years. These participants were hired from the local community, with most of them from the Moscow community. Since Moscow is a college town, an age group primarily between 18 to 30 years old was not entirely surprising.

Data analysis was only conducted using data from 21 out of the total 24 participants. This was due to the fact that some issues were encountered with data from 3 participants while converting the daq files (from the MiniSim program) into an hdf5 file and eventually into a csv file (into an excel file). While performing preliminary analysis, it was noticed that one participant was an outlier so that participant’s data was removed from the data analysis process. The following tables relate to the actual participant information on which data analysis was performed. Table 2 provides information about the gender groups. Table 3 provides information about the age groups, and Table 4 provides descriptive statistics among the final 20 participants.

Table 2: Gender groups

males	13 participants
females	7 participants

Table 3: Age groups

18-30 years old	13 participants
31-49 years old	4 participants
50-70 years old	3 participants

Table 4: Descriptive statistics of all 20 participants

youngers participant age	19 years old (female)
oldest participant age	64 years old (male)
average participant age	31.2 years old
average years of driving experience	15.0 years

While the two main driver performances analyzed in this study were lane position (through lane deviation), and vehicle speed, an initial assessment of the accelerator pedal position and steering wheel angle was completed. These driver performances were analyzed based on three edgeline widths (2 inch, 4 inch, and 6 inch) at four different edgeline deterioration percentages (0%, 25%, 50%, and 75%) that were tested on two types of roadway geometry (straight and curved horizontal segments) by different gender and age groups. The goal of the experiment was to determine if the 6 inch edgeline width would help drivers to maintain appropriate lane position and vehicle speed at those four different edgeline deterioration percentages on both types of roadway geometries when compared with the 4 inch (standard) width. The 2 inch edgeline width was included in this study for comparative purposes. The participants were neither asked to maintain lane position nor asked to drive at the speed limit of 60 mph. They were only reminded that the speed limit was 60 mph and asked to follow normal driving etiquette in order to assess their real driving behavior.

Accelerator Pedal Position and Steering Wheel Angle

The accelerator pedal position and steering wheel angle were evaluated, and Table 5 shows a summary related to those two factors.

Table 5: Summary of accelerator position and steering wheel angle

Measures	Accelerator pedal position	Steering wheel angle
min	0.292	-6.137
max	0.519	5.837
average	0.436	-0.002
standard dev.	0.039	2.520

For the accelerator, values were recorded as percentages, with a value of 0 denoting 0% or no pressure on the accelerator and a value of 1 denoting 100% and the accelerator being pressed to its maximum. This format follows SAE International recommended practice. Brake pressure or another indicator of brake position was evaluated in a similar manner. Normally, 0% of maximum brake pressure indicates that the foot is off the brake and 100% is maximum pressure (and full pedal application) *(16)*. For the steering wheel angle, a positive value means that the steering wheel angle is being turned to the right, and a negative value means that the steering wheel is being turned to the left. The values for the steering wheel denote angle in degrees, which follows the SAE International recommended practice. The amount of movement, such as angular rotation of the steering wheel, are usually measured in degrees *(16)*. By looking at the values obtained, it was concluded that the accelerator pedal position was almost constant throughout the experiment for all participants, and the steering wheel angle positions were small, which means that the position of the steering wheel was centered throughout the experiment for all participants.

Based on this information, it was determined that accelerator pedal position had a minimal effect on vehicle speed, and that the steering wheel angle did not have an effect on lane position.

Lane Position

Lane position was analyzed based on lane deviation. These values were measured off the centerline of the right lane, and followed the SAE International recommended practice. A value of 0 implied that the vehicle was centered on the right lane. A negative value meant that the vehicle moved to the left (towards the centerline of the roadway). A positive value meant that the vehicle moved to the right (towards the edgeline) from the center of the right lane.

Lateral distance is usually measured in feet or meters from the longitudinal centerline of the lane of travel to the longitudinal centerline of the vehicle, where the distance to the right of the lane centerline is positive and to the left is negative *(16)*.

Figures 29, 30, and 31 suggest that the drivers on average tended to move toward the edgeline from the centerline of the right lane (denoted by the thicker line). The y-axis represents the lane deviation of the vehicle that was recorded in feet. A value of 0 feet was recorded if the vehicle stayed centered on the right lane, while deviations from the center of the right lane to the center of the roadway provided negative values, and deviations toward the edgeline provided positive values. The x-axis shows the edgeline deterioration percentages, which was composed of four different percentages for each edgeline width as experienced by each participant. Also, the recurring spike present in these figures show the lane deviations when participants drove over the wide curved segments (while turning left). It can be observed that it happened at all four different edgeline deterioration percentages.

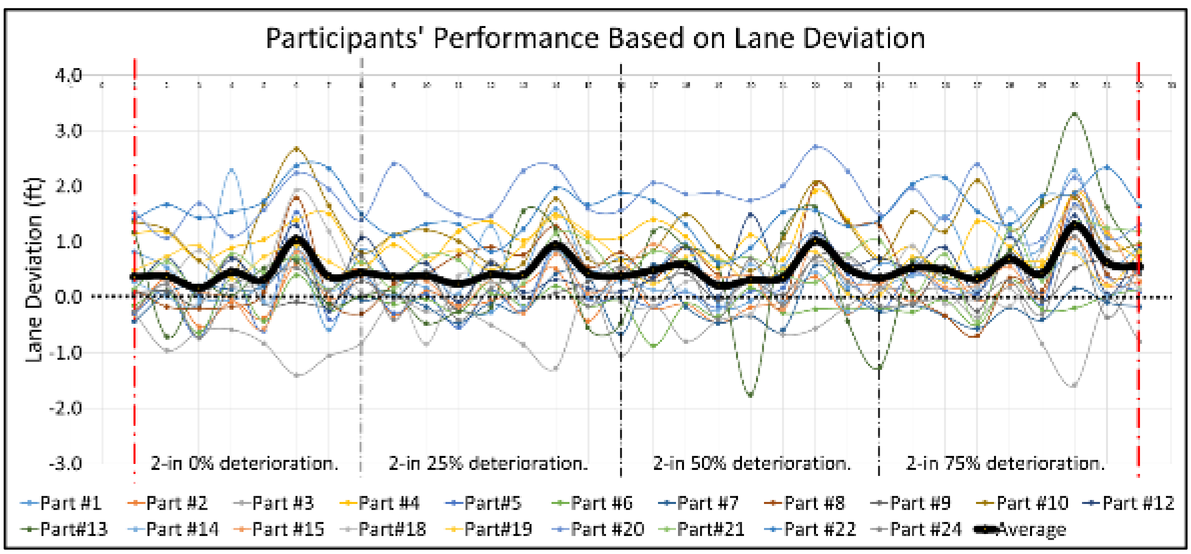

Figure 29: Participants' performance based on lane deviation - 2-in edgeline width

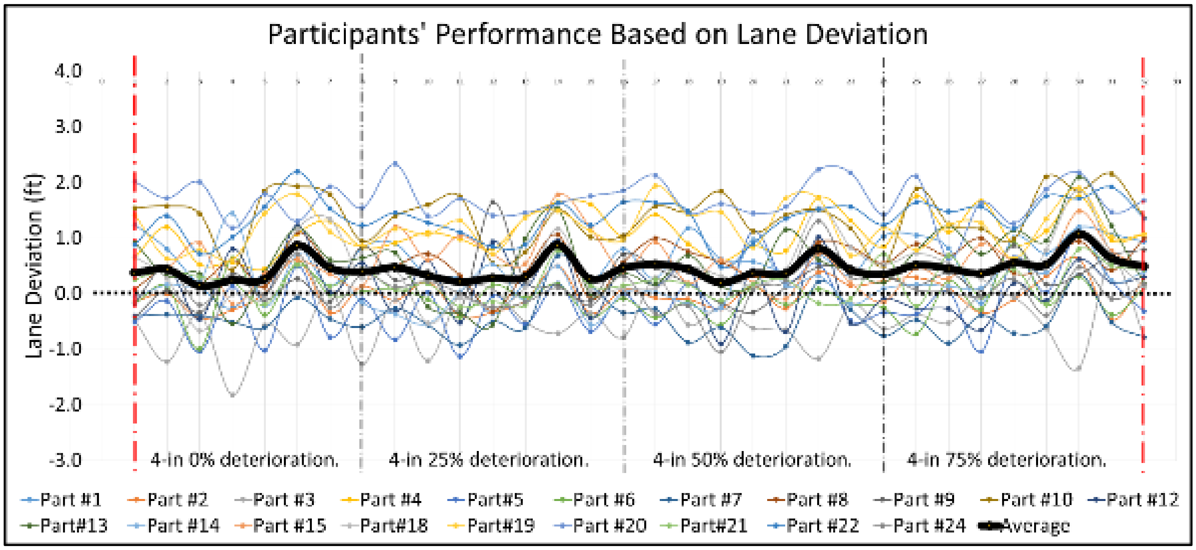

Figure 30: Participant's performance based on lane deviation - 4-in edgeline width

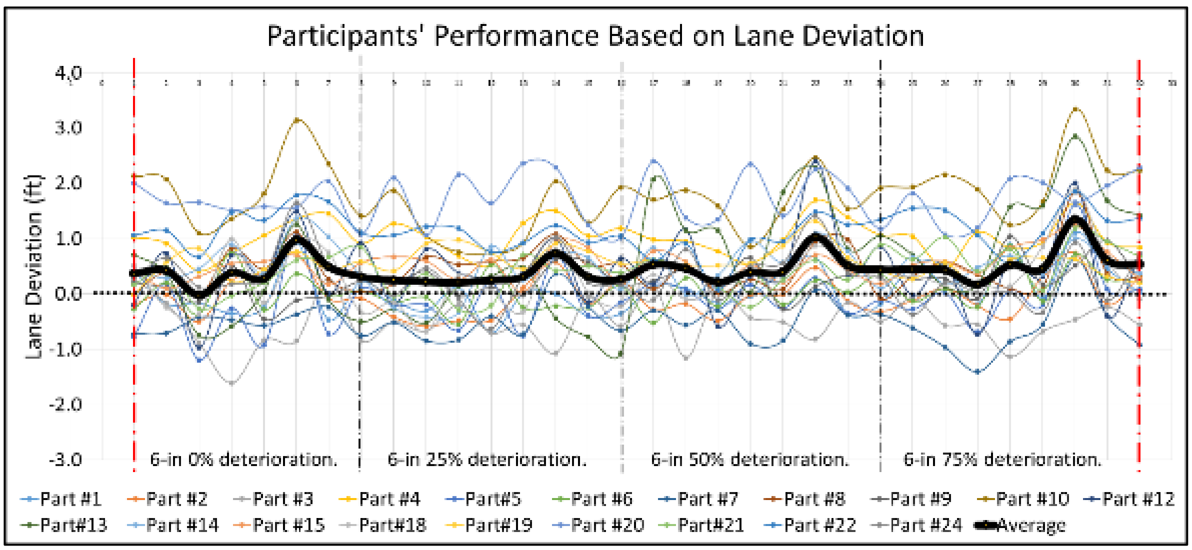

Figure 31: Participants' performance based on lane deviation - 6-in edgeline width

A three way ANOVA was used to determine if edgeline width, edgeline deterioration percentages, and roadway geometry had significant impact on lane deviation. A type I error probability of alpha = 0.05 was used during the analysis in order to draw conclusions from a statistical perspective.

Figure 32 shows the results obtained from the ANOVA analysis. These results show that edgeline deterioration percentages (p-value = 7.775e-05) and roadway geometry (p-value < 2.2e-16) had significant impact on lane deviation at the 0.05 significance level. On the other hand, edgeline width, interaction between edgeline width and edgeline deterioration percentages, interaction between edgeline width and roadway geometry, and interaction between edgeline width and edgeline deterioration percentages and roadway geometry did not have significant impact on lane deviation at the same significance level.

```
Analysis of Variance Table

Response: lane_deviation
                                                    Df Sum Sq Mean Sq F value    Pr(>F)
edgeline_width                                       2   1.11  0.5536  1.0617    0.3461
edgeline_deterioration                               3  11.34  3.7811  7.2510 7.775e-05 ***
roadway_geometry                                     3  80.04 26.6786 51.1609 < 2.2e-16 ***
edgeline_width:edgeline_deterioration                6   1.21  0.2014  0.3862    0.8882
edgeline_width:roadway_geometry                      6   1.27  0.2108  0.4043    0.8765
edgeline_deterioration:roadway_geometry              9   2.51  0.2793  0.5356    0.8494
edgeline_width:edgeline_deterioration:roadway_geometry  18   1.78  0.0988  0.1894    0.9999
Residuals                                         1872 976.18  0.5215
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 32: ANOVA based on lane deviation

Figure 33 shows the impacts of edgeline widths on lane deviation. All three edgeline widths (2 inch, 4 inch, and 6 inch) provide approximately the same lane deviation of 0.43 feet (5.2 inches) and was statistically unreliable.

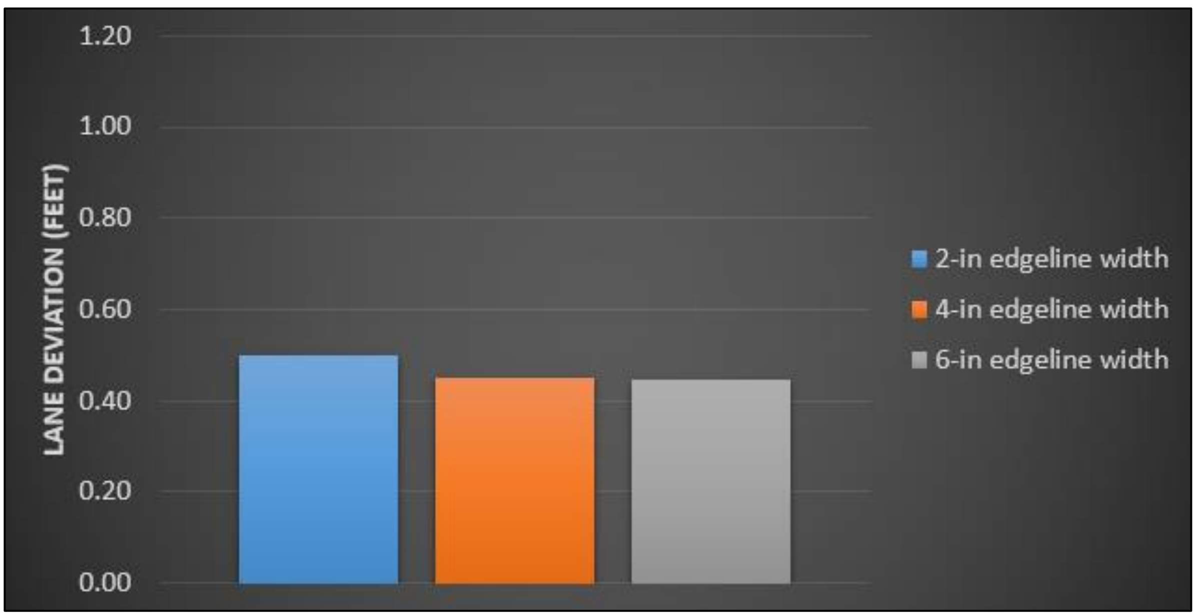

Figure 33: Impact of edgeline widths on lane deviation

Figure 34 describes the impact that edgeline deterioration percentages had on lane deviation. As the percentage of edgeline deterioration increased, lane deviation increased as well. When participants experienced 0% edgeline deterioration they had a lane deviation of about 0.43 feet (5.2 inches), and when they experienced 75% edgeline deterioration they had a lane deviation of about 0.60 feet (7.2 inches). The percentage of edgeline deterioration did have an impact on lane deviation and was statistically reliable.

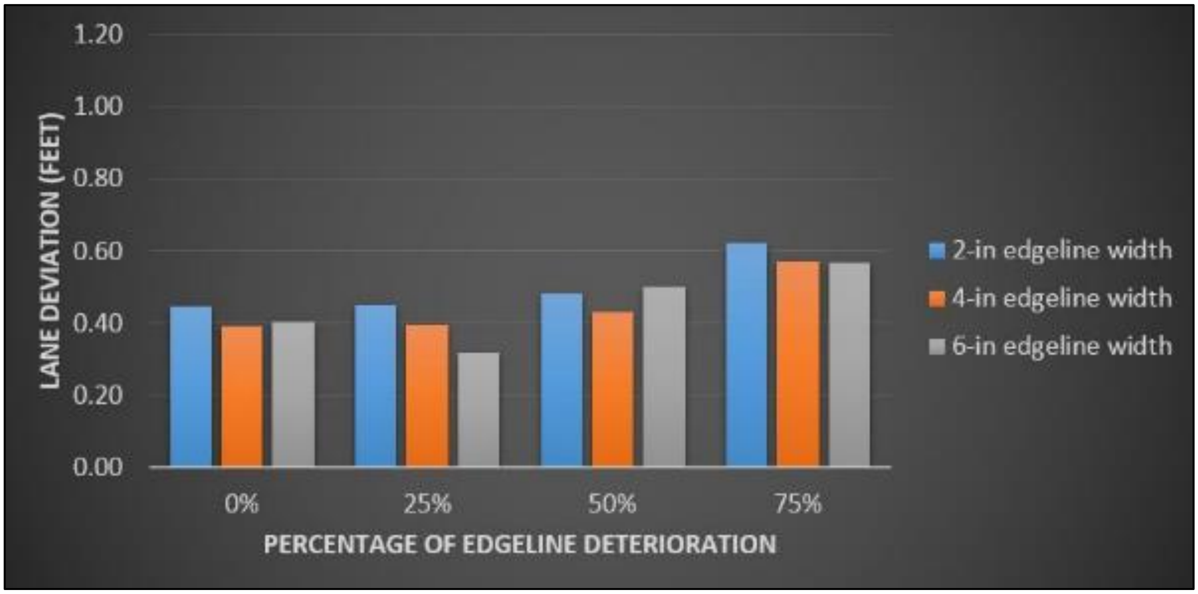

Figure 34: Impact of percentage of edgeline deterioration on lane deviation

Figure 35 shows a graphical representation of the impacts of edgeline widths on lane deviation at specific roadway geometries.

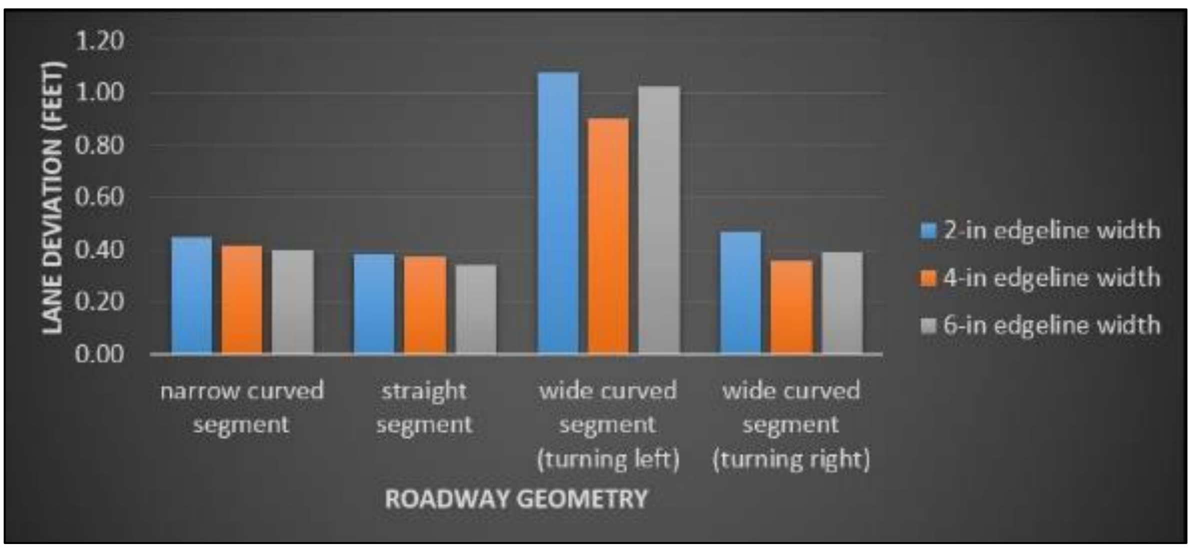

Figure 35: Impact of edgeline widths on lane deviation at different roadway geometries

From Figure 35, it can be observed that when participants drove over the wide curved segment while turning left, they experienced a higher lane deviation of about 1.00 foot (12.0 inches) as compared to the other roadway geometries that had lane deviations of about 0.40 feet (4.8 inches). According to the SAE International recommended practice, people tend to drive closer to the inside of the curve on roadway facilities, especially if the curve radius is small *(16)*. From Figure 35 it can be observed that the lane deviation values are positive, which means that participants moved towards the edgeline for all four roadway geometry types, and not closer to the inside of the curves. The specific cause of this behavior from this particular sample group was not clear.

Lane Deviation Based on Standard Deviation Values:

Figure 36 shows the results obtained from the ANOVA analysis. These results show that edgeline width (p-value = 0.04967) and roadway geometry (p-value < 2e-16) had significant impact on lane deviation at the 0.05 significance level based on standard deviation values. Edgeline deterioration, interaction between edgeline width and edgeline deterioration percentages, interaction between edgeline width and roadway geometry, and interaction between edgeline width and edgeline deterioration percentages and roadway geometry did not have significant impact on lane deviation at the same significance level.

```
Analysis of Variance Table

Response: lane_deviation_std
                                                     Df  Sum Sq Mean Sq  F value  Pr(>F)
edgeline_width                                        2   0.343  0.1713   3.0073 0.04967 *
edgeline_deterioration                                3   0.423  0.1409   2.4731 0.06000 .
roadway_geometry                                      3  39.132 13.0440 229.0314 < 2e-16 ***
edgeline_width:edgeline_deterioration                 6   0.209  0.0349   0.6125 0.72053
edgeline_width:roadway_geometry                       6   0.194  0.0323   0.5677 0.75636
edgeline_deterioration:roadway_geometry               9   0.166  0.0185   0.3247 0.96717
edgeline_width:edgeline_deterioration:roadway_geometry  18   0.730  0.0406   0.7121 0.80170
Residuals                                          1872 106.616  0.0570
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 36: ANOVA based on lane deviation

Figure 37 shows the impacts of edgeline widths on lane deviation based on standard deviation values. It can be observed that as the edgeline width increases from 2 inches to 4 inches the standard deviation increases as well, and keeps increasing as the edgeline width increases from 4 inches to 6 inches. The difference among the three edgeline widths were reliable based on standard deviation values. The 2 inch edgeline width had a standard deviation of 0.83 feet (10.0 inches), the 4 inch edgeline width had a standard deviation of 0.85 feet (10.2 inches), and the 6 inch edgeline width had a standard deviation of 0.87 feet (10.4 inches).

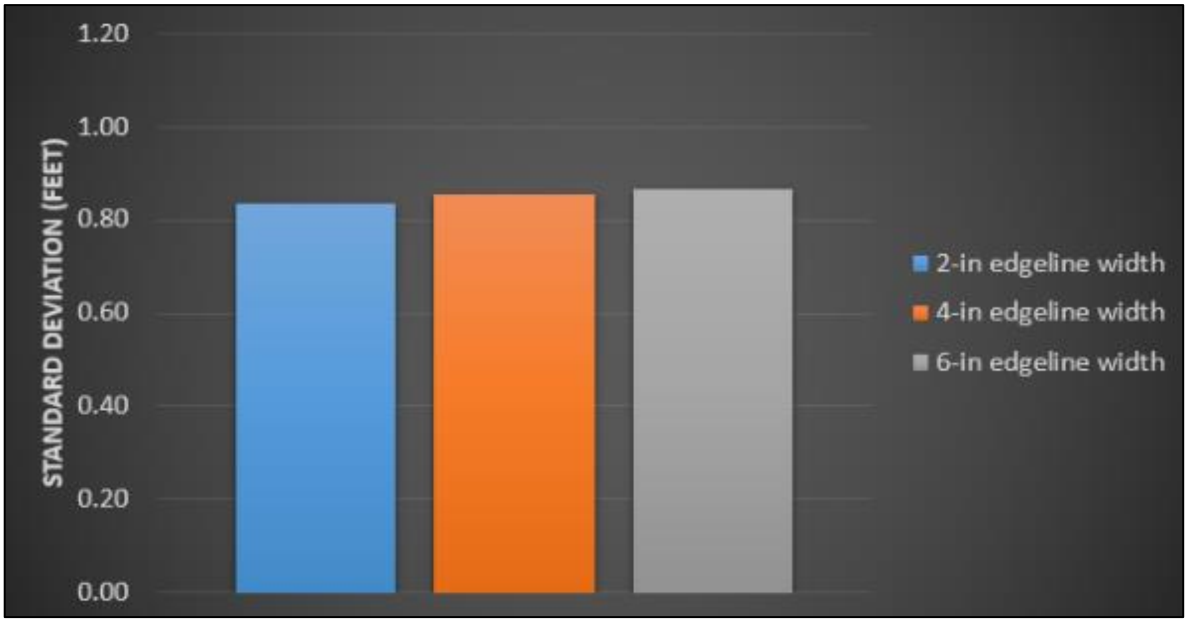

Figure 37: Impact of edgeline widths on lane deviation (standard deviation)

Figure 38 shows the impact that percentage of edgeline deterioration had on lane deviation based on standard deviation values. It can be observed that as the percentage of edgeline deterioration increases, the standard deviation increases as well, except when the edgeline deterioration reaches to 50%. These percentages of edgeline deterioration did not have an impact on lane deviation (standard deviation) and therefore were not statistically reliable.

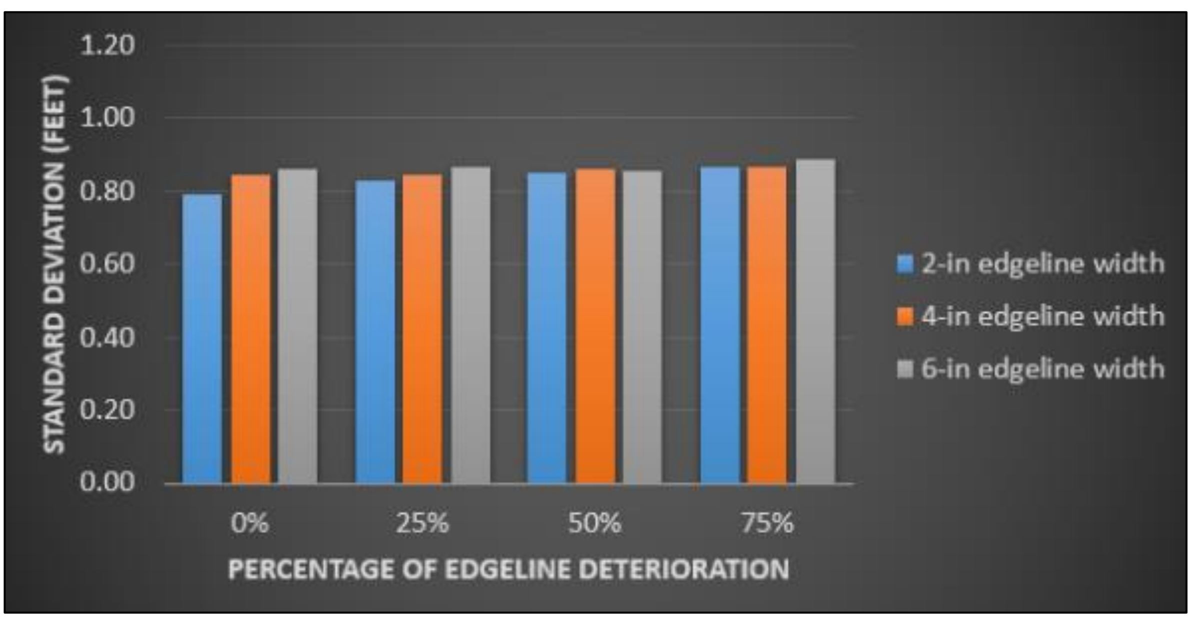

Figure 38: Impact of percentage of edgeline deterioration on lane deviation (standard deviation)

Figure 39 shows a graphical representation of the impacts of edgeline width on roadway geometry based on lane deviation and standard deviation values. It can be observed that there was a greater standard deviation when participants experienced the narrow curved segment as compared to the other roadway geometries.

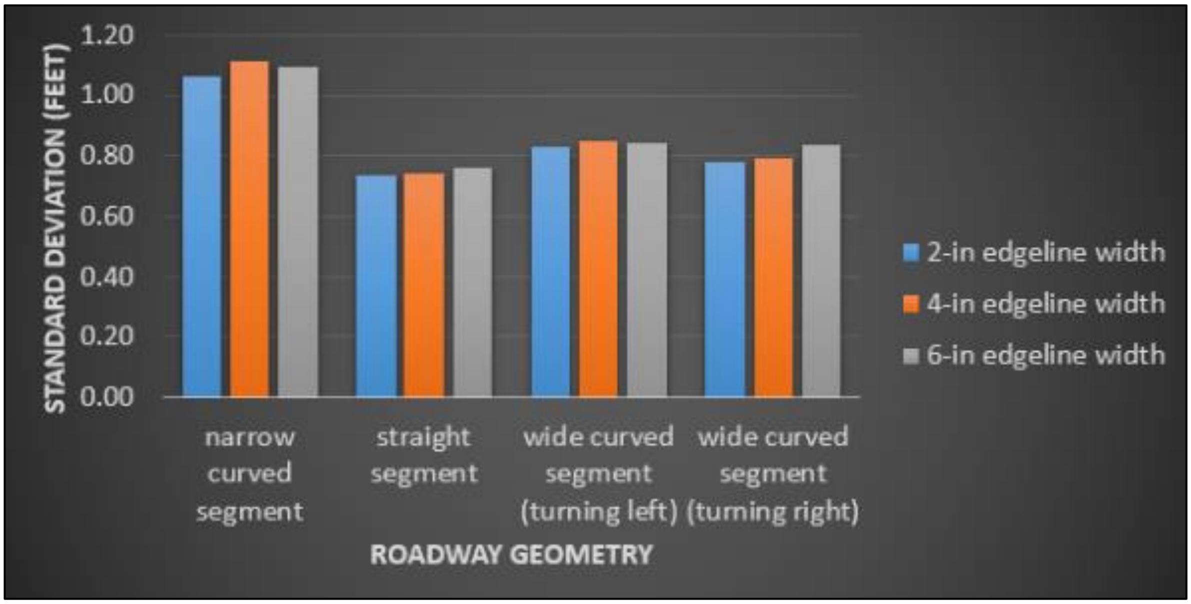

Figure 39: Impact of roadway geometry on lane deviation (standard deviation)

Comparison between Edgeline Widths Based on Lane Deviation:

An ANOVA with a single factor was conducted to compare specific edgeline widths at different deterioration percentages among the 2 inch, 4 inch, and 6 inch edgeline widths based on lane deviation. Table 6 shows the comparisons made between the 2 inch edgeline width against the 4 inch edgeline width at different edgeline deterioration percentages, and the statistical analyses are shown in Appendix D. These results are based on a 95% confidence interval.

Where N/A is shown, it means that no comparisons were performed on those cells, since no added value was gained.

As an example, the results indicate that the lane deviation was essentially the same for a driver exposed to either a 2 inch edgeline with 0% edgeline deterioration or a 4 inch edgeline with 25% edgeline deterioration.

Table 6: Comparison between edgeline widths (2-in vs 4-in) based on lane deviation at specific deteriorations

Lane Deviation				
	4"; 0%	4"; 25%	4"; 50%	4"; 75%
2"; 0%	N/A	same	same	same
2"; 25%	N/A	N/A	same	same
2"; 50%	N/A	N/A	N/A	same
2"; 75%	N/A	N/A	N/A	N/A

Table 7 shows the comparisons made between the 6 inch edgeline width against the 4 inch edgeline width at different edgeline deterioration percentages, and the statistical analyses are shown in Appendix D. These results are based on a 95% confidence interval.

Table 7: Comparison between edgeline widths (6-in vs 4-in) based on lane deviation at specific deteriorations

Lane Deviation			
	6"; 25%	6"; 50%	6"; 75%
4"; 0%	same	same	different (6"; 75% provides higher lane deviation)
4"; 25%	N/A	same	different (6"; 75% provides higher lane deviation)
4"; 50%	N/A	N/A	same
4"; 75%	N/A	N/A	N/A

Tables 6 and 7 indicate that most of the comparisons performed show that the means between them were statistically equivalent, which means that they result in about the same lane deviation. However, a 6 inch edgeline width with 75% edgeline deterioration compared with a 4 inch edgeline width with 0% edgeline deterioration was not statistically equivalent (p-value = 0.047), with the 6 inch edgeline width with 75% edgeline deterioration providing higher lane deviation. Also, there was not statistical equivalency (p-value = 0.049) between a 6 inch edgeline width with 75% edgeline deterioration and a 4 inch edgeline width with 25% edgeline deterioration; the 6 inch edgeline width with 75% edgeline deterioration provided higher lane deviation as well.

Vehicle Speed

The posted speed limit for this study was 60 mph. Figures 40, 41, and 42 suggest that drivers tended to go above the posted speed limit based on the average speed (denoted by the thicker line).

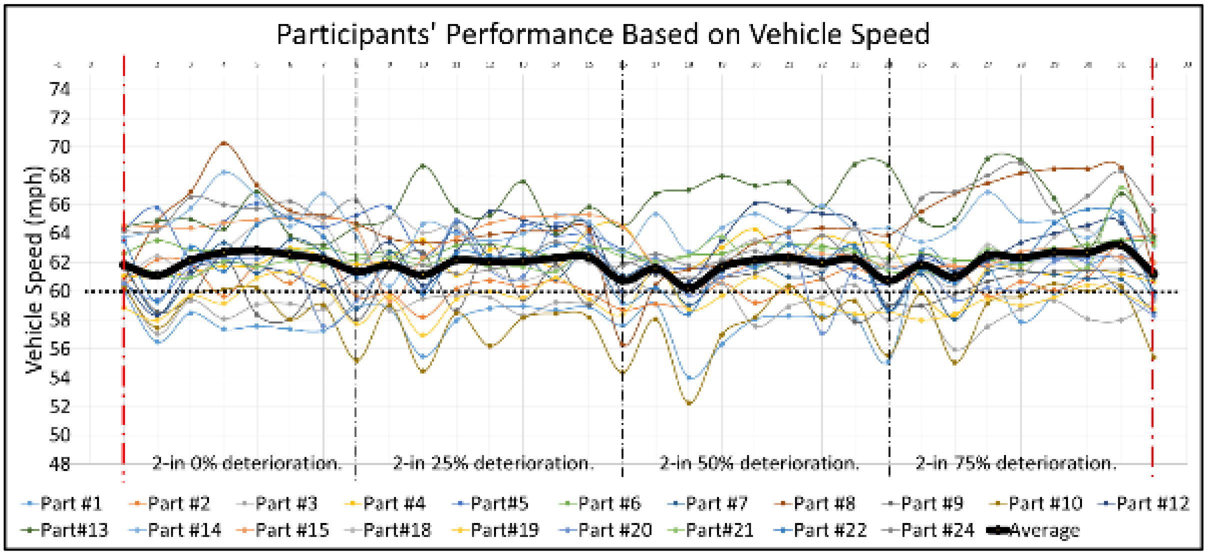

Figure 40: Participants' performance based on vehicle speed - 2-in edgeline width

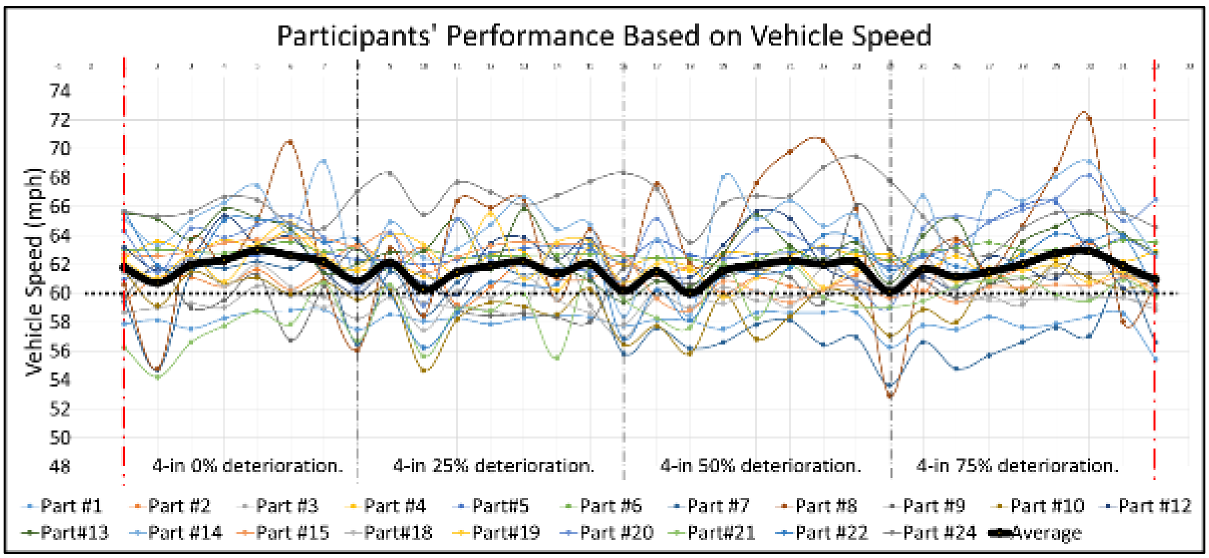

Figure 41: Participants' performance based on vehicle speed - 4-in edgeline width

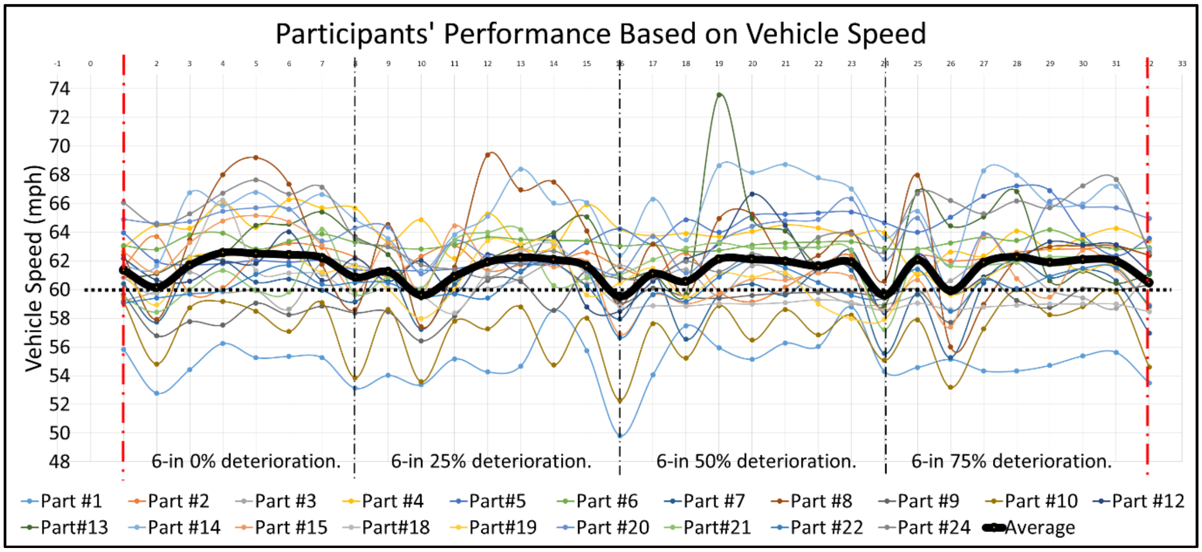

Figure 42: Participants' performance based on vehicle speed - 6-in edgeline width

A three way ANOVA was used to determine if edgeline width, edgeline deterioration, and roadway geometry had significant impact on vehicle speed. A type I error probability of alpha = 0.05 was used during the analysis in order to draw conclusions from a statistical perspective.

Figure 43 shows the results obtained from the ANOVA analysis. These results show that edgeline widths (p-value = 0.014), edgeline deterioration percentages (p-value = 0.013) and roadway geometry (p-value < 2e-16) had significant impact on vehicle speed at a significance level of 0.05. The interaction among each one of them show that they did not have significant impact on vehicle speed at a significance level of 0.05.

```
Analysis of Variance Table

Response: speed
                                                   Df  Sum Sq Mean Sq F value   Pr(>F)
edgeline_width                                      2    67.2  33.587  4.2758  0.01404 *
edgeline_deterioration                              3    85.5  28.508  3.6293  0.01251 *
roadway_geometry                                    3   880.9 293.626 37.3803  < 2e-16 ***
edgeline_width:edgeline_deterioration               6    10.1   1.677  0.2135  0.97264
edgeline_width:roadway_geometry                     6    19.3   3.212  0.4089  0.87354
edgeline_deterioration:roadway_geometry             9    15.8   1.753  0.2232  0.99129
edgeline_width:edgeline_deterioration:roadway_geometry  18    32.7   1.814  0.2310  0.99968
Residuals                                        1872 14704.7   7.855
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Figure 43: ANOVA based on vehicle speed

Figure 44 shows a graphical representation of the impacts of edgeline widths on vehicle speed, where it can be seen that, as the edgeline width increases the vehicle speed decreases, and these results were statistically reliable. Operationally speaking, it is acknowledged that this difference, for all practical purposes, is negligible.

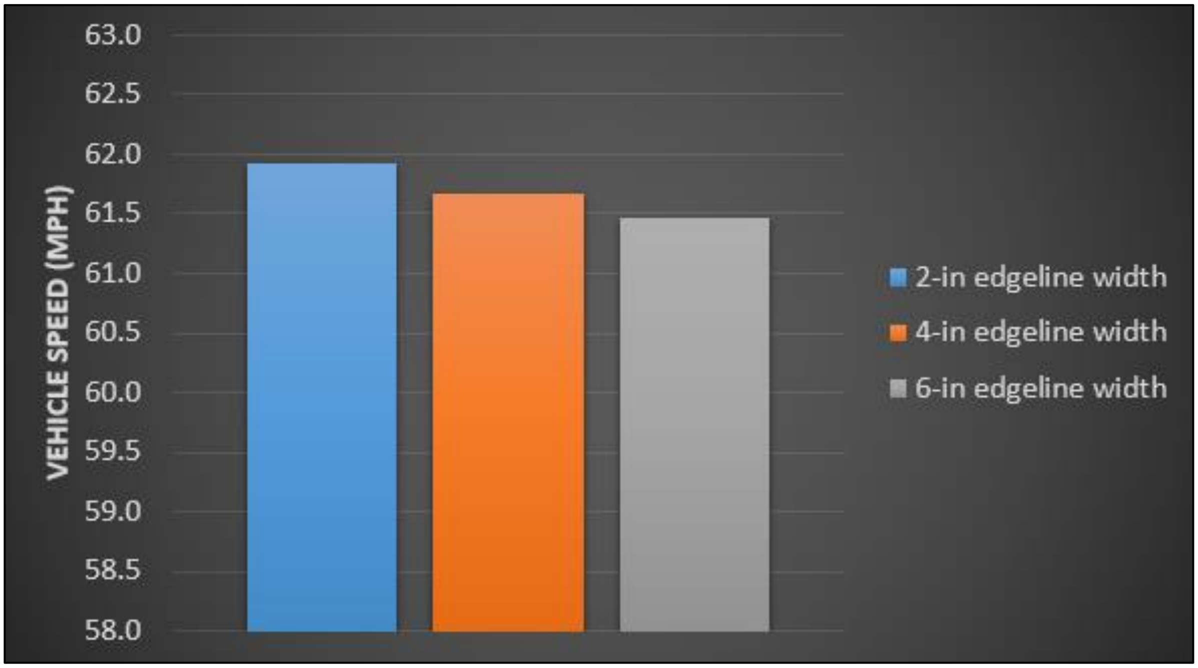

Figure 44: Impact of edgeline widths on vehicle speed

Figure 45 shows a graphical representation of the impacts that edgeline deterioration percentages had on vehicle speed. It can be observed that participants were able to maintain about the same vehicle speed when they experienced 25% and 50% edgeline deteriorations (lower vehicle speeds) as compared to when they experienced 0% and 75% edgeline deteriorations (higher vehicle speeds). The percentage of edgeline deterioration did have an impact on vehicle speed and was statistically reliable.

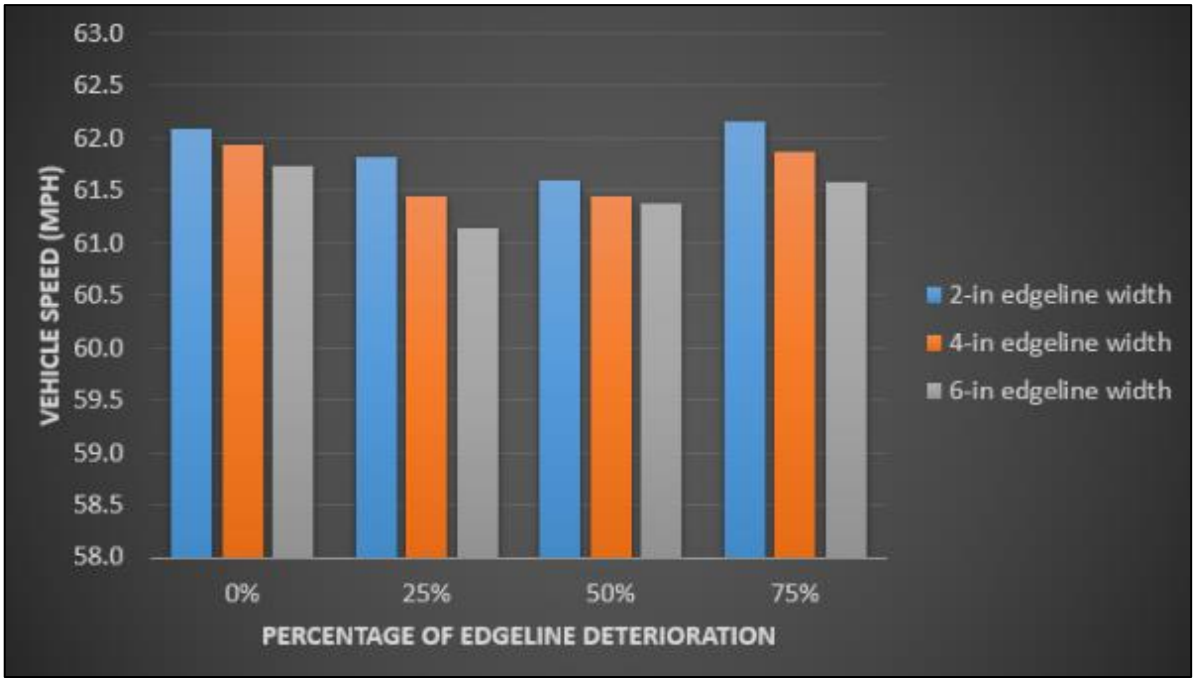

Figure 45: Impact of percentage of edgeline deterioration on vehicle speed

Figure 46 shows a graphical representation of the impacts that edgeline widths had on vehicle speed at specific roadway geometries.

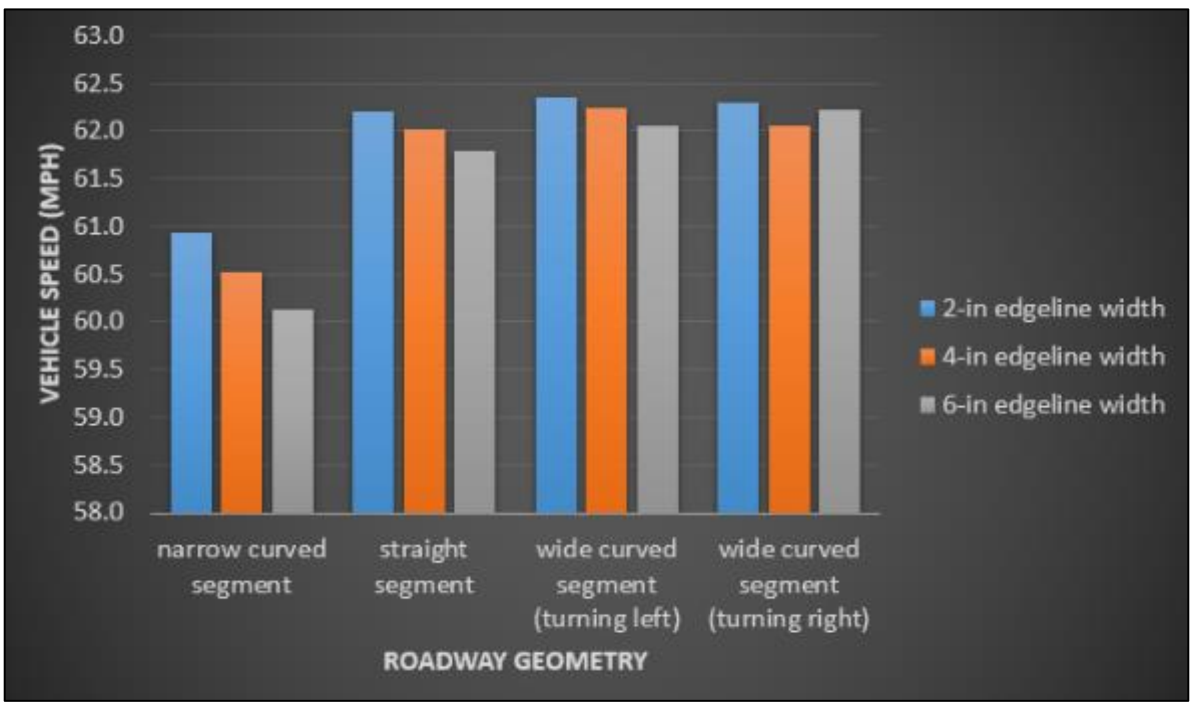

Figure 46: Impact of edgeline widths on vehicle speed at different roadway geometries

From Figure 46, it can be observed that when the participants drove over a narrow curved segment, they had a lower vehicle speed of about 60.0 to 61.0 mph as compared with the other roadway geometries where they experienced higher vehicle speeds of about 61.5 to 62.5 mph.

Comparison between Edgeline Widths Based on Vehicle Speed:

An ANOVA with a single factor was conducted to compare specific edgeline widths at different deterioration percentages among the 2 inch, 4 inch, and 6 inch edgeline widths based on vehicle speed. Table 8 shows the comparisons made between the 2 inch edgeline width against the 4 inch edgeline width at different edgeline deterioration percentages, and the statistical analyses are shown in Appendix E. These results are based on a 95% confidence interval.

Table 8: Comparison between edgeline widths (2-in vs 4-in) based on vehicle speed at specific deteriorations

Vehicle Speed				
	4"; 0%	4"; 25%	4"; 50%	4"; 75%
2"; 0%	N/A	different (2"; 0% provides higher speed)	same	same
2"; 25%	N/A	N/A	same	same
2"; 50%	N/A	N/A	N/A	same
2"; 75%	N/A	N/A	N/A	N/A

Table 9 shows the comparisons made between the 6 inch edgeline width against the 4 inch edgeline width at different edgeline deterioration percentages, and the statistical analyses are shown in Appendix E. These results are based on a 95% confidence interval.

Table 9: Comparison between edgeline widths (6-in vs 4-in) based on vehicle speed at specific deteriorations

Vehicle Speed			
	6"; 25%	6"; 50%	6"; 75%
4"; 0%	different (6"; 25% provides lower speed)	same	same
4"; 25%	N/A	same	same
4"; 50%	N/A	N/A	same
4"; 75%	N/A	N/A	N/A

From Tables 8 and 9 it can be observed that most of the comparisons performed show that the means between them were statistically equivalent, resulting in about the same vehicle speed. The results do not show statistical equivalency (p-value = 0.037) between the 2 inch edgeline width with 0% edgeline deterioration and a 4 inch edgeline width with 25% edgeline deterioration; the 2 inch edgeline width with 0% edgeline deterioration resulted in a higher vehicle speed. The results also show that there was not statistical equivalency (p-value = 0.014) between the 6 inch edgeline width with 25% edgeline deterioration and the 4 inch edgeline width with 0% deterioration; the 6 inch edgeline width with 25% edgeline deterioration resulted in a lower vehicle speed.

Based on the statistical results obtained from the ANOVA analysis, it was concluded that replacing a 4 inch edgeline width with a 2 inch edgeline width will not provide safety benefits and is not recommended. The hypothesis was that the 2 inch edgeline width with 0% edgeline deterioration would provide at least the same performance as a 4 inch edgeline width with 25% edgeline deterioration based on lane deviation and vehicle speed, but participant testing determined that their performances were not the same.

Based on the statistical results obtained with regard to the 6 inch edgeline width with 50% edgeline deterioration against a 4 inch edgeline width with 0% edgeline deterioration, it was concluded that replacing a 4 inch edgeline width by a 6 inch edgeline width will provide safety benefits. Even though the results showed that the 6 inch edgeline width with 50% edgeline deterioration does not provide safety benefits when compared to the 4 inch edgeline width with 0% edgeline deterioration, it does provide similar performances. This means that a 6 inch edgeline width, once implemented, would not need to be replaced after one year; instead, it could be replaced after one and a half years and still provide the same performance as a 4 inch edgeline width with 0% edgeline deterioration (brand new pavement marking).

Debriefing Information Analysis

Participants were asked different questions at the end of their third session about their experience with the driving simulator and overall experiment. Some of these questions were specifically related to the edgelines while others asked about what they experienced and how they felt about the experiment. The following information is a summary of all information that was collected. The complete debriefing questions and answers can be found in Appendix C.

Participants mentioned that the types of vehicles that they drive are cars (regular 4 door) and trucks, followed by vans, SUVs, commercial vehicles, semi-trucks, and motorcycles. Participants provided percentage ratings about driving on rural highways, towns, interstates, and cities. Some participants mentioned that they drive more on rural highways, while others mentioned that they drive more in cities. Most of the participants mentioned that they were defensive drivers, followed by aggressive, careful, and passive.

All participants stated that the simulation did make them feel as if they were driving in a three-dimensional environment. Sixty percent (12 out of the 20 participants) said that they did not notice anything unusual about the simulated environment, while others mentioned that the driving simulator vehicle's Revolution per Minute (RPM) would jump randomly while catching up to speed, and some would say that the steering wheel was almost too smooth to control. Sixty percent (12 out of the 20 participants) said that they did not notice anything unusual about the edgeline deterioration, while others did notice a change in brightness. Ninety percent (18 out of the 20 participants) did not notice anything unusual about the edgeline widths, while the remaining participants were unsure.

Sixty-five percent (13 out of the 20 participants) said that the edgelines did not affect their driving behavior, while some of the remaining mentioned that they used the edgelines to maintain their lane position, and some said that the edgelines did not affect their driving behavior where only the yellow markings did. Eighty percent (16 out of 20 participants) said that the edgelines did not affect their speed. Sixty-five percent (13 out of the 20 participants) said that the edgelines did affect how they maintained their lane position, while the remaining did not think so. Seventy percent (14 out of the 20 participants) said that the edgelines did not affect how they drove in general, while the remaining mentioned that the edgelines helped them to not go over the shoulder or stay centered on their lane.

All of the participants (20 out of the 20 participants) mentioned that they did notice the other vehicles in the simulation. All of the participants (20 out of the 20 participants) mentioned that they did notice vehicles ahead of and behind them in the simulation. All of the participants (20 out of the 20 participants) mentioned that they did notice vehicles in the opposing lane in the simulation.

Participants also shared the following feedback about what influenced their driving during the study: oncoming vehicles (which made them slow down on curve segments), speed limit, police vehicles, not having music or being entertained because of being bored, "it was just a simulation", and curve segments. Eighty percent (16 out of the 20 participants) mentioned that the speed of the vehicle in front of them did not influence their driving during the study. Ninety-five percent (19 out of the 20 participants) mentioned that the number of vehicles traveling in the lane ahead of them did not influence their driving during the study. Fifty percent (10 out of the 20 participants) said that the amount of traffic in the opposing lane influenced their driving during the study, while the other fifty percent said that the amount of traffic in the opposing lane did not influence their driving during the study. Sixty percent (12 out of the 20 participants) mentioned that the layout of the road did influence their driving during the study, while the remaining said that the layout of the road did not influence their driving during the study. Sixty-five percent (13 out of the 20 participants) mentioned that the markings on the road did not influence their driving during the study. Sixty percent (12 out of the 20 participants) mentioned that there were no other things that influenced their driving during the study, while the remaining mentioned: the vehicle’s RPM, switching from straight to curve segments, the change from concrete to pavement, police vehicles, speed limits, and turns.

Sixty percent (12 out of the 20 participants) mentioned that they did not have additional comments, while the remaining mentioned that the study was interesting, participants noticed the vehicle’s RPM would jump randomly, and others suggested including radio stereos and/or cruise control mechanisms in future studies since the majority of people use them nowadays.

CHAPTER 5: RESEARCH CONCLUSIONS

This chapter presents conclusions based on the results obtained and summarized in the previous chapter. Before proceeding with an interpretation and analysis of the results obtained, it is important to note that edgelines are replaced every one to two years in most states. For this study, it was assumed that pavement markings are replaced on a yearly basis, which follows Michigan DOT's restriping guidelines (as mentioned in the literature review section), as well as ITD's restriping protocol.

Lane Position

By performing this study it was observed that most of the participants tended to move toward the right of the center of the lane (toward the edgeline) rather than to the left of the center of the lane (toward the center line of the roadway).

All three edgeline widths provide approximately the same lane deviation. As percentage of edgeline deterioration increased, lane deviation increased as well.

Edgeline widths did not have an impact on lane position. Increasing the width of the edgeline from 4 inches to 6 inches would not provide lane position safety benefits based on lane deviation. At some edgeline deterioration percentages it provides higher lane deviation while at other edgeline deterioration percentages it provides about the same lane deviation.

A 6 inch edgeline width with 50% deterioration does not provide safety benefits as compared to a brand new 4 inch edgeline width marking, but it does provide the same performance based on lane deviation. This could be something to consider because the implementation of a 6 inch edgeline width could increase the service life of the pavement marking; replacement would occur after a year and a half but still provide the same performance based on lane deviation as a brand new 4 inch edgeline width marking despite 50% deterioration. The extra cost related to wider edgelines should be considered and a benefit/cost ratio analysis performed before a final decision is made.

Replacing a 4 inch edgeline width with a 2 inch edgeline width would not provide safety benefits at any edgeline deterioration percentage, but would provide about the same performance, based on lane deviation when comparing a brand new 2 inch edgeline width marking against a 4 inch edgeline width with 25% deterioration. This could be something to consider since the implementation of a 2 inch edgeline width could reduce the cost of pavement markings. At the same time, it would have to be replaced in less than a year because it would perform as a 4 inch edgeline width with 25% deterioration, keeping in mind that pavement markings are assumed to be replaced on a yearly basis once installed as brand new pavement markings.

Vehicle Speed

On average, participants tended to drive at or above the posted speed limit of 60 mph regardless of the edgeline width, edgeline deterioration percentage, and roadway geometry.

Edgeline widths do have an impact on vehicle speed. As the edgeline width increased, vehicle speeds decreased, although this reduction is minimal. Similarly, the percentage of edgeline deterioration also had a small benefit.

Increasing the width of the edgeline from 4 inches to 6 inches would provide safety benefits by reducing vehicle speed, but at the same time this positive impact, both statistically and operationally speaking, is minimal.

Safety benefits are realized when comparing a brand new 4 inch edgeline width marking with a 6 inch edgeline width with 25% deterioration, but the extra cost associated with wider edgelines might influence the decision to implement because of the minimal vehicle speed benefits. A 6 inch edgeline width with 50% deterioration would not provide safety benefits as when compared with the brand new 4 inch edgeline width marking, but would provide about the same performance based on vehicle speed, and will still provide the same performance when it deteriorates to 75%. This could be something to consider because implementing wider edgelines extends the replacement window in excess of one year.

Replacing a 4 inch edgeline width with a 2 inch edgeline width would not provide safety benefits at any of the edgeline deterioration percentages based on vehicle speed. A brand new 2 inch edgeline width marking would not provide the same performance as a 4 inch with 25% edgeline deterioration and therefore a 2 inch edgeline width should not be considered based on vehicle speed.

Edgeline Deterioration Percentages and Roadway Geometry

Edgeline deterioration percentages had an impact on both lane deviation and vehicle speed. The 75% edgeline deterioration (almost worn out) contributed to more lane deviation and slightly higher vehicle speeds.

Edgeline widths at specific roadway geometries had an impact on both lane deviation and vehicle speed. Participants experienced a greater lane deviation when driving along wide curved segments and turning left, which contradicts the SAE International recommended practice. Based on a visual review of the driving simulator, some of the oncoming vehicles appeared to encroach toward the center of the roadway, and this could have been one reason for the contradiction. Participants seemed to slow down when driving over the narrow curved segments, regardless of the edgeline width and edgeline deterioration percentage.

Future Research

One of the major limitations of this project was that a daytime environment was exclusively considered for this experiment. A nighttime environment is recommended in future research, since retro-reflectivity of the edgelines is one of the major factors that guide drivers when daylight is not present. Also, only two-lane highways were analyzed for this study, and it may be beneficial to study multi-lane highways as well. Lastly, only horizontal roadway alignments were considered in this study. Vertical roadway alignments should be incorporated in future studies, since this type of geometry is frequently encountered in the rural highway roadway environment.

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APPENDICES

Appendix A: Calculating Traffic Volume

Calculating the Annual Average Daily Traffic, AADT (veh/day):

#	ITD Distric Boundary	Automatic Traffic Counter #	Hwy #	Location	AADT (veh/day)	District Average
1	1	46	US-95	Copeland	1,181	2,651
2	1	114	US-2	Moyie Springs	1,134	
3	1	147	SH-57	Falls Inn	1,582	
4	1	26	SH-200	Kootenai	3,477	
5	1	47	US-2	Priest River	6,799	
6	1	112	SH-3	Santa	1,731	
7	2	45	SH-3	Bovill	426	2,607
8	2	126	US-95	North of Moscow	6,391	
9	2	15	US-95	Potlatch	3,061	
10	2	116	US-12	Lenore	3,292	
11	2	84	US-12	Powell	529	
12	2	49	US-95	Riggins	1,944	
13	3	244	SH-55	Packer Jhon	3,046	1,817
14	3	23	US-95	Council	1,598	
15	3	144	US-95	N. Weiser	3,289	
16	3	54	US-20	Mountain Home	1,811	
17	3	107	SH-78	Castle Creek	483	
18	3	83	SH-17	Garden Valley	673	
19	4	104	US-26	Gooding	1,390	2,463
20	4	28	SH-75	Ketchum	1,185	
21	4	14	SH-75	Shoshone	3,064	
22	4	105	US-30	Hansen	1,974	
23	4	91	US-30	Filer	4,704	
24	5	90	US-30	Georgetown	2,459	1,807
25	5	36	US-30	Border	1,154	
26	6	158	US-93	Gibbonsville	605	928
27	6	13	US-94	Salmon	2,441	
28	6	58	SH-28	Leadore	472	
29	6	82	SH-75	Clayton	580	
30	6	55	US-93	Dickey	542	
				Min	426	
				Max	6,799	
				Average AADT	2,101	
				ADDT used for Driver Simulator	**3,200**	
	AADT values highlighted in yellow are from year 2013					

Figure 47: Annual Average Daily Traffic (AADT)

Equation to Calculate the Directional Design Hourly Volume, DDHV (veh/hr):

Calculating the DDHV (veh/hr):

Table 10: Calculating Directional Design Hourly Volume (DDHV)

AADT (veh/day)	3200
k	0.1
D	0.5
DDHV (veh/hr)	160

Therefore, 160 veh/hr were placed on the oncoming lane.

Appendix B: Forms and Study Instructions

Craigslist Advertisement – Driving Study

uihumanfactors@gmail.com

pw: (same as lab computers)

University of Idaho IRB Approved

Participants needed IMMEDIATELY for Driving Simulator Study
3 hours across three 60 minute sessions over approximately 1 week

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

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

Please contact me ASAP if you are have any questions or are interested, and meet the requirements above.

The study pays $20 per hour and includes a $10 bonus for completing all three sessions (up to $70 total).

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

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

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

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

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

Your participation will require 3 sessions of approximately 60 minutes. You may withdraw from this study at any time without penalty. If you do wish to withdraw, simply inform the experimenter; you will receive full compensation for your time spent in the experiment up to that point. However, please be aware that your data will have the greatest scientific value if you complete the experiment in its entirety.

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

If you have further questions or issues please contact:

Dr. Brian P. Dyre
Department of Psychology and Communications Studies

University of Idaho
(208) 885-6927
bdyre@uidaho.edu

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

Participant Name ____
Date of Birth ______________________________________
Signature ____
Date ____
Experimenter Name____

Signature______________________________________

Date ____

Thank you for your participation.

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

UTC Study

Participant ID ________

Demographics

1. Age:_____, Gender:_______
2. Years of driving experience _________
    a. Types of vehicles______________
    b. Types of roadways (% of rural highways, towns, city, interstate)____________________________
3. Describe your real-life driving style (careful, defensive, passive, aggressive, NASCAR, downright mean, etc.)

    ____

    ____

Simulation

1. Did the simulation make you feel as if you were driving through a three-dimensional environment?

2. Did you notice anything unusual about the simulated environment?

    a. About the side line marking weathering?

   b. About the side line marking width?

3. Did these line markings affect your driving behavior?
   a. Speed?
   b. How you maintained your lane position?
   c. How you drove in general?
4. Did you notice the other vehicles in the simulation?
   a. Ahead of you?
   b. Behind you?
   c. Opposing Lane?
5. During the study what influenced your driving?
   a. Speed of vehicle in front of you?
   b. Number of cars traveling in the lane ahead of you?
   c. Amount of traffic in opposing lane?

d. The layout of the road?

e. The markings on the road?

f. Other?

(Encourage to elaborate as much as possible)

6. Please provide any additional comments you might have.

Appendix C: Debriefing Questions and Answers

Timestamp:	Participant Identification Number:	Participant Age:	Participant Sex:
1/16/2016 14:30	1	30	Male
1/7/2016 11:11	2	41	Female
1/11/2016 13:37	3	23	Male
1/12/2016 12:07	4	64	Male
1/15/2016 13:05	5	25	Male
1/12/2016 16:01	6	36	Male
3/4/2016 18:33	7	28	Female
4/9/2016 11:12	8	21	Male
1/12/2016 14:12	9	60	Male
1/18/2016 17:32	10	19	Female
2/23/2016 11:54	12	31	Male
2/20/2016 11:44	13	26	Male
2/23/2016 18:45	14	21	Female
2/27/2016 13:10	15	19	Female
3/1/2016 9:53	18	40	Male
3/9/2016 18:05	19	23	Male
3/6/2016 14:53	20	25	Male
3/10/2016 10:54	21	50	Male
3/10/2016 17:38	22	22	Female
3/23/2016 15:41	24	20	Female

Figure 48: Debriefing Information part 1

Participant Identification Number:	Years of Driving Experience:	Types of vehicles:
1	15	Cars and trucks
2	25	Cars and trucks
3	3	Truck, car, van, manual, automatic
4	48	Car and Trucks
5	9	Small to semi, everything
6	20	Commercial Vehicles, Cars, Trucks, Motorcycles
7	14	Car, trucks
8	5	Cars and trucks
9	45	Cars, Trucks, Box Trucks, Motorcycles
10	4	Trucks and cars
12	16	Cars, trucks, comercial
13	10	Sedan size, regular 4 door
14	6	Car
15	1	Truck, car
18	25	Vans cars suvs
19	7	Cars, trucks and motorcycles
20	3	Small cars to trucks and vans (12 seats).
21	34	Cars, trucks, firetruck
22	6	Suv Sadan
24	4	Cars

Figure 49: Debriefing information part 2

Participant Identification Number:	Types of Roadways:
1	25% rural, 50% town, 25% interstat
2	Mostly rural for the past 10 years, but a lot of city driving earlier in life.
3	No big city, a lot of town driving, a lot of rural highways
4	Mostly on Freeways and city, a lot of rural roadways
5	60 to 75 percent on rural highways. 25 percent on towns.
6	80% interstate, 15% rural, 5 City
7	70 percent rural, 20 percent in cites, and 10 percent in interstate.
8	50 percent highways, 25 percent city, and 25 percent town roads.
9	Mostly Town driving - 90%, 10 rural roads and highways
10	All of them
12	Mostly city, then some rural and interstate
13	Everything. 70 percent on rural highways, and 30 percent on more urban environments.
14	21 percent rural, cities 70 percent.
15	Mostly towns and rural highways
18	60 rural highways, 30 interstates, 10 backroads
19	60 percent rural highways, 30 percent cities, 10 percent interstate.
20	70 percent interstate and rural and drives everyday in town.
21	Town and rural 80%, 20% the rest
22	60% freeway, 40% town
24	60 percent cities, 20 percent highways, 10 percent interstate, and 10 percent towns.

Figure 50: Debriefing information part 3

Participant Identification Number:	Describe your real life driving style:	1. Did the simulation make you feel as if you were driving through a three-dimensional environment?
1	Defensive and passive	Yes
2	defensive	yes
3	Careful	yes
4	Defensive, Carful	yes
5	Aggressive	Yes, surprisinly
6	Defensive	Yes
7	Defensive	Yes
8	Passive	Yes
9	Passive	Yes
10	Agressive	Yes
12	Aggressive	Yes
13	Careful driver	Yes
14	Kinda aggressive,	Yes
15	Carful	Yes
18	Proactive	Yes
19	Passive	Yes
20	Careful	Yes
21	Defensive	Yes
22	Aggressve	Yes
24	Defensive	Yes

Figure 51: Debriefing information part 4

Participant Identification Number:	2. Did you notice anything unusual about the simulated environment?
1	Sprite trees, cars tail end enrorched on the lane. Repition of traffic
2	Not really, it all seemed pretty real
3	reweving of the engine, over time it felt as if I was going faster. Break pedal was stiff.
4	no, there was some repetition, participant noticed the LoD of the oncoming vehicles.
5	Not really. The steering wheel was almost too smooth.
6	No
7	The cars rpm goes high.
8	No
9	Occasional square corners on the trees
10	No
12	Small cosmetic issues like the barn and trees
13	No
14	No, but speed limit seemed slow.
15	No
18	No
19	No
20	He noticed that in the test drive the speed limit was 65mph and 60mph in the experiment. He also mentioned that in the curve segments he noticed more vehicles than on the other segments.
21	Repeated itself
22	Sometiems it seemed, as vehicles passed the simulator would lag a little
24	Not really.

Figure 52: Debriefing information part 5

Participant Identification Number:	2. a. About the side line marking weathering?
1	No
2	Sometimes it was bright, and sometimes it was faded
3	No
4	Some stretches of road where it was very bright and fresh and other times where it was rather dull-ish
5	No, seemed like a real road.
6	It was faded or spotted in some spots
7	No
8	No
9	No
10	No
12	No
13	No
14	Yes, noticed the deterioration.
15	In drive two ther was a small spot where the making was missing. On the turn with darker pavement the lines were more clear.
18	Sometiems the sides were dashed.
19	He noticed gaps in the side line marking but not weathering.
20	No
21	A couple of gaps
22	No
24	No

Figure 53: Debriefing information part 6

Participant Identification Number:	2. b. About the side line marking width?
1	No
2	No
3	no
4	No, occasionally looked like the shoulder was wider
5	Not really, but the brightness seemed a little faded.
6	It was more narrow than the yellow line
7	No
8	No
9	No
10	No
12	No
13	No
14	No
15	No
18	No
19	No
20	No
21	May have been a little more narrow today (was the 6" track today)
22	No
24	No

Figure 54: Debriefing information part 7

Participant Identification Number:	3. Did these line markings affect your driving behavior?
1	Yes, referenced the lines for maintaining lane position
2	I don't think so, I usually reference the center line
3	used them to try to stay between the lines
4	no
5	No
6	No
7	No
8	No
9	Yes, gave the driver perspective for staying centered in the lane
10	No
12	No
13	Yes
14	It did when she drove over the curve segments.
15	No
18	No
19	No. He followed the yellow.
20	No. They didnt affect his driving behavior, only the yellow markings did.
21	Used them to keep in center of lane
22	No
24	They helped her guide but didn't affect her in a negative way.

Figure 55: Debriefing information part 8

Participant Identification Number:	3. a. Your Speed?
1	No
2	No
3	no
4	Participant did not know, noted they went faster on the straight stretches
5	No
6	No
7	No
8	No
9	No
10	No, tried to maintain speed limit.
12	No
13	No.
14	At curve segments, they made her slow down.
15	No
18	No
19	No
20	Yes
21	No
22	On turns, it was more the gravel than the line though
24	No

Figure 56: Debriefing information part 9

Participant Identification Number:	3. b. How you maintained your lane position?
1	Yes, P used the lines for maintaining lane potition
2	I don't think so
3	Used the lines to maintain lane position
4	No
5	No
6	The side markings help
7	No
8	No
9	Yes
10	Maybe a little bit. Have tendency to follow the right side line markings.
12	No
13	Yes
14	Yes, made her slow down at the curves.
15	Yes, participant references lines for lane position.
18	No
19	Yes.
20	Yes
21	Yes
22	Yes, try to stay close without bing on the line. Used the yellow line more because it was easier.
24	Yes

Figure 57: Debriefing information part 10

Participant Identification Number:	3. c. How you drove in general?
1	Yes, maybe a little but, p was probably more cautious Whenthe yellow markings were no passing.
2	No
3	no
4	No
5	No, because the use of other objects of the surrounding environment.
6	No
7	No
8	No
9	Yes, they affected their sense of Spatial presence
10	No, not really.
12	No
13	No
14	No.
15	No
18	No
19	Slighty, because he used it to check his lane position.
20	Yes
21	Yes, making sure I was staying centered
22	No
24	The lines helped her to not go over the shoulder.

Figure 58: Debriefing information part 11

Participant Identification Number:	4. Did you notice the other vehicles in the simulation?	4. a. Ahead of you?
1	Yes	Yes
2	Yes	Yes
3	yes	yes
4	Yes	Yes
5	Yes	Yes
6	Yes	Yes
7	Yes	Yes
8	Yes	Yes
9	Yes	Yes
10	Yes	Yes
12	Yes	Yes
13	Yes	Yes
14	Yes	Yes
15	Yes	Yes
18	Yes	Yes
19	Yes	Yes
20	Yes	Yes
21	Yes	Yes
22	Yes	Yes
24	Yes	Yes

Figure 59: Debriefing information part 12

Participant Identification Number:	4. b. Behind you?	4. c. In the opposing lane?
1	Yes	Yes
2	Yes	Yes
3	yes	yes
4	Yes	Yes
5	Yes	Yes
6	Yes	Yes
7	Yes	Yes
8	Yes	Yes
9	Yes	Yes
10	Yes	Yes
12	Yes	Yes
13	Yes	Yes
14	Yes	Yes
15	Yes	Yes
18	Yes	Yes
19	Yes	Yes
20	Yes	Yes
21	Yes	Yes
22	Yes	Yes
24	Yes	Yes

Figure 60: Debriefing information part 13

Participant Identification Number:	5. During the study, what influenced your driving?
1	Vehicles in the other lane tended to be given more space.
2	Trying to obey the rules as per the instructions, probably better than I do in real life.
3	Nothing out of the ordinary
4	If the participant was on a curve and there was an oncoming vehicle crowding the center line, they would go closer to the shoulder. Participant noted that board may have influence their driving.
5	None
6	The speed limit
7	She knew it was a simulation and she wasn't going to get hurt.
8	The change in roadway geometries, like driving on straight segments and then switching onto curve segments. Would slow down when going from straight to curve segments.
9	Trying to stay aware of the speed, trying to be conscious of the steering being touchy.
10	The turns would make her slow down.
12	Mainly trying to maintain speed
13	The police car. Would slow down because of presence of police vehicle even if driving at speed limit. Another thing, not having music or entertained because he gets boring. On a 3d simulator environment is easy to loose your concentration and not pay attention. Found to be speeding more. Every car hes driven his always had the cruise control mechanism.
14	The speed limit sign, and police cars.
15	Confort with the handling the streaming. As well as corners.
18	Mostly the controls of the simulator.
19	The curvy nature of the road, and on stretched segments he drove above the speed limit.
20	Reducing his speed in curve segments. The white line made him reduce his speed at the curve segments.
21	Getting used to the simulator. Got board
22	The speed limit, the other vehicles, and the gravel.
24	The curve segments. The oncoming vehicles.

Figure 61: Debriefing information part 14

Participant Identification Number:	5. a. Speed of the vehicle in front of you?
1	P wanted to try to pass them, but did not want to speed to do it.
2	No
3	no
4	No
5	Yes, participant wanted to catch up to it.
6	No
7	No. She mentioned the vehicle in front kept a distance.
8	No
9	No
10	No, thinks the vehicle ahead of her was maintaining the same speed.
12	No
13	During the first drive it did. Normally try to never have vehicles in front. Then realized it was part of the simulation. On the other sessions he pretended they were not there.
14	No.
15	No
18	No
19	No
20	No.
21	No
22	Yes, sometimes try to catch up to it.
24	No.

Figure 62: Debriefing information part 15

Participant Identification Number:	5. b. Number of cars traveling in the lane ahead of you?
1	No
2	No
3	a little, participant uses other vehicles as a reference for speed. The other vehicle ahead made speed more variable as it was to far away to reference
4	No
5	Noticed one vehicle.
6	No
7	No.
8	No
9	No
10	Noticed 1 vehicle ahead
12	No
13	Didn't influenced him at all.
14	No. She got nervous when you were turning and there were cars in the other lane.
15	No
18	No
19	No.
20	No.
21	No
22	No
24	No.

Figure 63: Debriefing information part 16

Participant Identification Number:	5. c. The amount of traffic in the opposing lane?
1	Yes, was more careful to give them room on turns
2	No
3	Stayed in lane more when traffic was present
4	No
5	It didn't affect his speed but affected his lane position.
6	No
7	No.
8	Yes
9	Yes, being conscious of how far away they were from the center lines, drive stayed away from them toward the shoulder when there was oncoming traffic.
10	The more vehicles experienced, the more she wanted to slow down.
12	No
13	When there would be 2 or more cars or if it was a curve segment, he would slow down.
14	No.
15	Sometimes, if there were more cars, the participant could reference them for good lane position.
18	No
19	Sometimes. Specially on curve segments.
20	Yes, only when he faced the semi trucks. He would move more to the edge at these situations.
21	Only when it came close to the center line
22	No
24	Yes. Helped her stay more focused, specially on curve segments.

Figure 64: Debriefing information part 17

Participant Identification Number:	5. d. The layout of the road?
1	Yes, slowed down for turns
2	Yeah, probably, I slowed down on the curves
3	no
4	Participant thinks the straight stretches let the participant go fast, and they were more careful on curves.
5	No, because it was pretty common as normaly drive.
6	No, maintained the same speed throughout, the turns were not very tight
7	Yes
8	Yes
9	Yes, participant relaxed more in the straight stretch, and focused more on the turns.
10	Yes, the turns affected it.
12	No
13	Yes. When it was straight segment he would go faster, but slow down at curves.
14	Yes, there were lots of curves.
15	No
18	Yes, was more careful on the curves.
19	Yes.
20	Yes, whenever he faced a big vehicle he felt like there is not much space in the lane. But didn't affect him when he faced the other cars. Both in straight and curved segments.
21	Sowed down before turns
22	No
24	Yes, only curve segments.

Figure 65: Debriefing information part 18

Participant Identification Number:	5. e. The markings on the road?
1	Maybe a little
2	No
3	no
4	No
5	No, pretty normal.
6	No
7	No
8	No
9	No
10	No
12	No
13	Yes
14	No.
15	They were Helpful, but the particant tend to also reference the vehicle ahead of them.
18	No
19	Yes.
20	Yes
21	Ys, sometimes slowed down when thy could see lines turning in the distance
22	No
24	Yes.

Figure 66: Debriefing information part 19

Participant Identification Number:	5. f. Other?
1	No
2	No, I just drove
3	How far participant could see down the road. When participant could see further, they said they were more variable in their lane position.
4	In the 1st and second drives, brightly colored cars would make the participant move further to the shoulder. Specifically the yellow and red vehicles.
5	No, was realistic.
6	No
7	The rpm sometimes affected her driving.
8	The change in road material from concrete to pavement in some sections, would make the participant slow down sometimes.
9	No
10	No. On straight roads she wanted to go faster when no many vehicles on opposite lane.
12	No
13	Nope
14	Speed limits, police cars, and turns affected your driving.
15	When the road was darker it was easier to drive. There was a green car which was distracting. Sometimes she could see patterns in the textures.
18	No
19	No.
20	The information signs in the curve segments were really close to the curve.
21	No
22	The different colors of pavement, the lighter color was calming.
24	No.

Figure 67: Debriefing information part 20

Participant Identification Number:	6. Please provide any additional comments you might have.
1	P readjusted morrow, may have swerved a little a couple of times.
2	No one ever pulled off in front of me.
3	no
4	No
5	None.
6	Transmission seemed to slip to neutral for a split second from time to time.
7	No.
8	The participant noticed that the tachometer would jump in rpms randomly.
9	Participant never had the opportunity to pass the vehicle in front of them.
10	None.
12	No
13	Consider allowing external things. Like having radio, cruise control mechanism. Majority people have that and use it.
14	No. But She said she went above 5 more mph than the speed limit on stretch segments.
15	It was fun! Thearticipant learned more about how they drove in real life!
18	No
19	No.
20	No.
21	The study was interesting
22	No
24	No.

Figure 68: Debriefing information part 21

Appendix D: Lane Deviation Results

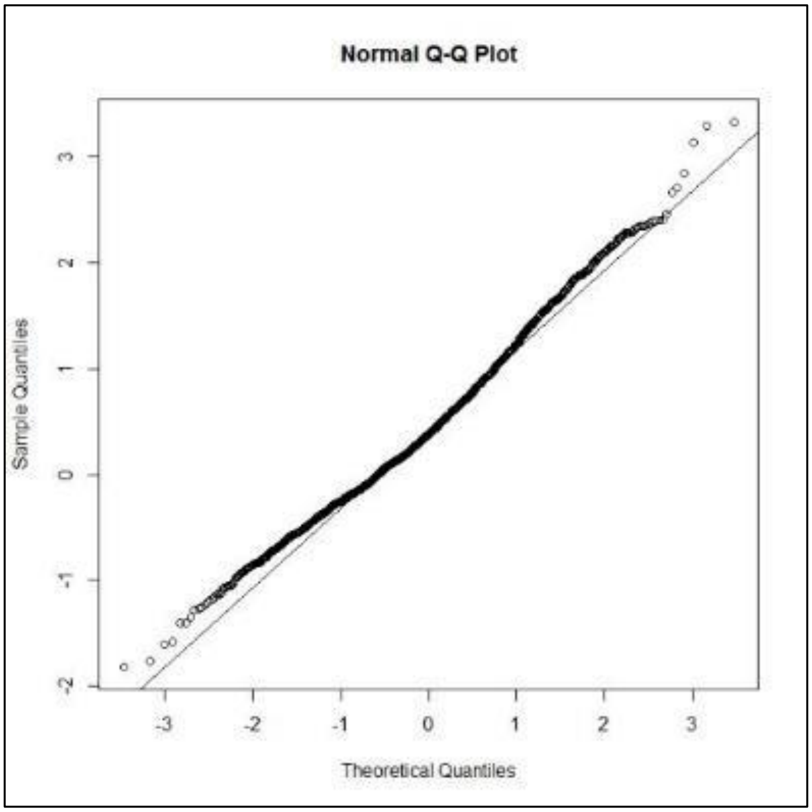

Figure 69: Lane deviation - normality assumption met

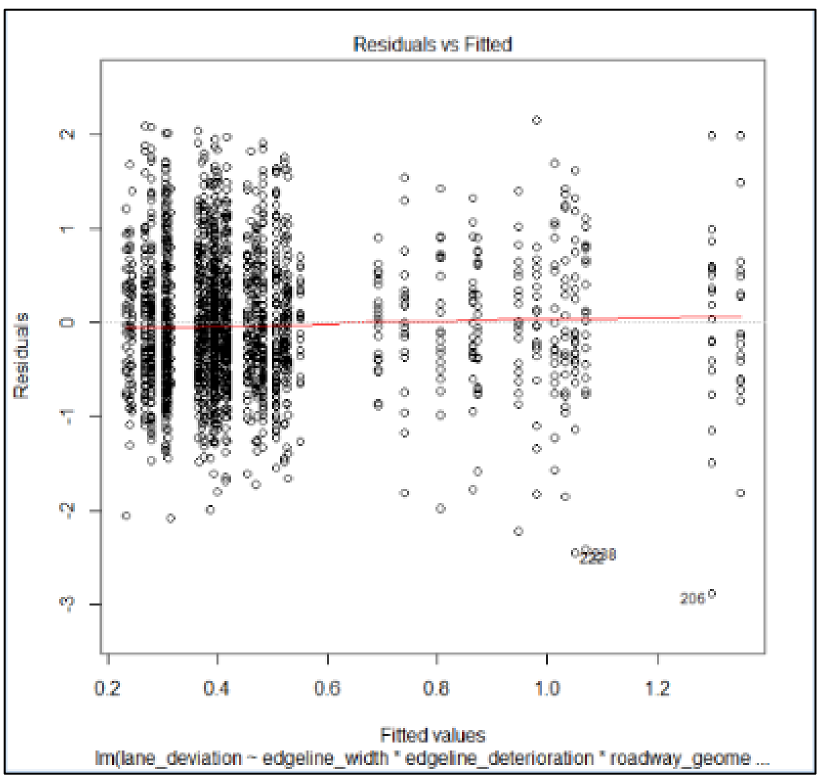

Figure 70: Lane deviation - homogeneity of variances met

Lane Deviation Based on Standard Deviation Values:

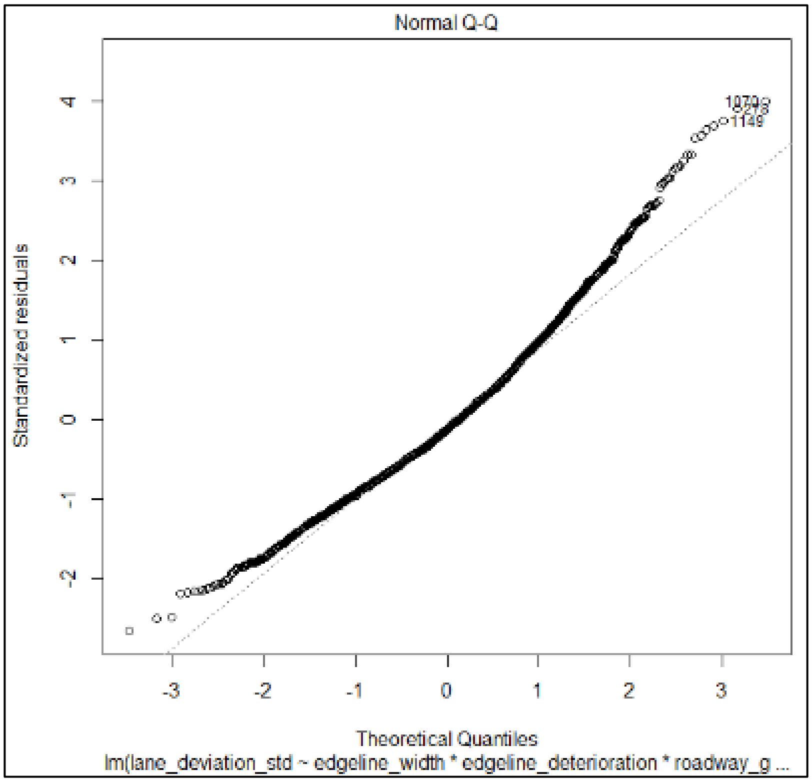

Figure 71: Lane deviation (standard deviation) - normality assumption met

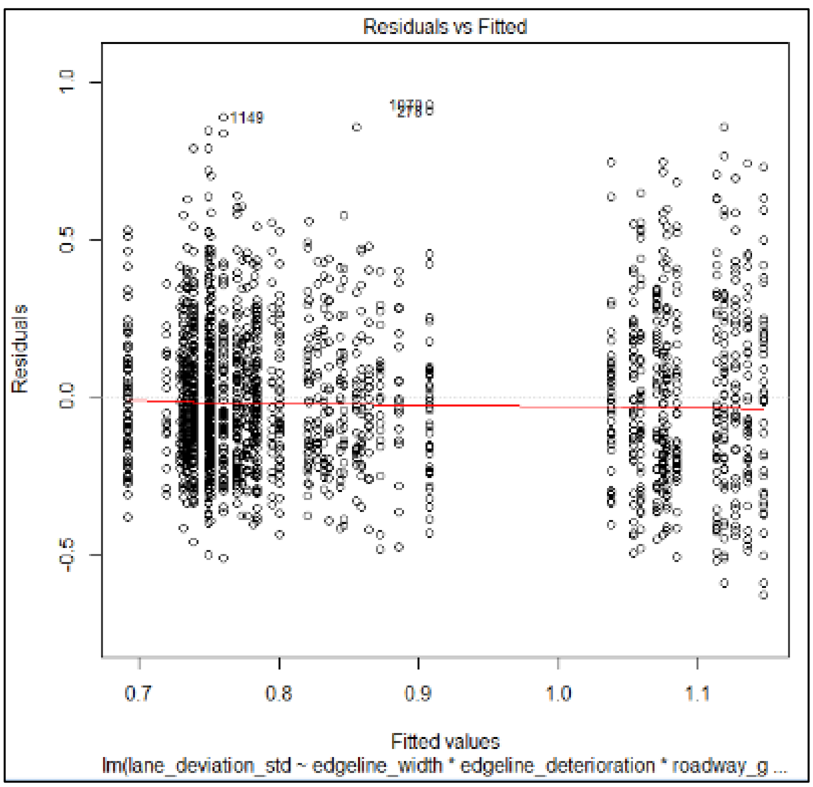

Figure 72: Lane deviation (standard deviation) - homogeneity of variances met

ANOVA between Edgelines Based on Lane Deviation:

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 0% deterioration	160	71.27999666	0.445499979	0.569849306		
4" edgeline with 25% deterioraton	160	63.55372208	0.397210763	0.53583222		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.186547872	1	0.186547872	0.337435088	0.561724944	3.870867167
Within Groups	175.8033626	318	0.552840763			
Total	175.9899105	319				

Figure 73: Lane deviation - ANOVA 2-in 0% deterioration vs 4-in 25% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 0% deterioration	160	71.27999666	0.445499979	0.569849306		
4" edgeline with 50% deterioration	160	69.19929342	0.432495584	0.54447382		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.013529144	1	0.013529144	0.024282263	0.87626773	3.870867167
Within Groups	177.177377	318	0.557161563			
Total	177.1909062	319				

Figure 74: Lane deviation - ANOVA 2-in 0% deterioration vs 4-in 50% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 25% deterioration	160	71.80482116	0.448780132	0.476088159		
4" edgeline with 50% deterioration	160	69.19929342	0.432495584	0.54447382		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.021214921	1	0.021214921	0.041574979	0.838562512	3.870867167
Within Groups	162.2693547	318	0.51028099			
Total	162.2905696	319				

Figure 75: Lane deviation - ANOVA 2-in 25% deterioration vs 4-in 50% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	Count	Sum	Average	Variance		
2" edgeline with 0% deterioration	160	71.27999666	0.445499979	0.569849306		
4" edgeline with 75% deterioration	160	91.79891582	0.573743224	0.566004352		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.315706385	1	1.315706385	2.316682921	0.128986449	3.870867167
Within Groups	180.6007316	318	0.567926829			
Total	181.916438	319				

Figure 76: Lane deviation - ANOVA 2-in 0% deterioration vs 4-in 75% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	Count	Sum	Average	Variance		
2" edgeline with 25% deterioration	160	71.80482116	0.448780132	0.476088159		
4" edgeline with 75% deterioration	160	91.79891582	0.573743224	0.566004352		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.249261941	1	1.249261941	2.39760276	0.122515942	3.870867167
Within Groups	165.6927093	318	0.521046256			
Total	166.9419712	319				

Figure 77: Lane deviation - ANOVA 2-in 25% deterioration vs 4-in 75% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	Count	Sum	Average	Variance		
2" edgeline with 50% deterioration	160	76.90023997	0.4806265	0.529728817		
4" edgeline with 75% deterioration	160	91.79891582	0.573743224	0.566004352		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.693657944	1	0.693657944	1.266107414	0.261346741	3.870867167
Within Groups	174.2215738	318	0.547866584			
Total	174.9152318	319				

Figure 78: Lane deviation - ANOVA 2-in 50% deterioration vs 4-in 75% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 0% deterioration	160	71.27999666	0.445499979	0.569849306		
6" edgeline with 25% deterioration	160	50.8181877	0.317613673	0.504839261		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.308392581	1	1.308392581	2.434924163	0.119654244	3.870867167
Within Groups	170.8754822	318	0.537344284			
Total	172.1838748	319				

Figure 79: Lane deviation - ANOVA 2-in 0% deterioration vs 6-in 25% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 0% deterioration	160	71.27999666	0.445499979	0.569849306		
6" edgeline with 50% deterioration	160	80.09552856	0.500597053	0.52898814		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.242855008	1	0.242855008	0.442021718	0.50663012	3.870867167
Within Groups	174.7151539	318	0.549418723			
Total	174.9580089	319				

Figure 80: Lane deviation - ANOVA 2-in 0% deterioration vs 6-in 50% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 25% deterioration	160	71.80482116	0.448780132	0.476088159		
6" edgeline with 50% deterioration	160	80.09552856	0.500597053	0.52898814		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.214799466	1	0.214799466	0.427429173	0.513725591	3.870867167
Within Groups	159.8071316	318	0.50253815			
Total	160.0219311	319				

Figure 81: Lane deviation - ANOVA 2-in 25% deterioration vs 6-in 50% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 0% deterioration	160	71.27999666	0.445499979	0.569849306		
6" edgeline with 75% deterioration	160	90.81493841	0.567593365	0.658674722		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.192543592	1	1.192543592	1.941424936	0.164487015	3.870867167
Within Groups	195.3353205	318	0.614262014			
Total	196.5278641	319				

Figure 82: Lane deviation - ANOVA 2-in 0% deterioration vs 6-in 75% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 25% deterioration	160	71.80482116	0.448780132	0.476088159		
6" edgeline with 75% deterioration	160	90.81493841	0.567593365	0.658674722		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.129326743	1	1.129326743	1.9904189	0.159274591	3.870867167
Within Groups	180.4272982	318	0.567381441			
Total	181.5566249	319				

Figure 83: Lane deviation - ANOVA 2-in 25% deterioration vs 6-in 75% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 50% deterioration	160	76.90023997	0.4806265	0.529728817		
6" edgeline with 75% deterioration	160	90.81493841	0.567593365	0.658674722		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.605058853	1	0.605058853	1.018271711	0.31369651	3.870867167
Within Groups	188.9561627	318	0.59420177			
Total	189.5612216	319				

Figure 84: Lane deviation - ANOVA 2-in 50% deterioration vs 6-in 75% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 25% deterioration	160	50.8181877	0.317613673	0.504839261		
4" edgeline with 0% deterioration	160	62.94792099	0.393424506	0.563401593		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.459782593	1	0.459782593	0.86082196	0.354212438	3.870867167
Within Groups	169.8502958	318	0.534120427			
Total	170.3100784	319				

Figure 85: Lane deviation - ANOVA 6-in 25% deterioration vs 4-in 0% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 50% deterioration	160	80.09552856	0.500597053	0.52898814		
4" edgeline with 0% deterioration	160	62.94792099	0.393424506	0.563401593		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.918876391	1	0.918876391	1.682323375	0.195556275	3.870867167
Within Groups	173.6899675	318	0.546194866			
Total	174.6088439	319				

Figure 86: Lane deviation - ANOVA 6-in 50% deterioration vs 4-in 0% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 50% deterioration	160	80.09552856	0.500597053	0.52898814		
4" edgeline with 25% deterioration	160	63.55372208	0.397210763	0.53583222		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.855098005	1	0.855098005	1.606088759	0.205969742	3.870867167
Within Groups	169.3064372	318	0.53241018			
Total	170.1615352	319				

Figure 87: Lane deviation - ANOVA 6-in 50% deterioration vs 4-in 25% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 75% deterioration	160	90.81493841	0.567593365	0.658674722		
4" edgeline with 0% deterioration	160	62.94792099	0.393424506	0.563401593		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.426783312	1	2.426783312	3.971574086	0.047128834	3.870867167
Within Groups	194.3101341	318	0.611038158			
Total	196.7369174	319				

Figure 88: Lane deviation - ANOVA 6-in 75% deterioration vs 4-in 0% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 75% deterioration	160	90.81493841	0.567593365	0.658674722		
4" edgeline with 25% deterioration	160	63.55372208	0.397210763	0.53583222		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.322418488	1	2.322418488	3.888497264	0.049484261	3.870867167
Within Groups	189.9266038	318	0.597253471			
Total	192.2490223	319				

Figure 89: Lane deviation - ANOVA 6-in 75% deterioration vs 4-in 25% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 75% deterioration	160	90.81493841	0.567593365	0.658674722		
4" edgeline with 50% deterioration	160	69.19929342	0.432495584	0.54447382		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.460112839	1	1.460112839	2.42715307	0.120243924	3.870867167
Within Groups	191.3006182	318	0.601574271			
Total	192.760731	319				

Figure 90: Lane deviation - ANOVA 6-in 75% deterioration vs 4-in 50% deterioration

Appendix E: Vehicle Speed Results

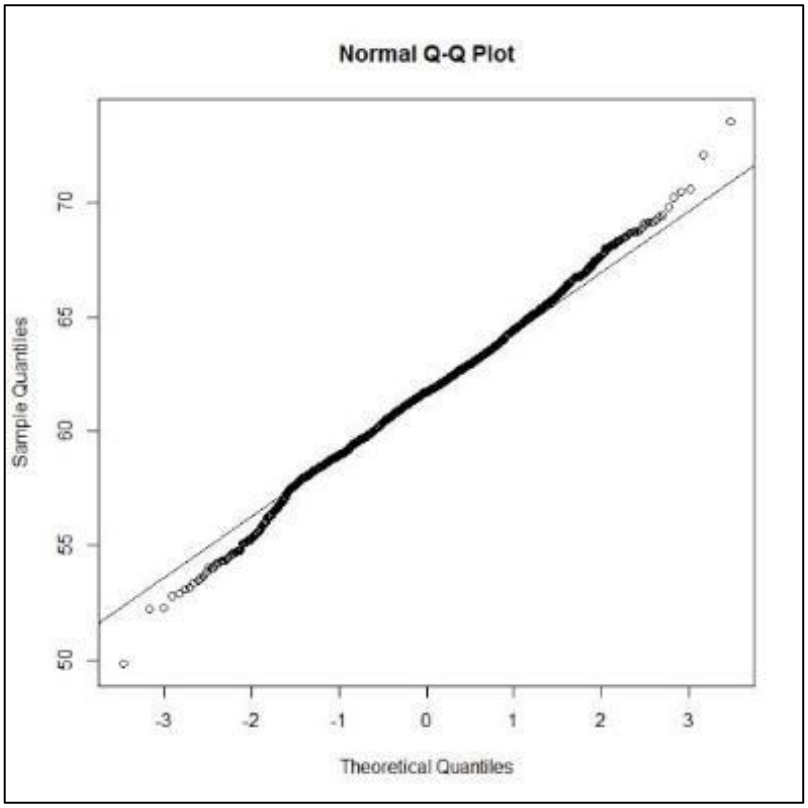

Figure 91: Vehicle speed - normality assumption met

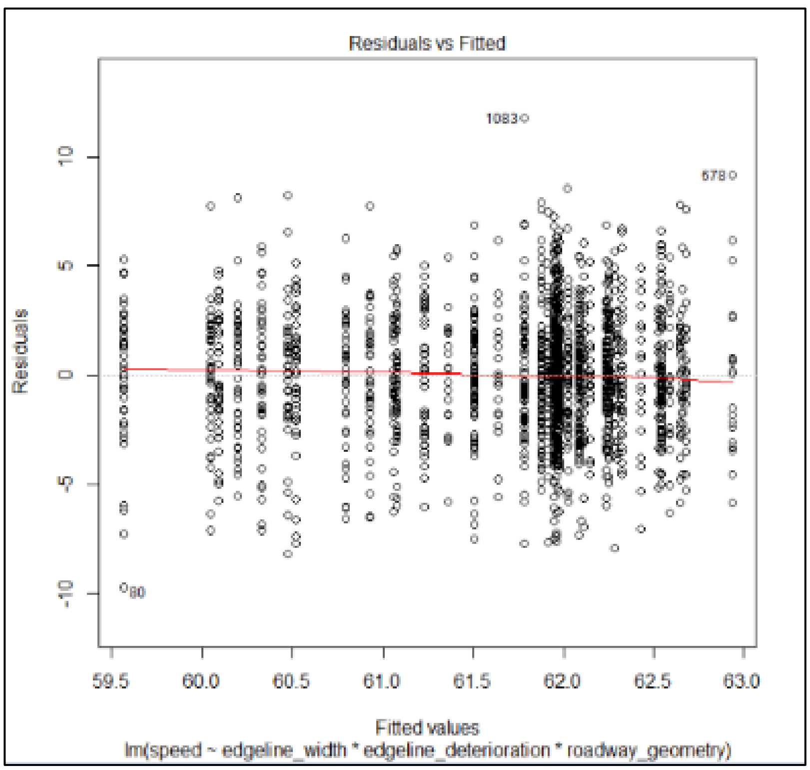

Figure 92: Vehicle speed - homogeneity of variances met

ANOVA between Edgelines Based on Vehicle Speed:

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	Count	Sum	Average	Variance		
2" edgeline with 0% deterioration	160	9933.325433	62.08328396	7.518239537		
4" edgeline with 25% deterioraton	160	9830.838229	61.44273893	7.428249435		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	32.82383474	1	32.82383474	4.392179969	0.03689442	3.870867167
Within Groups	2376.491747	318	7.473244486			
Total	2409.315581	319				

Figure 93: Vehicle speed - ANOVA 2-in 0% deterioration vs 4-in 25% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	Count	Sum	Average	Variance		
2" edgeline with 0% deterioration	160	9933.325433	62.08328396	7.518239537		
4" edgeline with 50% deterioration	160	9832.104251	61.45065157	9.048933797		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	32.01789899	1	32.01789899	3.865221706	0.050166352	3.870867167
Within Groups	2634.18056	318	8.283586667			
Total	2666.198459	319				

Figure 94: Vehicle speed - ANOVA 2-in 0% deterioration vs 4-in 50% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	Count	Sum	Average	Variance		
2" edgeline with 25% deterioration	160	9890.515735	61.81572335	6.333164488		
4" edgeline with 50% deterioration	160	9832.104251	61.45065157	9.048933797		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	10.66219204	1	10.66219204	1.386311782	0.2399094	3.870867167
Within Groups	2445.753627	318	7.691049143			
Total	2456.415819	319				

Figure 95: Vehicle speed - ANOVA 2-in 25% deterioration vs 4-in 50% deterioration

Anova: Single Factor						
SUMMARY (vehicle Speed)						
Groups	Count	Sum	Average	Variance		
2" edgeline with 0% deterioration	160	9933.325433	62.08328396	7.518239537		
4" edgeline with 75% deterioration	160	9899.6636	61.8728975	7.866569345		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.540996883	1	3.540996883	0.460323805	0.497966108	3.870867167
Within Groups	2446.184612	318	7.692404441			
Total	2449.725609	319				

Figure 96: Vehicle speed - ANOVA 2-in 0% deterioration vs 4-in 75% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	Count	Sum	Average	Variance		
2" edgeline with 25% deterioration	160	9890.515735	61.81572335	6.333164488		
4" edgeline with 75% deterioration	160	9899.6636	61.8728975	7.866569345		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.261510732	1	0.261510732	0.036833188	0.847927564	3.870867167
Within Groups	2257.757679	318	7.099866917			
Total	2258.01919	319				

Figure 97: Vehicle speed - ANOVA 2-in 25% deterioration vs 4-in 75% deterioration

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
2" edgeline with 50% deterioration	160	9856.800909	61.60500568	7.004629735		
4" edgeline with 75% deterioration	160	9899.6636	61.8728975	7.866569345		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.741282159	1	5.741282159	0.772134396	0.380221035	3.870867167
Within Groups	2364.520654	318	7.43559954			
Total	2370.261936	319				

Figure 98: Vehicle speed - ANOVA 2-in 50% deterioration vs 4-in 75% deterioration

Anova: Single Factor						
SUMMARY (Lane Deviation)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 0% deterioration	160	9933.325433	62.08328396	7.518239537		
6" edgeline with 25% deterioration	160	9783.360457	61.14600285	8.705490676		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	70.27966933	1	70.27966933	8.663811392	0.003484787	3.870867167
Within Groups	2579.573104	318	8.111865107			
Total	2649.852773	319				

Figure 99: Vehicle speed - ANOVA 2-in 0% deterioration vs 6-in 25% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 0% deterioration	160	9933.325433	62.08328396	7.518239537		
6" edgeline with 50% deterioration	160	9821.200951	61.38250594	9.22565906		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	39.28718636	1	39.28718636	4.692716709	0.031033318	3.870867167
Within Groups	2662.279877	318	8.371949299			
Total	2701.567063	319				

Figure 100: Vehicle speed - ANOVA 2-in 0% deterioration vs 6-in 50% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 25% deterioration	160	9890.515735	61.81572335	6.333164488		
6" edgeline with 50% deterioration	160	9821.200951	61.38250594	9.22565906		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	15.01418557	1	15.01418557	1.929989825	0.165731568	3.870867167
Within Groups	2473.852944	318	7.779411774			
Total	2488.86713	319				

Figure 101: Vehicle speed - ANOVA 2-in 25% deterioration vs 6-in 50% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 0% deterioration	160	9933.325433	62.08328396	7.518239537		
6" edgeline with 75% deterioration	160	9852.535921	61.5783495	10.02987182		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	20.3967043	1	20.3967043	2.324660914	0.128331843	3.870867167
Within Groups	2790.149706	318	8.77405568			
Total	2810.54641	319				

Figure 102: Vehicle speed - ANOVA 2-in 0% deterioration vs 6-in 75% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 25% deterioration	160	9890.515735	61.81572335	6.333164488		
6" edgeline with 75% deterioration	160	9852.535921	61.5783495	10.02987182		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.507707275	1	4.507707275	0.550962204	0.458472708	3.870867167
Within Groups	2601.722773	318	8.181518155			
Total	2606.230481	319				

Figure 103: Vehicle speed - ANOVA 2-in 25% deterioration vs 6-in 75% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
2" edgeline with 50% deterioration	160	9856.800909	61.60500568	7.004629735		
6" edgeline with 75% deterioration	160	9852.535921	61.5783495	10.02987182		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.05684415	1	0.05684415	0.006674002	0.934940994	3.870867167
Within Groups	2708.485748	318	8.517250779			
Total	2708.542592	319				

Figure 104: Vehicle speed - ANOVA 2-in 50% deterioration vs 6-in 75% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 25% deterioration	160	9783.360457	61.14600285	8.705490676		
4" edgeline with 0% deterioration	160	9910.257948	61.93911218	7.668829523		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	50.32179184	1	50.32179184	6.146428215	0.013685758	3.870867167
Within Groups	2603.516912	318	8.1871601			
Total	2653.838703	319				

Figure 105: Vehicle speed - ANOVA 6-in 25% deterioration vs 4-in 0% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 50% deterioration	160	9821.200951	61.38250594	9.22565906		
4" edgeline with 0% deterioration	160	9910.257948	61.93911218	7.668829523		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	24.78484023	1	24.78484023	2.934074046	0.087703081	3.870867167
Within Groups	2686.223685	318	8.447244291			
Total	2711.008525	319				

Figure 106: Vehicle speed - ANOVA 6-in 50% deterioration vs 4-in 0% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 50% deterioration	160	9821.200951	61.38250594	9.22565906		
4" edgeline with 25% deterioration	160	9830.838229	61.44273893	7.428249435		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.29024103	1	0.29024103	0.034855605	0.852017603	3.870867167
Within Groups	2647.971451	318	8.326954247			
Total	2648.261692	319				

Figure 107: Vehicle speed - ANOVA 6-in 50% deterioration vs 4-in 25% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 75% deterioration	160	9852.535921	61.5783495	10.02987182		
4" edgeline with 0% deterioration	160	9910.257948	61.93911218	7.668829523		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10.41197658	1	10.41197658	1.176580855	0.278874821	3.870867167
Within Groups	2814.093514	318	8.849350672			
Total	2824.50549	319				

Figure 108: Vehicle speed - ANOVA 6-in 75% deterioration vs 4-in 0% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 75% deterioration	160	9852.535921	61.5783495	10.02987182		
4" edgeline with 25% deterioration	160	9830.838229	61.44273893	7.428249435		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.471218226	1	1.471218226	0.16854256	0.681686818	3.870867167
Within Groups	2775.84128	318	8.729060629			
Total	2777.312498	319				

Figure 109: Vehicle speed - ANOVA 6-in 75% deterioration vs 4-in 25% deterioration

Anova: Single Factor						
SUMMARY (Vehicle Speed)						
Groups	*Count*	*Sum*	*Average*	*Variance*		
6" edgeline with 75% deterioration	160	9852.535921	61.5783495	10.02987182		
4" edgeline with 50% deterioration	160	9832.104251	61.45065157	9.048933797		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.304540954	1	1.304540954	0.136752895	0.711776804	3.870867167
Within Groups	3033.530093	318	9.53940281			
Total	3034.834634	319				

Figure 110: Vehicle speed - ANOVA 6-in 75% deterioration vs 4-in 50% deterioration