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Data analysis of lane merge and lane shift sign configurations in a freeway workzone

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DATA ANALYSIS OF LANE MERGE AND LANE SHIFT SIGN CONFIGURATIONS IN A FREEWAY WORK ZONE

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ABSTRACT

In this study, driver responses to alternative lane shift and lane merge signs are analyzed and compared using a driving simulation system. In particular, driver responses to the lane merge signs proposed by the Missouri Department of Transportation (MoDOT) are compared to the current lane merge signs recommended by the Manual on Uniform Traffic Control Devices (MUTCD) and driver responses to the lane shift signs proposed by MoDOT are compared to current lane shift signs recommended by MUTCD. The driving simulation system is composed of a driving simulator and a PC with data recording program such that the position coordinates, speed, braking amount, and steering amount are recorded each second. For lane merge signs, four scenarios are simulated: two with MUTCD (left merge and right merge) sign configurations and two with MoDOT (left merge and right merge) sign configurations. For lane shift signs, two driving scenarios are simulated: one with MUTCD lane shift sign configuration and the other with the MoDOT lane shift sign configuration. 75 participants with varying demographic characteristics drove on the four lane merge sign configuration scenarios and different 75 participants with varying demographic characteristics drove on the two lane shift sign configuration scenarios. The data collected is analyzed with statistical data analysis tools. The results of the analysis show that while each individual driving group has similar responses to the alternative sign configurations, there are significant differences among the driving groups' responses to the individual sign configurations. This study also demonstrates the feasibility of the driving simulation system for analyzing driving patterns.

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ABBREVIATION LIST

MoDOT – Missouri Department of Transportation

DOT – Departments of Transportation

FHWA – Federal Highway Administration

MUTCD – Manual on Uniform Traffic Control Devices

RCB – Randomized Complete Block

ANOVA – Analysis of Variance

1. INTRODUCTION

The aging of the roads has increased the need of maintenance and rehabilitation operations on roads. Though these operations are necessary to preserve the transportation infrastructure throughout the United States, increased number of work zones can result in higher number of accidents compared to the normal road conditions [1]. The reasons behind this are the changed road conditions, such as lane closures, lane merges, lane shifts, required to complete the maintenance and rehabilitation operations. Such road conditions might impose risky driving maneuvers; hence, decrease traffic safety. Regarding the Federal Highway Administration (FHWA) statistics, 1.8 fatalities were recorded in work zones per day in 2014 [2]. In the state of Missouri, on average, two persons were killed or injured in work zone traffic crashes per day in 2011 [3]. Therefore, Departments of Transportation (DOTs) have always been interested in evaluating the risk factors and improvement of safety associated with work zones [4].

DOTs use different methods to enhance the safety of drivers in work zones. Work zone traffic sign configuration is one of the ways to inform the upcoming traffic about the work zone. Therefore, it is important that drivers understand those work zone traffic signs. DOTs can propose and implement work zone traffic sign configurations alternative to the nationally standardized configurations suggested by FHWA within the Manual on Uniform Traffic Control Devices (MUTCD) (see [5]). However, by law, it is required for DOTs to test the effectiveness and safety of any alternative work zone signage configuration before making implementation decisions [4]. Specifically, drivers' reactions to a new signage configurations and their driving patterns through the work zones with the new signage configurations should be studied to make good implementation decisions [6]. Studies on evaluating driving behavior in different situations have been a field of interest for several researchers.

Recently, MoDOT has considered implementing alternative work zone signs in work zones that require lane shift and lane merge. As per the requirements of law, a comparison between these alternative sign configurations and MUTCD sign configurations should be carried out by MoDOT. The first part of this study compares alternative lane merge signs proposed by MoDOT to the current MUTCD lane merge signs. The second part of this study compares alternative lane shift signs proposed by MoDOT to the current MUTCD lane shift signs. For comparisons in each part, a driving simulation system is used to collect data and the collected data is analyzed using data analysis tools.

The driving simulator system used in this study is present in the Engineering Research Labs building of the Missouri University of Science and Technology, and is a fixed base simulator with Ford ranger pickup truck cabin. The cabin of the driving simulator consists of a steering wheel, accelerator pedal, brake pedal, speedometer which give participants a realistic driving experience. The driving simulator system also includes a data acquisition system, three projectors, a projection screen, and a simulation computer. The projection screen has width of 25 feet and height of 6.5 feet. The driving scenarios are simulated using BLENDER 3D software and PYTHON. The data acquisition system records speed, position, acceleration, deceleration and steering angle during a simulation. Figure 1.1 illustrates the driving simulator used in this study.

Figure 1.1. Driving simulator

2. LITERATURE REVIEW

Studies on evaluating driving behavior in different situations have been field of interest for many researchers. According to [7], there are two types of driving behavior research, one type is Surveys, to get estimates of self-reported driving behaviors, and the other type is Field experiments, to observe aggressive behaviors in specific settings and evaluating such behaviors. The aggressive behavior defined by [7] doesn't include the intention of a driver to harm anyone; it includes impatience, hostility or an attempt to save time. According to the American Automobile Association, aggressive driving behavior is an operation of a motor vehicle without caring about the safety of other people [8]. The American Automobile Association's definition also doesn't include road rage behavior, which is defined as an assault with the intentions of doing harm to anyone by using a motor vehicle [8].

According to [9], teenagers, who possess substance use, are more likely to take high risk driving behavior and get into serious vehicle accidents in both men and women. Less parental involvement was also mentioned to increase the risk of serious vehicle crashes in teenagers [9]. In [10], it is mentioned that family role transition and risky driving behavior are inversely related. People, who have children, are less likely to show risky driving behavior. The relationship between performance at school and risky driving behavior is explained in [11]. Students, who showed risky driving behavior, had poor performance at school. The correlation between use of substances/environmental factors and high risk driving behavior is noted to be stronger among young women than among young men [12]. It is discussed that if men and women eventually receive equal levels of substance use, women are more likely to retain less risky driving behavior [12].

According to the results of [13], young women from 16- to 20-year-old, have lower fatality risk than men when they have the same blood alcohol concentration levels. In study [14], a regression model is developed to study the relationship between age, gender and risky driving behavior, the adult and female drivers are found to possess less risky behavior as compared to teen and male drivers.

The above studies focus on evaluating driving behaviors of different driver groups. Similar to those studies, in this study, driving behaviors of different driver groups are analyzed under different scenarios. Particularly, this study uses driving simulation to investigate driver patterns in work zones as response to different sign configurations. In literature, there are other studies using driving simulation for analyzing driving behaviors in work zones. Specifically, it is discussed that field experiments can be expensive as well as dangerous [4]. For instance, [18] pointed out the usefulness of the driving simulation to investigate driving behaviors in an economic way as compared to the field experiments. Due to such cost and safety issues, many researchers have used driving simulation to study driving behaviors, as is done in this study. Below such related studies are briefly summarized.

In research [15], the effects of environment, vehicle and driver characteristics on the driving behavior in work zone were analyzed. It is 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. Furthermore, it is noted that middle-aged male drivers, who have an airbag system in vehicle and are going straight ahead, are more likely to show risky behavior in work zones than middle aged female drivers [15]. A microscopic traffic simulation model was used in [16] to investigate the effects of capacity enhancement and traffic management strategies in a work zone on an interstate highway. These strategies would help to reduce the congestion caused by reduction of lanes [16].

A driving simulator was used to study the effect of lane width reduction in work zone on the driving speed [17]. The results of study showed that if the lane width is reduced by 18% or more from the ideal lane width, it causes drivers to reduce their speeds. In study [18], researchers used a 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 an economical way than performing the expensive road tests.

The effects of using an alternative merge sign configuration within a freeway work zone are evaluated in [20]. The graphical lane closed sign from MUTCD to Merge/arrow sign on one side and RIGHT LANE CLOSED sign on the other side were compared. It is found that the open lane occupancy was higher upstream for the alternative sign whereas occupancy values were similar for both configurations leading to a taper.

[19] examined the influences of different work zone configurations on a driver behavior using a simulation study. The MUTCD lane merge sign 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. It is noticed that there was no significant difference in drivers' speed between the two signs.

3. LANE MERGE SIGN ANALYSIS

3.1 PROJECT DESCRIPTION AND DATA COLLECTION

The first part of this study compares the existing left and right lane merge sign configurations per the MUTCD to left and right lane merge sign configurations proposed by MoDOT. The driving simulator is used to perform this comparison. Two scenarios are simulated for left merging (one with MUTCD left merge sign and one with MoDOT left merge sign) and two scenarios are simulated for right merging (one with MUTCD right merge sign and one with MoDOT right merge sign).

Figure 3.1 (a) and (b) illustrates the left merge signs of MUTCD and MoDOT, respectively. Figure 3.1 shows that the right lane is closed in both left merge scenarios.

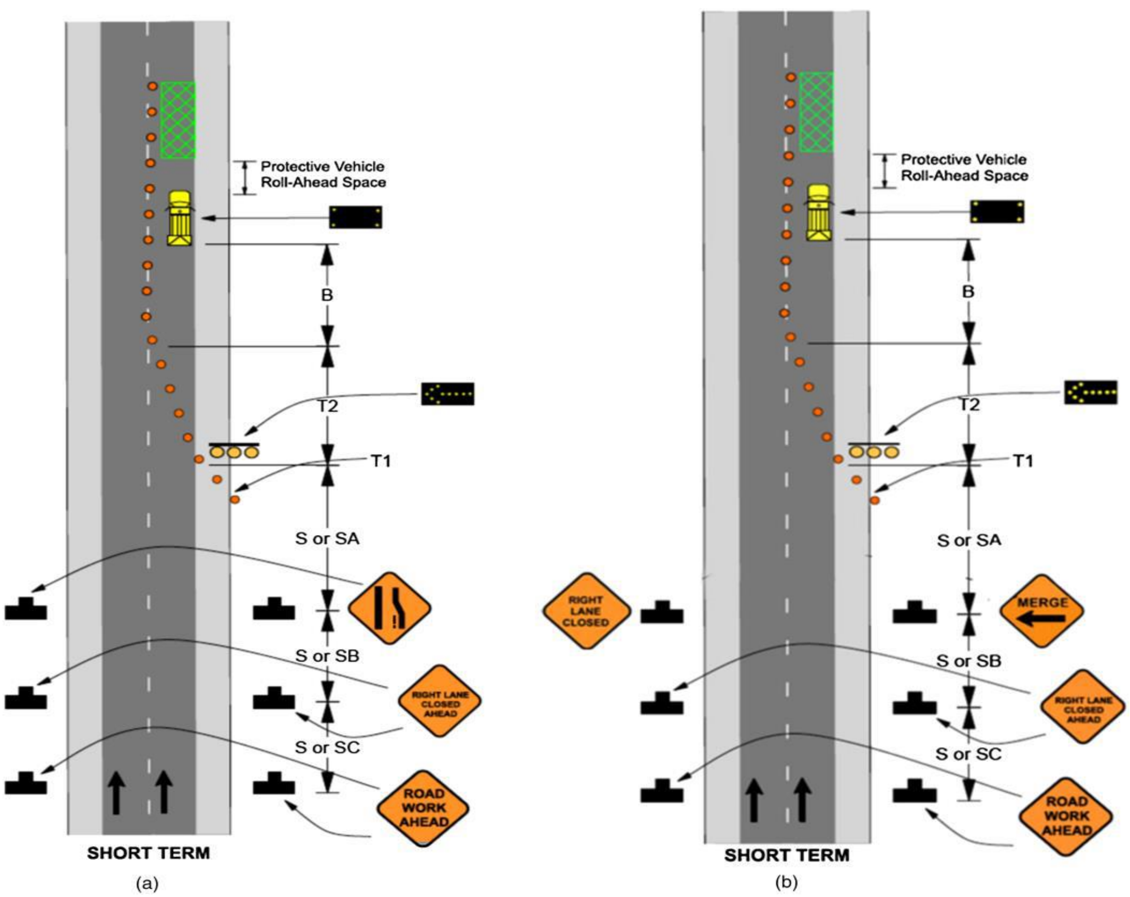

Figure 3.1. Merge left driving scenarios
a) MUTCD merge left b) MoDOT's proposed alternative merge left

Figure 3.2 (a) and (b) illustrate the right merge scenarios of MUTCD and MoDOT, respectively. It is shown in Figure 3.2 that left lanes are closed in both scenarios while all signs other than merge sign in both scenarios same.

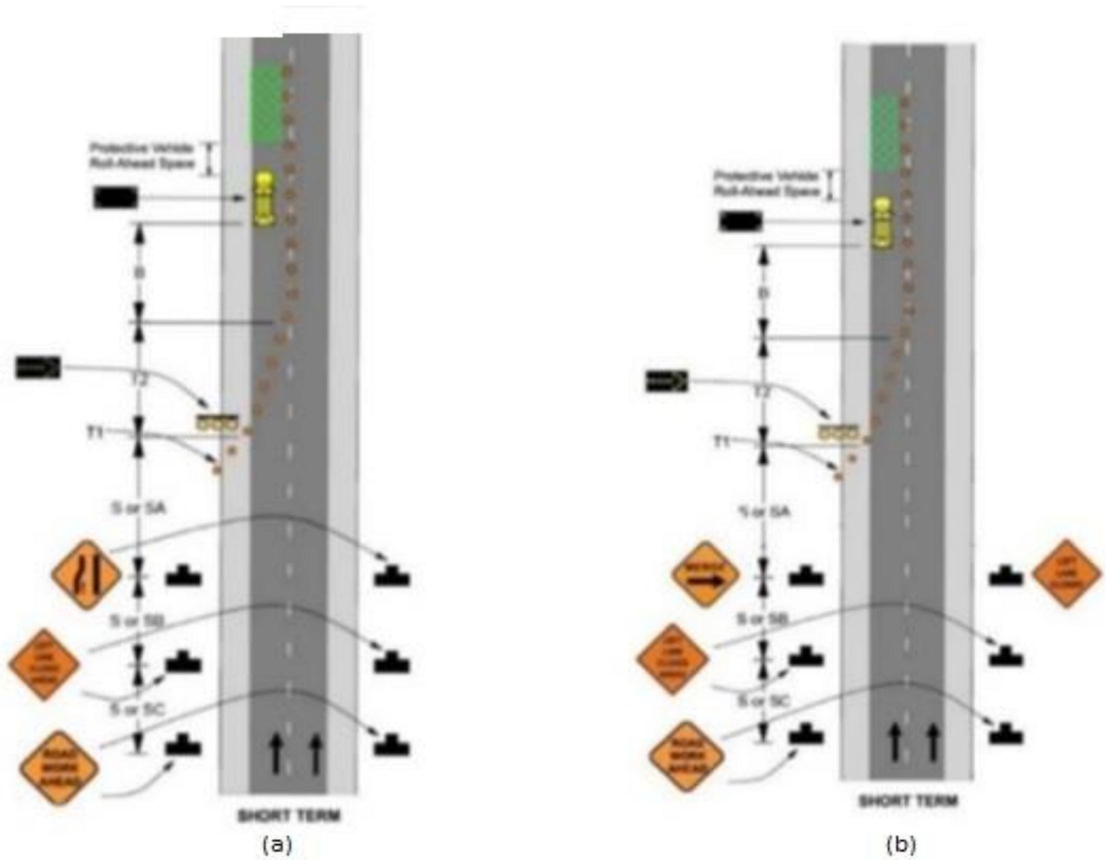

Figure 3.2. Merge right driving scenarios
a) MUTCD merge right, b) MoDOT alternate merge right

These designs of scenarios helped in understanding the effect of different merge signs on the driving behavior.

The motivation behind the first part of this study is to compare the human driving behavior in two different sign configurations of left and right merging. To do so, 4 driving scenarios in total are designed through a planned work zone area according to the details provided by MoDOT. These 4 scenarios are as follows:

- Scenario-1: MUTCD approved merge left sign configuration,

- Scenario-2: MUTCD approved merge right sign configuration,
- Scenario-3: Alternate merge left sign configuration proposed by MoDOT,
- Scenario-4: Alternate merge right sign configuration proposed by MoDOT.

75 participants with different driving experience and age took part in this driving simulation study. Before the start of simulation, participants were asked to answer a questionnaire, which recorded the age, gender and driving experience of the participants. The participants drove on the 4 different driving scenarios: MUTCD merge left and MUTCD merge right, MoDOT alternate merge left, and MoDOT alternate merge right. Each participant's position co-ordinates, speed, brake amount and steering amount were recorded by the driving simulator system. Participants were required to hold a current driver's license. The participants were given a chance to get used to the driving simulator environment by driving on the practice scenario and participants could stop if they didn't feel good at any point during the simulation. The participants' demographic information and driving history are summarized in Table 3.1.

Table 3.1. Demographic information and driving experience of participants

Age Groups				Gender		No. of years of driving experience			
18-24	25-44	45-64	65+	Female	Male	<1	1-5	5-10	>10
11	28	27	9	41	34	2	9	3	61

In each scenario, the driving simulator records five parameters for each participant. These parameters are position coordinates, speed, brake amount, steering amount and time. Therefore, driving simulator generates a data set for each driver under each scenario. The datasets of drivers are further needed to be refined before being used for data analysis.

3.2 DESCRIPTIVE ANALYSIS OF LANE MERGE SIGN CONFIGURATIONS

In this part, the participant drivers' reactions to alternative merge sign configurations are compared using the data collected with the driving simulator. In particular, the focus is to compare the left merge signs of MUTCD to MoDOT left merge signs and the right merge signs of MUTCD to MoDOT right merge signs. Figure 3.3 shows a typical driving pattern with left merge and right merge signs.

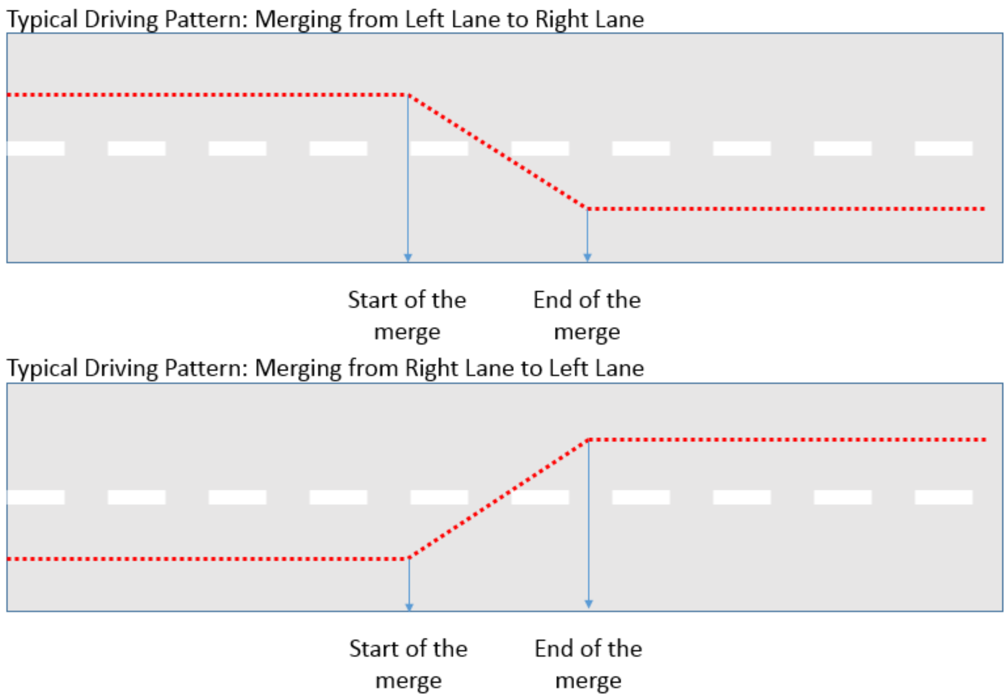

Figure 3.3. Typical left merge and right merge pattern

The start-of-merge and end-of-the-merge are two important points for analyzing a driver's reaction to different merge signs. It can be accepted that the sooner the merge starts and ends, it is safer to travel through a work zone. Therefore, the focus is on determining how the start-of-the-merge and end-of-the-merge change with alternative signs on average using the driver patterns collected with the driving simulation.

In doing so, an immediate approach could be used to generate the average driving pattern under each configuration and compare the average driving patterns. However, this approach will have issues in determining the start- and end-of-the-merge. In particular, the average driving pattern will observe a merging pattern with the earliest individual start-of-the-merge point. In addition, the average driving pattern will observe non-merging pattern after the latest individual end-of-the-merge point. These issues are illustrated in Figure 3.4.

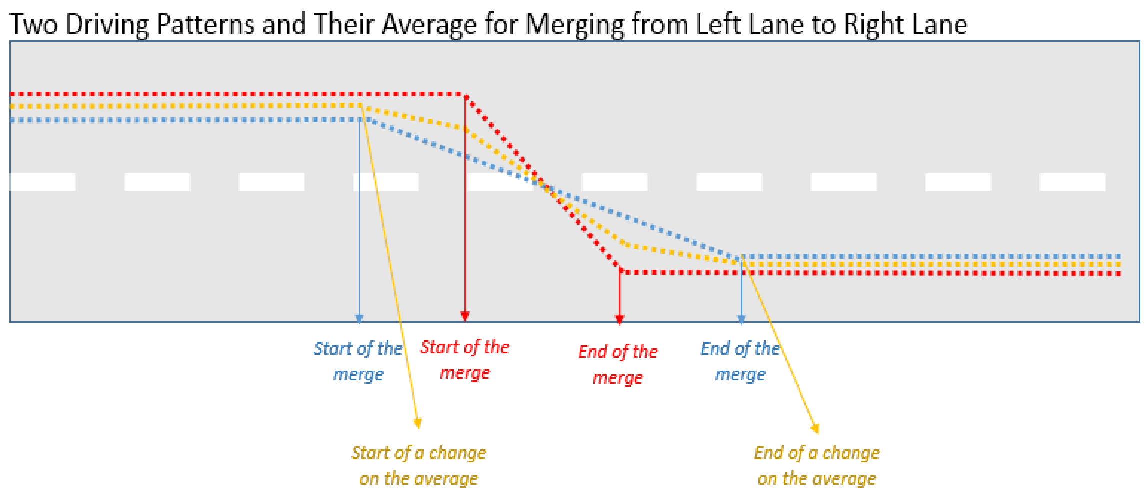

Figure 3.4. Two right merge patterns and their average

To avoid these issues, the focus was on descriptive analysis. Instead of getting the average driving pattern and then determining representative start- and end-of-the-merge points from the average pattern, the start- and end-of-the merge-points on each driver's pattern were determined individually under each configuration, then those individual points were used to determine representative start- and end-of-the-merge points. Below the details of the methodology and results are explained step by step.

Step 1. Determining the individual start- and end-of-the-merge points: Each participant has been simulated under four different scenarios: MUTCD left-lane-merge, MoDOT left-lane-merge, MUTCD right-lane-merge, MoDOT right-lane-merge. That is, each participant has four different driving patterns collected. A driving pattern consist of (x,y)-coordinates measured approximately each second while the individual is driving on the simulated road. Figure 3.5 illustrates the start-of-merge and end-of-merge points for left-lane-merge and right-lane-merge signs.

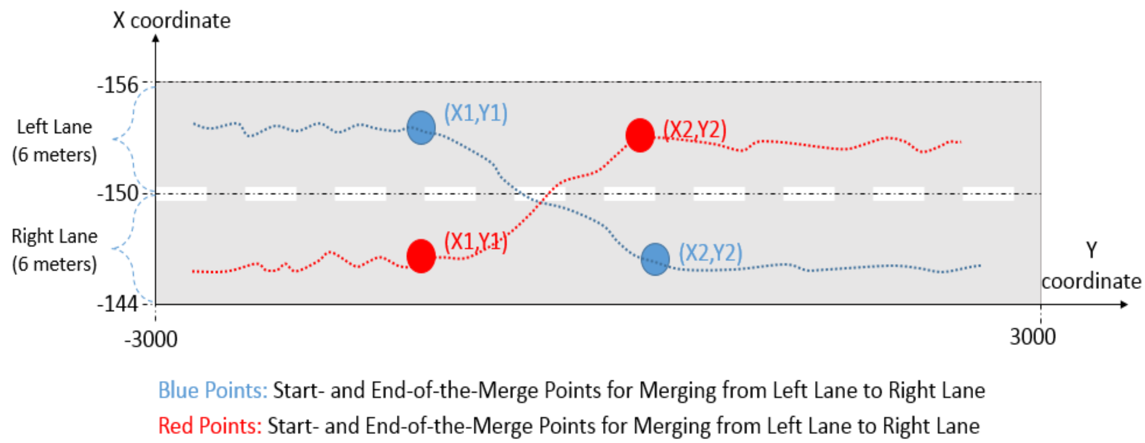

Figure 3.5. Starting and ending of merge coordinates

Using the individual driving patterns, at first, the start- and end-of-the merge coordinates for each participant under each of the four scenarios were determined. Particularly, in doing so, at first the graph of driving pattern is made and the graph reveals the start- and end-of-the-merge points. Figure 3.6 illustrates how these points are recorded for an individual participant.

	Left-Lane-Merge								Right-Lane-Merge							
	MUTCD				MODOT				MUTCD				MODOT			
	Start-of-the-Merge		End-of-the-Merge		Start-of-the-Merge		End-of-the-Merge		Start-of-the-Merge		End-of-the-Merge		Start-of-the-Merge		End-of-the-Merge	
Participant	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*
A	-153.63	14.76	-147.55	363.5	-153.67	16.32	-147.09	557.76	-147.58	-303.64	-152.03	231.13	-147.31	-7.38	-153.16	313.78

Figure 3.6. Coordinates of start and end of merge of one participant

Step 2. Selecting representative participant data for comparison: At this step, the elimination of driving patterns that are not typical is done. The following patterns are eliminated from further analysis.

- For merging to left lane: If a participant started driving on the left lane or moved to the left lane as soon as the simulation started and has not been on the right lane, no pattern to merging to left lane from the right lane is observed. Therefore, this driving pattern is eliminated. In addition, those drivers, who did not merge to left lane throughout the work zone, are also eliminated.

- For merging to right lane: If a participant started driving on the right lane or moved to the right lane as soon as the simulation started and has not been on the left lane, no pattern to merging to right lane from the left lane is observed. Therefore, this driving pattern is eliminated. In addition, those drivers, who did not merge to right lane throughout the work zone, are also eliminated.

After eliminations, the drivers whose patterns are not eliminated from MUTCD left-lane-merge and MoDOT left-lane-merge scenarios are used to compare MUTCD left-lane-merge and MoDOT left-lane-merge signs. Similarly, the drivers whose patterns are not eliminated from MUTCD right-lane-merge and MoDOT right-lane-merge scenarios are used to compare MUTCD right-lane-merge and MoDOT right-lane-merge signs.

Step 3. Comparative analysis: After elimination of the patterns as described above, there are 2 participants to compare MUTCD left-lane-merge and MoDOT left-lane-merge signs (see Table 3.2 for their merge coordinates) and 27 participants are chosen to compare MUTCD right-lane-merge and MoDOT right-lane-merge (see Table 3.3 for their merge coordinates). Table 3.2 and Table 3.3 are given next.

Table 3.2. Left-lane-merge participants

	Left-Lane-Merge							
	MUTCD				**MODOT**			
	Start-of-the-Merge		End-of-the-Merge		Start-of-the-Merge		End-of-the-Merge	
Participant	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*
1	-148.68	25.84	-153.74	346.99	-141.31	-7.38	-153.87	543.02
48	-147.58	-303.64	-152.03	231.13	-147.31	-7.38	-153.16	313.78
Average	-148.13	-138.90	-152.89	289.06	-144.31	-7.38	-153.52	428.40

Table 3.3. Right-lane-merge participants

	Right-Lane-Merge							
	MUTCD				**MODOT**			
	Start-of-the-Merge		End-of-the-Merge		Start-of-the-Merge		End-of-the-Merge	
Participant	*x*	*y*	*x*	*y*	*x*	*y*	*x*	*y*
3	-153.63	14.76	-147.55	363.50	-153.67	16.32	-147.09	557.76
4	-153.14	-287.99	-148.66	-3.73	-152.66	-261.70	-147.49	170.10
8	-152.14	-164.79	-146.33	382.00	-154.03	-110.29	-147.87	140.03
10	-153.85	352.97	-147.02	668.49	-153.38	-124.35	-147.43	382.85
11	-153.72	274.02	-146.69	705.56	-152.98	358.52	-145.96	599.41
21	-152.97	-119.49	-147.54	433.13	-153.11	-143.05	-149.16	164.71
25	-153.70	-96.16	-147.15	224.16	-151.96	-50.40	-147.57	177.24
26	-152.14	-67.09	-148.39	208.11	-153.10	-41.21	-148.38	206.73
29	-154.04	-109.64	-147.33	62.47	-153.45	-196.98	-146.57	38.07
33	-153.40	48.40	-148.70	276.92	-153.81	-234.39	-147.84	318.99
34	-152.93	-173.07	-148.50	-1.36	-151.95	-37.98	-147.96	49.89
42	-153.42	-84.74	-146.30	155.51	-153.47	-13.63	-146.94	185.57
43	-153.40	-250.68	-147.45	71.22	-153.00	-100.70	-147.66	80.07
44	-153.05	-102.53	-148.49	213.72	-153.32	-106.84	-147.41	305.55
45	-153.01	-178.99	-148.34	-18.91	-152.44	-223.07	-148.37	-30.56
46	-152.75	-228.76	-147.44	76.84	-153.07	-117.12	-147.24	181.00
47	-153.29	-2.83	-147.43	211.14	-152.89	-86.26	-147.10	147.93
52	-152.79	-69.65	-148.36	61.03	-152.86	-56.83	-147.21	79.02
53	-153.57	-156.02	-147.04	230.47	-153.36	-118.39	-146.97	230.04
61	-153.28	-1.69	-149.71	229.74	-152.99	-86.48	-148.42	89.45
63	-153.43	-164.79	-146.46	135.82	-153.23	-57.31	-147.85	-143.29
64	-152.96	-102.81	-146.96	537.30	-152.55	-199.97	-148.42	348.50
66	-153.07	-140.76	-148.18	17.60	-152.95	-175.23	-146.74	-61.34
68	-151.47	32.66	-146.59	189.60	-152.17	2.42	-146.77	147.53
72	-151.50	-122.48	-147.46	-22.52	-151.98	-162.59	-147.64	-28.48
73	-152.39	456.84	-146.72	851.52	-153.01	219.24	-147.51	879.64
75	-153.16	-246.00	-147.69	344.88	-153.59	-383.25	-148.79	160.32
Average	-153.04	-62.64	-147.57	244.60	-153.00	-92.28	-147.57	199.14

3.3 RESULTS OF LANE MERGE ANALYSIS

Based on the data above, the following results are observed:

1. For merging to left lane: Unfortunately, many of the drivers started driving on the left-lane under MUTCD left-lane-merge scenario. Therefore, there were only 2 participants, who showed merging patterns under both MUTCD left-lane-merge

and MODOT left-lane-merge scenarios. Based on comparing the average over these two instances, we can say that participants started and completed lane merge earlier under MUTCD sign compared to MODOT sign. However, this is based on only 2 participants; and thus, is not a conclusive result.

2. For merging to right lane: There were 27 participants, who showed merging patterns under both MUTCD right-lane-merge and MODOT right-lane-merge scenarios. Based on comparing the average over these instances, we can say that participants started and completed lane merge earlier under MODOT sign compared to MUTCD sign.

Overall, the average reactions for each scenario are given in Figures 3.7 and 3.8 for left merge and right merge respectively.

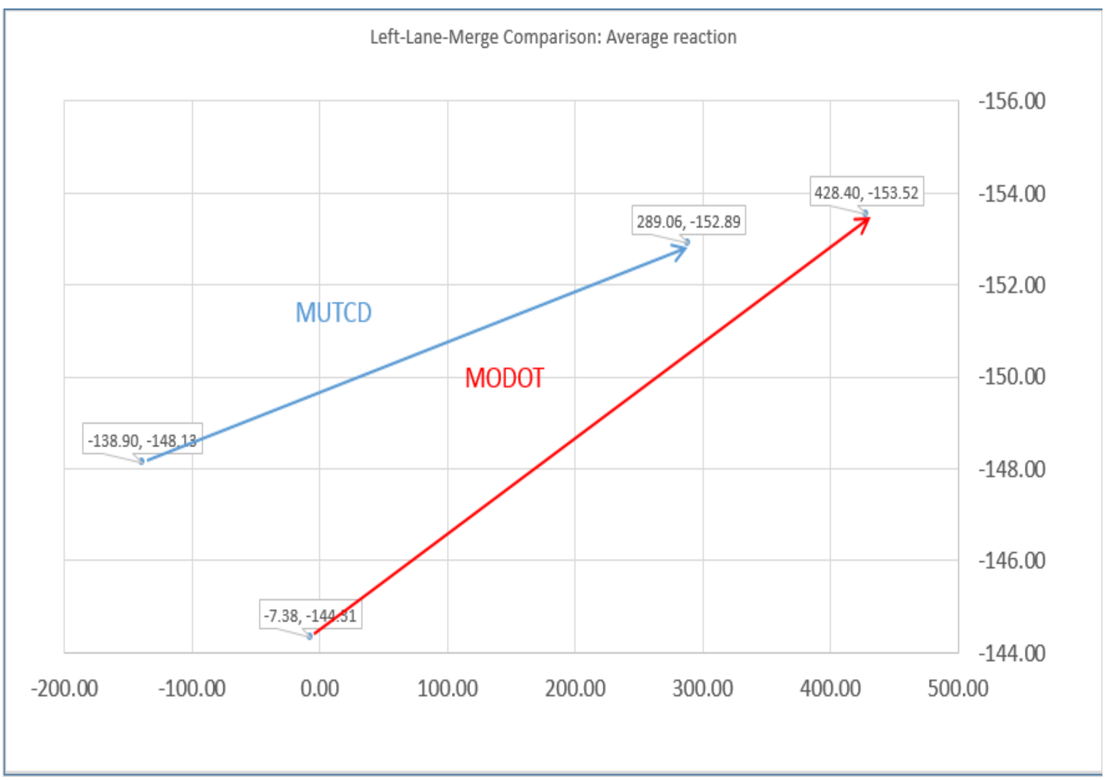

Figure 3.7. Left lane merge average coordinates of both scenarios

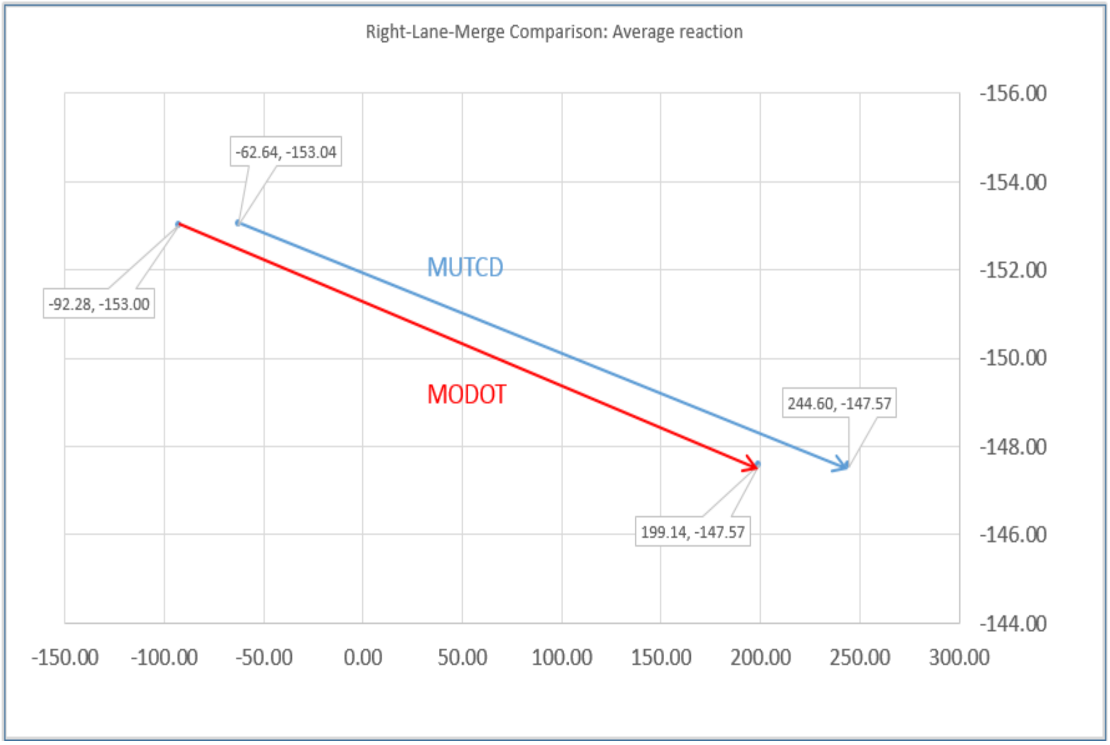

Figure 3.8. Right lane merge average coordinates of both scenarios

Based on Result 1, there was not enough data for complete comparative analyses of the left-lane-merge signs. Based on Result 2, it was observed that MODOT's right-lane-merge resulted in slight decrease in time to start to merge to the right lane. Therefore, the hypothesis testing is done that the y-coordinates of the start-of-the-merges have the same mean and the same standard deviation.

- For the means, the t-test was conducted and the result are shown in Figure 3.9, 3.10, 3.11 and 3.12. Based on the t-test, there is no significant evidence that the mean of start and end of merge coordinates are different under alternative signs.
- For the variances, f-test was conducted and result are shown in Figure 3.13, 3.14, 3.15 and 3.16. From f-test, there is no significant evidence that the variances of start and end of merge coordinates are different under alternative signs.

t-Test: Paired Two Sample for Means for right lane merge	Start of merge X coordinates	
	MUTCD	MoDOT
Mean	-153.0444444	-152.9992593
Variance	0.420525641	0.306676353
Observations	27	27
Pearson Correlation	0.346810665	
Hypothesized Mean Difference	0	
df	26	
t Stat	-0.339557861	
P(T<=t) one-tail	0.368458591	
t Critical one-tail	1.70561792	
P(T<=t) two-tail	0.736917182	
t Critical two-tail	2.055529439	

Figure 3.9. T test start of merge x coordinates results

t-Test: Paired Two Sample for Means for right lane merge	Start of merge Y coordinates	
	MUTCD	MoDOT
Mean	-62.64111111	-92.27851852
Variance	31281.37768	20293.72076
Observations	27	27
Pearson Correlation	0.655765187	
Hypothesized Mean Difference	0	
df	26	
t Stat	1.13130575	
P(T<=t) one-tail	0.134126871	
t Critical one-tail	1.70561792	
P(T<=t) two-tail	0.268253742	
t Critical two-tail	2.055529439	

Figure 3.10. T test start of merge y coordinates results

t-Test: Paired Two Sample for Means for right lane merge	End of merge X coordinates	
	MUTCD	MoDOT
Mean	-147.573	-147.569
Variance	0.735585	0.522572
Observations	27	27
Pearson Correlation	0.336609	
Hypothesized Mean Difference	0	
df	26	
t Stat	-0.02519	
P(T<=t) one-tail	0.490049	
t Critical one-tail	1.705618	
P(T<=t) two-tail	0.980099	
t Critical two-tail	2.055529	

Figure 3.11. T test end of merge x coordinates results

t-Test: Paired Two Sample for Means for right lane merge	End of merge Y coordinates	
	MUTCD	MoDOT
Mean	244.6004	199.1381
Variance	53555.67	47173.43
Observations	27	27
Pearson Correlation	0.832277	
Hypothesized Mean Difference	0	
df	26	
t Stat	1.808439	
P(T<=t) one-tail	0.04106	
t Critical one-tail	1.705618	
P(T<=t) two-tail	0.082119	
t Critical two-tail	2.055529	

Figure 3.12. T test end of merge y coordinates results

F-Test Two-Sample for Variances for right lane merge	Start of merge X coordinates	
	MUTCD	MoDOT
Mean	-153.0444444	-152.9992593
Variance	0.420525641	0.306676353
Observations	27	27
df	26	26
F	1.371235951	
P(F<=f) one-tail	0.213137694	
F Critical one-tail	1.929212675	

Figure 3.13. F test start of merge x coordinates results

F-Test Two-Sample for Variances for right lane merge	Start of merge Y coordinates	
	MUTCD	MoDOT
Mean	-62.64111111	-92.27851852
Variance	31281.37768	20293.72076
Observations	27	27
df	26	26
F	1.541431364	
P(F<=f) one-tail	0.138193591	
F Critical one-tail	1.929212675	

Figure 3.14. F test start of merge y coordinates results

F-Test Two-Sample for Variances	End of merge	
for right lane merge	X coordinates	
	MUTCD	MoDOT
Mean	-147.5733333	-147.5688889
Variance	0.735584615	0.522571795
Observations	27	27
df	26	26
F	1.407624029	
P(F<=f) one-tail	0.194542544	
F Critical one-tail	1.929212675	

Figure 3.15. F test end of merge x coordinates results

F-Test Two-Sample for Variances	End of merge	
for right lane merge	Y coordinates	
	MUTCD	MoDOT
Mean	244.6003704	199.1381481
Variance	53555.66628	47173.42707
Observations	27	27
df	26	26
F	1.135293101	
P(F<=f) one-tail	0.374367376	
F Critical one-tail	1.929212675	

Figure 3.16. F test end of merge y coordinates results

4. LANE SHIFT SIGN ANALYSIS

4.1 PROJECT DESCRIPTION AND DATA COLLECTION

In the second part of this study, the driving simulation is used to evaluate a lane shift sign configuration proposed by MoDOT and compare it to the conventional lane shift sign configuration suggested by FHWA within MUTCD. In particular, a lane shift is used when there is a lane closure but the total capacity of a highway should not be reduced, due to capacity considerations. Figures 4.1 and 4.2 illustrate the conventional lane shift sign (MUTCD sign) and the alternative lane shift sign proposed by MoDOT (MoDOT sign), respectively. As can be seen from the figures, MUTCD sign configuration consists of two signs, whereas MoDOT sign configuration has one sign. The single sign proposed by MoDOT may make it easier for the travelers get the sufficient information on the availability of all lanes for shifting. On the other hand, MUTCD sign configuration demands drivers to observe and comprehend two separate signs. The objective of this project is to investigate basic driving characteristics under these two sign configurations.

Figure 4.1. MUTCD lane shift sign configuration

Figure 4.2. MODOT lane shift sign configuration

As noted before, the objective of the study is to evaluate MoDOT's alternative lane shift sign configuration and compare it with the MUTCD sign configuration. To do so, two driving simulation scenarios are designed through a planned work zone area, of which details are provided by MoDOT to the researchers:

- **Scenario-1:** MUTCD approved lane shift sign configuration, i.e., MUTCD signs (see Figure 4.1),
- **Scenario-2:** Alternative lane shift sign configuration proposed by MoDOT i.e., MoDOT sign (see Figure 4.2).

In the second part, similar to first part, a total of 75 participants were recruited with varying demographics. Specifically, the number of participants is recruited based on age (age categories are 18-24, 25-44, 45-64, and over 65 years) and gender (male and female). The numbers of participants required in each group was determined considering Missouri's demographic population information. Participants were required to hold a current driver's license. Each participant drove on the driving simulator twice: once for each scenario. In total, 150 data sets are collected (2 data sets for each participant). The participants drove the simulator before driving the scenarios to get familiar with the driving simulator. Furthermore, a questionnaire is given before the scenarios to confirm demographic information as well as to learn the participants' driving history. Table 4.1 summarizes the participants' demographic information and driving history.

Table 4.1. Demographic information and driving experience of the participants

Age (year)				Gender		Driving Experience (Year)			
18-24	25-44	45-64	≥65	Female	Male	<1	1-5	5-10	>10
10	31	27	7	40	35	1	12	5	57

4.2 STATISTICAL ANALYSIS OF LANE SHIFT SIGN CONFIGURATIONS

The average speed of all the age groups and genders in both driving scenarios are given in Table 4.2.

Table 4.2. 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 Scenario (MoDOT and MUTCD) are blocks and Gender and Age Group are 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 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 and alternate hypothesis are:

- **H_0:** All the average speeds are statistically the same
- **H_1: H_0** is false.

The RCB design test is performed by using JMP-Statistical Analysis software. The results of the test are given in Table 4.3.

Table 4.3. 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 4.3) shows that the P-value is 0.0024 which is less than 0.05 (significance level), therefore, it is concluded that **H_0** is rejected, there is statistically significant difference between the average speeds of all the treatments, which means that 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 4.4.

Table 4.4. 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 effects of Gender and Age Group interaction are analyzed.

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

From the effect tests results (Table 4.4), 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, $H_{0\text{-Age Group*Gender}}$, 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.

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

The P-value for Driving Scenario, 0.5436, from the effect tests (Table 4.4) is greater than 0.05, which means that there is no significant effect of driving scenario 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, i.e., $\mu_{i1k}= \mu_{i2k}$

The P-value of the factor Gender in effect tests (Table 4.4) is 0.0118, which is less than 0.05, therefore, $H_{0\text{-Gender}}$ is rejected, which means that 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.

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

The P-value of Age Group is 0.0079 in Table 4.4, which is less than 0.05, therefore, $H_{0\text{-Age Groups}}$ is rejected, which means Age Group have significant effect on the average speed of a driver. There are four levels of Age Group, the average speed of at least one level is different from the others.

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

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 4.5 shows the LSMeans student's t test results for Gender.

Table 4.5. 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 4.6 shows the LSMeans student's t test results for Age Group.

Table 4.6. LSMeans student's t test results for Age Group

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, Age Group 25-44 and (65+ and 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 that the average speeds of this age group is statistically same as other age groups.

Based on the above results, next analyses focus on investigating each Gender 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 4.7.

Table 4.7. 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 Group 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 and alternate hypothesis are:

- $H_{0\text{-females}}$: The average speed of all female drivers is the same
- $H_{1\text{-females}}$: At least one female driver has different average speed than other female drivers

The ANOVA results derived from the female participants' data are given in Table 4.8.

Table 4.8. 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 4.8 is 0.0009, which is less than the significance level 0.05, therefore, the null hypothesis $H_{0\text{-females}}$ 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, $H_{0\text{-females}}$ is rejected.

To understand the effect of the blocks, Driving Scenario, 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 4.9.

Table 4.9. Effects test results over female participants' average speeds

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob> F**
Driving Scenario	1	1	23.11990	1.7495	0.1900
Age Group	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.

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

The P-value, 0.1900, from the effects test result given in Table 4.9, is greater than 0.05, which means that there is no significant effect of driving scenario on the average speed of the female drivers. Therefore, $\mathrm{H}_{0-\text{Driving Scenario}}^{\text{females}}$ is not rejected.

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

The P-value from the effects test results given in Table 4.9 is 0.0006 and less than 0.05, which means that there is significant effect of Age Group on the average speed of female drivers. Therefore, $H_{0-\text{Age Group}}^{\text{females}}$ 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 4.10.

Table 4.10. 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 4.10, the age groups 45-64, 65+, and 18-24 are represented by the 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 that this age group is significantly different from the other age groups. The females from age group 25-44 have a higher average speed than the 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 4.11.

Table 4.11. 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 across different age groups. One way RCB design in ANOVA analysis with Age Group 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 and alternate hypothesis are:

- $H_{0\text{-males}}$: The average speed of all male drivers is the same
- $H_{1\text{-males}}$: At least one male driver has different average speed than other male drivers

The ANOVA results derived from the male participants' data are given in Table 4.12.

Table 4.12. 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 4.12 is 0.2954, which is greater than the 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 4.13.

Table 4.13. 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 the same. To understand the driving behavior within this age group, ANOVA test was done. Here, Driving Scenario were blocks and Gender was a factor.

Here, the null hypothesis and alternate hypothesis are:

- $H_{0\text{-}(18\text{-}24)}$: The average speed of all drivers in age group 18-24 is the same.
- $H_{1\text{-}(18\text{-}24)}$: 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 4.14.

Table 4.14. ANOVA result of 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 4.14 is greater than the significance level (0.05). Therefore, $H_{0\text{-}(18\text{-}24)}$ 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 4.15.

Table 4.15. 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 the same. To understand the driving behavior within this age group, ANOVA was done and its results are shown in table 4.16. Here, Driving Scenario were blocks and Gender was a factor.

Here, the null hypothesis and alternate hypothesis are:

- $H_{0\text{-}(25\text{-}44)}$: The average speed of all drivers in age group 25-44 is the same
- $H_{1\text{-}(25\text{-}44)}$: At least one driver in age group 25-44 has different average speed than other drivers in age group 25-44

Table 4.16. ANOVA result of 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 4.16 is greater than the significance level (0.05). Therefore, $H_{0\text{-}(25\text{-}44)}$ 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 4.17.

Table 4.17. 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 the same. To understand the driving behavior within this age group, ANOVA test was done. Here, Driving Scenario were blocks and Gender was a factor.

Here, the null hypothesis and alternate hypothesis are:

- $H_{0\text{-}(45\text{-}64)}$: The average speed of all drivers in age group 45-64 is the same
- $H_{1\text{-}(45\text{-}64)}$: 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 4.18.

Table 4.18. ANOVA result of 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 4.18 is very close to the significance level (0.05), therefore, $H_{0\text{-}(45\text{-}64)}$ should not be rejected right away. Further analysis, i.e., effects test, to understand the effects of the factors on response variable should be conducted. The results of the effects test are shown in Table 4.19.

Table 4.19. Effects test results of 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.

- $H_{0-\text{Driving Scenario}}^{45-64}$ **:** 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 4.19 is greater than the significance level (0.05), which means that there is no significant effect of driving scenario on the average speed of the drivers in age group 45-64. Therefore, $H_{0-\text{Driving Scenario}}^{45-64}$ is not rejected.

- $H_{0-\text{Gender}}^{45-64}$**:** 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 4.19 for the factor Gender is less than the significance level (0.05), therefore, $H_{0-\text{Gender}}^{45-64}$ is rejected, which means that 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, and 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 4.20.

Table 4.20. LSMeans student's t test for gender using in age group 45-64

Level			Least Sq Mean
MALE	A		41.083578
FEMALE		B	38.933273

As can be seen from Table 4.20, male and female are represented with different letters, which means that 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 4.21.

Table 4.21. 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 Scenario was blocks and Gender was a factor.

Here, the null hypothesis and alternate hypothesis are:

- $H_{0-(65+)}$: The average speed of all drivers in age group 65+ is the same
- $H_{1-(65+)}$: 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 4.22.

Table 4.22. ANOVA results of 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 4.22 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 Shift Signs: The difference in the average speed of the driver before the lane shift sign compared to the average speed after the lane shift 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 shift 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 shift sign is called average speed before the sign and the average of 10 speed readings after the lane shift 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 Scenario (MoDOT and MUTCD) were blocks. Therefore, this test design is RCB Design as well.

Here, the null hypothesis and alternate hypothesis are:

- $H_{0\text{-Before \& After sign}}$: The average speed of all participants before and after signs are the same
- $H_{1\text{-Before \& After sign}}$: 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 4.23.

Table 4.23. 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 4.23 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 effects test was conducted and the results of effects test are shown in Table 4.24.

Table 4.24. 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 4.24), it can be seen that the effect of interaction between factor Before & After sign, Gender and Age Group 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 & 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 4.24, 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.

- $H_{0\text{-Age Group*Before \& After Sign}}$: The Age Group and Before & 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 4.24, it can be seen that the effect of interaction between factor Before & 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 & After Sign position.

- $H_{0\text{-Gender*Before \& After Sign}}$: The Gender and Before & 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 4.24, it can be seen that the effect of interaction between factor Gender and Before & 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 it is concluded that there is no interaction between the Gender and Before & 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 4.24 is greater than 0.05, which means that 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 that 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.

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

The P-value of Age Group is <0.0001 in Table 4.24, which is less than the significance level, therefore, $H_{0\text{-Age Group}}$ 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.

- $H_{0\text{-Before \& After Sign}}$: 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 & After sign in effects test in Table 4.24 is greater than 0.05, therefore, $H_{0\text{-Before \& After Sign}}$ is not rejected, which means that factor Before & 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 4.25.

Table 4.25. 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 4.26.

Table 4.26. LSMeans student's t test results with before and after the sign average speeds for age group

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 the same letter have no significant difference in the average speeds. The Age Group 18-24 has a higher average speed than the other Age Group at this part of the road but it is statistically the same as age group 25-44. Age groups 45-64 and 65+ are 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 $H_{0\text{-Before \& After sign}}$ 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 and alternate hypothesis are:

- $H^{MoDOT}_{0-Before\ \&\ After\ Sign}$: The average speed of all participants before and after the sign is the same under MoDOT scenario
- $H^{MoDOT}_{1-Before\ \&\ After\ Sign}$: 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 4.27.

Table 4.27. 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 4.27 is 0.0628, which is very close to the significance value (0.05), therefore, $H^{MoDOT}_{0-Before\ \&\ After\ Sign}$ cannot be rejected right away. Further analysis is needed to reject or accept $H^{MoDOT}_{0-Before\ \&\ After\ Sign}$.

To understand the effect of factors on average speeds under MoDOT scenario, the effects test was conducted and the results of the test are shown in Table 4.28.

Table 4.28. 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 & After Sign	1	1	43.31721	0.6421	0.4244
Gender*Before & After Sign	1	1	13.00325	0.1927	0.6613
Age Group*Before & After Sign	3	3	20.83953	0.1030	0.9582
Gender*Age Group*Before & 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.

- $H_{0-\text{Gender}*\text{Age Group}*\text{Before \& After Sign}}^{\text{MoDOT}}$: The Gender, Age Group and Before & 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 4.28, it can be seen that the effect of interaction between factor Gender, Age Group and Before & 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 & After Sign position in MoDOT scenario.

- $H_{0-\text{Gender}*\text{Age Group}}^{\text{MoDOT}}$: 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 4.28, 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.

- $H_{0-\text{Age Group}*\text{Before \& After Sign}}^{\text{MoDOT}}$: The Age Group and Before & 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 4.28, it can be seen that the effect of interaction between factor Age Group and Before & 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 & After Sign position in MoDOT scenario.

- $H^{MoDOT}_{0-Gender*Before\,\&\,After\,Sign}$: The Gender and Before & 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 4.28, it can be seen that the effect of interaction between factor Gender and Before & 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 & 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.

- $H^{MoDOT}_{0-Gender}$: 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 4.28, the P-value, 0.0777, of the factor Gender in effect tests is greater than 0.05, therefore, $H^{MoDOT}_{0-Gender}$ is not rejected, which means that 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.

- $H^{MoDOT}_{0-Age\,Group}$: The average speed is not affected by Age Group in MoDOT scenario

From the results of the effects test for MoDOT scenario given in Table 4.28, the P-value of Age Group is 0.0367, which is less than 0.05, therefore, $H_{0-\text{Age Group}}^{\text{MoDOT}}$ 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.

- $H_{0-\text{Before \& After sign}}^{\text{MoDOT}}$: 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 & After sign in effect tests is greater than 0.05, therefore, $H_{0-\text{Before \& After sign}}^{\text{MoDOT}}$ is not rejected, which means that factor Before & 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 Group 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 4.29.

Table 4.29. 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 4.29 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 to 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 and alternate hypothesis are:

- $H_{0-\text{Before \& After sign}}^{\text{MUTCD}}$: The average speed of all participants before and after the sign is the same under MUTCD scenario
- $H_{1-\text{Before \& After sign}}^{\text{MUTCD}}$: 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 4.30.

Table 4.30. 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 4.30 is 0.0593, which is very close to the significance value (0.05), therefore, $H_{0-\text{Before \& After sign}}^{\text{MUTCD}}$ cannot be rejected right away. Further analysis is needed to reject or accept $H_{0-\text{Before \& After sign}}^{\text{MUTCD}}$.

To understand the effects 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 4.31.

Table 4.31. 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 & After the Sign	1	1	53.26797	0.9358	0.3351
Gender*Before & After the Sign	1	1	16.82844	0.2956	0.5875
Age Group*Before & After the Sign	3	3	59.76940	0.3500	0.7892
Gender*Age Group*Before & 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.

- $H_{0-\text{Gender}*\text{Age Group}*\text{Before \& After Sign}}^{\text{MUCTD}}$: The Gender, Age Group and Before & 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 4.31, it can be seen that the effect of interaction between factor Gender, Age Group and Before & 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 & After Sign position in MUTCD scenario.

- $H_{0-Gender*Age\ Group}^{MUCTD}$: 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 4.31, 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.

- $H_{0-Age\ Group*Before\ \&\ After\ Sign}^{MUCTD}$: The Age Group and Before & 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 4.31, it can be seen that the effect of interaction between factor Age Group and Before & 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 & After Sign position in MUTCD scenario.

- $H_{0-Gender*Before\ \&\ After\ Sign}^{MUCTD}$: The Gender and Before & 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 4.31, it can be seen that the effect of interaction between factor Gender and Before & 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 & 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.

- $\mathrm{H}_{0-\mathrm{Gender}}^{\mathrm{MUCTD}}$: 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 4.31, the P-value, 0.2130, of the factor Gender in effect tests is greater than 0.05, therefore, $\mathrm{H}_{0-\mathrm{Gender}}^{\mathrm{MUCTD}}$ is not rejected, which means factor Gender does not have 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.

- $\mathrm{H}_{0-\mathrm{Age\ Group}}^{\mathrm{MUCTD}}$: The average speed is not affected by Age Group in MUTCD scenario

From the results of the effects test for MUTCD scenario given in Table 4.31, the P-value of Age Group is 0.1783, which is greater than 0.05, therefore, $\mathrm{H}_{0-\mathrm{Age\ Group}}^{\mathrm{MUCTD}}$ 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.

- $\mathrm{H}_{0-\mathrm{Before\ \&\ After\ sign}}^{\mathrm{MUCTD}}$: 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 4.31, the P-value, 0.3351, of the factor Before & After sign in effect tests is greater than 0.05, therefore, $\mathrm{H}_{0-\mathrm{Before\ \&\ After\ sign}}^{\mathrm{MUCTD}}$ is not rejected, which means factor Before & 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.

4.3 RESULTS OF LANE SHIFT SIGN ANALYSIS

Data analyses of average speeds of 75 participants with different characteristics were conducted. The participants' average speed in scenarios, MUTCD lane shift and MoDOT lane shift, showed interesting trends.

The results showed that age affects the average speed of a driver. As age increased, the average speed of a driver decreased. The significant effect of Gender on average speed was also noticed. Females and Males had significant difference in their average speeds. Females had lower average speed than males. All males had no statistical difference in their average speeds. According to the results found in this study, the lane shift sign configurations did not affect the overall average speed of the participants. Further analysis is required to understand the lane changing behaviors of the drivers.

5. CONCLUSIONS AND FUTURE WORK

For Lane Merge Sign Analysis, a significant difference in left and right lane merges patterns of drivers in MUTCD and MoDOT scenarios was not noticed. The average merge coordinates of the drivers are the same with MUTCD and MoDOT sign configurations and significant evidence is not present to prove the effectiveness of one sign configuration over the other. The mobility of vehicles in a work zone is not effected by using either one of the sign configurations.

For Lane Shift Sign Analysis, there is no significant difference found between MUTCD lane shift sign configuration and MoDOT’s alternative lane sign configuration and both sign configurations do not affect the mobility of vehicles in work zones. The average speed of all drivers is same in both scenarios. On the other hand, there is difference in average speed of males and females. Males have higher average speed than females. The driver age is found to be an important factor to affect driver behavior. The average speed of younger people is higher than the older people. Still, there is not enough evidence to claim that one sign configuration affects the driving behavior of people more than the other.

The results obtained from this study show the feasibility of the driving simulator system. Driving simulator system can be used for different types of traffic studies, like comparison of different type of traffic signage. This approach is cost effective, safe and can be programmed according to the requirements of an experiment.

An extension to this research can be made in future, to study the effectiveness of traffic signs at night or in less visibility weather conditions. The design of experiment can be made more efficient by balancing the number of participants in each age group.

APPENDIX

Matlab Codes

Matlab was used to extract the required data from datasets. The matlab codes which were used are given below.

For extracting the speed readings before and after the traffic sign in lane shift sign analysis following codes were used.

To extract speed reading from MUTCD dataset before sign following code was used:

```
clear;
clc;

for m = 1:1:75;
a = zeros(250,1);
ra = zeros(250,1);
da = zeros(250,1);
d = zeros(250,1);

ra = xlsread(strcat(num2str(m),'.xlsx'),'old','H1:H250');
da = xlsread(strcat(num2str(m),'.xlsx'),'old','D1:D250');
for n = 1:1:length(ra);
   if (ra(n) < -550)
   a(n,1) = ra(n);
   d(n,1) = da(n);
   a_all(n,m) = a(n,1);
   d_all(n,m) = d(n,1);

   end
end
end
```

To extract speed reading from MoDOT dataset before sign following code was used:

```
clear;
clc;

for m = 1:1:75;
a = zeros(250,1);
ra = zeros(250,1);
```

```
da = zeros(250,1);
d = zeros(250,1);

ra = xlsread(strcat(num2str(m),'.xlsx'),'new','H1:H250');
da = xlsread(strcat(num2str(m),'.xlsx'),'new','D1:D250');
for n = 1:1:length(ra);
   if (ra(n) < -550)
   a(n,1) = ra(n);
   d(n,1) = da(n);
   a_all(n,m) = a(n,1);
   d_all(n,m) = d(n,1);

   end
end
end
```

To extract speed reading from MUTCD dataset after sign following code was used

```
clear;
clc;

for m = 1:1:75;
a = zeros(250,1);
ra = zeros(250,1);
da = zeros(250,1);
d = zeros(250,1);

ra = xlsread(strcat(num2str(m),'.xlsx'),'old','H1:H250');
da = xlsread(strcat(num2str(m),'.xlsx'),'old','D1:D250');
for n = 1:1:length(ra);
   if (ra(n) > -550)
   a(n,1) = ra(n);
   d(n,1) = da(n);
   a_all(n,m) = a(n,1);
   d_all(n,m) = d(n,1);

   end
end
end
```

To extract speed reading from MoDOT dataset after sign following code was used

```
clear;
clc;

for m = 1:1:75;
a = zeros(250,1);
ra = zeros(250,1);
da = zeros(250,1);
d = zeros(250,1);

ra = xlsread(strcat(num2str(m),'.xlsx'),'new','H1:H250');
da = xlsread(strcat(num2str(m),'.xlsx'),'new','D1:D250');
for n = 1:1:length(ra);
   if (ra(n) > -550)
   a(n,1) = ra(n);
   d(n,1) = da(n);
   a_all(n,m) = a(n,1);
   d_all(n,m) = d(n,1);

   end
end
end
```

To extract the average speed of all participants from datasets and exporting it to a single excel file following codes were used.

Code used to get the average speed of drivers in MUTCD scenario datasets is given below.

```
clear all;
clc;
close all;

speed_all = zeros(250,75);

for n = 1:1:75;
speed = xlsread(strcat(num2str(n),'.xlsx'),'old','H1:H250');
speed_all(250,n) = speed;
avg_speed(1,n) = mean(speed_all);
end
```

Code used to get the average speed of drivers in MoDOT scenario datasets is given below.

```
clear all;
clc;
close all;

speed_all = zeros(250,75);

for n = 1:1:75;
speed = xlsread(strcat(num2str(n),'.xlsx'),'new','H1:H250');
speed_all(250,n) = speed;
avg_speed(1,n) = mean(speed_all);
end
```

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