01 Feb 2017

Work Zone Simulator Analysis: Driver Performance and Acceptance of Missouri Alternate Lane Shift Configurations

Suzanna Long
Missouri University of Science and Technology, longsuz@mst.edu

Ruwen Qin
Missouri University of Science and Technology, qinr@mst.edu

Dincer Konur
Missouri University of Science and Technology, konurd@mst.edu

Ming-Chuan Leu
Missouri University of Science and Technology, mleu@mst.edu

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/engman_syseng_facwork/528

Work Zone Simulator Analysis: Driver Performance and Acceptance of Missouri Alternate Lane Shift Configurations

Prepared by
Suzanna Long, Ph.D., Principal Investigator
Missouri University of Science and Technology

Final Report Prepared for Missouri Department of Transportation
February 2017 Project TR201612 Report cmr17-002

Disclaimer

The contents of this report reflect the opinion and findings of the author(s), who are responsible for the facts and the accuracy of information presented herein. This document is disseminated under the sponsorship of the Missouri Department of Transportation, University Intelligent System Center and Engineering Management and System Engineering at the Missouri University of Science and Technology, in the interest of information exchange.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. cmr 17-002	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Work Zone Simulator Analysis: Driver Performance and Acceptance of Missouri Alternate Lane Shift Configurations		**5. Report Date** January 13, 2017 Published: February 2017 **6. Performing Organization Code**
7. Author(s) S.K. Long http://orcid.org/0000-0001-6589-5528, R. Qin, D. Konur, M. Leu, S. Moradpour, S. Thind, H. Nadathur		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Missouri University of Science and Technology Department of Engineering Management and Systems Engineering Rolla, MO 65409		**10. Work Unit No.** **11. Contract or Grant No.** MoDOT Project #TR201612
12. Sponsoring Agency Name and Address Missouri Department of Transportation (SPR) Construction and Materials Division P.O. Box 270 Jefferson City, MO 65102		**13. Type of Report and Period Covered** Final Report (May 2015-January 2017) **14. Sponsoring Agency Code**

15. Supplementary Notes

The investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration. MoDOT research reports are available in the Innovation Library at https://www.modot.org/services/or/byDate.htm. This report is available at https://library.modot.mo.gov/RDT/reports/TR201612/.

16. Abstract

The objective of this project is to evaluate MoDOT's alternate lane shift sign configuration for work zones. The single sign proposed by MoDOT provides the traveler with enough information to let them know that all lanes are available to shift around the work zone, whereas the MUTCD signs require drivers to see two signs. This research simulation project evaluates the drivers' lane shifting performance and acceptance of the alternate lane shift sign proposed by MoDOT to be used on work zones as compared to the MUTCD lane shift signs. Based on the study results, no difference was observed between MUTCD lane shift sign and MoDOT lane shift sign lane shift patterns with respect to driving patterns. In summary, statistical data analysis clearly demonstrated that there was not a noticeable, statistical difference between lane change patterns of drivers in the MoDOT alternate signs with MUTCD signs in the work zone.

17. Key Words Driving simulators; Merging traffic; Statistical analysis; Work zone safety; Work zone traffic control. Work Zone Configuration, Alternate Lane Shift, Travel Path		**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified.	**20. Security Classif. (of this page)** Unclassified.	**21. No. of Pages** 70	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Executive Summary

The objective of this project is to evaluate MoDOT's alternate lane shift sign configuration for work zones. Drivers completed the following two driving simulation scenarios:

- Scenario 1: Federal Highway Administration (FHWA) approved merge sign configurations, i.e., MUTCD lane shift signs (see Figure 1),
- Scenario 2: Alternate merge sign configuration proposed by Missouri Department of Transportation (MoDOT) for multiple lane shifts (see Figure 2).

The single sign proposed by MoDOT provides the traveler with enough information to let them know that all lanes are available to shift around the work zone, whereas the MUTCD signs require drivers to see two signs. This research simulation project evaluates the drivers' lane shifting performance and acceptance of the alternate lane shift sign proposed by MoDOT to be used on work zones as compared to the MUTCD lane shift signs.

Figure 1. MUTCD lane shift sign

Figure 2. Missouri alternate lane shift sign

Based on the study results, no difference was observed between MUTCD lane shift sign and MoDOT lane shift sign lane shift patterns with respect to driving patterns. In summary, statistical data analysis clearly demonstrated that there was not a noticeable, statistical difference between lane change patterns of drivers in the MoDOT alternate signs with MUTCD signs in the work zone. Gender did have an impact on average speed. Female drivers had a lower average speed than males. The average speed of drivers in MoDOT scenario is less than MUTCD scenario but this difference is not statistically significant. In reviewing the post-simulator questionnaire responses, more drivers were more satisfied with the MoDOT sign configuration than the MUTCD sign configuration and found it more intuitive. Because driver preference is anecdotal rather than statistical, an expanded study might prove useful in refining results and better determining driver preferences and performance.

Contents

List of Tables

List of Figures

ABBREVIATION LIST

MoDOT - Missouri Department of Transportation

DOT - Departments of Transportation

FHWA - Federal Highway Administration

MUTCD - Manual on Uniform Traffic Control Devices

TTC - Temporary Traffic Control

CLM - Conventional Lane Merge

JLM - Joint Lane Merge

RCB - Randomized Complete Block

ANOVA - Analysis of Variance

1. Literature Review

Due to the aging of transportation infrastructure, work zones are necessary to maintain, rebuild, and rehabilitate the roadways. In work zones, usually one or more lanes are closed, so the capacity of roadways decreases. In addition, in work zones drivers should merge to open lanes, and this merging can be dangerous. These reasons increase the rate of accidents in work zones as compared to normal roads. Many researchers and Department of Transportations (DOT) investigate how to increase safety in work zones. Traffic signs play a significant role for driving safely through work zones as these signs convey the road conditions, lane closures, and traffic requirements along the work zones to the drivers. Some DOTs propose new temporary traffic control signs (TTC) that inform drivers approaching a work zone. Evaluation of new signs is necessary before using new signs in roadways. A summary of related studies from the literature follows.

Edara et al. (2013) evaluated the effects of using an alternative merge sign configuration within a freeway work zone. The graphical lane closed sign from the Manual on Uniform Traffic Control Devices (MUTCD) was compared with a MERGE/arrow sign on one side and a RIGHT LANE CLOSED sign on the other side. They measured driver behavior characteristics, including speed and open lane occupancy. They found that the open lane occupancy was higher upstream for the alternate sign. Occupancy values were similar for both configurations leading to a taper. The alternate sign seemed an acceptable option with respect to safety statistics as well.

Long et al. (2016) evaluated the Conventional Lane Merge (CLM) configurations against Missouri Department of Transportation (MoDOT) alternate configurations. Based on the data analysis, the researchers did not observe a noticeable statistical difference between the MoDOT alternate signs and MUTCD signs in work zones. As expected, the results showed that age had a significant effect on travel time. An increase in the age of the participant, increased the travel time. Similarly, the data showed a significant effect on travel time due to gender. The female travel time tended to be more than male drivers.

Aghazadeh et al. (2013) had a simulation based study to explore the influences of different work zone configurations on a driver behavior. The CLM and the Joint Lane Merge (JLM) were simulated in three different conditions: a) standard sign distance, b) a 25% reduction, and c) a

25% increase in the distance between traffic signs in the advance warning zone. Based on the research no significant differences were found in drivers' speed between the two signs.

According to Tasca (2000), there are two types of driving behavior researches, where one is surveys, to get estimates of self-reported driving behaviors; and other type is field experiments, to evaluate drivers' aggressive behaviors. The aggressive behavior defined by Tasca (2000) doesn't include the intention of a driver to harm anyone, it includes impatience, hostility or attempt to save time of a driver. According to the definition of aggressive behavior by American Automobile Association, aggressive driving behavior is an operation of a motor vehicle without caring about the safety of other people. The American Automobile Association's definition also doesn't include road rage behavior, which is defined as assault with the intentions of doing harm to anyone by using a motor vehicle (Goehring, 2000).

Arnett (1998) mentioned that family role transition and risky driving behavior are inversely related. People, who have children, are less likely to show risky driving behavior. Murray (1998) explained the relationship between performance at school and risky driving behavior. Students who showed risky driving behavior had poor performance at school. The correlation between use of substances/environmental factors and high risk driving behavior was evaluated in a research study. Based on the authors' findings if men and women receive equal levels of substance use, women are more likely to retain less risky driving behavior (Elliott et al., 2006). According to the results of Zador (2000), young women from 16- to 20-year-old, at same blood alcohol concentration levels have lower fatality risk than men. Rhodes and Pivik (2011) developed a regression model to study the relationship between age, gender and risky driving behavior. They found that regarding gender females possess less risky behavior than men. In addition based on drivers' age, teenagers drive more risky than adults.

In the research of Weng and Meng (2012), the effects of environment, vehicle and driver characteristics on the driving behavior in work zone were analyzed. The authors found that on single lane roads, drivers engage in risky driving behavior mostly under bad weather conditions, and on multiple lane roads, drivers possess risky driving behavior under good light/weather conditions. The middle-aged male drivers, who have an airbag system in vehicle and are going straight ahead, are more likely to show more risky behavior in work zones than middle aged female drivers (Weng and Meng, 2012).

A microscopic traffic simulation model was used to assist in evaluating the capacity enhancement and traffic management strategies at a work zone on an interstate highway. These strategies would help to reduce the congestion caused by reduction of lanes (Kamyab et al., 1999).

Van Der Horst and Hoekstra (1994) used a driving simulator to study the effect of reduction of lane width in work zones on driving. The results of the study showed that if the lane width is reduced by 18 percent from the ideal lane width, it causes drivers to reduce their speeds. Hoe et al. (2003) used driving simulator to identify the older drivers at inflated risk of vehicle crashes. The results of the study showed the usefulness of the driving simulator to conduct the experiments in a more economical way than performing the expensive road tests.

2. Methodology

The objective of this project is to evaluate MoDOT's alternate lane shift sign configuration for work zones. Drivers completed the following two driving simulation scenarios:

- Scenario 1: Federal Highway Administration **(**FHWA) approved merge sign configurations, i.e., MUTCD lane shift signs (see Figure 3),
- Scenario 2: Alternate merge sign configuration proposed by Missouri Department of Transportation (MoDOT) for multiple lane shifts (see Figure 4).

The single sign proposed by MoDOT provides the traveler with enough information to let them know that all lanes are available to shift around the work zone, whereas the MUTCD signs require drivers to see two signs. This research simulation project evaluates the drivers' lane shifting performance and acceptance of the alternate lane shift sign proposed by MoDOT to be used on work zones as compared to the MUTCD lane shift signs.

Figure 3. MUTCD lane shift sign

Figure 4. Missouri alternate lane shift sign

3. Data Collection

In the first step of the project, 75 participants were recruited within different demographic age categories. Participants in this research were separated into four age groups: 18-24, 25-44, 45-64, and over 65 years.

The numbers of participants required in each group was determined considering Missouri's demographic population information. Furthermore, the participants were grouped based on gender, race, and native language. Figures 5-8 show the number of participants in each age, gender, race, and native language category, respectively.

Based on the demographic information, there were 10 participants in age 18-24, 31 participants in age 25-44, 27 participants in age 45-64 and 7 participants over 65 years old. Regarding the gender, 40 of participants were women and 35 of them were men. Based on the race category 62 of participants were white, 12 of them were Asian and 1 was African American. Sixty two of them were native English speakers and 13 of them were non English native speakers. Each participant read and signed a consent form (see Appendix 1).

The participants completed the two driving scenarios using the Driving Simulator (DS) at Missouri S&T. Participants are required to hold a current valid driver license. The participants were given the opportunity to become familiar with the DS before the test began. Each participant tested a trial environment before the full recorded simulation began. They were also able to stop the test at any time if they felt uncomfortable.

In addition to completing the driving simulation of each of two scenarios, each participant completed two questionnaires.

- The first questionnaire (pre-questionnaire, see Appendix 2) was given before the participants entered the simulator and it asked questions about the demographic information and driving history of the participants. Figures 9-10 show driving experience of the participants based on the pre-questionnaire.
- The second questionnaire (post-questionnaire, see Appendix 3) was given after the participants completed the simulation, and asked questions about the scenarios and the DS.

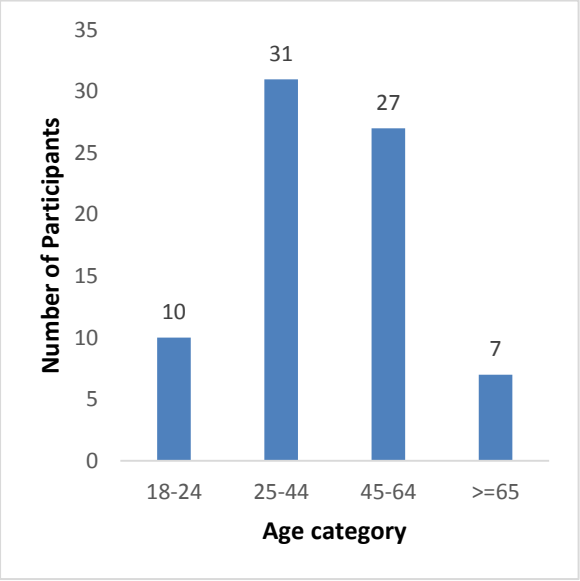


Figure 5. Age of participants

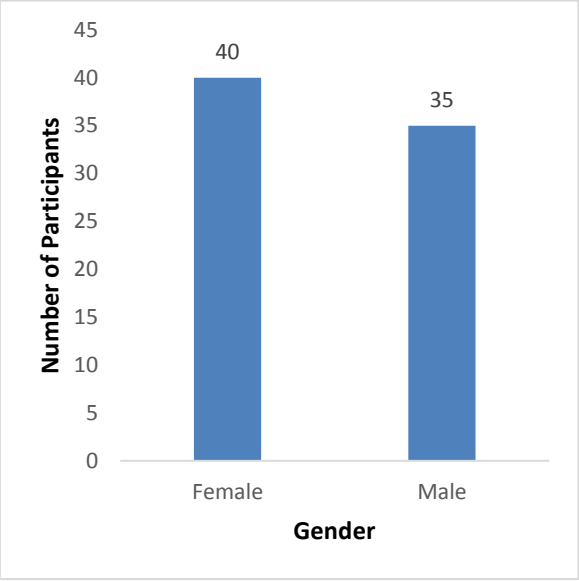


Figure 6. Gender of participants

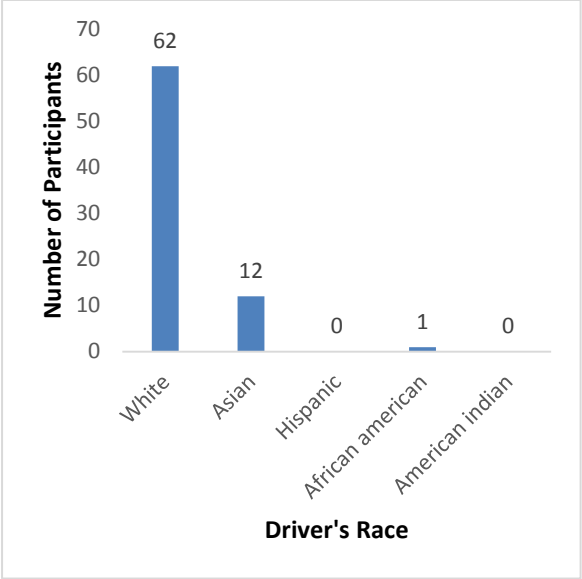


Figure 7. Race of participants

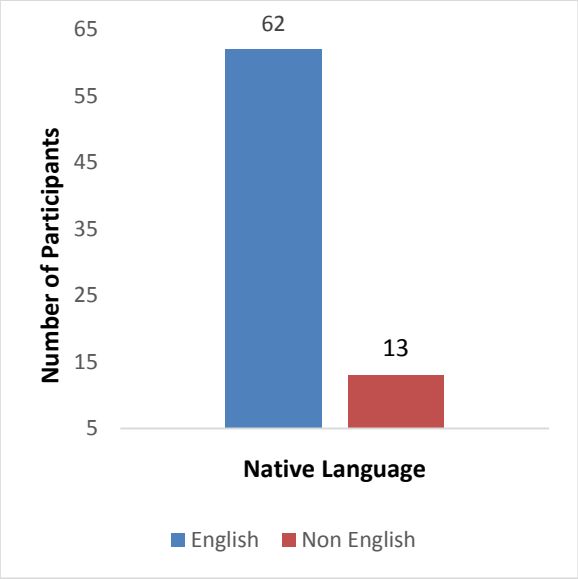


Figure 8. Native language of participants

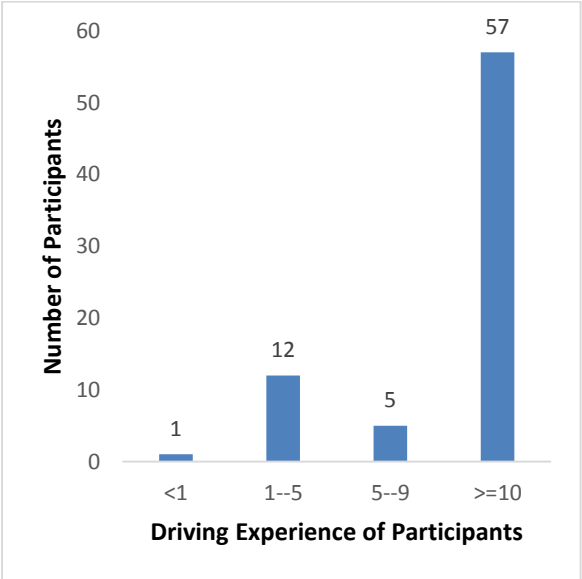


Figure 9. Driving experience of participants

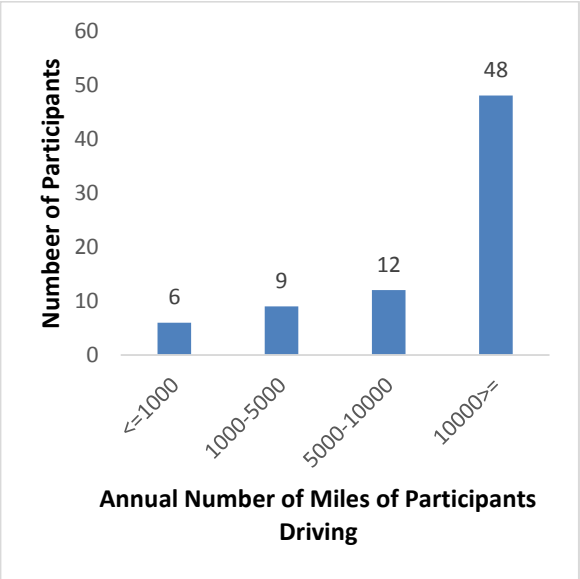


Figure 10. Annual number of miles participants driving

Regarding driving experience, 1 of the participants has less than 1 year, 12 of them had driving experience between 1 to 5 years, 5 of them had 5 to 9 years, and 57 drivers had more than 10 years of driving experience. The results showed 6 participants drove less than 1,000 miles annually, 9 of them between 1,000 to 5,000 miles, 12 of them drove between 5,000 to 10,000 miles, and 48 participants drove more than 10,000 miles annually.

4. Data Analyses

Statistical data analysis techniques were used to measure the effectiveness of the MoDOT lane shift alternate sign configuration against the MUTCD lane shift sign configuration. This analysis integrated qualitative and quantitative information from the simulator data collection and compared results. The independent variables used in this study were: location of signs and location of taper. The dependent variables were: speed and location of changing lane.

4.1. Lane Change Location

4.1.1. Data Preparation

Raw data obtained from the driving simulator is refined and adjusted for the purpose of analysis. A driving path produced from the simulation is a series of (X,Y) locations, where Y is along the driving direction, as illustrated in Figure 11. Similarly, X location is the position across lanes. Location X ranges between right edge of right-most lane and the left edge of left-most lane. The range of the simulation is from Y= -1640 (start) feet to 2500 (end) feet. The range of X locations is from X = -210 feet to 30 feet. X locations initially denote the position of driver along the exit ramp. As the driver begins the simulation he/she drives along the exit ramp and merges onto the 4 lane freeway.

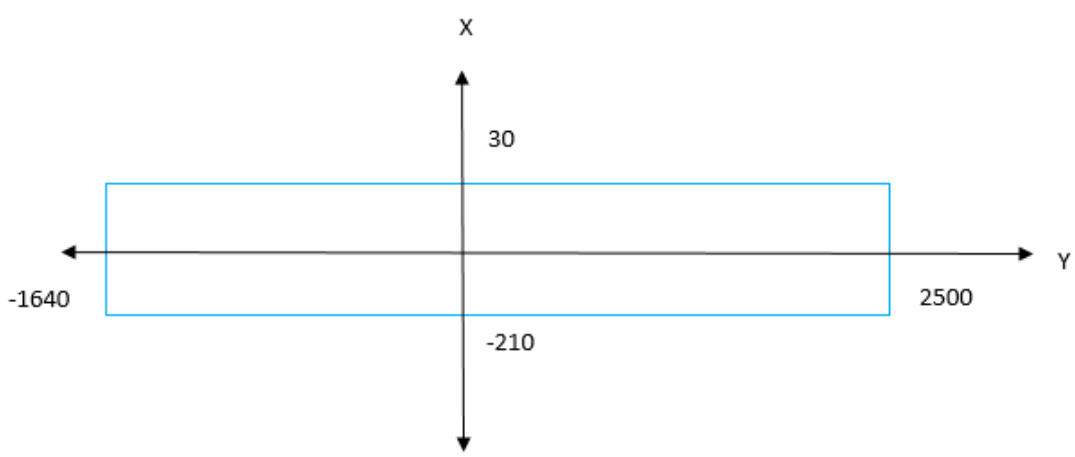


Figure 11. Lane setting

4.1.2. Interpolation of Y values – Location Series Data

A set of "check points" is defined along the driving direction (i.e.,Y), at an even interval of Δy feet, in order to measure and analyze the x-location of drivers (i.e., their position on the lanes). For this study, $\Delta y = 10$ feet were chosen with j index of check points and J is the index set for check points. The y-location of the jth checkpoint, y_j, is equal to $(j - 1)\Delta y$. X values of the 75 driving paths were not read at the same y-locations; therefore, each driving path were interpolated to "read" x values at the defined checkpoints from the start to end of the simulation. The x-location of the ith driver at y_j is denoted by $x_{i,j}$. Finally, a matrix of interpolated x locations vs. y was created as partially illustrated in Table 1. The complete data matrix contains 76 column vectors. The length of each vector is 415. In this data matrix, the first column saves the checkpoints and the $(i + 1)$th column is the x values of the ith participant at these checkpoints,$\forall i \in I$, as demonstrated in Table 1.

Table 1. Multivariate y-location series data sample

Y	X1	X2	X3	X4	X5	X6	X7
-1640	-204.917	-204.909	-204.738	-204.885	-204.912	-204.901	-204.898
-1630	-195.306	-195.147	-195.244	-195.182	-195.286	-195.132	-195.085
-1620	-185.927	-185.59	-185.789	-185.667	-185.882	-185.493	-185.364
-1610	-176.74	-176.416	-176.595	-176.393	-176.736	-176.002	-175.889
-1600	-167.728	-167.786	-167.706	-167.432	-167.951	-166.707	-166.922
-1590	-158.93	-159.698	-159.058	-158.835	-159.521	-157.681	-158.701
-1580	-150.43	-152.097	-150.754	-150.641	-151.425	-149.005	-151.185
-1570	-142.296	-144.871	-142.89	-142.89	-143.643	-140.759	-144.01
-1560	-134.583	-137.919	-135.535	-135.596	-136.175	-133.009	-136.997
-1550	-127.331	-131.209	-128.73	-128.741	-129.075	-125.769	-130.248
-1540	-120.571	-124.736	-122.39	-122.302	-122.407	-119.024	-123.835
…….							

4.1.3. Driving Patterns – Exploratory Analysis

A plot of the 75 driving paths simulated under the MUTCD and MoDOT sign configurations are illustrated in Figures 12 and 13. A significant difference between the driving plots for both the sign configurations is not observed. One can see a few driving patterns from this plot. It indicates about half of the drivers split to the left-most lane immediately upon merging to the freeway. The remaining drivers keep to the right-most lane. This indicates near equal split of drivers between the left and right lane.

Figure 12. Driving plots of 75 drivers for the MUTCD sign configurations

Figure 13. Driving plots of 75 drivers for the MoDOT sign configurations

When reviewing Figures 12 and 13, several patterns emerge.

1. Drivers divided to two groups when they entered highway from ramp near x= -1400. Drivers in the 4th age category (drivers over 64 years old) prefer lane 1 for lane change. Drivers in the 1st age category (drivers over 18 and younger 24 years old) and the 2nd category (drivers over 25 and younger 44 years old) prefer lane 2 for lane change.
2. After the shift signs shown in Figure 12 in MUTCD scenario and Figure 13 in MoDOT scenario at x=-500, most of the drivers continue driving in their chosen lane but some drivers change their lane and go through lane 4 and continue through the work zone. Drivers in the 4th age category (drivers over 64 years old) prefer lane 1 for lane change.

Drivers in the 1st age category (drivers over 18 and younger 24 years old) and the 2nd category (drivers over 25 and younger 44 years old) prefer lane 3 for lane change.

3. After the work zone near x=1800 most of the drivers continue their lane but just a few of them change their lane. Drivers in the 4th age category (drivers over 64 years old) prefer lane 1 to continue driving. Drivers in the 1st age category (drivers over 18 and younger 24 years old) and the 2nd category (drivers over 25 and younger 44 years old) prefer lane 2 to continue their driving.

From the two plots, no dramatic difference is observed in the driving patterns obtained for the MUTCD and MoDOT sign configurations. This is an indication both sign configurations provided similar results with respect to drivers' response to the sign. For comparison, Figure 14 shows the two driving patterns and the location of signs configurations.

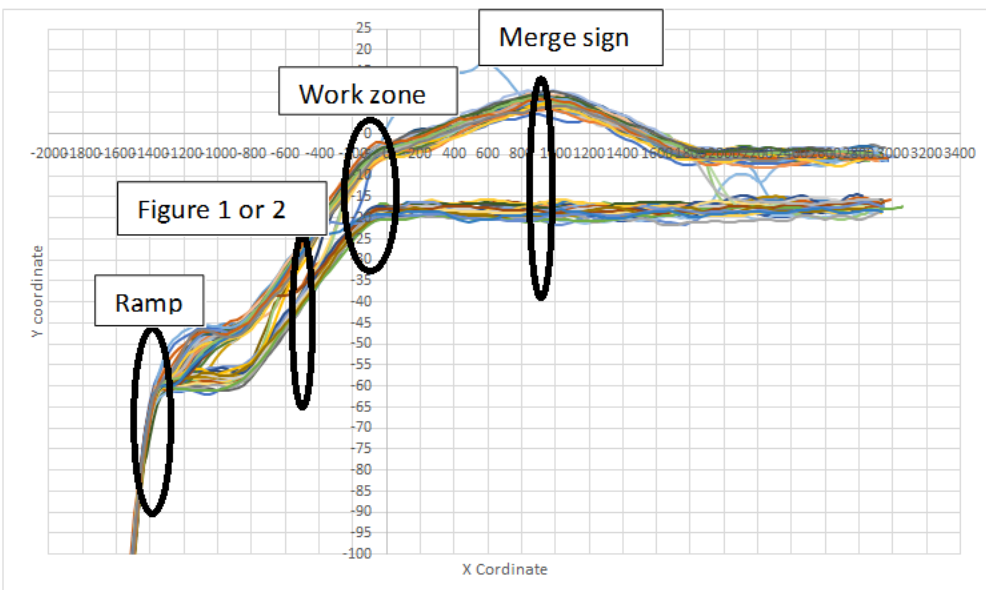


Figure 14. Plot of drivers' lane change patterns

4.1.4. Characterization of Drivers Based on Merge Positions

By comparing Figures 12 and 13, two driving patterns are clearly revealed for both of the sign configurations. In what follows, the driving patterns are identified the drivers are characterized based on demographic information.

Classification of drivers for the MUTCD sign configuration: There were two clusters of drivers that split to the left-most and right-most lane during the simulation. These lanes are on either side of the work zone which starts at y=0 feet. This is classified as drivers that left split and right split based on the driving path. A driver is said to be part of the left split if he/she occupies the left-most lane available during the simulation. Similarly, a driver is said to be part of the right split if he/she occupies the right-most lane available during the simulation. The left split and right split clusters are obtained for the MUTCD sign configurations as illustrated in Table 2.

Table 2. Clustering of drivers into left and right split for the MUTCD sign configurations

	Left Split	**Right Split**
Total Drivers	41	34

Characterization of drivers based on age for the MUTCD sign configuration: The drivers are characterized into the four age groups of 18-24 years, 25-44 years, 45-64 years and 65+. Table 3 summarizes the total number of drivers for each split for each of the four age categories.

Table 3. Summary of total number of drivers for each split based on different age categories for the MUTCD sign configurations

	AGE			
Split direction	18-24	25-44	45-64	65+
Left Split	6	22	12	1
Right Split	4	8	16	6
Total	10	30	28	7

Figure 15 illustrates the distribution of the split of drivers based on the age category. The distribution of left split and right split drivers were analyzed with respect to the total distribution of 75 drivers. The blue bar indicates the percentage of left split drivers for each age category while the red bar indicates the percentage of drivers for the right split. The green bar indicates the total distribution of 75 drivers which captures the demography of all Missouri drivers.

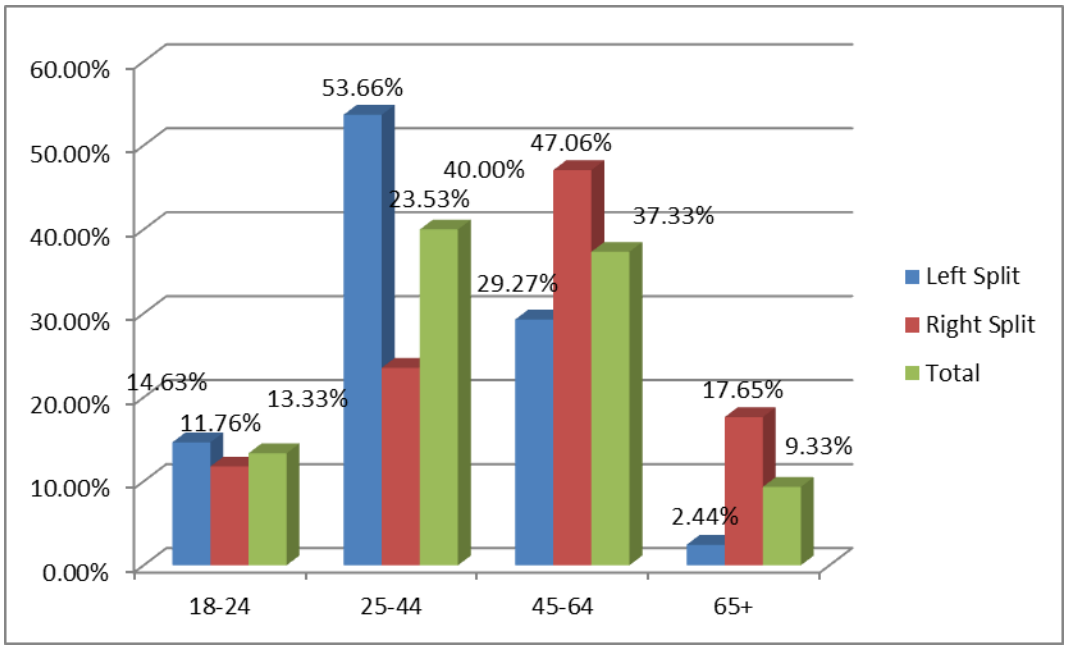


Figure 15. Characterization of split drivers based on age for the MUTCD sign configurations

Characterization of drivers based on gender for the MUTCD sign configuration: The split drivers are characterized based on gender. Table 4 indicates the total number of left and right split drivers under each category of gender. Figure 16 illustrates the percentage distribution of split drivers based on gender.

Table 4. Total number of left and right split drivers based on gender for the MUTCD sign configurations

	GENDER	
Split direction	Female	Male
Left Split	21	20
Right Split	20	14
Total	41	34

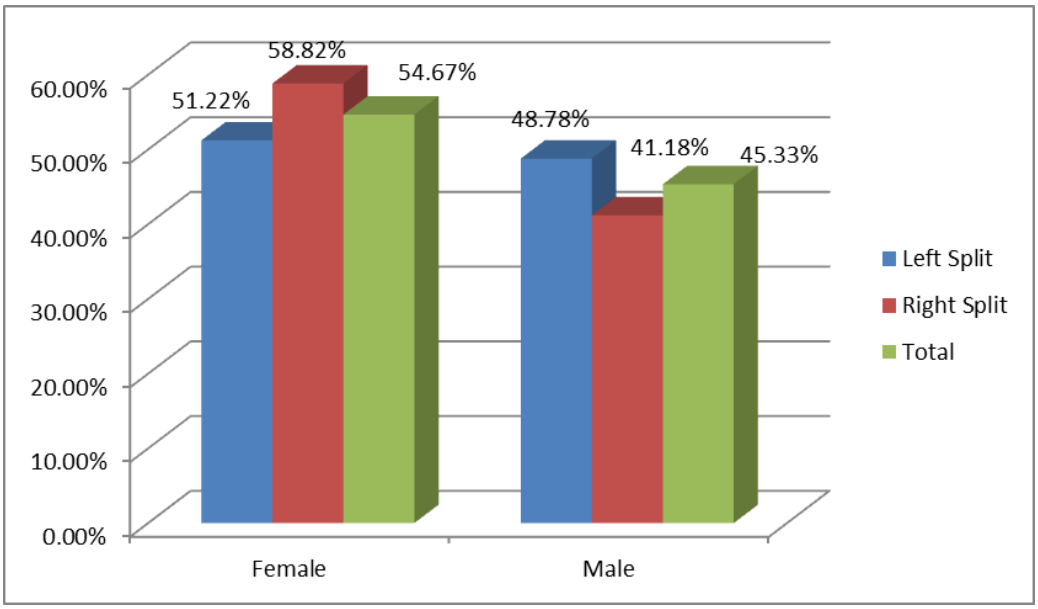


Figure 16. Percentage distribution of left and right split drivers based on gender for the MUTCD sign configurations

Characterization of drivers based on driving experience for the MUTCD sign configuration: Left and right split drivers are characterized based on the number of years of driving experience. The four categories for driving experience are <1 year, 1 to 5 years, 5-9 years and > 10 years. Table 5 indicates the total number of left and right split drivers under each category of driving experience. Figure 17 illustrates the percentage distribution.

Table 5. Total number of left and right split drivers under each category of driving experience for the MUTCD sign configurations

	DRIVING EXPERIENCE IN YEARS			
Split direction	<1	1--5	5--9	>=10
Left Split	0	10	3	28
Right Split	1	2	2	29
Total	1	12	5	57

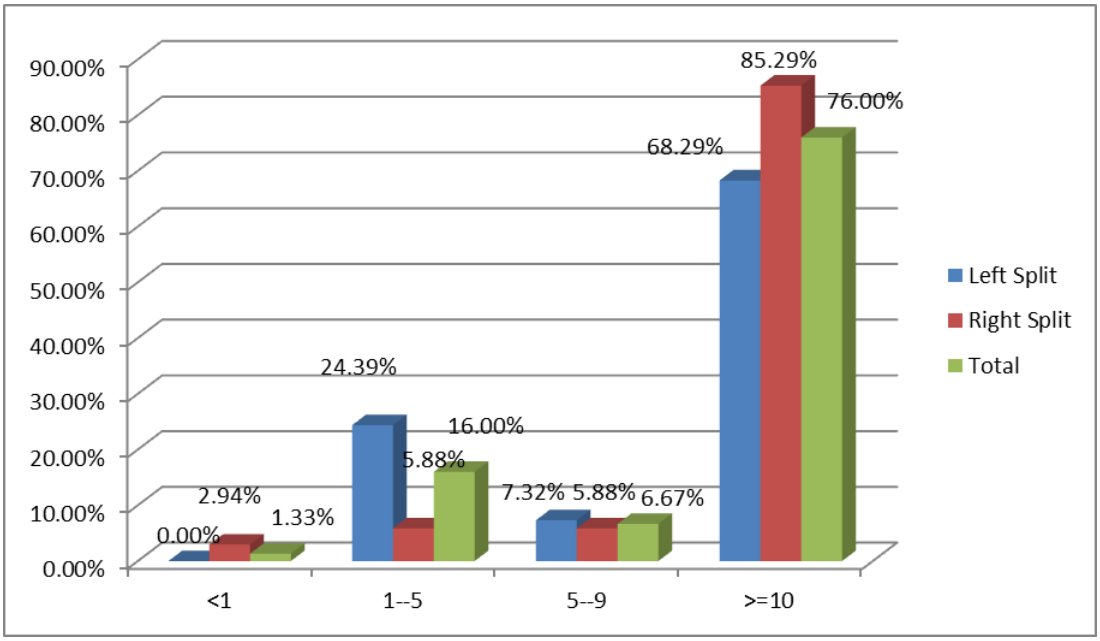


Figure 17. Percentage distribution of left and right split drivers based on driving experience for the MUTCD sign configurations

Characterization of drivers based on number of miles driven for the MUTCD sign configuration: Left and right split drivers are characterized based on the annual number of miles driven. The four categories for miles driven are < 1000 miles, 1000-5000 miles, 5000-10,000 miles and > 10,000 miles. Table 6 indicates the total number of left and right split drivers under each category of miles driven. Figure 18 illustrates the percentage distribution.

Table 6. Total number of left and right split drivers based on annual number of miles driven for the MUTCD sign configurations

	ANNUAL NUMBER OF MILES DRIVEN			
Split direction	<=1000	1000-5000	5000-10000	>=10000
Left Split	3	2	7	29
Right Split	3	6	6	19
Total	6	8	13	48

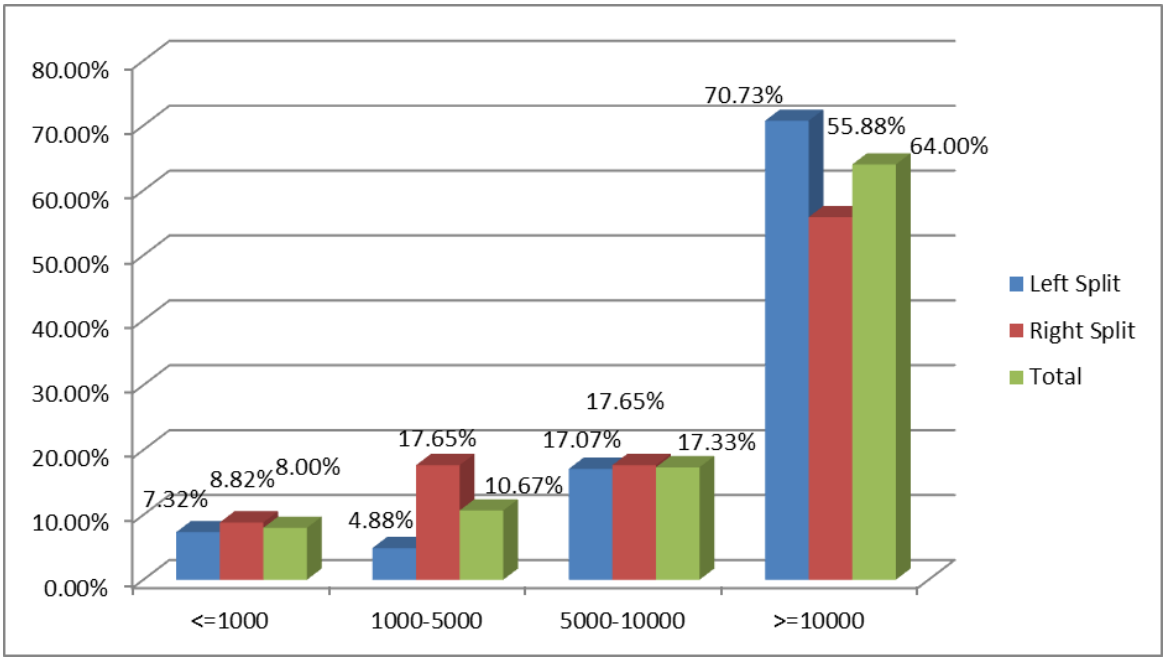


Figure 18. Percentage distribution of left and right split drivers based on annual number of miles driven for the MUTCD sign configurations

Classification of drivers for the MoDOT sign configuration: Similar set of analysis and characterization is conducted for the MoDOT sign configurations to spot differences in split patterns or distributions based on demography. Table 7 indicates the clustering of drivers into left and right split for the MoDOT sign configuration.

Table 7. Clustering of drivers into left and right split for the MoDOT sign configurations

	Left Split	**Right Split**
Total Drivers	45	30

Characterization of drivers based on age for the MoDOT sign configuration: The drivers are characterized into the four age groups. Table 8 summarizes the total number of drivers for each split for each of the four age categories. Figure 19 illustrates the distribution of the split of drivers based on the age category.

Table 8. Summary of total number of drivers for each split based on different age categories the MoDOT sign configurations

	AGE			
Split direction	18-24	25-44	45-64	65+
Left Split	7	21	16	1
Right Split	3	10	11	6
Total	10	31	27	7

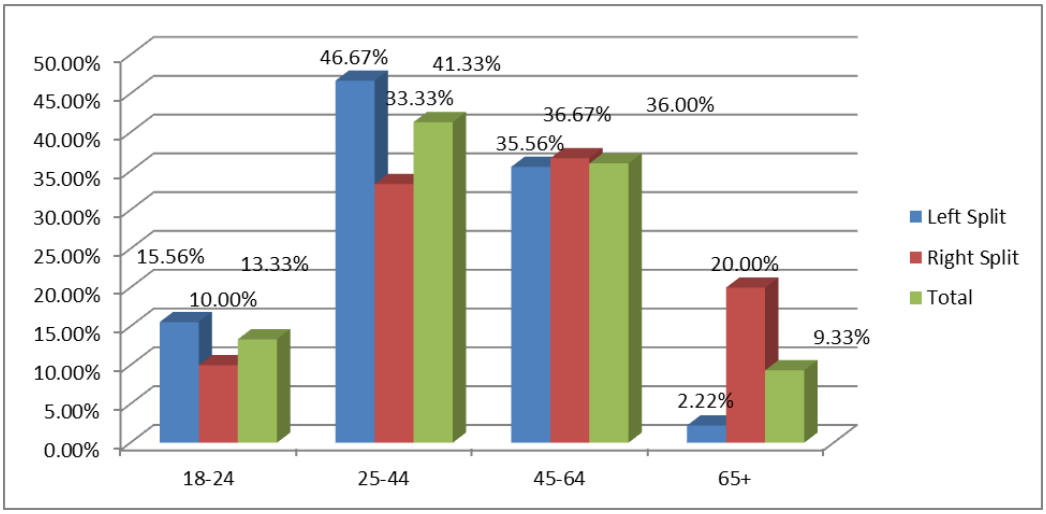


Figure 19. Characterization of split drivers based on age for the MoDOT sign configurations

Characterization of drivers based on gender for the MoDOT sign configuration: The split drivers are characterized based on gender. Table 9 indicates the total number of left and right split drivers under each category of gender. Figure 20 illustrates the percentage distribution of split drivers based on gender.

Table 9. Total number of left and right split drivers based on gender for the MoDOT sign configurations

	GENDER	
Split direction	Female	Male
Left Split	24	21
Right Split	17	13
Total	41	34

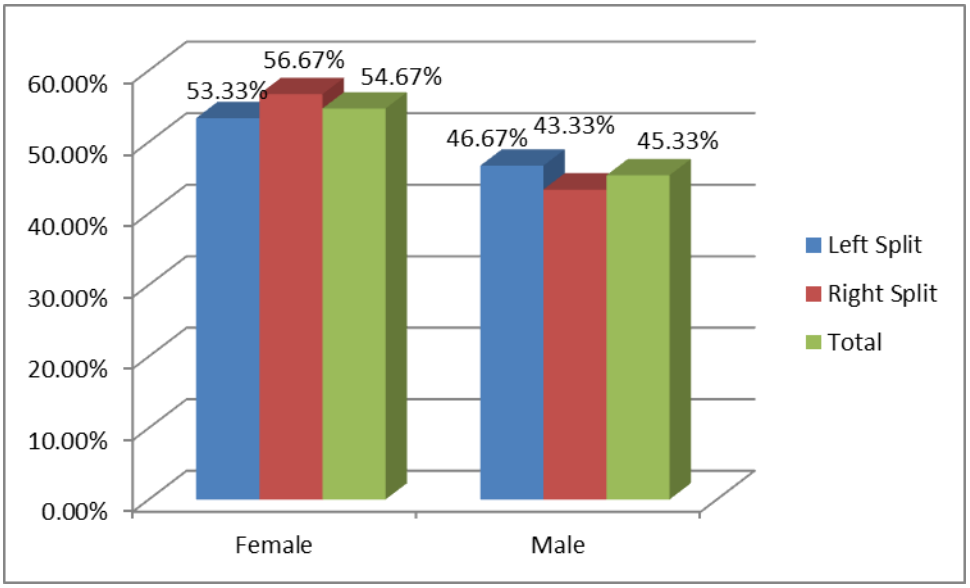


Figure 20. Percentage distribution of left and right split drivers based on gender for the MoDOT sign configurations

Characterization of drivers based on driving experience for the MoDOT sign configuration: Left and right split drivers are characterized based on the number of years of driving experience. Table 10 indicates the total number of left and right split drivers under each category of driving experience. Figure 21 illustrates the percentage distribution.

Table 10. Total number of left and right split drivers under each category of driving experience for the MoDOT sign configurations

	DRIVING EXPERIENCE IN YEARS			
Split direction	<1	1--5	5--9	>=10
Left Split	0	8	5	32
Right Split	1	4	0	25
Total	1	12	5	57

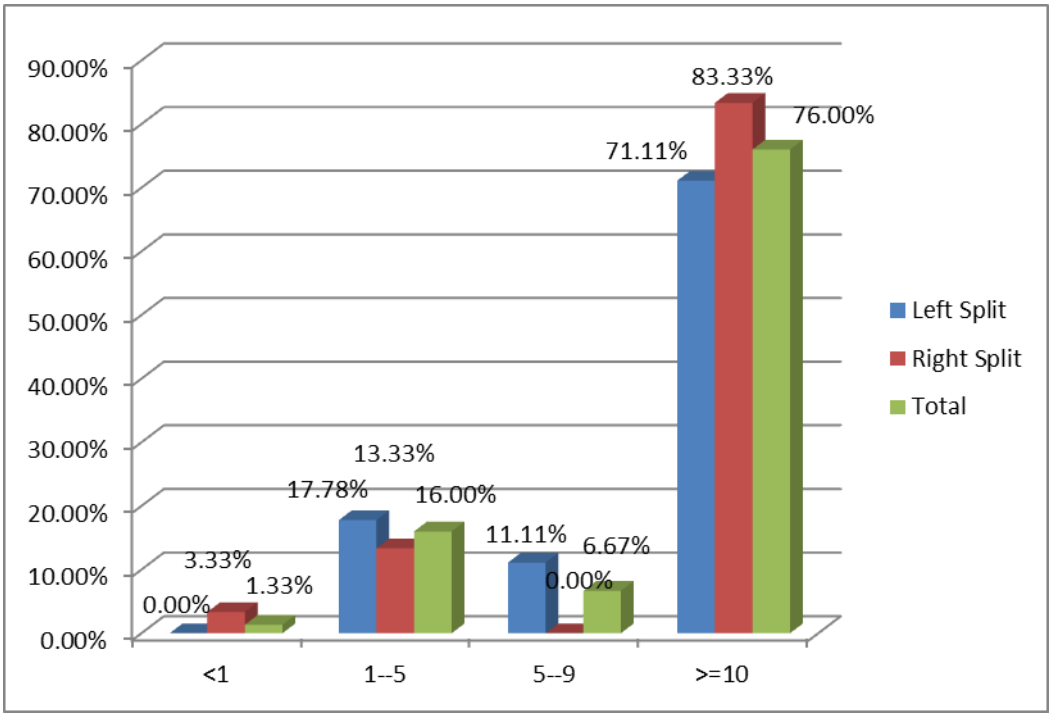


Figure 21. Percentage distribution of left and right split drivers based on driving experience for the MoDOT sign configurations

Characterization of drivers based on number of miles driven for the MoDOT sign configuration: Left and right split drivers are characterized based on the number of miles driven annually. Table 11 indicates the total number of left and right split drivers under each category of miles driven. Figure 22 illustrates the percentage distribution.

Table 11. Total number of left and right split drivers based on annual number of miles driven for the MoDOT sign configurations

	ANNUAL NUMBER OF MILES DRIVEN			
Split direction	<=1000	1000-5000	5000-10000	>=10000
Left Split	3	5	8	29
Right Split	3	4	4	19
Total	6	9	12	48

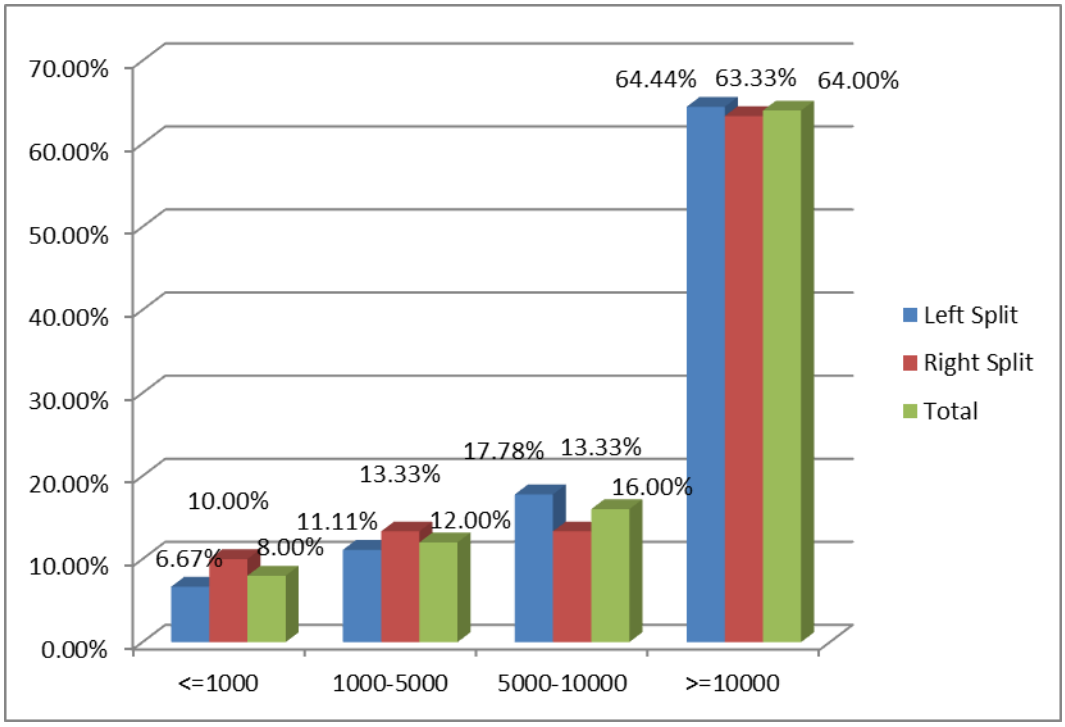


Figure 22. Percentage distribution of left and right split drivers based on annual number of miles driven for the MoDOT sign configurations

4.1.5. Statistical Data Analysis for Drivers Lane Change

The first step for statistical data analysis is considering lane change of drivers in two scenarios and used Analysis of Variance (ANOVA) test to analyze if there was a significant difference between the lane changes of drivers in the two scenarios according to the following hypotheses at α=0.05 significance level. ANOVA is a statistical method that is widely used in researches to evaluate differences between one or more means.

- **H0-1:** There was no significant difference between the lane changes of drivers in two scenarios versus,
- **Ha-1:** At least one of the scenarios had a different lane change pattern, i.e., the assumption of **H0-1** is not correct (Moradpour et al. 2015).

Based on the data analysis, there was not a noticeable, statistical difference between lane change patterns of drivers in the MoDOT alternate signs with MUTCD signs in the work zone. In addition gender does not have significant effect on drivers' lane change pattern. It was observed that in the case of the scenario and gender, P-value is >0.05, hence rejecting H0 and indicating that there is not sufficient evidence to conclude that both of these factors have significant effects on drivers lane change pattern. But regarding the age, the P-value is <0.05, which means that age has significant effect on drivers' lane change pattern (see Table 12).

Table 12. ANOVA analysis of drivers' lane change patterns

Source	DF	ADJ SS	ADJ MS	F-Value	P-Value
Scenario	1	0.16	0.16	0.76	0.38
Gender	1	0.13	0.13	0.61	0.43
Age	3	5.48	1.82	8.39	0

4.2. Speed

After analyzing lane change pattern, drivers' speeds were analyzed. Figures 23 and 24 illustrate the plot of drivers' speed in each scenario, respectively. Drivers' average speed in two scenarios is shown in Figure 25. Based on Figure 25, average speed of drivers is 40.82 and 41.27 in MoDOT and MUTCD scenarios, respectively. So the drivers' average speed in the MoDOT scenario is less than that in the MUTCD scenario.

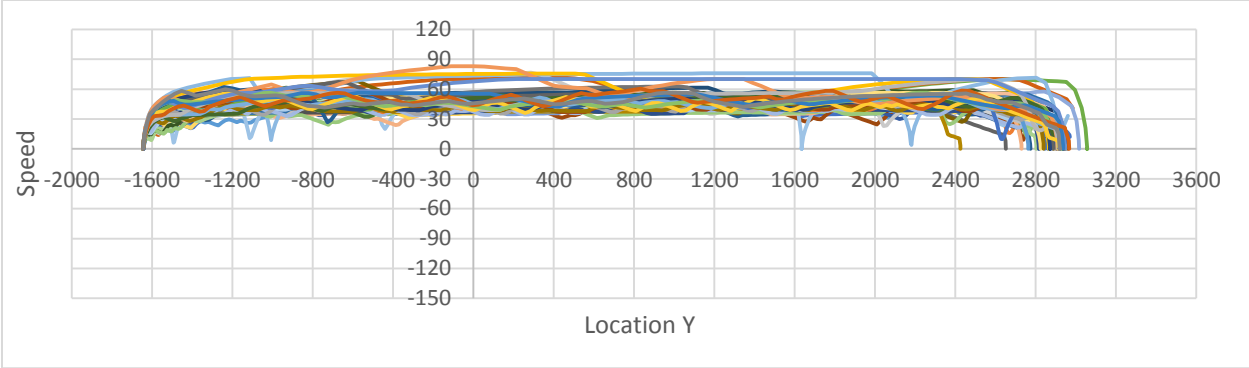


Figure 23. Average speed of drivers in MoDOT scenario

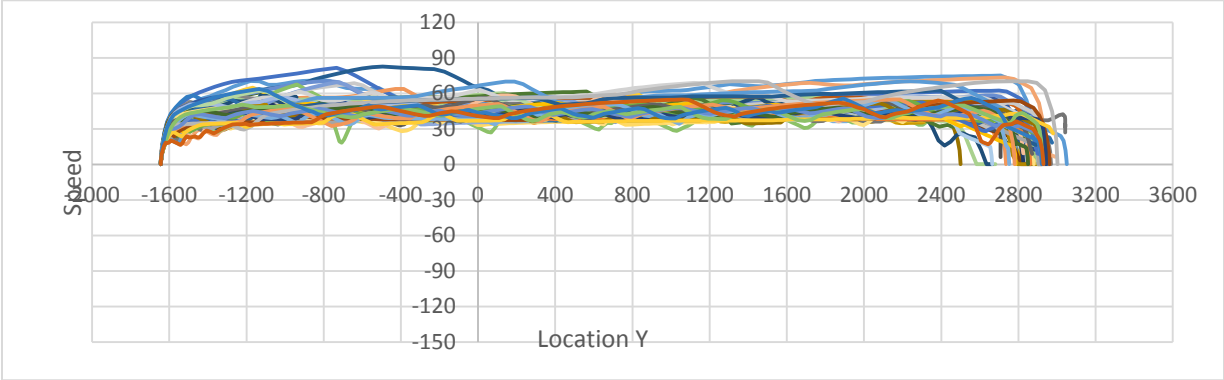


Figure 24. Average speed of drivers in MUTCD scenario

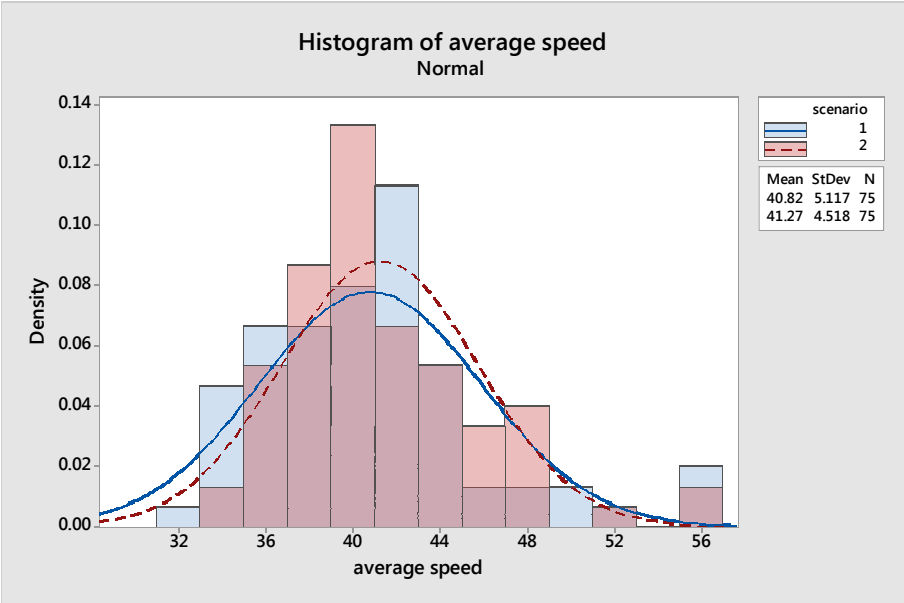


Figure 25. Histogram of average speed in MoDOT scenario (scenario 1) and MUTCD scenario (scenario 2)

4.2.1. Statistical Data Analysis for Drivers Speed

Analysis of Average Speeds: The average speed of all the age groups and genders in both driving scenarios is given in the following table.

Table 13. Average speed of all age groups and genders in both driving scenarios

	MoDOT		MUTCD	
	Male	Female	Male	Female
18-24	44.09	36.06	42.64	37.32
25-44	42.65	41.62	43.10	42.61
45-64	41.23	38.28	40.93	39.59
65+	39.20	38.46	39.05	37.99

To determine if there is any significant difference in the average speeds, the hypothesis test using two way ANOVA table where Driving Scenarios (MoDOT and MUTCD) are blocks, Gender and Age Groups as factors, was conducted. Therefore, this test design was Randomized Completely Block (RCB) Design. Due to different number of participants in each age group, the repetitions of all treatment combinations are not the same.

The linear model of this experiment is

$$Y = \mu + \tau_i + \beta_j + (\tau_i\beta_j) + \delta_k + \epsilon_{ijk}$$

Here, Y is the average speed of a treatment combination, μ is the mean of all the treatments, β_j represents the Gender effect on the average speed, τ_i is the Age Group effect on the average speed, δ_k represents the Driving Scenario (block) effect, $(\tau_i\beta_j)$ is the interaction between the factors age group and gender, and ϵ_{ijk} is the error component.

Now, the null hypothesis is:

- **H0:** All the average speeds are statistically the same.

The alternate hypothesis is:

- **H1: H0** is false.

The RCB design test is performed by using JMP-Statistical Analysis software. The results of the test are given in Table 14.

Table 14. ANOVA analysis over all participants' average speeds

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	527.2063	65.9008	3.1735
Error	141	2927.9878	20.7659	**Prob > F**
C. Total	149	3455.1941		0.0024*

The ANOVA table (Table 14) shows that the P-value is 0.0024 which is less than 0.05 (significance level), therefore, it is concluded that **H0** is rejected, there is statistically significant difference between the average speeds of all the treatments, which means at least either one of the factors or the blocks is affecting the average speed of the driver.

To understand the effects of factors and blocks on the average speed, the Effects Test was conducted and the results of the effects test are shown in Table 15.

Table 15. Effects test results over all participants' average speeds

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Driving Scenarios	1	1	7.69617	0.3706	0.5436
Gender	1	1	135.05727	6.5038	0.0118*
Age group	3	3	256.09278	4.1108	0.0079*
Gender*Age group	3	3	96.31002	1.5460	0.2053

Test for Interactions using All Participants' Average Speeds: Here, the effect of Gender and Age Group interaction is analyzed.

- $\mathbf{H_{0\text{-Age Group*Gender}}}$**:** The Age Group and Gender do not interact with each other in the model and thus the effect is additive in nature, equivalently;
- $\mathbf{H_{0\text{-Age Group*Gender}}}$**:** $\mu_{ijk} - \mu_{ij'k} = \mu_{i'jk} - \mu_{i'j'k}$.

From the Effect Tests results (Table 15), it can be seen that the effect of interaction between factors Gender and Age Group on the average speed is not significant because its P-value, 0.2053, is greater than 0.05. The null hypothesis, $\mathbf{H_{0\text{-Age Group*Gender}}}$, with 95% confidence is not rejected and it is concluded that there is no interaction between the gender and age group.

Test for Main Effects using All Participants' Average Speeds: Here, the effects of individual factors and blocks on average speed are analyzed.

- $\mathbf{H_{0\text{-Driving Scenario}}}$**:** The average speed in both driving scenarios is the same, i.e.,
- $\mathbf{H_{0\text{-Driving Scenario}}}$**:** $\mu_{ij1} = \mu_{ij2.}$

The P-value for Driving Scenarios, 0.5436, from the effect tests (Table 15) is greater than 0.05, which means there is no significant effect of driving scenario on the average speed. Therefore, $\mathbf{H_{0\text{-Driving Scenario}}}$ is not rejected.

- $\mathbf{H_{0\text{-Gender}}}$**:** The average speed of both genders is the same, i.e.,
- $\mathbf{H_{0\text{-Gender}}}$**:** $\mu_{i1k} = \mu_{i2k.}$

The P-value of the factor gender in effect tests (Table 15) is 0.0118, which is less than 0.05, therefore, $\mathbf{H_{0\text{-Gender}}}$ is rejected, which means factor gender has significant effect on the average speed of a driver. There are two levels of this factor, male and female, the average speed of both levels is different from each other.

- $\mathbf{H_{0\text{-Age Groups}}}$**:** The average speed of all age groups is the same, i.e.,
- $\mathbf{H_{0\text{-Age Groups}}}$**:** $\mu_{1jk} = \mu_{2jk} = \mu_{3jk} = \mu_{4jk.}$

The P-value of Age Groups is 0.0079 in Table 15, which is less than 0.05, therefore, $\mathbf{H_{0\text{-Age Groups}}}$ is rejected, which means Age Groups have significant effect on the average speed of a driver. There are four levels of age groups, the average speed of at least one level is different from others.

Based on the above results, Gender and Age Group have effects on average speeds. Additional tests like Least Squares Means Differences should be conducted to better understand the effect of gender and age groups. In what follows, the results of Least Squares Means Differences test (LSMeans student's t test) are discussed for gender and age groups.

Analysis using Least Squares Means using All Participants' Average Speeds: To better understand the effects of the factors and blocks, the LSMeans student's t test was performed on the whole data. The results of LSMeans student's t test for the factors and the blocks are given below.

Table 16 shows the LSMeans student's t test results for gender.

Table 16. LSMeans student's t test results for gender

Level			Least Sq Mean
MALE	A		41.609299
FEMALE		B	38.991137

For Gender, the levels male and female are represented with different letters, therefore, the average speeds of males and females are significantly different.

Table 17 shows the LSMeans student's t test results for age groups.

Table 17. LSMeans student's t test results for age groups

Level			Least Sq Mean
25-44	A		42.494518
18-24	A	B	40.027071
45-64		B	40.008425
65+		B	38.670858

Here, the age groups 25-44 and (65+& 45-64) are represented with different letters, therefore, it can be said that the average speeds of these age groups are statistically different from each other and the other age group is represented with both letters, which means the average speeds of this age groups is statistically same as other age groups.

Based on the above results, next analyses focus on investigating each gender group and each age group individually.

Analysis of Average Speeds of Females: Here, the average speeds of the females from the different age groups are compared with each other. The average speeds of females within different age groups in both scenarios are given in Table 18.

Table 18. Average speeds of females from all age groups in both driving scenarios

Average Speeds of Female Participants				
	Age Groups			
Driving Scenario	**18-24**	**25-44**	**45-64**	**65+**
MoDOT	36.06	41.62	38.28	38.46
MUTCD	37.32	42.61	39.59	37.98

The hypothesis test was done to analyze any significant difference in the average speed of the females from different age groups. One way RCB design in ANOVA analysis with Age Groups as a factor and Driving Scenario as a block was conducted. In the one way RCB design, it is assumed that there is no interaction between Driving Scenario and Age Group based on the previous results as well as due to the different number of participants in each age group (i.e., the repetitions of all treatment combinations are not same).

Here, the null hypothesis is:

- $\mathbf{H_{0\text{-females}}}$**:** The average speed of all female drivers is the same.

The alternate hypothesis is:

- $\mathbf{H_{1\text{-females}}}$**:** At least one female driver has different average speed than other female drivers.

The analysis of variance results derived from the female participants' data are given in Table 19.

Table 19. ANOVA analysis over female participants' average speeds

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	278.2645	69.5661	5.2640
Error	75	991.1568	13.2154	**Prob > F**
C. Total	79	1269.4213		0.0009*

The P-value in Table 19 is 0.0009, which is less than the significance level 0.05, therefore the null hypothesis $\mathbf{H_{0\text{-females}}}$ is rejected. The average speeds of all female drivers are not the same, i.e., at least one female driver has different average speed than the other female drivers. Therefore, $\mathbf{H_{0\text{-females}}}$ is rejected.

To understand the effect of the block, Driving Scenarios, and the factor, age group, on the female participants' average speeds, the effects test was conducted using female participants' average speed data and the results of the effects test are shown in Table 20.

Table 20. Effects test results over female participants' average speeds

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Driving Scenarios	1	1	23.11990	1.7495	0.1900
Age Groups	3	3	255.14459	6.4355	0.0006*

Test for Main Effects using Female Participants' Average Speeds: Here, the effects of individual factors and blocks on average speed of female drivers are analyzed.

- $\mathbf{H_{0\text{-Driving Scenario}}}$**:** The average speed of female drivers in both driving scenarios is the same, i.e.,
- $\mathbf{H_{0\text{-Driving Scenario}}}$**:** $\mu_{i1} = \mu_{i2}$.

The P-value, 0.1900, from the effects test result given in Table 20 is greater than 0.05, which means there is no significant effect of driving scenario on the average speed of the female drivers. Therefore, $\mathbf{H_{0\text{-Driving Scenario}}}$ is not rejected.

- $\mathbf{H_{0\text{-Age Groups}}}$**:** The average speed of female drivers of all age groups is the same, i.e.,
- $\mathbf{H_{0\text{-Age Groups}}}$**:** $\mu_{1k} = \mu_{2k} = \mu_{3k} = \mu_{4k}$.

The P-value from the effects test results given in Table 20 is 0.0006 and less than 0.05, which means there is significant effect of age groups on the average speed of female drivers. Therefore, $\mathbf{H_{0\text{-Age Groups}}}$ is rejected.

Based on the above results, Age Group has effects on the average speeds of the female drivers. In what follows, the results of LSMeans student's t test using female participants' average speeds are discussed for age groups.

Analysis using Least Squares Means using Female Participants' Average Speeds: To better understand the effects of age groups on female drivers' average speeds, LSMeans student's t test was performed on the female participants' data. The results of the LSMeans student's t test using female participants' average speeds for age groups are given in Table 21.

Table 21. LSMeans student's t test results for age groups using female driver data

Level			Least Sq Mean
25-44	A		42.118454
45-64		B	38.933273
65+		B	38.222298
18-24		B	36.690525

As can be seen from Table 21, the age groups 45-64, 65+, and 18-24 are represented by same letter, therefore, it can be concluded that these age groups do not have significant difference in their average speeds. But, the age group 25-44 is represented by different letter, which means this age group is significantly different from other age groups. The females from age group 25-44 have a higher average speed than other age groups.

Analysis of Average Speeds of Males: Here, the average speeds of the male drivers from the different age groups are compared with each other. The average speeds of males within different age groups in both scenarios are given in Table 22.

Table 22. Average speeds of males from all age groups in both driving scenarios

Average Speeds of Male Participants				
	Age groups			
Driving Scenario	18-24	25-44	45-64	65+
MoDOT	44.09	42.64	41.23	39.19
MUTCD	42.64	43.10	40.93	39.05

The hypothesis test was done to analyze any significant difference in the average speed of the males from different age groups. One way RCB design in ANOVA analysis with Age Groups as a factor and Driving Scenarios as a block was conducted. In the one way RCB design, it is assumed that there is no interaction between Driving Scenario and Age Group based on the previous results as well as due to the different number of participants in each age group (i.e., the repetitions of all treatment combinations are not same).

Here, the null hypothesis is:

- $\mathbf{H_{0\text{-}males}}$**:** The average speed of all male drivers is the same.

The alternate hypothesis is:

- **$H_{1\text{-males}}$:** At least one male driver has different average speed than other male drivers.

The analysis of variance results derived from the male participants' data are given in Table 23.

Table 23. ANOVA analysis over male participants' average speeds

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	148.7061	37.1765	1.2584
Error	65	1920.2424	29.5422	**Prob > F**
C. Total	69	2068.9484		0.2954

The P-value in Table 23 is 0.2954, which is greater than significance level 0.05, therefore the null hypothesis $H_{0\text{-males}}$ is not rejected. The average speed of all male drivers is the same, i.e., there is no significant difference between average speeds of male drivers.

Analysis of Average Speeds within Age Group 18-24: Here, the average speeds of the drivers within age group 18-24 from the different gender groups are compared with each other. The average speeds of drivers within age group 18-24 from the different gender groups in both scenarios are given in Table 24.

Table 24. Average speeds of drivers in age group 18-24

	18-24	
	MALE	FEMALE
MoDOT	44.09	36.06
MUTCD	42.64	37.32

The number of repetitions of all treatment combinations is not same. To understand the driving behavior within this age group ANOVA test was done. Here, Driving scenarios were blocks and gender was a factor.

Here, the null hypothesis is:

- **$H_{0\text{-}(18\text{-}24)}$:** The average speed of all drivers in age group 18-24 is the same.

The alternate hypothesis is:

- **$H_{1\text{-}(18\text{-}24)}$:** At least one driver in age group 18-24 has different average speed than other drivers in age group 18-24.

The ANOVA results are given in Table 25.

Table 25. ANOVA analysis over average speeds of participants in age group 18-24

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	152.48320	50.8277	2.0749
Error	16	391.95090	24.4969	**Prob > F**
C. Total	19	544.43410		0.1439

The P-value, 0.1439, in Table 25 is greater than the significance level (0.05). Therefore, $\mathbf{H_{0\text{-}(18\text{-}24)}}$ is not rejected. In this age group, males and females have no significant difference in their average speeds in both driving scenarios.

Analysis of Average Speeds within Age Group 25-44: Here, the average speeds of the drivers within age group 25-44 from the different gender groups are compared with each other. The average speeds of drivers within age group 25-44 from the different gender groups in both scenarios are given in Table 26.

Table 26. Average speeds of drivers in age group 25-44

	25-44	
	MALE	FEMALE
MoDOT	42.64	41.62
MUTCD	43.10	42.61

The number of repetitions of all treatment combinations is not same. To understand the driving behavior within this age group ANOVA test was done. Here, Driving scenarios were blocks and gender was a factor.

Here, the null hypothesis is:

- $\mathbf{H_{0\text{-}(25\text{-}44)}}$**:** The average speed of all drivers in age group 25-44 is the same.

The alternate hypothesis is:

- $\mathbf{H_{1\text{-}(25\text{-}44)}}$**:** At least one driver in age group 25-44 has different average speed than other drivers in age group 25-44.

The ANOVA results are given in Table 27.

Table 27. ANOVA analysis over average speeds of participants in age group 25-44

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	18.7447	6.2482	0.1980
Error	58	1829.9546	31.5509	**Prob > F**
C. Total	61	1848.6993		0.8973

The P-value, 0.8973, in Table 27 is much greater than the significance level (0.05). Therefore, $\mathbf{H_{0\text{-}(25\text{-}44)}}$ is not rejected. In this age group, males and females have no significant difference in their average speeds in both driving scenarios.

Analysis of Average Speeds within Age Group 45-64: Here, the average speeds of the drivers within age group 45-64 from the different gender groups are compared with each other. The average speeds of drivers within age group 45-64 from the different gender groups in both scenarios are given in Table 28.

Table 28. Average speeds of drivers in age group 45-64

	45-64	
	MALE	FEMALE
MoDOT	41.23	38.28
MUTCD	40.93	39.59

The number of repetitions of all treatment combinations is not same. To understand the driving behavior within this age group ANOVA test was done. Here, Driving scenarios were blocks and gender was a factor.

Here, the null hypothesis is:

- $\mathbf{H_{0\text{-}(45\text{-}64)}}$**:** The average speed of all drivers in age group 45-64 is the same.

The alternate hypothesis is:

- $\mathbf{H_{1\text{-}(45\text{-}64)}}$**:** At least one driver in age group 45-64 has different average speed than other drivers in age group 45-64.

The ANOVA results are given in Table 29.

Table 29. ANOVA analysis over average speeds of participants in age group 45-64

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	71.37581	23.7919	2.5921
Error	50	458.94015	9.1788	**Prob > F**
C. Total	53	530.31596		0.0630

The P-value, 0.063, in Table 29 is very close to the significance level (0.05), therefore, $\mathbf{H_{0\text{-}(45\text{-}64)}}$ should not be rejected right away. Further analysis, i.e., Effects Test, to understand the effects of factors on response variable should be conducted. The results of the effects test are shown in Table 30.

Table 30. Effects test results over average speeds of participants in age group 45-64

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Driving Scenario	1	1	3.066726	0.3341	0.5658
Gender	1	1	55.485731	6.0450	0.0175*

Test for Main Effects using the Average Speeds of Participants in Age Group 45-64: Here, the effects of individual factors and blocks on average speed of the drivers in age group 45-64 are analyzed.

- $\mathbf{H_{0\text{-}Driving\ Scenario}}$**:** The average speeds of the drivers in age group 45-64 are the same in both driving scenarios.

The P-value, 0.5658, in Table 30 is greater than the significance level (0.05), which means there is no significant effect of driving scenario on the average speed of the drivers in age group 45-64. Therefore, $\mathbf{H_{0\text{-}Driving\ Scenario}}$ is not rejected.

- $\mathbf{H_{0\text{-}Gender}}$**:** The average speeds of the drivers in age group 45-64 are the same for both genders (male and female).

The P-value, 0.0175, in Table 30 for the factor gender is less than the significance level (0.05), therefore, $\mathbf{H_{0\text{-}Gender}}$ is rejected, which means factor gender has significant effect on the average

speed of a driver in this age group. There are two levels of this factor, male and female, the average speed of both levels is different from each other.

Based on the above results, gender has effects on the average speeds of the drivers in age group 45-64. In what follows, the results of LSMeans student's t test using average speeds of the participants in age group 45-64 are discussed for gender.

Analysis using Least Squares Means using Average Speeds of the Participants in Age Group 45-64: To better understand the difference in the levels of factor Gender on age group 45-64, LSMeans student's t test was performed on the data of the drivers in age group 45-64. The results of LSMeans student's t test for Gender are given in Table 31.

Table 31. LSMeans student's t test for gender using average speeds of participants in age group 45-64

Level			Least Sq Mean
MALE	A		41.083578
FEMALE		B	38.933273

As can be seen from Table 31, male and female are represented with different letters, which means the difference in their speed is significant and males have higher average speed than females in this age group.

Analysis of Average Speeds within Age Group 65+: Here, the average speeds of the drivers within age group 65+ from the different gender groups are compared with each other. The average speeds of drivers within age group 65+ from the different gender groups in both scenarios are given in Table 32.

Table 32. Average speeds of drivers in age group 65+

	65+	
	MALE	FEMALE
MoDOT	39.20	38.46
MUTCD	39.05	37.98

The number of repetitions of all treatment combinations is not same. To understand the driving behavior within this age group ANOVA test was done. Here, Driving scenarios were blocks and gender was a factor.

Here, the null hypothesis is:

- **$H_{0\text{-}(65+)}$:** The average speed of all drivers in age group 65+ is the same.

The alternate hypothesis is:

- **$H_{1\text{-}(65+)}$:** At least one driver in age group 65+ has different average speed than other drivers in age group 65+.

The ANOVA results are given in Table 33.

Table 33. ANOVA analysis over average speeds of participants in age group 65+

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	2.57602	0.8587	0.0393
Error	10	218.48052	21.8481	**Prob > F**
C. Total	13	221.05654		0.9890

The P-value, 0.9890, in Table 33 is much greater than the significance level (0.05). Therefore, $H_{0\text{-}(65+)}$ is not rejected. In this age group, males and females have no significant difference in their average speeds in both driving scenarios.

Analysis of Average Speeds Before and After the MUTCD and MoDOT Lane Split Signs: The difference in the average speed of the driver before the lane split sign compared to the average speed after the lane split sign was analyzed. The results from this analysis can be used to determine if there is any change in the driving speed after a driver notices the sign.

The position of the lane split sign is (-550, 30) & (-550, -30) in both scenarios. The data was analyzed to determine if there is any difference in the average speed of the drivers before and after the sign. The average of 10 speed readings before the lane split sign is called average speed before the sign and the average of 10 speed readings after the lane split sign is called average speed after the sign. Therefore, for each driver before and after the sign average speeds in each scenario, i.e., 4 different average speeds, are collected.

To determine whether there is any significant difference in the average speeds, the hypothesis test using three way ANOVA table analysis, where Age Group, Gender and Before & After sign position were factors, was conducted. The Driving Scenarios (MoDOT and MUTCD) were blocks. Therefore, this test design is RCB Design as well.

Here, the null hypothesis is:

- **$H_{0\text{-before \& after sign}}$:** The average speed of all participants before and after signs are the same.

The alternate hypothesis is:

- **$H_{1\text{-before \& after sign}}$:** At least one participant has different average speed than the other participants.

JMP-Statistical Analysis software was used to analyze the data and the ANOVA results are shown in Table 34.

Table 34. ANOVA analysis over all participants' before and after sign average speeds

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	16	2805.330	175.333	2.9166
Error	283	17012.672	60.115	**Prob > F**
C. Total	299	19818.002		0.0002*

The P-value in Table 34 is 0.0002, which is less than the significance value (0.05). This means that at least one of the participants has different average speed from the rest. Therefore, **$H_{0\text{-before \& after sign}}$** is rejected.

To understand the effect of factors and blocks on the average speeds, the Effect tests was conducted and the results of effects test are shown in Table 35.

Table 35. Effects test results over all participants' before and after sign average speeds

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Driving Scenario	1	1	8.62625	0.1435	0.7051
Gender	1	1	289.02172	4.8078	0.0291*
Age Group	3	3	679.65973	3.7686	0.0112*
Gender*Age Group	3	3	606.47604	3.3628	0.0192*
Before & After Sign	1	1	96.32819	1.6024	0.2066
Gender*Before & After Sign	1	1	0.12313	0.0020	0.9639
Age Group*Before & After Sign	3	3	60.28430	0.3343	0.8006
Gender*Age Group*Before & After Sign	3	3	59.00561	0.3272	0.8057

Test for Interactions using All Participants' Before and After the Sign Average Speeds: Here, the effects of factor interactions are analyzed.

- **$H_{0\text{-Age Group*Gender*Before \&After Sign}}$:** The Age Group, Gender and Before & After Sign do not interact with each other in the model and thus the effect is additive in nature.

From the effects test results (Table 35), it can be seen that the effect of interaction between factor Before & After sign, Gender and Age Groups on the average speed is not significant because its P-value, 0.8057, is greater than the significance level (0.05). The null hypothesis with 95% confidence is not rejected and it can be concluded that there is no three way interaction between the Driving Scenario, Gender and Before or After Sign position.

As there is no three way interaction present, now all of the two interactions are checked.

- **$H_{0\text{-Age Group*Gender}}$:** The Age Group and Gender do not interact with each other in the model and thus the effect is additive in nature.

From the effects test results in Table 35, it can be seen that the effect of interaction between factor Gender and Age Group on the average speed is significant because it's P-value, 0.0192, is less than 0.05. The null hypothesis with 95% confidence is rejected and it is concluded that there is significant interaction between the Age Group and Gender in this part of the data.

- **$H_{0\text{-Age Group*Before or After Sign}}$:** The Age Group and Before or After Sign position do not interact with each other in the model and thus the effect is additive in nature.

From the effects test results in Table 35, it can be seen that the effect of interaction between factor Before or After Sign and Age Group on the average speed is not significant because its P-value, 0.8006, is greater than 0.05. The null hypothesis with 95% confidence is not rejected and it is concluded that there is no interaction between the Age Group and Before or After Sign position.

- **$H_{0\text{-Gender*Before or After Sign}}$:** The Gender and Before or After Sign position do not interact with each other in the model and thus the effect is additive in nature.

From the effects test results in Table 35, it can be seen that the effect of interaction between factor Gender and Before or After Sign on the average speed is not significant because its P-value, 0.9639, is greater than 0.05. The null hypothesis with 95% confidence is not rejected and conclude that there is no interaction between the Gender and Before or After Sign position.

Test for Main Effects using All Participants' Before and After the Sign Average Speeds: Here, the effects of individual factors and blocks on average speeds are analyzed.

- **$H_{0\text{-Driving Scenario}}$:** The average speed in both driving scenarios is the same.

The P-value for Driving Scenario, 0.7051, from the effects test in Table 35 is greater than 0.05, which means there is no significant effect of driving scenario (blocks) on the average speed. Therefore, $H_{0\text{-Driving Scenario}}$ is not rejected.

- **$H_{0\text{-Gender}}$:** The average speed of both genders is the same.

The P-value of the factor gender, 0.0291, in effect tests is less than 0.05, therefore, $H_{0\text{-Gender}}$ is rejected, which means factor gender has significant effect on the average speed of a driver. There are two levels of this factor, male and female, the average speed of both levels is different from each other.

- **$H_{0\text{-Age Groups}}$:** The average speed of participants is not affected by age groups.

The P-value of Age Groups is <0.0001 in Table 35, which is less than the significance level, therefore, $H_{0\text{-Age Groups}}$ is rejected, which means factor age group has significant effect on the average speed of a driver around the sign as well. There are four levels of this factor, the average speed of at least one of the levels is different from others.

- **$H_{0\text{-Before or After Sign}}$:** The average speed of all the participants is same regardless of the driver position to the sign.

The P-value, 0.2066, of the factor Before or After sign in effects test in Table 35 is greater than 0.05, therefore, **$H_{0\text{-Before or After Sign}}$** is not rejected, which means factor Before or After Sign does not have a significant effect on the average speed of a driver. There are two levels of this factor, the average speed of both levels is not different from each other.

Analysis using Least Squares Means using All Participants' Before and After the Sign Average Speeds: To better understand the difference in the levels of Gender, LSMeans student's t test was performed. The results of LSMeans student's t test results for Gender are given in Table 36.

Table 36. LSMeans student's t test results with before and after the sign average speeds for gender

Level			Least Sq Mean
MALE	A		46.985454
FEMALE		B	44.277211

Male and female are represented with different letters that means the difference in their speed is significant and males have higher average speed than females in this part of the data.

To better understand the difference in the levels of Age Group, LSMeans student's t test was performed. The results of LSMeans student's t test results for Age Group are given in Table 37.

Table 37. LSMeans student's t test results with before and after the sign average speeds for age groups

Level			Least Sq Mean
18-24	A		48.668620
25-44	A		46.622844
45-64		B	44.389629
65+		B	42.844237

The Age Groups represented with same letter have no significant difference in the average speeds. The Age Group 18-24 has a higher average speed than the other age groups at this part of

the road but it is statistically the same as age group 25-44. Age group 45-64 and 65+ is represented with a different letter than 18-24 and 25-44, therefore, the average speed of 45-64 and 65+ is significantly different than 18-24 and 25-44.

Before and After Sign Average Speed Comparison for MoDOT Scenario: As for overall comparison, the $\mathbf{H_{0\text{-before \& after sign}}}$ is rejected, which means all the average speeds are not the same. Now, only the before and after the sign average speeds under the MoDOT scenario are analyzed. This analysis will show if any change in average speed of a driver occurs after noticing the MoDOT sign. There are 2 average speeds of each driver (before and after the sign), hence there are 150 average speeds to be compared with each other.

To determine any significant differences in the average speeds, the hypothesis test using two way ANOVA table, where Gender, Age Group and Before & After sign position were the factors, was conducted.

Here, the null hypothesis is:

- $\mathbf{H_{0\text{-MoDOT-before \& after sign}}}$**:** The average speed of all participants before and after the sign is the same under MoDOT scenario.

The alternate hypothesis is:

- $\mathbf{H_{1\text{-MoDOT-before \& after sign}}}$**:** At least one participant has different average speed than the other participants under MoDOT scenario.

The JMP-Statistical Analysis software was used to carry out analysis. The results of the comparison are given in Table 38.

Table 38. ANOVA analysis over all participants' before and after sign average speeds in MoDOT scenario

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	1696.312	113.087	1.6763
Error	134	9040.157	67.464	**Prob > F**
C. Total	149	10736.469		0.0628

The P-value in Table 38 is 0.0628, which is very close to the significance value (0.05), therefore, $\mathbf{H_{0\text{-MoDOT-before \& after sign}}}$ cannot be rejected right away. Further analysis is needed to reject or accept the $\mathbf{H_{0\text{-MoDOT-before \& after sign}}}$.

To understand the effect of factors on the average speeds under MoDOT scenario, the effects test was conducted and the results of the effects test are shown in Table 39.

Table 39. Effects test results over all participants' before and after sign average speeds in MoDOT scenario

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Gender	1	1	213.20584	3.1603	0.0777
Age Group	3	3	589.87975	2.9145	0.0367*
Gender*Age Group	3	3	485.43514	2.3985	0.0708
Before or After Sign	1	1	43.31721	0.6421	0.4244
Gender*Before or After Sign	1	1	13.00325	0.1927	0.6613
Age Group*Before or After Sign	3	3	20.83953	0.1030	0.9582
Gender*Age Group*Before or After Sign	3	3	51.84956	0.2562	0.8568

Test for Interactions using All Participants' Before and After the Sign Average Speeds in MoDOT Scenario: Here, the interaction effects are investigated.

- **$H_{0\text{-Gender*Age Group*Before or After Sign}}$:** The Gender, Age Group and Before or After Sign position do not interact with each other in the model in MoDOT scenario and thus the effect is additive in nature.

From the results of the effects test for MoDOT scenario given in Table 39, it can be seen that the effect of interaction between factor Gender, Age Group and Before or After Sign on the average speed is not significant because its P-value, 0.8568, is greater than 0.05. The null hypothesis with 95% confidence is not rejected and it is concluded that there is no interaction between the Gender, Age Group and Before or After Sign position in MoDOT scenario.

- **$H_{0\text{-Gender*Age Group}}$:** The Gender and Age Group do not interact with each other in the model in MoDOT scenario and thus the effect is additive in nature.

From the results of the effects test for MoDOT scenario given in Table 39, it can be seen that the effect of interaction between factor Gender and Age Group on the average speed is not significant because its P-value, 0.0708, is greater than 0.05. The null hypothesis with 95%

confidence is not rejected and it is concluded that there is no interaction between the Gender and Age Group in MoDOT scenario.

- **$H_{0\text{-Age Group*Before or After Sign}}$:** The Age Group and Before or After Sign position do not interact with each other in the model in MoDOT scenario and thus the effect is additive in nature.

From the results of the effects test for MoDOT scenario given in Table 39, it can be seen that the effect of interaction between factor Age Group and Before or After Sign on the average speed is not significant because its P-value, 0.9582, is greater than 0.05. The null hypothesis with 95% confidence is not rejected and it is concluded that there is no interaction between the Age Group and Before or After Sign position in MoDOT scenario.

- **$H_{0\text{-Gender*Before or After Sign}}$:** The Gender and Before or After Sign position do not interact with each other in the model in MoDOT scenario and thus the effect is additive in nature

From the results of the effects test for MoDOT scenario given in Table 39, it can be seen that the effect of interaction between factor Gender and Before or After Sign on the average speed is not significant because its P-value, 0.6613, is greater than 0.05. The null hypothesis with 95% confidence is not rejected and it is concluded that there is no interaction between the Gender and Before or After Sign position in MoDOT scenario.

Test for Main Effects using All Participants' Before and After the Sign Average Speeds in MoDOT Scenario: As two way interaction was absent, the effects of the factors were analyzed.

- **$H_{0\text{-Gender}}$:** The average speed of both genders is the same in MoDOT scenario.

From the results of the effects test for MoDOT scenario given in Table 39, the P-value, 0.0777, of the factor gender in effect tests is greater than 0.05, therefore, $\mathbf{H_{0\text{-Gender}}}$ is not rejected, which means factor gender does not have a significant effect on the average speed of a driver in MoDOT scenario. There are two levels of this factor, male and female, the average speed of both levels is not different from each other.

- **$H_{0\text{-Age Groups}}$:** The average speed is not affected by age groups in MoDOT scenario.

From the results of the effects test for MoDOT scenario given in Table 39, the P-value of Age Groups is 0.0367, which is less than 0.05, therefore, $\mathbf{H_{0\text{-Age Groups}}}$ is rejected, which means, in MoDOT scenario, factor age group has significant effect on the average speed of a driver around

the sign as well. There are four levels of this factor, the average speed of at least one of the levels is different from others.

- **$H_{0\text{-Before or After Sign}}$:** The average speed of all the participants is the same regardless of the driver position to the sign in MoDOT scenario.

The P-value, 0.4244, of the factor Before or After sign in effect tests is greater than 0.05, therefore, **$H_{0\text{-Before or After Sign}}$** is not rejected, which means factor Before or After Sign does not has significant effect on the average speed of a driver in MoDOT scenario. There are two levels of this factor, the average speed of both levels is not different from each other.

Analysis using Least Squares Means using All Participants' Before and After the Sign Average Speeds in MoDOT Scenario: To get the better understanding of the effects of age groups in MoDOT scenario, LSMeans student's t test was performed on the MoDOT data. The results of the LSMeans student's t test for all the age groups are given in Table 40.

Table 40. LSMeans student's t test results with before and after the sign average speeds in MoDOT scenario for age groups

Level				Least Sq Mean
18-24	A			50.891472
25-44	A	B		47.475291
45-64		B	C	44.734278
65+			C	41.231689

It can be observed from Table 40 that the age group 18-24 has the highest average speed, which is represented with letter A and is not significantly different from the age group 25-44, but is different from 45-64 and 65+ age groups. Age group 45-64 is not significantly different from age groups 25-44 and 65+.

Before and After Sign Average Speed Comparison for MUTCD scenario: Now, only the before and after the sign average speeds under the MUTCD scenario are analyzed. This analysis will show if any change in average speed of a driver occurs after noticing the MUTCD sign. There are 2 average speeds of each driver (before and after the sign), hence there are 150 average speeds to be compared with each other.

To determine any significant differences in the average speeds, the hypothesis test using two way ANOVA table, where Gender, Age Group and Before & After sign position were the factors, was conducted.

Here, the null hypothesis is:

- **$H_{0\text{-MUTCD-before \& after sign}}$:** The average speed of all participants before and after the sign is the same under MUTCD scenario.

The alternate hypothesis is:

- **$H_{1\text{-MUTCD-before \& after sign}}$:** At least one participant has different average speed than the other participants under MUTCD scenario.

The JMP-Statistical Analysis software was used to carry out analysis. The results of the comparison are given in Table 41.

Table 41. ANOVA analysis over all participants' before and after sign average speeds in MUTCD scenario

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	1445.5328	96.3689	1.6930
Error	134	7627.3744	56.9207	**Prob > F**
C. Total	149	9072.9072		0.0593

The P-value in Table 41 is 0.0593, which is very close to the significance value (0.05), therefore, $\mathbf{H_{0\text{-MUTCD-before \& after sign}}}$ cannot be rejected right away. Further analysis is needed to reject or accept the $\mathbf{H_{0\text{-MUTCD-before \& after sign}}}$.

To understand the effect of factors on the average speeds under MUTCD scenario, the effects test was conducted and the results of the effects test are shown in Table 42.

Table 42. Effects test results over all participants' before and after sign average speeds in MUTCD scenario

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Gender	1	1	89.13180	1.5659	0.2130
Age Group	3	3	283.72193	1.6615	0.1783
Gender*Age Group	3	3	214.84942	1.2582	0.2914
Before or After the Sign	1	1	53.26797	0.9358	0.3351
Gender*Before or After the Sign	1	1	16.82844	0.2956	0.5875
Age Group*Before or After the Sign	3	3	59.76940	0.3500	0.7892
Gender*Age Group*Before or After the Sign	3	3	28.16661	0.1649	0.9198

Test for Interactions using All Participants' Before and After the Sign Average Speeds in MUTCD Scenario: Here, the interaction effects are investigated.

- **$H_{0\text{-Gender*Age Group*Before or After Sign}}$:** The Gender, Age Group and Before or After Sign position do not interact with each other in the model in MUTCD scenario and thus the effect is additive in nature.

From the results of the effects test for MUTCD scenario given in Table 42, it can be seen that the effect of interaction between factor Gender, Age Group and Before or After Sign on the average speed is not significant because its P-value, 0.9198, is greater than 0.05. The null hypothesis with 95% confidence is not rejected and it is concluded that there is no interaction between the Gender, Age Group and Before or After Sign position in MUTCD scenario.

- **$H_{0\text{-Gender*Age Group}}$:** The Gender and Age Group do not interact with each other in the model in MUTCD scenario and thus the effect is additive in nature

From the results of the effects test for MUTCD scenario given in Table 42, it can be seen that the effect of interaction between factor Gender and Age Group on the average speed is not significant because its P-value, 0.2914, is greater than 0.05. The null hypothesis with 95% confidence was not rejected and it is concluded that there is no interaction between the Gender and Age Group in MUTCD scenario.

- **$H_{0\text{-Age Group*Before or After Sign}}$:** The Age Group and Before or After Sign position do not interact with each other in the model in MUTCD scenario and thus the effect is additive in nature

From the results of the effects test for MUTCD scenario given in Table 42, it can be seen that the effect of interaction between factor Age Group and Before or After Sign on the average speed is not significant because its P-value, 0.7892, is greater than 0.05. The null hypothesis with 95% confidence is not rejected and it is concluded that there is no interaction between the Age Group and Before or After Sign position in MUTCD scenario.

- **$H_{0\text{-Gender*Before or After Sign}}$:** The Gender and Before or After Sign position do not interact with each other in the model in MUTCD scenario and thus the effect is additive in nature

From the results of the effects test for MUTCD scenario given in Table 42, it can be seen that the effect of interaction between factor Gender and Before or After Sign on the average speed is not significant because its P-value, 0.5875, is greater than 0.05. The null hypothesis with 95% confidence is not rejected and it is concluded that there is no interaction between the Gender and Before or After Sign position in MUTCD scenario.

Test for Main Effects using All Participants' Before and After the Sign Average Speeds in MUTCD Scenario:

As three way and two way interactions are absent, now the effects of the factors were analyzed.

- **$H_{0\text{-Gender}}$:** The average speed of both genders is the same in MUTCD scenario.

From the results of the effects test for MUTCD scenario given in Table 42, the P-value, 0.2130, of the factor gender in effect tests is greater than 0.05, therefore, **$H_{0\text{-Gender}}$** is not rejected, which means factor gender does not has significant effect on the average speed of a driver in MUTCD scenario. There are two levels of this factor, male and female, the average speed of both levels is not different from each other.

- **$H_{0\text{-Age Groups}}$:** The average speed is not affected by age groups in MUTCD scenario.

From the results of the effects test for MUTCD scenario given in Table 42, the P-value of Age Groups is 0.1783, which is greater than 0.05, therefore, **$H_{0\text{-Age Groups}}$** is not rejected, which means factor age group has no significant effect on the average speed of a driver around the sign in MUTCD scenario. There are four levels of this factor, the average speed of all levels is statistically same.

- **$H_{0\text{-Before or After Sign}}$:** The average speed of all the participants is the same regardless of the driver position to the sign in MUTCD scenario.

From the results of the effects test for MUTCD scenario given in Table 42, the P-value, 0.3351, of the factor Before or After sign in effect tests is greater than 0.05, therefore, **$H_{0\text{-Before or After Sign}}$** is not rejected, which means factor Before or After Sign does not have a significant effect on the average speed of a driver in MUTCD scenario. There are two levels of this factor, the average speed of both levels is not different from each other.

4.2.2. Clustering of Drivers

Clustering methods are widely used in transportation problems. These methods cluster data based on their similarities and group information into segments with common characteristics. Clustering methods are useful for finding patterns between large amounts of data. K mean clustering is one of the common clustering methods which is used to determine centers of average speed. Given the number of clusters, K, is chosen, the following optimization model determines the cluster means, $\{\bar{y}_k\}$, through minimizing the sum of squared error.

Minimize:

$$\underset{\{\bar{y}_k\}}{sse_K} = \sum_{i \in I_{ML}} \sum_{k=1}^{K} z_{ki} \left(y_{ML,i} - \bar{y}_k\right)^2$$

Subject to:

$$\sum_{k=1}^{K} z_{ki} = 1, \text{ for } i \in I_{ML}$$

$$z_{ki}{}'s \text{ are binary variables}$$

The optimization problem above is solved at different K by using Minitab 17 statistical software. The objective function value with $K = 3$ is lower than that with other K. Hence, three clusters of drivers are selected for clustering (Table 43 & 44). In this method drivers are clustered based on their average speed. Tables 43 and 44 show the average speed, age and gender of drivers in each cluster.

Table 43. Clustering of MoDOT scenario

Cluster 1				Cluster 2				Cluster 3			
Driver	**Gender**	**Age Category**	**Average Speed**	**Driver**	**Gender**	**Age Category**	**Average Speed**	**Driver**	**Gender**	**Age Category**	**Average Speed**
1	Female	2	44.43	6	Female	2	39.12	5	Male	2	56.6
2	Male	3	43.75	12	Male	4	36.33	8	Female	2	51.57
3	Male	1	45.5	19	Male	2	38.32	18	Male	2	55.92
4	Male	1	43.17	23	Female	3	35.28	31	Male	1	49
7	Female	3	46.07	27	Female	1	37.66	39	Male	1	55.45
9	Female	3	39.92	29	Male	2	36.4	45	Female	2	47.85
10	Female	2	40.76	30	Female	3	34.3	56	Male	2	50.36
11	Male	3	42.66	34	Female	3	32.79	70	Male	4	49.08
13	Female	2	44.86	35	Female	4	39.24				
14	Female	2	40.72	36	Male	4	35.84				
15	Male	2	41.68	37	Female	3	36.78				
16	Female	2	41.22	43	Female	3	34.78				
17	Female	2	41.41	44	Male	1	37.9				
20	Male	1	43.03	46	Female	1	34.46				
21	Female	2	42.38	48	Male	3	37.06				
22	Male	2	41.6	50	Female	2	33.08				
24	Male	2	44.46	51	Female	4	37.67				
25	Female	2	42.55	53	Female	3	36.38				
26	Female	3	41.48	57	Male	2	36.63				
28	Male	2	42.5	58	Male	4	37.54				
32	Female	3	40.18	60	Male	4	37.18				
33	Female	2	41.33	63	Male	1	34.7				
38	Female	2	39.81	65	Female	3	37.72				
40	Female	3	41.77	66	Male	3	38.48				
41	Male	3	39.42	67	Female	3	36.7				
42	Female	3	41.7	68	Female	3	35.07				
47	Male	1	43.95	69	Female	3	36.38				
49	Female	3	41.71	71	Male	2	34.08				
52	Male	2	41.82	74	Female	2	37.48				
54	Male	3	41.9	75	Male	2	33.96				
55	Female	2	40.12								
59	Female	3	39.97								
61	Male	3	41.58								
62	Male	3	44.01								
64	Male	3	42.25								
72	Female	2	40.27								
73	Female	2	40.28								
Count	37			Count	30			Count	8		
Average speed	42.06			Average speed	36.30			Average speed	51.97		

Table 44. Clustering of MUTCD scenario

Cluster 1				Cluster 2				Cluster 3			
Driver	Gender	Age Category	Average Speed	Driver	Gender	Age Category	Average Speed	Driver	Gender	Age Category	Average Speed
1	Female	2	55.71	2	Male	3	40.45	3	Male	1	45.56
5	Male	2	55.51	6	Female	2	40.81	4	Male	1	41.48
52	Male	2	52.031	9	Female	3	40.75	7	Female	3	47.07
				11	Male	3	39.62	8	Female	2	48.88
				12	Male	4	37.68	10	Female	2	42.29
				14	Female	2	39.81	13	Female	2	45.91
				19	Male	2	37.83	15	Male	2	42.15
				23	Female	3	36.32	16	Female	2	41.93
				26	Female	3	41.46	17	Female	2	43.71
				27	Female	1	38.27	18	Male	2	48.44
				29	Male	2	33.69	20	Male	1	43.02
				30	Female	3	34.47	21	Female	2	42.03
				33	Female	2	39.61	22	Male	2	42.58
				34	Female	3	39.27	24	Male	2	45.72
				35	Female	4	36.63	25	Female	2	41.83
				36	Male	4	36.75	28	Male	2	44.53
				37	Female	3	39.86	31	Male	1	48.78
				40	Female	3	37.92	32	Female	3	43.98
				41	Male	3	40.54	38	Female	2	41.75
				43	Female	3	35.24	39	Male	1	45.54
				44	Male	1	39.28	42	Female	3	43.34
				46	Female	1	36.37	45	Female	2	46.7
				47	Male	1	40.02	54	Male	3	43.9
				48	Male	3	37.67	56	Male	2	47.97
				49	Female	3	40.01	62	Male	3	44.58
				50	Female	2	35.24	64	Male	3	43.05
				51	Female	4	39.34	70	Male	4	47.37
				53	Female	3	37.3	74	1	2	42.01
				55	Female	2	39.51				
				57	Male	2	37.1				
				58	Male	4	35.69				
				59	Female	3	39.12				
				60	Male	4	37.74				
				61	Male	3	40.31				
				63	Male	1	37.43				
				65	Female	3	38.39				
				66	Male	3	38.28				
				67	Female	3	39.21				
				68	Female	3	39.01				
				69	Female	3	39.89				
				71	Male	2	35.38				
				72	Female	2	38.87				
				73	Female	2	40.44				
				75	Male	2	37.37				
Count	3			Count	44			Count	28		
Average speed	54.42			Average speed	38.32			Average speed	44.50		

In the MoDOT scenario cluster one average speed is 42.06 and contains 37 drivers. Cluster two average speed is 36.3 and contains 30 drivers. Cluster three has the highest average speed at 51.97 and contains 8 drivers (Table 43).

In MUTCD scenario, cluster one contains 3 drivers and has the highest speed by 54.42. Cluster two contains 44 drivers and the average speed of 38.32. Cluster three average speed is 44.50 and contain 28 drivers (Table 44).

4.3. Likert Analysis

Based on De Winter & Dodou (2010) research Likert Scale is important in research such as usability, environmental, and behavioral science. In Likert Scale responders express their level of agreement with five or seven scales in response level. In get rid of 1st person Likert Scale based on seven scale questionnaire to find out drivers level of satisfaction of signs in the two scenarios. The first step in analyzing the data of questionnaire is calculation of Cronbach's alpha that is a measure of reliability on questions. Cronbach's alpha reliability coefficient range is between 0 and 1. The closer Cronbach's alpha coefficient is to 1.0 the greater the internal consistency of the items in the scale. In total Cronbach's alpha reliability coefficient greater than 0.7 is acceptable. In this research Cronbach's alpha reliability coefficient is 0.7442 that is in the range of acceptable. The questionnaire consists of following questions:

Q1: Were you comfortable with the MoDOT signs

Q2: Did the sign make you notice you were approaching the work zone (MoDOT Scenario)

Q3: Did the sign make you notice ending the work zone and you can merge into other lane (MoDOT Scenario)

Q4: Were you comfortable with the MUTCD signs

Q5: Did sign make you notice you were approaching the work zone (MUTCD Scenario)

Q6: Did sign make you notice ending the work zone and you can merge into other lane (MUTCD Scenario)

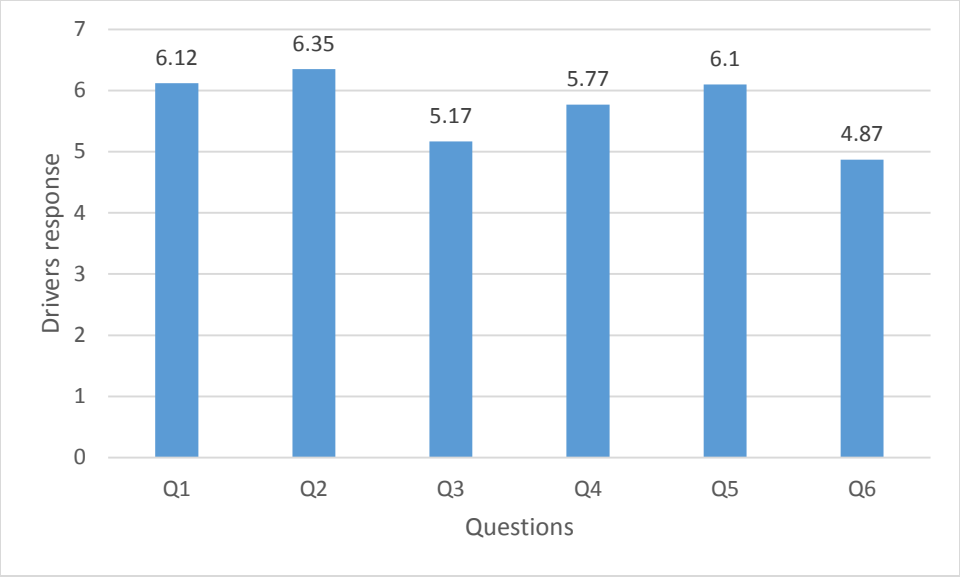


Figure 26. Analysis of questionnaire

Based on the results of the questionnaire drivers were more comfortable with the MoDOT sign rather than the MUTCD sign.

5. Conclusion

In this study, a simulator was used to evaluate an alternate lane shift sign configuration against the current MUTCD sign configuration. Three lanes, two lanes on one side and one lane on the other side of the work area are simulated. The study considered whether the traveling public better responded to split signs or combined signs. If a driver misses one sign due to vehicles blocking their view, they may think they have only one option and may make an aggressive lane shift to get into a "perceived open lane" when in reality they had open lanes if they would have stayed in their original lane. Two driving scenarios were considered as part of this study.

Based on the data analysis, no difference was observed between MUTCD lane shift sign and MoDOT lane shift sign lane shift pattern with respect to driving patterns. In summary, statistical data analysis clearly demonstrated that there was not a noticeable, statistical difference between lane change patterns of drivers in the MoDOT alternate signs with MUTCD signs in the work zone. In addition, gender does not have significant effect on driver lane change patterns, but drivers' age does have an effect. As age increased, the average speed of a driver decreased.

Gender did have an impact on average speed. Female drivers had a lower average speed than males. The average speed of drivers in MoDOT scenario is less than MUTCD scenario, but this difference is not statistically significant. In reviewing the post-simulator questionnaire responses, most of the drivers preferred the MoDOT sign configuration over the MUTCD sign configuration and found the MoDOT sign configuration more intuitive. Because driver preference is anecdotal rather than statistical, an expanded study might prove useful in refining results and better determining driver preferences and performance.

6. References

1. Edara, P. K., Sun, C., & Zhu, Z., 2013. Investigation of Alternative Work Zone Merging Sign Configurations (No. MATC-MU: 176).
2. Long, S. K., Qin, R., Konur, D., Leu, M., Moradpour, S., & Wu, S., 2016. Work Zone Simulator Analysis: Driver Performance and Acceptance of Alternate Merge Sign Configurations. Technical Report, Report # cmr16-014, Available at https://library.modot.mo.gov/RDT/reports/TR201512/cmr16-014.pdf.
3. Aghazadeh, F., Ikuma, L. H., & Ishak, S., 2013. Effect of Changing Driving Conditions on Driver Behavior towards Design of a Safe and Efficient Traffic System (No. SWUTC/13/600451-00103-1).
4. Moradpour, S., Wu, S., & Leu, M. C., 2015. Use of Traffic Simulators to Determine Driver Response to Work Zone Configurations. Proc. of the International Annual Conference of the American Society for Engineering Management, October 7-10, Indianapolis, Indiana, 1-9.
5. Tasca, L., 2000. A review of the literature on aggressive driving research. Ontario Advisory Group on Safe Driving Secretariat, Road User Safety Branch, Ontario Ministry of Transportation.
6. Goehring, J. B., 2000. Aggressive driving: background and overview report.
7. Murray, A., 1998. The home and school background of young drivers involved in traffic accidents. Accident Analysis & Prevention 30.2: 169-182.
8. Arnett, J. J., 1998. Risk behavior and family role transitions during the twenties. Journal of youth and adolescence 27.3: 301-320.
9. Elliott, M. R., Shope, J. T., Raghunathan, T. E., & Waller, P. F., 2006. Gender differences among young drivers in the association between high-risk driving and substance use and environmental influences. Journal of studies on alcohol 67.2: 252.
10. Zador, P.L., Krawchuk, S.A., & Voas, R.B., 2000. Alcohol-related relative risk of driver fatalities and driver involvement in fatal crashes in relation to driver age and gender: An update using 1996 data. J. Stud. Alcohol. 61:387–395.
11. Rhodes, N., & Pivik, K., 2011. Age and gender differences in risky driving. The roles of positive affect and risk perception. Accident Analysis & Prevention 43.3: 923-931.
12. Weng, J., & Meng, Q., 2012. Effects of environment, vehicle and driver characteristics on risky driving behavior at work zones. Safety science 50.4: 1034-1042.

13. Kamyab, A., Maze, T.H., Nelson, M., & Schrock, S D., 1999. Using Simulation to Evaluate the Performance of Smart Work Zone Technologies and Other Strategies to Reduce Congestion. In Proceedings for the 6th World Congress on Intelligent Transport Systems.
14. Van Der Horst, R., & Hoeskstra, W., 1994. Testing Speed Reduction Designs for 80 Kilometer per Hour Reads with Simulator. Transportation Research Record, No. 1464, pp. 63–68.
15. Lee, Hoe C., Lee A. H., Cameron D., & Li-Tsang C., 2003. Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes. Journal of safety research 34.4: 453-459.
16. De Winter, J. C., & Dodou, D., 2010. Five-point Likert items: t test versus Mann-Whitney-Wilcoxon. Practical Assessment, Research & Evaluation, 15(11), 1-12.

7. Appendix

7.1. Appendix 1: Consent Form

Title of research:

Work Zone Simulator Analysis: Driver Performance and Acceptance of Missouri Alternate Lane Shift Configurations

Investigators:

Dr. Suzanna Long, Engineering Management and Systems Engineering (EMSE), Missouri S&T, 230 EMGT, 600 W. 14th Street, Rolla, MO 65409, Phone: 573/341-7621, FAX: 573/ 341-6990, Email: longsuz@mst.edu

Dr. Ming Leu, Mechanical and Aerospace Engineering, Missouri S&T, 320 Engineering Research Lab, ROLLA, MO 65409, Phone: 573/341-4482, Email: mleu@mst.edu

Dr. Ruwen Qin, EMSE, Missouri S&T, 218 Engineering Management, 600 W. 14th Street, Rolla MO 65406-037, Office: (573) 341-4493, Email: qinr@mst.edu

Dr. Dincer Konur , EMSE, Missouri S&T, 206 Engineering Management, 600 W. 14th Street, Rolla MO 65406-037, Office: (573) 341-7256, Mobile: (352) 870-5269, Email: konurd@mst.edu

Samareh Moradpour, EMSE, Missouri S&T

Satwinder Singh Thind, EMSE, Missouri S&T

Hari Narayanan Vijaya Raghavan Nadathur, EMSE, Missouri S&T

Purpose of research:

This project will develop driving scenarios using the S&T driver simulator for use in the evaluation of a Missouri alternate lane shift sign configuration for work zones. Drivers will complete the scenarios comparing the current FHWA approved merge sign configuration with an alternate merge sign configuration proposed by MoDOT.

Procedure:

The first step is read and the consent form. After you will complete the demographic form. Then you will get familiar with the DS experiment before the real test by driving through a trial environment. You can stop the test if feel uncomfortable.

Financial information:

To encourage participation, $10 gift cards will be provided to all participants who complete the study.

Privacy:

The identity of all participants will remain confidential. Results of research will be published without identifying information of the participants.

Please keep your driver's license with you on the day of experiment.

Please wear your prescription glasses required for driving on the day of experiment.

I agree to participate in this research explained above.

Subject signature: Date:

Print name: Email

7.2. Appendix 2: Pre-Questionnaire

Demographic form

- It is important not to drink alcohol for 24 hours before participation in the experiment.
- It is important not to use any drugs (mainly recreationally) one week before scheduled participation.

Gender	Male		Female		Other
Age	18-24	25-44	45-64	>64	
Driving experience (Years)	<1	1-5	5-9	>=10	
Race/Ethnicity	White	Asian	Hispanic	African American	American Indian
Native language	English		Non English		
Education	Undergraduate		Graduate		
Age received license					
Years licensed					
Number of miles driving yearly					
Number of driving accidents in last 12 months					
Number of driving violations in last 12 months					

7.3. Appendix 3: Post-Questionnaire

Post questionnaire

1. **Did you have a positive experience using the driving simulator? Why or why not?**

1 – Completely dissatisfied 2 – Mostly dissatisfied 3 – Somewhat dissatisfied

4 – Neither satisfied or dissatisfied 5 – Somewhat satisfied 6 – Mostly satisfied

7 – Completely satisfied

2. **Did the driving simulator cause symptoms of dizziness at all while driving?**

1 – Completely dissatisfied 2 – Mostly dissatisfied 3 – Somewhat dissatisfied

4 – Neither satisfied or dissatisfied 5 – Somewhat satisfied 6 – Mostly satisfied

7 – Completely satisfied

Scenario 1: MoDOT scenario

3. **Were you comfortable with the signs?**

1 – Completely dissatisfied 2 – Mostly dissatisfied 3 – Somewhat dissatisfied

4 – Neither satisfied or dissatisfied 5 – Somewhat satisfied 6 – Mostly satisfied

7 – Completely satisfied

4. **Did sign make you notice approaching the work zone?**

1 – Completely dissatisfied 2 – Mostly dissatisfied 3 – Somewhat dissatisfied

4 – Neither satisfied or dissatisfied 5 – Somewhat satisfied 6 – Mostly satisfied

7 – Completely satisfied

5. **Did sign make you notice ending the work zone and you can merge other lane?**

1 – Completely dissatisfied 2 – Mostly dissatisfied 3 – Somewhat dissatisfied

4 – Neither satisfied or dissatisfied 5 – Somewhat satisfied 6 – Mostly satisfied

7 – Completely satisfied

Scenario 2: MUTCD scenario

6. **Were you comfortable with the signs?**

1 – Completely dissatisfied 2 – Mostly dissatisfied 3 – Somewhat dissatisfied

4 – Neither satisfied or dissatisfied 5 – Somewhat satisfied 6 – Mostly satisfied

7 – Completely satisfied

7. **Did sign make you notice approaching the work zone?**

1 – Completely dissatisfied 2 – Mostly dissatisfied 3 – Somewhat dissatisfied

4 – Neither satisfied or dissatisfied 5 – Somewhat satisfied 6 – Mostly satisfied

7 – Completely satisfied

8. **Did sign make you notice ending the work zone and you can merge other lane?**

1 – Completely dissatisfied 2 – Mostly dissatisfied 3 – Somewhat dissatisfied

4 – Neither satisfied or dissatisfied 5 – Somewhat satisfied 6 – Mostly satisfied

7 – Completely satisfied

7.4. Appendix 4: Driving Simulator of Missouri University of Science and Technology

A driving simulator was used as component of this study. This driving simulator was a fixed base driving simulator with a Ford ranger pickup cabin (Figure 27). This simulated cabin included a steering wheel, accelerator pedal, brake pedal, and speedometer. The driving simulator assembly included a data acquisition system, three 3,000 lumen Liquid Crystal Display (LCD) projectors, a projection screen, and a master simulation computer. The steering wheel was encompassed with force feedback to imitate realistic driving. The data such as speed, time, position, acceleration, braking amount and steering angle was recorded by acquisition board while drivers driving the driving simulator.

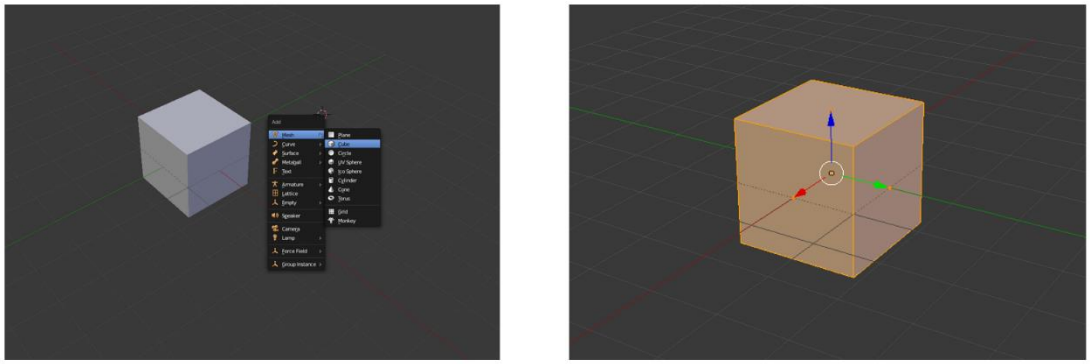
Figure 27. Driving simulator

In follow different steps of driving simulator programming discussed in brief:

1. Software information: Blender 3D software was used to simulate the road, signs, tapers, and virtual environment.

2. Objects in virtual driving environment

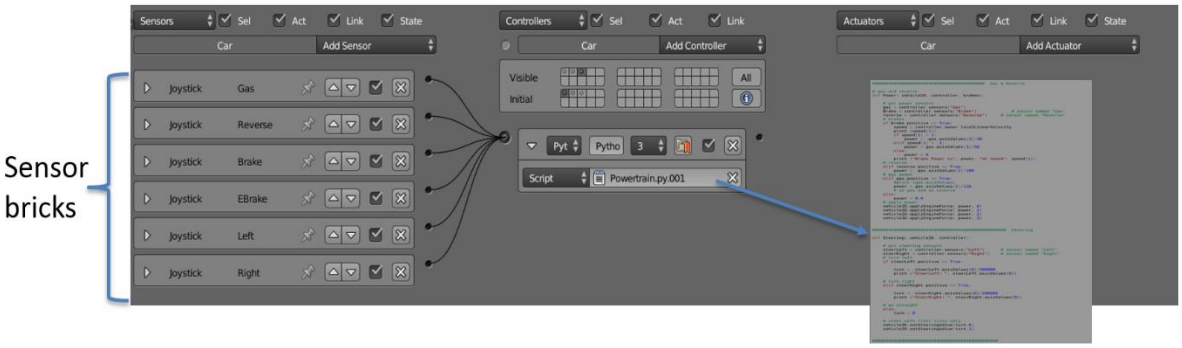
   To build the 3D model of a real-world object in Blender 3D, basic mesh such as plane, cube, cylinder, etc are used as a starting point. After that the geometry of the mesh is modified by editing its vertex, edge and face.



(a) (b)

Figure 28. (a) Basic mesh for a cube, (b) the mesh in an edit model

3. Python script in BGE: A system of graphical "logic bricks" which consist of sensor, controller, and actuator uses to control movement and show objects in the game engine by binding the Python script.



(e)

Figure 29. The logic bricks and Python script used to control the vehicle's movement

4. Simulator operation: This step consist of some sub steps such as:

   Step 1: Powering the Simulator

   Step2: Configuring the Projectors

   Step3: Configuring the Arduino

   Step4: Configuring the Steering Wheel

   Step5: Configuring Blender