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Data analysis for driving pattern identification and driver's behavior modeling in a freeway work zone

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DATA ANALYSIS FOR DRIVING PATTERN IDENTIFICATION AND DRIVER'S BEHAVIOR MODELING IN A FREEWAY WORK ZONE

by

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ABSTRACT

A variety of methods are used by Departments of Transportation (DOT) for informing drivers about upcoming work zones. One such method is work zone signage configuration. Signage plays an important role in work zones to provide guidance to drivers when conditions on the road vary from normal. Therefore, it is necessary to evaluate the effectiveness of different configurations, by law, before implementation of new signage designs that deviate from the national standards.

The Manual on Uniform Traffic Control Devices (MUTCD) is a compilation of national standards for all traffic control devices, including road markings, highway signs, and traffic signals. In the present work which is funded by the Missouri Department of Transportation (MoDOT), the safety effect of an alternative merge sign configuration provided by MoDOT is investigated in a freeway work zone. This investigation is based on a simulation study that involves a total of 75 study participants representing an overall distribution of drivers in the state of Missouri. This simulation study required the participants to experience four work zone configurations on a driving simulator. Right merge and left merge scenarios were simulated for two work zone sign configurations, one being the national standard from MUTCD and the other being an alternate work zone sign configuration proposed by MoDOT. The objective of this study is to establish the effectiveness of both these configurations by data analyses.

Results of the statistical analysis indicate that MUTCD left merge was significantly different than the driving patterns for the other three scenarios. There was significant difference between MUTCD left merge and MoDOT alternate left merge but no dramatic differences were observed for the right merge scenarios.

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TABLE OF CONTENTS

Page

ABSTRACT iii

ACKNOWLEDGEMENT iv

LIST OF ILLUSTRATIONS viii

LIST OF TABLES ix

SECTION

1. INTRODUCTION 1

1.1. BACKGROUND 1

1.2. PROBLEM STATEMENT 3

1.3. MOTIVATION 3

2. LITERATURE REVIEW 5

2.1. SAFETY IN WORK ZONES 5

2.2. STUDIES ANALYZING DRIVER BEHAVIOR 9

2.3. DRIVING SIMULATOR STUDIES 11

3. ANALYSIS 13

3.1. PROJECT DESCRIPTION 13

3.1.1. Simulator Environment 16

3.1.2. Goals and Objectives of Research..16

3.2. THE DATA…. 18

3.2.1. Data Collection 18

3.2.2. Data Preparation 20

3.2.3. Interpolation of x Positions 21

3.3. ANALYSIS OF LEFT MERGE SCENARIO……………………………………23

3.3.1. Exploratory Analysis-Visual 24

3.3.2. Dynamic Distribution of Drivers- Evolution of Probability Density..... 27

3.3.3. Feature Extraction 30

3.3.4. Classification of Drivers.. 32

3.3.4.1. Groups A vs B 32

3.3.4.2. Groups B.1 vs B.2 32

3.3.4.3. Groups C.1~C.5.. 33

3.3.4.4. Groups D.1 vs D.2 33

3.3.5. Characterization of High Risk Drivers.. 35

3.4. SUMMARY OF MAJOR FINDINGS OF LEFT MERGE SCENARIO…….39

3.5. ANALYSIS OF RIGHT MERGE SCENARIO………………………………39

3.5.1. Exploratory Analysis- Visual...……………39

3.5.2. Dynamic Distribution of Drivers- Evolution of Probability Density..... 42

3.5.3. Classification of Drivers.. 46

3.5.4. Characterization of High Risk Drivers.. 50

3.6. SUMMARY OF MAJOR FINDINGS OF RIGHT MERGE SCENARIO.......50

3.7. COMPARISON BETWEEN RIGHT AND LEFT MERGE SCENARIOS.....51

3.7.1. MUTCD Left vs Right Merge 51

3.7.2. Missouri Alternate Left vs Right Merge 51

4. RESULTS AND CONCLUSION 52

4.1. RESULTS.. 52

4.2. CONCLUSIONS……………………………………………………………...53

4.3. FUTURE WORK…………………………………………………………..54

APPENDIX ……………………………………………………………………...55

BIBLIOGRAPHY……………………………………………………………..61

VITA……………………………………………………………………………64

LIST OF ILLUSTRATIONS

Figure Page

3.1. Work zone sign configurations 14

3.2. Merge scenarios 15

3.3. Missouri S&T simulator room 17

3.4. Lane setting with adjusted data 20

3.5. Plot of driver positions *x* vs *y* for the original data 22

3.6. Plot of driver positions *x* vs *y* for the interpolated data 22

3.7. Lane description for the simulation scenarios 25

3.8. Driving paths of 75 drivers for MUTCD left merge scenario 25

3.9. Driving paths of 75 drivers for MoDOT alternate left merge 26

3.10. Density plots of MUTCD left merge 29

3.11. Density plots of MoDOT alternate left merge 31

3.12. Characterization of high risk drivers based on Age for MUTCD left merge 37

3.13. Characterization of high risk drivers based on Gender for MUTCD left merge 38

3.14. Driving path of 75 drivers for MUTCD right merge 40

3.15. Driving path of 75 drivers for MoDOT alternate right merge 41

3.16. Density distribution for MUTCD right merge 44

3.17. Density distribution for Missouri alternate right merge 46

3.18. Characterization of groups A.1 and A.2 based on age for Missouri alternate right merge 49

3.19. Characterization of groups A.1 and A.2 based on gender 49

LIST OF TABLES

Table Page

3.1. Raw data collected in its original form 19

3.2. Interpolated data set values for 75 drivers 23

3.3. Driving zone description for MUTCD left merge 28

3.4. Classification of drivers for MUTCD left merge 34

3.5. High risk driver set for left merge scenario 35

3.6. Distribution of 75 drivers based on demographic information for MUTCD left merge. 36

3.7. High risk driver distribution 37

3.8. Zone descriptions for MUTCD right merge scenario 43

3.9. Zone descriptions for Missouri alternate right merge scenario 45

3.10. Classification of drivers for MUTCD right merge 47

3.11. Classification of drivers for Missouri alternate right merge 48

3.12. Characterization of high risk drivers for right merge configuration 50

1. INTRODUCTION

1.1. BACKGROUND

The world has come a long way from when the first mass produced automobile was invented by Karl Benz in 1885. Better transport and transportation systems are being developed every day to support the emergence of auto-piloted cars such as the Tesla. Several advances in data collection techniques and analysis methods have led to important contributions in transportation theory and traffic management. Many theories, such as estimation and prediction of traffic flows [1] and the usage of technology such as google maps and GPS systems have made drivers ever aware of the road conditions. However, the validation of these predictions is necessary in order to develop a fool proof system. Newer methods in data collection coupled with analysis of behavioral aspects, namely human behavior are required to handle this challenge. Through the right kind of modeling techniques and testing, driving behavior can be incorporated in this validation.

The term cyber-physical system (CPS) refers to a new generation of systems with integrated computational and physical capabilities that can interact with humans through many new modalities [2]. The ability to interact with, and expand the capabilities of the physical world through computation, communication, and control is a key enabler for future technology developments. Analyzing human driving behavior is one of the keys to develop a robust cyber physical transportation system which ensures utmost safety and ease of access. Furthermore, this is necessary to minimize human related errors on the road. In particular, identifying driving patterns plays an important role in understanding and modelling the drivers' behavior. While models may not always be accurate, they provide a strong platform to conduct tests and enhance the accuracy of predictive models.

This testing environment can be used to improve several safety aspects of transportation infrastructure.

Safety, maintenance, and ease of mobility through a work zone are important concerns for the US Department of Transportations (DOT) [3]. Highway work zones result in congestion and traffic delays leading to increased driver frustration, traffic accidents and road user delay costs [4]. Highway work zones also interfere with traffic flow because they reduce the cross section of the available road and force drivers to perform several maneuvers in order to adapt to the modified road configuration [5]. Hence, significantly higher rate of accidents are observed in work zones every year during maintenance activities which result in reduced drive space as these highways require periodic maintenance in order to adhere to national standards.

The Manual on Uniform Traffic Control Devices [6], or MUTCD, defines the standards used by road managers nationwide to install and maintain traffic control devices on all public streets, highways, bikeways, and private roads open to public travel. The MUTCD, published by the Federal Highway Administration (FHWA), is a compilation of national standards for all traffic control devices, including road markings, highway signs, and traffic signals. The manual is updated periodically to accommodate the nation's changing transportation needs and addresses new safety technologies, traffic control tools and traffic management techniques. One of the primary objectives of MUTCD is the safety of road users, including pedestrians and cyclists, as well as personnel in work zones. This is an integral and high priority element of every road maintenance project in the planning, design, maintenance, and construction phases [6].

1.2. PROBLEM STATEMENT

Various methods are used by DOTs to notify upcoming work zone areas on a highway. The use of work zone signage configuration is one such method. The aim of this study is to evaluate a driver's response to two different work zone signage configurations and present comparisons between the configurations. This study has compared the Conventional Lane Merge (CLM) configurations provided by MUTCD against Missouri Department of Transportation's (MoDOT) alternate configurations. A driving simulator based study is used to analyze the effectiveness of MUTCD left merge vs Missouri alternate left merge and MUTCD right merge vs Missouri alternate right merge configurations on a two lane freeway. Study participants have been chosen in such a way that the demographic information of the overall population of drivers in the state of Missouri is captured.

The research conducted includes analyses of driving behavior of 75 different participants by measuring their response and reactions to the four work zone signage configurations. Merge patterns have been identified that demonstrate the states of driver behavior. Drivers are then characterized on their demographic information based on age and gender.

1.3. MOTIVATION

Although the graphical-only MUTCD signage for work zones has been in use for several years, it is not known if the signage recommended by the MUTCD offers the highest safety for all jurisdictions [7]. This provides a strong motivation to compare the present sign configurations with an alternate configuration proposed by MoDOT.

Comparisons between the MUTCD and MoDOT alternate sign configurations are also crucial as the law requires a complete evaluation of the effectiveness of different configurations before a new signage which deviates from national standards is implemented anywhere. The comparisons also provide value to both transportation agencies and drivers.

Transportation practitioners have conventionally used test tracks on the highway to record responses to different traffic signage configurations [7]. However, such usage has proven to be dangerous, time consuming, and a costly affair. A lot of other factors such as environmental conditions and lack of adaptability to different traffic scenarios have proven to be a hindrance in evaluating the effectiveness of the configurations. The use of driving simulator presents a number of positive elements: experimental control, efficiency, low expense, safety, and ease of data collection [26]. Missouri S&T is equipped with an in-house driving simulator in its Engineering Research Lab making it advantageous to perform this study.

Driver behaviors, driving styles or characteristics need to be recognized and predicted in order to design and develop intelligent and human-centered control systems in transportation [5]. As mentioned in the problem statement, the aim of this study is to identify merge patterns of different drivers and characterize them based on age and gender. Driving pattern identification and driver's behavior modeling are important aspects of cyber physical systems in transportation research and the results of this study can be of value to transportation researchers.

2. LITERATURE REVIEW

2.1. SAFETY IN WORK ZONES

With increasing vehicular volume on the highway systems nationwide, maintenance and construction for work zones play an important role in how traffic is regulated. A previous field study evaluated the safety effect of an alternate merge signage configuration in a highway work zone [7]. This field study was conducted on Interstate 70 highway in Missouri and compared the graphical-only lane merge closed signage from MUTCD with MERGE (arrow) signage on one side and Lane Closed sign on the other i.e. the MoDOT alternate sign. The driver behavior characteristics included driving speeds and open lane occupancies. Considering all the performance measures, the alternative sign configuration was not superior, but performed equally to the MUTCD sign configuration. Transportation researchers have conducted various studies to improve merging operations amongst work zones since lane closures reduce vehicular capacity and increase traffic delays. Early merge and late merge concepts emerge as the most encouraging methods to assuage safety related incidents and reduced capacities. The dynamic late merge concept revealed that the number of vehicles in the closed lane increased from 33.7% to 38.8%, when compared with MUTCD late merge scenario [13]. Apart from static methods, dynamic approaches and use of Intelligent Transportation Systems (ITS) have been applied worldwide for lane merge control.

Chinese researchers in [8] and [9] carried out different techniques to evaluate speed reduction methods around a work zone. Yanli et al., [8] used adaptive speed control methods using ITS techniques to increase safety and capacity in the work zone. Based on the analysis of speed change of vehicles coupled with additional sensors and data transmission technology, the validation of the adaptive model was carried out and this method achieved an effective reduction in speed of vehicles in the work zone. Kai et al., [9] used statistical analysis to evaluate three different speed reduction strategies and concluded that individual warning signs were not effective while speed limit sign with camera graph proved to be a useful technique to reduce driver speeds.

Research carried out on work zone crashes commonly identified a combination of injuries, fatal injuries and property damage to list the factors that aided unsafe conditions within the work zone. Harb et al., [3] conducted comparison studies between single vehicle and two vehicle crashes in Florida and used multiple and conditional logical regression models to identify characteristics and risk factors such as drivers, vehicles and environmental conditions that contribute to work zone crashes. This study indicated the highest queue discharge values (or capacity) of the work zone in the early merging scenarios were remarkably higher than the conventional Florida Department of Transportation (FDOT) plans.

In [10], authors claim that accident rates increase 7~119 % in work zones with a majority being fatal or multi vehicle crashes. Over the past several years, many techniques and programs have been implemented to enhance work zone safety and facilitate traffic progression including static and conventional techniques. These techniques include work zone intrusion alarms, portable rumble strips, flashing stop/slow paddles and barrier lighting units. While these measures have their advantages, their inability to dynamically direct and respond to changing traffic scenarios results in failure to increase mobility and economic productivity, as well as failure to reduce costs and environmental impacts.

Intelligent lane merge control systems with Intelligent Transportation System (ITS) techniques have been used to reduce the influence of lane closures. Yulong et al., [10] used Intelligent Lane Merge Control System (ILMCS) with ITS techniques and concluded that the performance of ILMCS exceeded the performance of conventional methods, dynamic early merge and dynamic late merge in terms of improving safety and traffic capacity around the work zone. Jacob et al., [11] used reinforcement learning to provide real time, adaptive and optimal control for traffic mobility in a work zone. A simulation model called Paramics was used to predict traffic flow, manage traffic, and design roadway operations before field work. Further traffic model research was reported by Kejun et al., [12] wherein model predictive control was used to determine optimal variable speed control in a freeway work zone.

The MUTCD divides a work zone into four distinct areas: advance warning, transition, activity, and termination [6]. The advance-warning area tells traffic to expect construction work ahead. In the transition area, traffic is channelized from obstructed to unobstructed lanes on either the left or the right side. Zhu et al., [14] investigated safety implications of current left lane and right lane closures of 3 lane freeways in Ontario, Canada. The approach aimed to improve inherent safety issues in the current lane by developing an alternative merge scenario and compare the two layouts for crash risk. Two safety indicators- uncomfortable deceleration and speed variance were used to explore the relative collision risks of different work zone lane closure layouts. By using a micro level simulation to obtain safety indicators, the researchers concluded that the alternate approach indicated better results.

Beacher et al., [13] evaluated the Late Merge (LM) system by deploying detailed studies and analysis of traffic simulations and field experiments. LM system was compared to traditional MUTCD lane closure control that was adopted in the Virginia Work Area Protection Manual (VAWAPM). The research about the dynamic late merge concept revealed that the number of vehicles in the closed lane increased from 33.7% to 38.8%, when compared with MUTCD late merge scenario. While late merge systems were deployed in Pennsylvania and Virginia, many Departments of Transportation use Dynamic Late Merge systems to increase safety and mobility within work zones. Kansas, Minnesota, Texas and Maryland have been found to use this concept and study results obtained were promising [15].

Michigan DOT installed Dynamic Late Lane Merge System (DLLMS) at freeway work zones and conducted studies to evaluate the effectiveness in 2006. Datta et al., [15] conducted research to validate the effectiveness of DLLMS by utilizing a designated point to merge to open lanes. The studies use travel time delay in seconds per 10,000 feet travelled and mean speeds as measures for effectiveness and concluded that DLLMS improved the flow of travel and increased the percentage of merging vehicles at the taper. The core concept of the Dynamic Late Merge (DLM) control strategy is to dynamically direct drivers' merging actions, based on detected traffic conditions and the proper control thresholds [16]. Kang et al., [16] proposed an advanced DLM control model that accounted for interactions between the speed, flow and available work zone capacity in the model. The proposed model utilized varying traffic conditions such as moderate, congested, heavily congested and adapted to either Early Merge control mode or Late Merge control mode.

2.2. STUDIES ANALYZING DRIVER BEHAVIOR

Having understood the important research conducted in work zone safety and merge techniques, it is imperative to analyze the concepts of human driving behavior and pattern recognition methods as this study discusses possible driving behavior models based on merge positions. Human driving behavior has multiple influencing factors such as emotions, personality, medical conditions, hunger or thirst and thus, trying to model the behavior can prove to be a difficult task to accomplish as drivers react differently when similar situations presents itself. Drivers' behavior can be formally defined as the function that maps traffic states to a driver's actions [17]. Higgs et al., [17] developed a two state algorithm that segments and clusters car following behavior to investigate characteristics of a wide range of driving behaviors by linking driver states to drivers' actions. The research findings indicated that the naturalistic data examined can be characterized into 30 unique clusters.

The idea behind predicting driver behavior styles is to develop a driving model that takes into account basic driving actions such as lane keeping, lane changing and obstacle avoidance. Once the driving actions are considered, extractions of useful characteristics are followed. This methodology is called indirect or model-based method [5]. Wang et al., [5] proposed a rapid pattern-recognition approach to identify driving behavior while negotiating a curve. k- mean clustering based on a support vector machine was used to classify drivers into aggressive and moderate based on their behavior. Bella et al., [18] also investigated driver speed behaviors on combined curves. This study was conducted using CRISS driving simulator to analyze speed patterns and compare the results with the perception hypothesis based on the speed data collected during the simulation.

Lane changing algorithms and merge patterns have attracted a lot of interest lately but limited research has been conducted to determine the probability of changing lanes and vehicle interactions that occur [19]. Sun et al., [19] conducted two different experiments: a field focus study and an in-vehicle driving test and used the data collected to model the probability of urban lane changing maneuvers under various discretionary lane changes. For the in-vehicle data group, 40 drivers with differing ages, occupation and other characteristics were assigned to drive on the roadway segment with an in-vehicle camera to record their behavior. The model was implemented in the CORSIM microscopic simulator and obtained promising results of predicting the probability in comparison to the field study based on three performance measures: lane based travel time, lane distribution and cumulative number of lane changes.

Lane changing and merging occurs more frequently in work zones than other roadway conditions due to mandatory lane changes that occur in work zones with lane closures. Thus, understanding the driver behavior with respect to merging in a work zone can be useful in order to design and operate safe work zones [20]. He et al., [20] developed a lane changing model in work zones using logistic regression. This model estimated the probability of a lane maneuver. There are two possible outcomes in such a scenario: (1) the lane change is completed; and (2) there was no lane change. The researchers concluded that the number of lane changes increase with traffic flow. Further, 25.53 % of the merges occurred extremely late in the region of within 100 feet from the closure of lane. Most of late merge drives were willing to overtake the slow moving vehicles and merge back into the lane. Weng et al., [21] carried out similar research in order to investigate the speed-flow relationship and drivers' merging behavior in work zone merging areas. A model was developed to determine desired merging location of the drivers along with a binary logit model to estimate the merging probability into current gaps. A merging distance model was then formulated to estimate the merge distance of a merging vehicle and the findings of this study showed that speed-flow relationship in the through lane is affected by merge lane traffic under uncongested conditions.

2.3. DRIVING SIMULATOR STUDIES

Field experiments are shown to be expensive and dangerous for both drivers and researchers. Many investigators prefer to use simulators for their research. The use of driving simulators presents a number of positive elements: experimental control, efficiency, low expense, safety, and ease of data collection. Bella [26] conducted studies to validate CRISS, a driving simulator for work zone design. The research was developed through the following steps: (a) a survey of speed measurements on highways next to a work zone of medium duration, (b) reconstruction in virtual reality of the real situation by using the driving simulator and subsequent running of a series of driving tests, and (c) statistical analysis of the field speeds and of the speeds from driving simulations for validation of the simulator. Bella concluded that the driving simulator was a reliable tool for analyzing speeds on work zones by comparing the field speeds and speeds obtained on the driving simulator.

Driving simulator studies have clear advantages over field data collection as they allow the study of driver behavior that may not be replicable in field tests for a wide range of scenarios including traffic control devices, state of traffic and composition, and the environment [23]. Bham et al., [23] proposed a validation framework using a driving simulator for overcoming challenges of identifying safe data collection points in a work zone. The fixed based driving simulator addressed the challenge. Park et al., [24] also conducted similar studies to validate microscopic simulator for work zone studies. A previously developed microscopic simulation model (VISSIM) calibration and validation procedure was applied to a freeway work zone network. The performance of the procedure was tested by comparing distributions of simulation outputs and field travel time data. The calibrated set of parameters for the VISSIM model (Genetic Algorithm-based parameter set) provided simulation results similar to the field data and validity of the procedure was proved for a freeway network. Kai et al., [25] utilized a method for microscopic simulation model to validate parameters in VISSIM by using data collected in work zones by means of orthogonal experimental design. The study investigated the relationship between the speed limits and standard deviation of the speed to obtain appropriate speeds in a work zone. The results obtained in the simulator suggested a speed reduction of 30km/hour downwards in work zones compared to the upper section in order to decrease potential accidental rates. In the next chapter, the methodologies used for analysis are discussed.

3. ANALYSIS

3.1. PROJECT DESCRIPTION

The project compares the driver response to two different merge sign configurations- MUTCD and MoDOT. The driving simulation studies are replicated for the left merge and right merge scenarios for each sign configuration. These set up the experiment with 2 treatment tests which is replicated 4 times i.e. merge left and merge right scenarios for each signage. In the alternative left merge configuration, the MUTCD graphical right lane-closed sign shown in Figure 3.1.a is replaced with a MERGE/arrow sign on the closed-lane and a Right lane closed sign on the other side, as shown in Figure 3.1.b. In Figure 3.1, SA, SB, SC, T1, T2, and B refer to distances between signs or taper lengths, and are computed based on the road type, offset, and posted speed. The right merge sign configuration for MUTCD and Missouri alternate is a mirror image of Figure 3.1.a and 3.1.b respectively.

The process of understanding human driving behavior is accomplished in a simulated environment. A previous field study evaluated an alternative merge sign configuration of the MUTCD configuration in a freeway work zone [7]. In contrast to [7], this project utilizes the Missouri S&T driving simulator to create a virtual driving environment that allows MoDOT and FHWA to better assess differences between the two configurations and uses the data produced from the simulation study to evaluate the effectiveness of the MoDOT alternate merge sign.

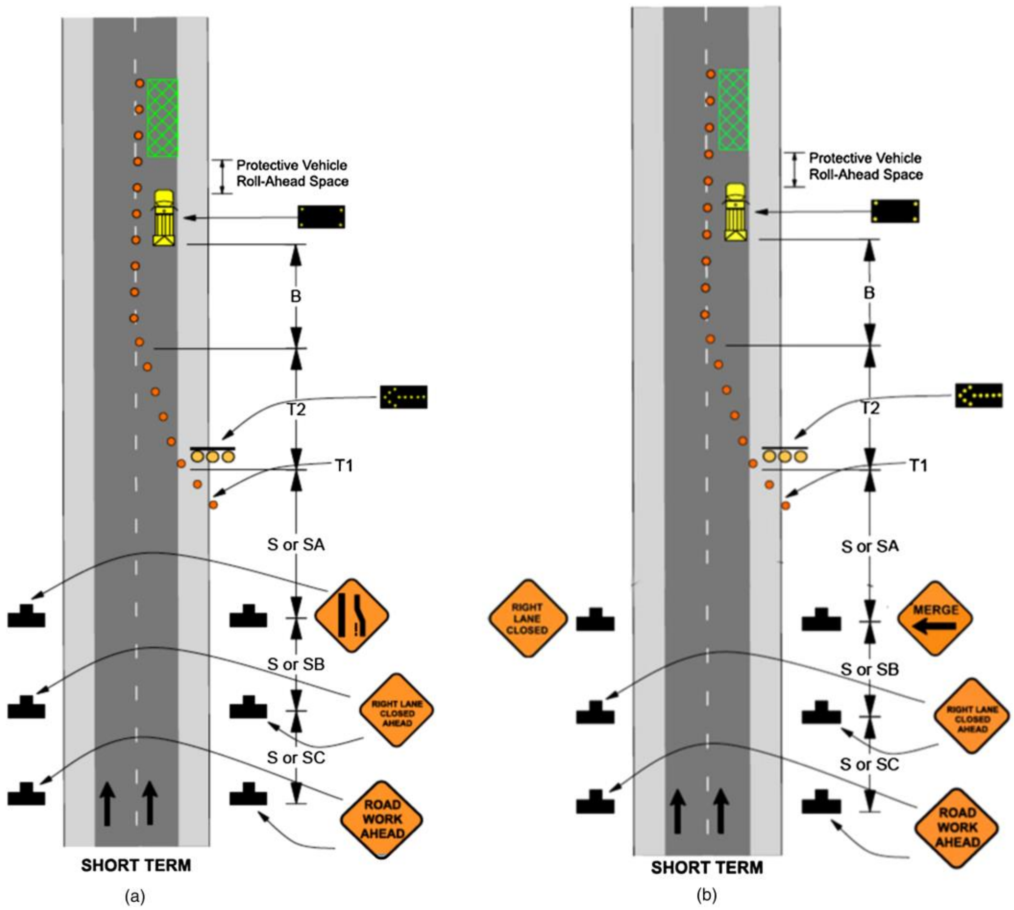
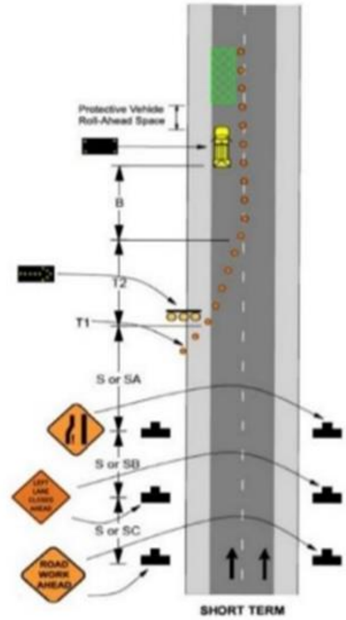
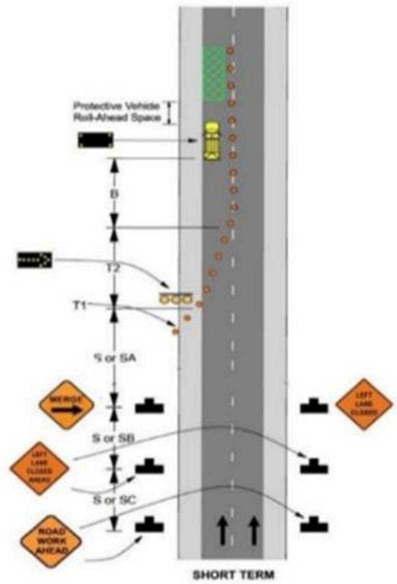


Figure 3.1. Work zone sign configurations. (a) MUTCD merge configuration
(b) Missouri alternate merge configuration

A simulation test was conducted involving 75 different participants who had varying driving experience and patterns. The important characteristics of each individual participant such as age, gender and driving experience were initially recorded before the start of simulation. The participants then experienced the various driving scenarios - MUTCD left merge and right merge and MoDOT alternate left merge and right merge as illustrated in Figure 3.2. Driving patterns and observations such as speed of the vehicle in the simulator and distance between lane switch and time intervals were recorded.





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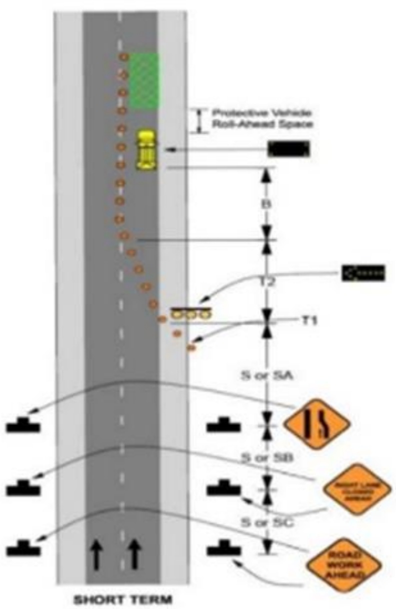

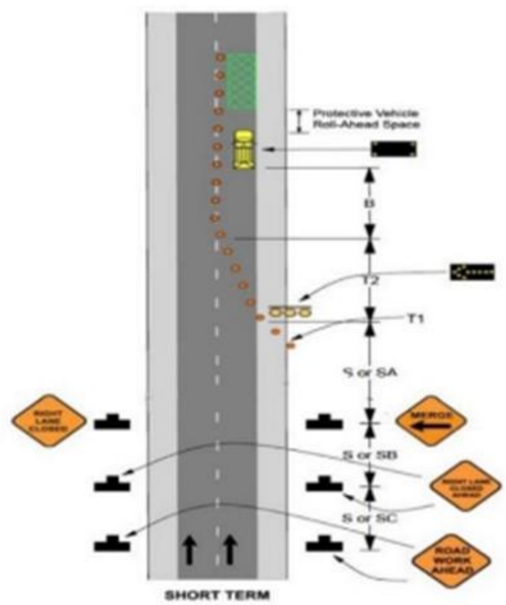

c

d

Figure 3.2. Merge scenarios. (a) MUTCD right merge, (b) Missouri alternate right merge, (c) MUTCD left merge, (d) Missouri alternate left merge

The 4 different simulator scenarios shown in Figure 3.2 are as follows: (a) MUTCD right merge, (b) Missouri alternate right merge, (c) MUTCD left merge, (d) Missouri alternate left merge, respectively. Each participant in the simulator is tested for the four aforementioned scenarios and driver reactions and behavior are recorded. The computer records the distance travelled every second in feet along the lanes and position of driver across lanes.

3.1.1. Simulator Environment. The Missouri S&T simulator room, illustrated in Figure 3.3., consists of a prototype vehicle (Ford ranger pickup truck) that the driver can settle inside to drive. The vehicle is fixed with additional parts such as the steering wheel, accelerator pad, brake pedal, speedometer and sensors which feed the vehicular movements to an attached computer. The simulator is equipped with a data acquisition system. The computer records the data while an overhead projector (3000 lumen LCD) maps the lane environment onto a screen in front of the vehicle.

This video game like environment is additionally equipped with a force feedback mechanism with the steering wheel in order to mimic real time driving. The driving interface is programmed using a combination of BLENDER 3D (graphics software) and PYTHON software to obtain the requisite driving environment.

3.1.2. Goals and Objectives of Research. The goal of the research is to conduct a comparative study of human driving behaviors and identify driving patterns in work zones when exposed to two different configurations of merge left and merge right signage in a simulated driving environment.

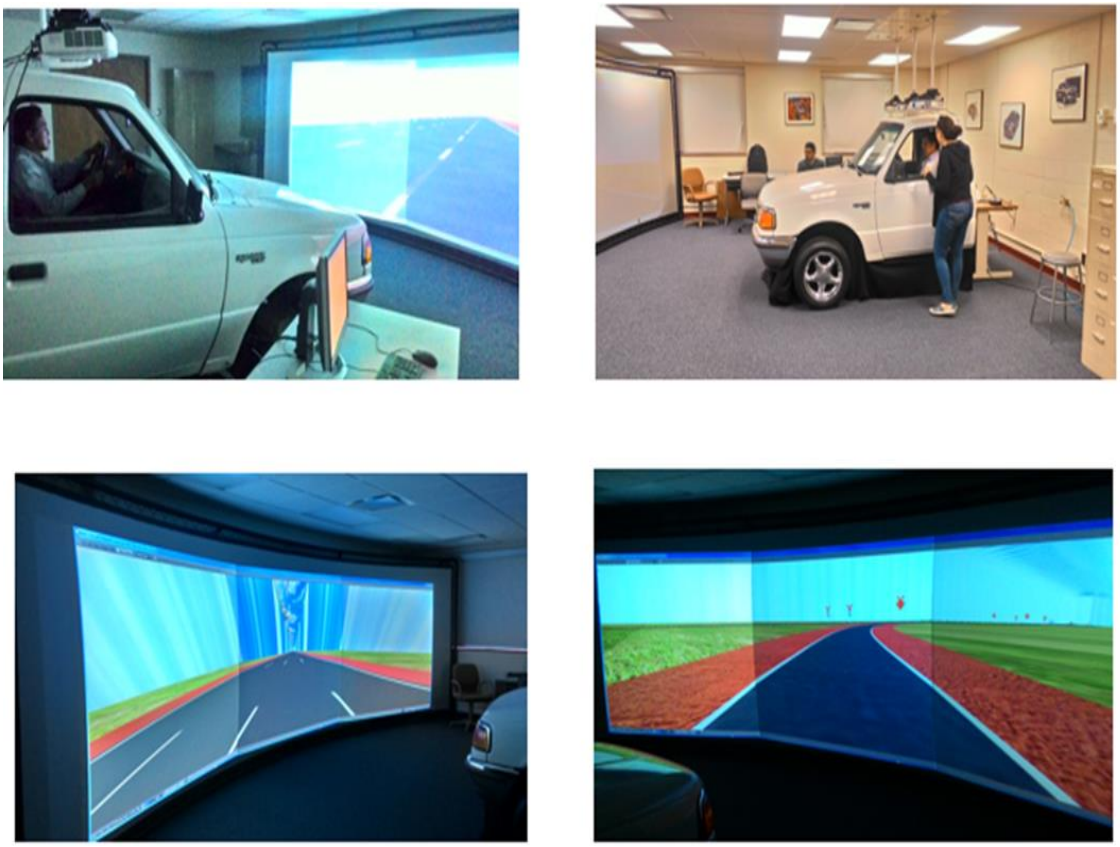

Figure 3.3. Missouri S&T simulator room. The figure shows the driving environment that drivers experience during the course of the simulation

The following objectives are desired to be achieved during the course of this study:

- Conduct visual and exploratory analysis of driving paths of participating drivers in the simulated driving environment.
- Examine the response of drivers to merge signs during each simulation from a statistical point of view.
- Extract features for analyzing and modeling drivers' behaviors, and group drivers accordingly.

- Characterize high-risk drivers.
- Compare the two configurations in terms of their ability to assist drivers to safely travel through work zones.

This research proves to be valuable mainly from a safety perspective as the results can be used to minimize accidents around the work zone. MoDOT reports a higher occurrence of crashes around a work zone [12].

3.2. THE DATA

75 driving paths simulated in each of the four merge scenarios are analyzed for identifying driving patterns and modeling driver's behavior, in response to the work zone traffic signs. Each driving path is associated with one individual participant of the simulation (termed drivers in the remainder of the report). Let i be the index of drivers, and $I = \{1, 2\ldots 75\}$ be the index set of drivers.

3.2.1. Data Collection. The following section discusses the data analysis approaches used to characterize and classify drivers based on their driving behavior.

The first and foremost approach towards data analysis is to gather the requisite data in its raw form and convert it to a suitable and readable format. The Missouri S&T driving simulator automatically collects data during the course of the simulation which then needs to be refined.

From Table 3.1, it can be observed that the simulator records 5 different parameters for each individual driver during every individual merge scenario. The x locations (driver position across lanes) range from -154 feet to -144 feet. This data is converted such that the road width ranges from 0 to 10 feet with 0 being the right end of the right lane and 10 being the left end of the left lane. The merge and work zone sign configurations appear as the driver drives through the simulator environment. The *y* location (driver position along the lanes) ranges from -2378 feet to +2378 feet. The data is converted to 0 - 4756 feet which is equal to the length of the lane on the simulator. The raw data obtained as an Excel file is converted to csv (comma separated values) format for it to be read by the software, R Studio.

Table 3.1. Raw data collected in its original form

Time	Speed	Steer amount	Location x	Location y
0.124839	0.253497	-4.034482759	-153.6863251	-2378.719238
1.148524	2.067573	-6.147783251	-153.6863098	-2378.332275
2.141676	5.312149	-6.147783251	-153.6847687	-2376.008545
3.165339	9.690034	-6.147783251	-153.6775513	-2371.218506
4.171091	15.13124	-6.147783251	-153.6522675	-2363.040283
5.191263	20.52836	-6.147783251	-153.5888977	-2351.572754
6.1977	26.09536	-6.147783251	-153.4530945	-2336.300049
7.214082	30.91244	-3.938423645	-153.2131042	-2317.880615
8.232192	36.45781	-3.938423645	-152.8406677	-2295.563232
9.245145	41.44242	-3.938423645	-152.3109741	-2269.938477
11.26699	46.33557	-3.938423645	-150.7110291	-2212.182129
12.26566	48.39045	0.32820197	-149.6743469	-2181.651855

The locations are converted to a standard set of lane and driver locations starting from 0 as shown in Figure 3.4. The new range of lane positions are from 0 to 4756 feet and range for driver position is from 0 to 10 feet. As the driver moves along the road (*y*-direction), driving patterns are identified and positions along the width of the road (*x* – direction) are observed for analysis. These positions form the base for learning driver behavior during a merge scenario.

Figure 3.4. Lane setting with adjusted data

3.2.2. Data Preparation. Having collected the *x* and *y* positions of 75 drivers along the lanes, the next process is to utilize the data points to conduct the analysis. As the primary goal is to conduct work zone simulator analysis and the acceptance of the Missouri alternate merge sign, the requisite data is refined in order to obtain accurate results. Firstly, even-spaced checkpoints are defined, indexed by *j* along the driving direction for every 10 feet. These checkpoints enable to obtain greater number of data points with respect to driver position which increases the accuracy of analysis. For instance, consider driver $i = 8$ during the MUTCD merge left scenario. The driver is at *x*

= 9.865 feet at y = 0 (beginning of simulation) and x = 3.148315 feet at y = 4606.802 feet (end of simulation). There are a total of 103 different x positions and corresponding y positions along the lane for driver 8. Now, by defining checkpoints at every 10 feet from y = 0 to y = 4606.802 feet, a total of 460 positions of driver 8 is obtained for which corresponding x positions are interpolated. This procedure enables the viewer to understand the exact location of driver 8 at all times during the simulation.

3.2.3. Interpolation of x Positions. The next stage of analysis is done using R programming. The requisite data is imported onto the analysis software for interpolation.

The y-location of the jth check point is denoted as y_j. x -locations at the checkpoints are interpolated from the raw data. The x-location of the i^{th} driver at Y_j is denoted by X_{ij}. A set of "checkpoints" is defined along the driving direction (i.e.,y), at an even interval of Δy feet, where the x-location of drivers (i.e., their position across the lanes) is measured and analyzed. $\Delta y = 10$ feet is chosen and hence, there are 476 checkpoints in total, including the two boundaries.

Let j be the index of check points and $J = \{1, 2, \cdots, 476\}$ be the index set for checkpoints. The y-location of the j^{th} checkpoint,y_j, is equal to $(j - 1)\Delta y$. The values pertaining to variable x of the 75 driving paths were not read at the same y-locations and therefore, each driving path is interpolated to "read" x values at the defined checkpoints. Interpolation of x values is done using the spline () function on R studio.

By comparing Figures 3.5 and 3.6, the interpolated X_{ij} positions provide a greater set of data points to visualize the driving path and understand the position of i^{th} driver.

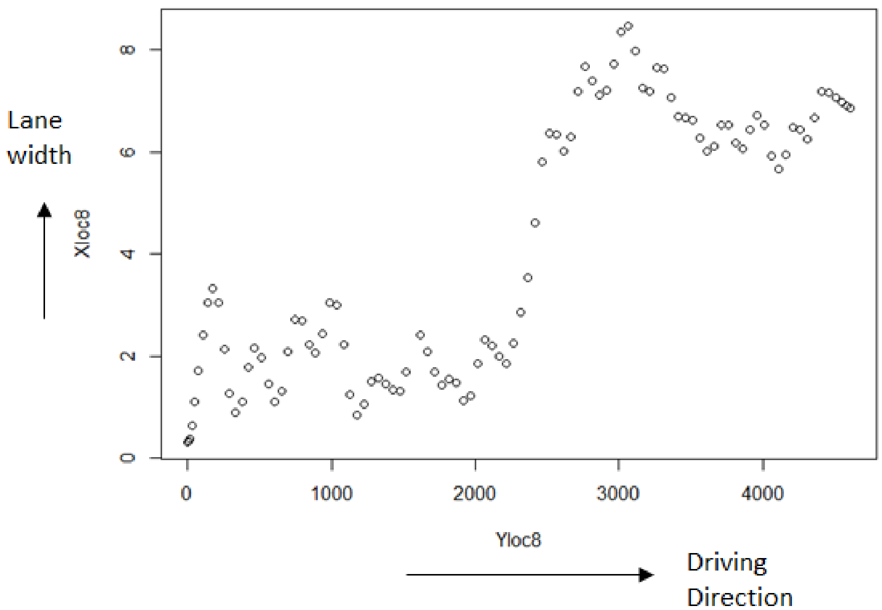

Figure 3.5. Plot of driver positions *x* vs *y* for the original data

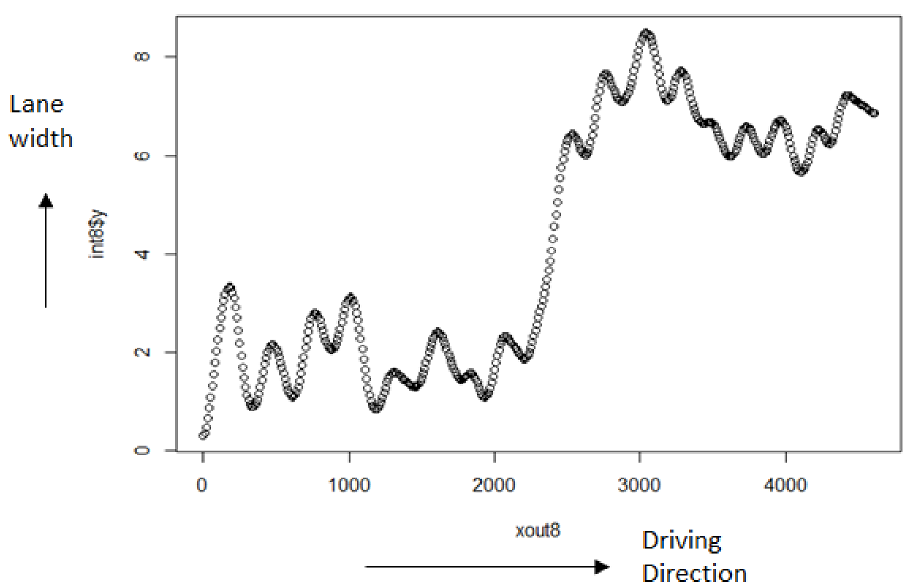

Figure 3.6. Plot of driver positions *x* vs *y* for the interpolated data

X-location data set is a 476 by 76 matrix created by interpolation as illustrated in Table 3.2, the first column saves y_j and the $(i+1)^{th}$ column is X_{ij} for $i = 1, \cdots, 75$ and $j = 0,1, \cdots, 476$. Multivariate x-location series data is a data matrix containing 76 column vectors. The length of the vectors is 476. Table 3.2 represents the interpolated data set values for 7 drivers.

Table 3.2. Interpolated data set values for 75 drivers

Y	*X1*	*X2*	*X3*	*X4*	*X5*	*X6*	*X7*
0	0.313556	0.313675	0.313675	0.313705	0.313675	0.313675	0.312424
10	0.328427	0.322979	0.313675	0.313827	0.31357	0.357419	0.313918
20	0.367778	0.368251	0.313675	0.31341	0.31512	0.469236	0.314036
30	0.431945	0.470618	0.313675	0.331331	0.328149	0.64699	0.323009
40	0.521354	0.640143	0.313675	0.376824	0.361122	0.891862	0.351779
50	0.636691	0.879919	0.313675	0.448129	0.413381	1.204029	0.411295
60	0.774495	1.189717	0.313675	0.545783	0.484434	1.584428	0.510397
70	0.929891	1.568647	0.313675	0.664245	0.575115	2.033282	0.648844
….							

3.3. ANALYSIS OF LEFT MERGE SCENARIO

Having obtained *x* and *y* locations, data analysis is performed on the data sets. Figure 3.7 depicts the lane orientation for the 4 merge scenarios: (MUTCD/MoDOT for left merge/right merge scenarios). The distance travelled along lanes is along *Y* axis and position of drivers across lanes is along *X* axis. The start of *X* axis is the right edge of the right lane and the end point of *X* axis is the left edge of left lane, with each lane being 5 feet wide.

For the purpose of analysis, all *x* locations greater than $x = 4$ feet are defined as the left lane and all *x* locations lesser than $x = 4$ feet are defined as the right lane. This lane definition is considered after carefully observing the driving patterns that are visible in later stages. One may argue as to why $x = 5$ is not considered as the point to distinguish lanes. This is because the driving positions occupied by drivers during the simulation does not range from 0 to 10 feet but in reality, ranges between 0 to 8.5~9 feet. $x = 4$ feet proves to be a reasonable estimate of dividing the driver positions among the right and left lanes without dramatically affecting the driving patterns. This classification aids in the ease of analysis by defining a single point (at $x = 4$ feet) to denote lane change.

Locations of traffic signs and work zone are illustrated in Figure 3.7. The traffic signage is placed at the following locations along the lanes.

- Work zone ahead at $y = 1438$ feet.
- 1st Traffic sign: Merge at $y = 2226$ feet.
- 2nd Traffic sign: Merge at $y = 2667$ feet.
- Traffic sign: Work Zone starts at $y = 2958$ feet.
- Traffic sign: Work zone ends at $y = 3322$ feet.
- $x = 0$ to 4 feet denotes the right lane and $x = 4$ to 10 feet denotes left lane.

3.3.1. Exploratory Analysis– Visual. Visual analysis for driving paths of 75 drivers for the two sign configurations of MUTCD left merge and Missouri alternate left merge is performed.

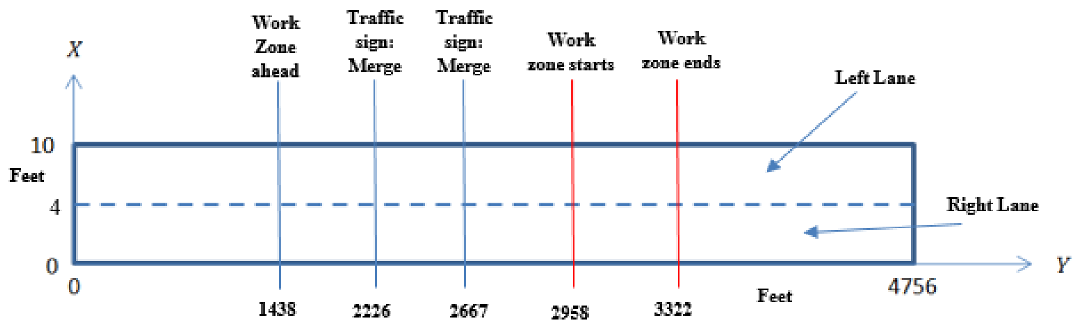

Figure 3.7. Lane description for the simulation scenarios

A plot of the 75 driving paths simulated in the MUTCD left merge scenario is illustrated in Figure 3.8. Few driving patterns are observed from this plot. The plot indicates that about half the drivers merge to the left lane immediately at the start of simulation.

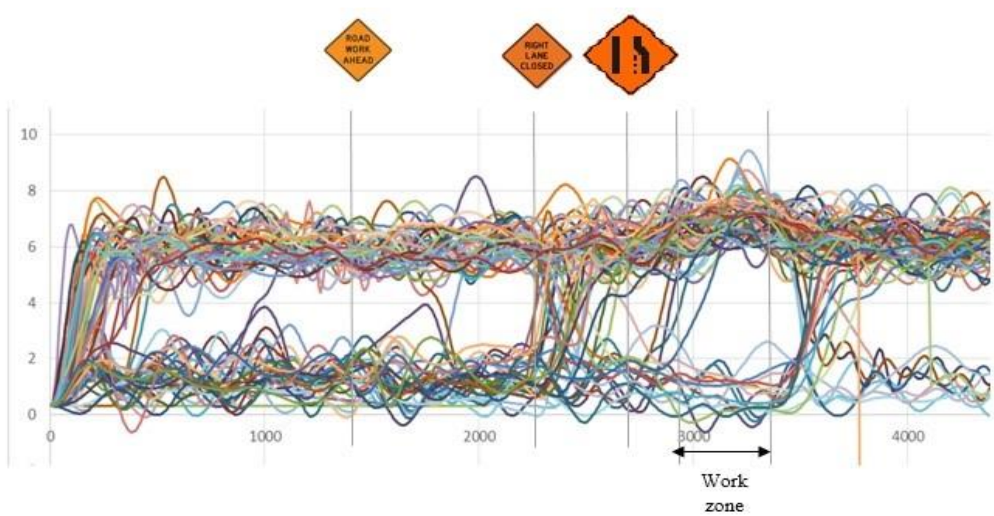

Figure 3.8. Driving paths of 75 drivers in the MUTCD left merge scenario

The remaining drivers stay on the right lane for more than 2000 feet following which another group of drivers merge to the left. A few drivers merge to the left lane very late, after 3300 feet. Some drivers merge back to the right lane during the simulation, but most drivers are on the left lane when the simulation is completed. This indicates around half of the drivers often drive on the left lane during driving. For those who often drive on the right lane, patterns of merging to the left lane are clearly observed in Figure 3.8.

A slightly varying pattern is observed for the Missouri alternate left merge configuration in Figure 3.9. Again, about half of the drivers merge to the left lane immediately at the start of the simulation. The remaining drivers stay on the right lane for more than 2000 feet following which another group of drivers merge to the left.

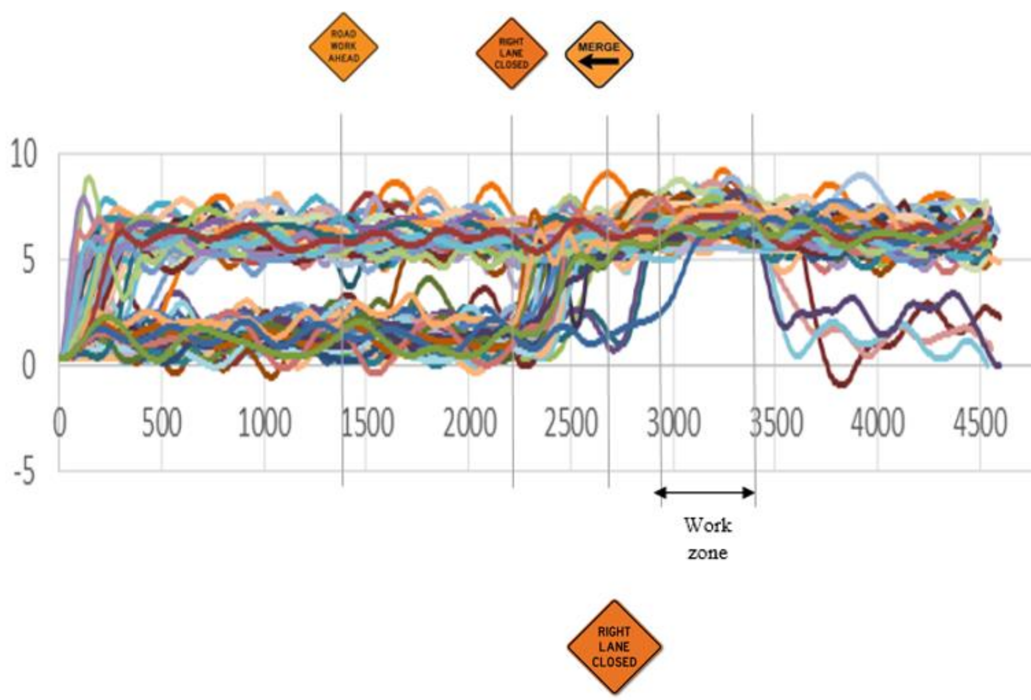

Figure 3.9. Driving paths of 75 drivers in the MoDOT alternate left merge

Almost all of the drivers have merged to the left lane in this scenario before 2958 feet i.e. start of the work zone. The observations in Figure 3.9 indicate a better response from drivers to the Missouri alternate left merge configuration.

3.3.2. Dynamic Distribution of Drivers– Evolution of Probability Density. From the driving patterns observed in both the left merge scenario, the visual plots indicate the existence of at least two zones where many drivers are actively merging to the left (for the first time), one is within y = [0,400] and the other is within y = [2300, 2900], termed Z_{A1} and Z_{A2}, respectively. Between these two zones is an inactive zone where only a few participants changed lane, which is termed Z_{N1}. The remaining segment after Z_{A2} is named Z_{N2}.

Figure 3.8 and 3.9 indicate the distribution of driver's x-locations changed along the driving direction. The evolution of the distribution within each zone and across zones is analyzed. For each zone, three kernel density estimations (KDE) are fitted to represent the density of driver's x-locations at three selected y-locations and arranged in a row. Therefore, Figures 3.10 and 3.11 are a matrix of 4 by 3 plots. Table 3.3 summarizes the x-location data points.

The distribution of drivers on the two lanes at each of 12 sampled y- locations (3 for each zone) is represented by a kernel density estimated using their x-locations. In Figures 3.10 and 3.11, the three kernel densities in the first row are for Z_{A1}. Row 2, 3 and 4 are for Z_{N1}, Z_{A2}, and Z_{N2}, respectively. x = 4 feet distinguishes between right and left lane. The density plots are plotted on R using codes that are illustrated in Appendix A of this report.

Table 3.3. Driving zone description for MUTCD left merge

Zone	Y range [ft.]	Description	Sample Y-locations [ft.]
Z_{A1}	[0, 400)	A large group of drivers move from the right lane to the left lane	50, 100, 260
Z_{N1}	[400, 2300)	Most drivers follow a straight path	400, 1250, 2250
Z_{A2}	[2300, 2900)	A second large group of drivers move from the right lane to the left lane	2300, 2400, 2600
Z_{N2}	[2900, 4760]	Most drivers follow a straight path	2900, 3600, 4000

From Figure 3.10 for zone Z_{A1}, three KDEs are fit at $y = 50, 100,$ and 260 feet (in the first row). At $y = 50$ feet, almost all drivers were on the right lane. At $y = 100$ feet the KDE is skewed to the left lane, indicating some participants merged to the left lane by this y-location. At $y = 260$ feet, the KDE clearly has two modes, but contains a mixture of two densities with large overlap. The KDE indicates a group of drivers merging to the left lane at that y-location. The single group of drivers at the beginning of this zone split into two groups soon.

For zone Z_{N1}, three KDEs are fit at $y = 400, 1250,$ and 2250 feet (second row). The three KDEs are similar in that they all have two modes, indicating a mixture of two distributions. The KDE is relatively stable during this lengthy zone, indicating most drivers kept on their own lane. But the mode on the left lane increases at y=2250 feet (end of this zone), indicating that some drivers have started to merge to the left lane.

For zone Z_{A2}, three KDE are fit at $y = 2300, 2400,$ and 2600 feet (in the third row). All KDEs have two modes, but the mode on the right lane decreases and the mode on the left lane increases. The dynamic of the KDE within this short zone indicates that a number of drivers merged to the left lane and more drivers were on the left than on the right in this zone.

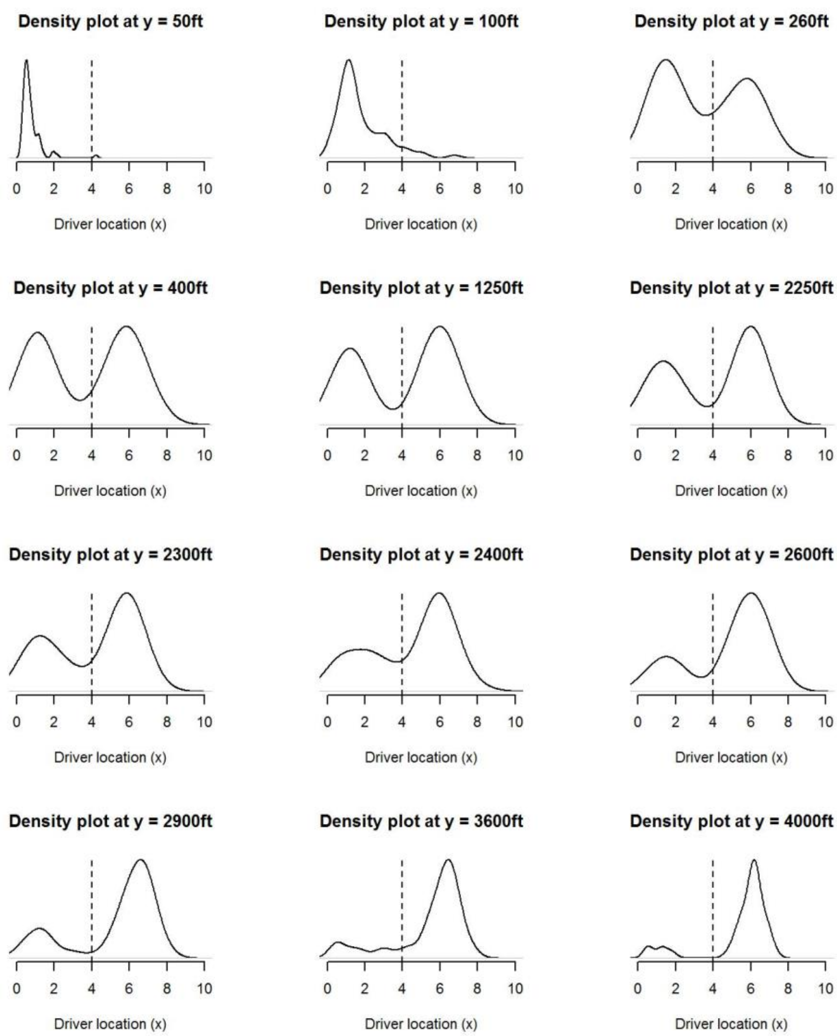

Figure 3.10. Density plots of MUTCD left merge

For zone Z_{N2}, three KDE at $y = 2900, 3600,$ and 4000 feet (in the fourth row). The mode on the right lane diminishes rapidly and the kurtosis of the distribution on the right lane rapidly increases. This indicates that at *y* = 4000 feet, most drivers were on the left lane.

Within zone Z_{A1} one observes the largest change of driver distribution on the two lanes, followed by zone Z_{A2} and Z_{N2} where slightly significant changes are seen. In zone Z_{N1} the driver distribution on the two lanes are relatively stable.

From Figure 3.11., the density distribution for zones Z_{A1} and Z_{N1} are similar for both left merge scenarios. Zones Z_{A2} and Z_{N2} are also comparable.

For zone Z_{A2} the mode on the right lane decreases while the mode on the left lane increases. The dynamic of the KDE within this zone indicates that almost all of the drivers merged to the left lane before the start of the work zone.

For zone Z_{N2}, the mode on the right lane diminishes rapidly while the kurtosis of the distribution on the right lane rapidly increases. This indicates that at y = 2900 feet, all drivers were on the left lane prompting a better response to the Missouri alternate left merge signage.

3.3.3. Feature Extraction. The position of driver along lanes (y-location) is identified wherein each driver merged to the left lane (for the first time), $y_{ML,i}$ for $i \in I_{ML}$where I_{ML} is the set of drivers who merged to the left during the simulation. I_{ML} is found to contain every driver except for drivers 52 and 53 who did not merge to the left for the MUTCD left merge scenario. This metric is used to cluster drivers into groups.

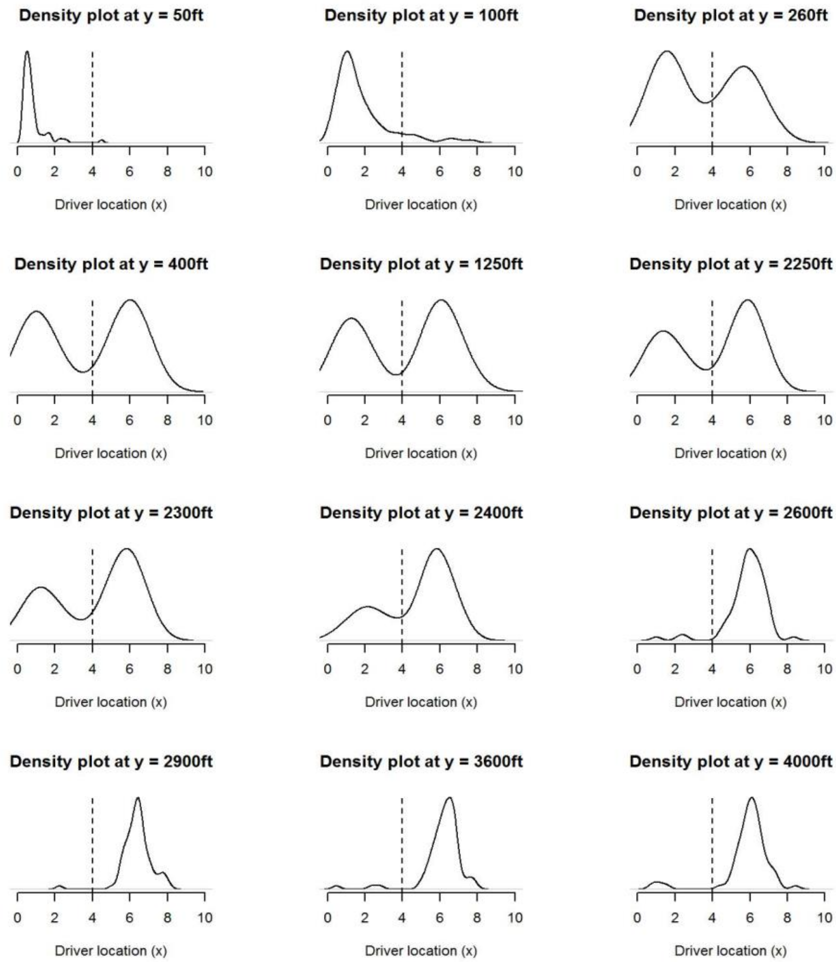

Figure 3.11. Density plots of MoDOT alternate left merge

Y-location where the i^{th} driver merged back to the right lane (for the first time) is identified and denoted as $y_{MR,i}$. Y-location where the i^{th} driver merged back to the left lane (for the second time) is identified and denoted as $y_{MLL,i}$. These metrics are further analyzed to extract suitable features that define driver behavior or characteristics for both the left merge scenarios.

The merge positions, $y_{ML,i}$, $y_{MR,i}$ and $y_{MLL,i}$ are identified using codes generated on R. For codes, refer Appendix.

3.3.4. Classification of Drivers. 75 drivers are classified under different groups based on their merge positions for the left merge scenarios. The classification is as follows:

3.3.4.1. Groups A vs B. Did driver i switch to the left lane (for the first time) before the work zone starts? Group A consists of all drivers that merged to the left lane before 2958 feet. Group B consists of all drivers that did not merge before 2958 feet. The cumulative number of participants who have merged to the left lane (for the first time) by the location y_j, denoted by N_j , is computed as

$$N_j = \sum_{i=1}^{75} 1\{y_{ML,i} \leq y_j\}$$

$$y_{ML,i} < 2958 \text{ ft} \qquad (1)$$

3.3.4.2. Groups B.1 vs B.2. Early vs late left merge (for the first time). Clustering is used to classify drivers as candidates that merged early (B1) or drivers that merged late (B2). A k-mean clustering method is used to determine centers of the two active merging locations. Given the number of clusters,K is chosen to be K=2 and the following optimization model determines the cluster mean,$\{\bar{y}_k\}$, through minimizing the sum of squared error. The optimization model is solved using the solver function available in the data analysis tab in Microsoft Excel.

Minimize:

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

Subject to:

$\sum_{k=1}^{K} z_{ki} = 1, \forall\ i \in I_{ML}$, $z_{ki}'s$ are binary variables, $\bar{y}_k$ >= 0, $\forall\ k \in K$

The optimization problem above is solved at $K = 2$ to obtain

$$\bar{y}_1 = 209 \text{ ft } (\text{before any traffic sign}) \text{ and,}$$

$$\bar{y}_2 = 2446 \text{ ft (between the two merge signs)}$$

Thus, drivers that merged closer to 209 feet are classified under group B1 and drivers that merged closer to 2446 feet are classified under group B2.

3.3.4.3. Groups C.1~C.5. Where did the driver merge back to the right lane (for the first time)? This classification is done for drivers that switched back to the right lane having made the initial merge to the left lane during the course of the simulation.

$y_{MR,i} \in [0,2226), [2226, 2667), [2667, 2958), [2958, 3322), [3322, \infty)$.

3.3.4.4. Groups D.1 vs D.2. Did the driver merge back to left lane before work zone starts?

$$y_{MLL,i} < 2958 \text{ ft}$$

Group D.2 are notably the high risk drivers that did not merge to the left lane before the work zone starts as they appear to have seemingly driven through the work zone. High risk drivers are further characterized to understand the nature for this driving behavior. Table 3.4 summarizes the classification of drivers for MUTCD left merge.

Table 3.4. Classification of drivers for MUTCD left merge

Group	Description	No. of drivers in group	Sample drivers in group	Merge Position during 1st switch in feet
A	Merged to the left lane before work zone	68	16,27,13,45,39	Before 2958
B.1	Belong to K1 cluster	43	16,27,31,32,35,38,6	208.60
B.2	Belong to K2 cluster	25	13,4,66,72,45,5,17	2446.40
F- Failed simulation	Drove through the work zone	7	43,46,52,53, 55,65,73	
Merge positions during 2nd switch				
	Description	No. of drivers	Sample drivers	Merge positions
C.1	Belong to switch position before 1st traffic merge sign	2	30 , 36	500, 1820
C.2	Belong to switch position between 1st and 2nd traffic merge sign	8	20,47,48,49,51, 56,57,59	between 2226 and 2667
C.3	Belong to switch position before work zone starts	1	50	2680
C.4	Belong to switch position after work zone ends	4	4,17,34,26	after 3321
Merge positions during 3rd switch				
D.1	Belong to switch position before work zone starts	1	36	before 2957
D.2	Belong to switch position after work zone ends	8	20,47,48,50,51 56,57,59	after 3321

MUTCD left merge scenario obtained 68 drivers that merged from right to left lane before the start of the work zone while 7 drivers did not make the lane change entirely during the simulation. B1 = 43 drivers made an early switch which implies they like to drive on the left lane. B2 = 25 drivers that made a late switch are the drivers that respond to merge signs.

Risk analysis is performed to identify drivers that entered the work zone. Drivers are classified as High Risk if they display driving behaviour that may prove risky from a safety perspective. Drivers that either drove through the work zone or made an extremely late merge (i.e. y >=2800 feet), are classified as high risk drivers. MUTCD merge left scenario has 17 high risk drivers while MoDOT merge left has 1 high risk driver shown in Table 3.5.

Table 3.5. High risk driver set for left merge scenario

"High-risk" drivers who entered the work zone		
	MUTCD Merge Left (17 drivers)	**MoDOT Alternate merge left (1 driver)**
participant ID	20, 30, 43, 46, 47, 48, 49, 50, 51, 52, 53, 55, 56, 57, 59, 65, 73	73

3.3.5. Characterization of High Risk Drivers. Table 3.6 summarizes the distribution of drivers based on the demographic information obtained from participants of the simulator study. Characterization of high risk drivers based on their age and gender is obtained in Table 3.7.

Based on the demographic information, Figures 3.12 and 3.13 compare the overall participant information with high risk drivers for the MUTCD left merge scenario. The blue bar in Figures 3.12 and 3.13 represent the distribution of the 75 participants while the red bar represents the 17 high risk driver distributions obtained for the MUTCD left merge scenario.

Table 3.6. Distribution of 75 drivers based on demographic information for MUTCD left merge

Group	**18-24**	**25-44**	**45-64**	**65+**	**Male**	**Female**
B.1	11.63%	27.91%	46.51%	13.95%	39.53%	60.47%
B.2	24.00%	40.00%	32.00%	4.00%	56.00%	44.00%
F- Failed simulation	0.00%	57.14%	28.57%	14.29%	57.14%	42.86%
C.1	50.00%	50.00%	0.00%	0.00%	100.00%	0.00%
C.2	0.00%	25.00%	37.50%	37.50%	62.50%	37.50%
C.3	0.00%	0.00%	0.00%	100.00%	0.00%	100.00%
C.4	0.00%	100.00%	0.00%	0.00%	50.00%	50.00%
D.1	100.00%	0.00%	0.00%	0.00%	100.00%	0.00%
D.2	0.00%	25.00%	37.50%	37.50%	62.50%	37.50%

Table 3.7. High risk driver distribution

	% age Age group of				% male or female in group	
Group	**18-24**	**25-44**	**45-64**	**65+**	**Male**	**Female**
High Risk Drivers	0.00%	41.18%	29.41%	29.41%	64.71%	35.29%

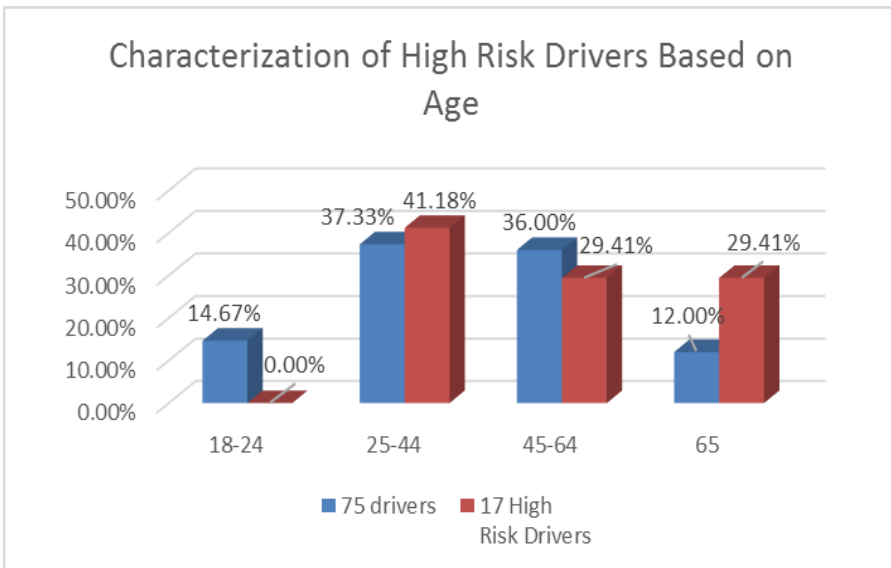

Figure 3.12. Characterization of high risk drivers based on Age for MUTCD left merge

MUTCD left merge: The distributions of high risk drivers on age and gender are different from the distributions of 75 participating drivers.

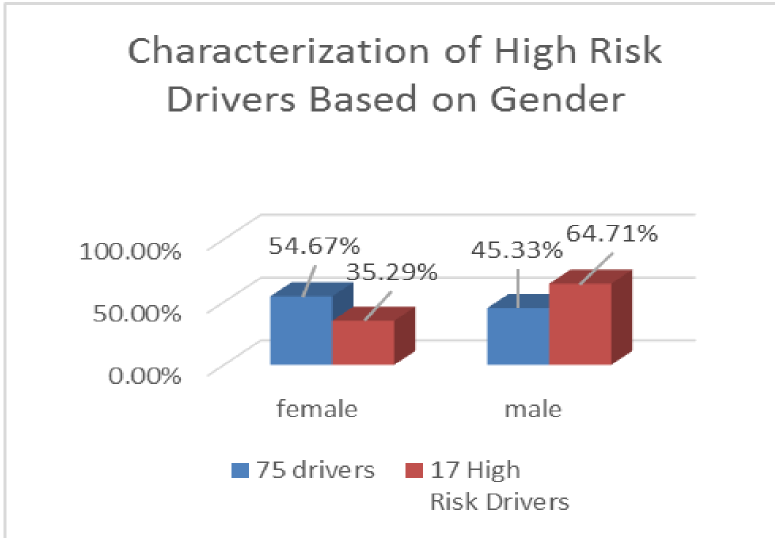

Figure 3.13. Characterization of high risk drivers based on Gender for MUTCD left merge

The important observations from Figures 3.12 and 3.13 are as follows:

- 41.18% and 29.18% of high risk drivers are in the age group of 25-44 and 65+ respectively. Hence, a higher percentage of high risk drivers are present in 25-44 and 65+ age segments.
- 64.71% of high risk drivers are male drivers and hence, a higher percentage of male drivers are present.

Missouri alternate left merge: Driver ID 73 who is male and in the age group of 45-64, briefly entered the work zone and is classified as the only high risk driver in this scenario. Major findings for this scenario and analysis for the right merge scenario is performed in the following sections.

3.4. SUMMARY OF MAJOR FINDINGS OF LEFT MERGE SCENARIO

Based purely on the number of high risk drivers for both left merge configurations, Missouri Alternate left merge configuration provides a better result in terms of driver behavior and response to sign configurations. More than half the drivers (57.33 %) in MUTCD left merge scenario chose to merge to the left lane well before they were exposed to the merge signs. Missouri Alternate merge sign displays better driver behavior as more number of drivers reacted to the road signs evident from the visual analysis. Further explanation for these patterns and comparisons are made in further sections.

3.5. ANALYSIS OF RIGHT MERGE SCENARIO

Visual and exploratory analysis for the right merge scenarios are discussed in the following sections.

3.5.1. Exploratory Analysis– Visual. Driving paths of 75 drivers is analyzed for the two sign configurations of MUTCD right merge and Missouri alternate right merge.

A plot of the 75 driving paths simulated in the MUTCD Merge Right scenario is illustrated in Figure 3.14. Few driving patterns are observed from this plot. The plot indicates about half of the drivers merge to the left lane immediately at the start of simulation. The remaining drivers stay on the right lane until the end or merge to the left lane after the work zone ends. The drivers that merge to the left lane immediately seemingly respond to the signage and merge to the right lane after 2300 feet.

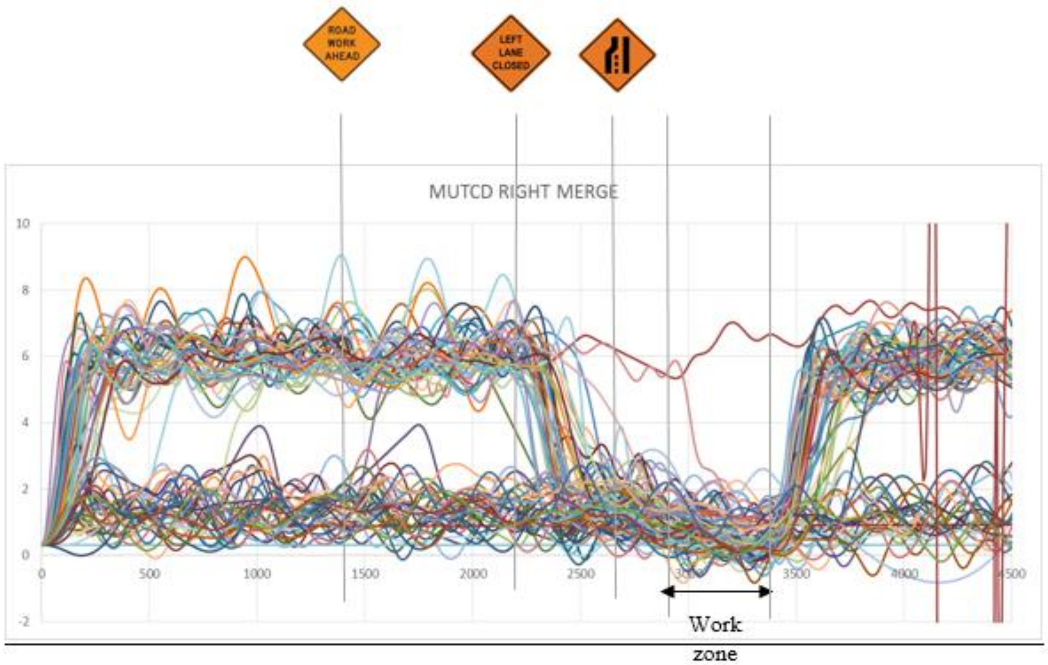

Figure 3.14. Driving path of 75 drivers for MUTCD right merge

Almost all drivers are observed to be on the right lane between 2900 feet to 3300 feet (work zone area). 3 plot lines can be spotted between 2900 and 3300 feet at x > 4 indicating that these drivers have driven through the work zone area. Analysis of the driver IDs and characterization of high risk drivers is carried out in the following sections.

A similar pattern is observed for the Missouri alternate right merge scenario as illustrated in Figure 3.15. To begin with, a number of drivers start the simulation from the left lane. Almost all drivers continue to remain on the left lane before merging to the right lane by responding to the work zone signage. A handful of drivers immediately merge to the right lane and remain there until the end of the simulation or merge left after the work zone ends.

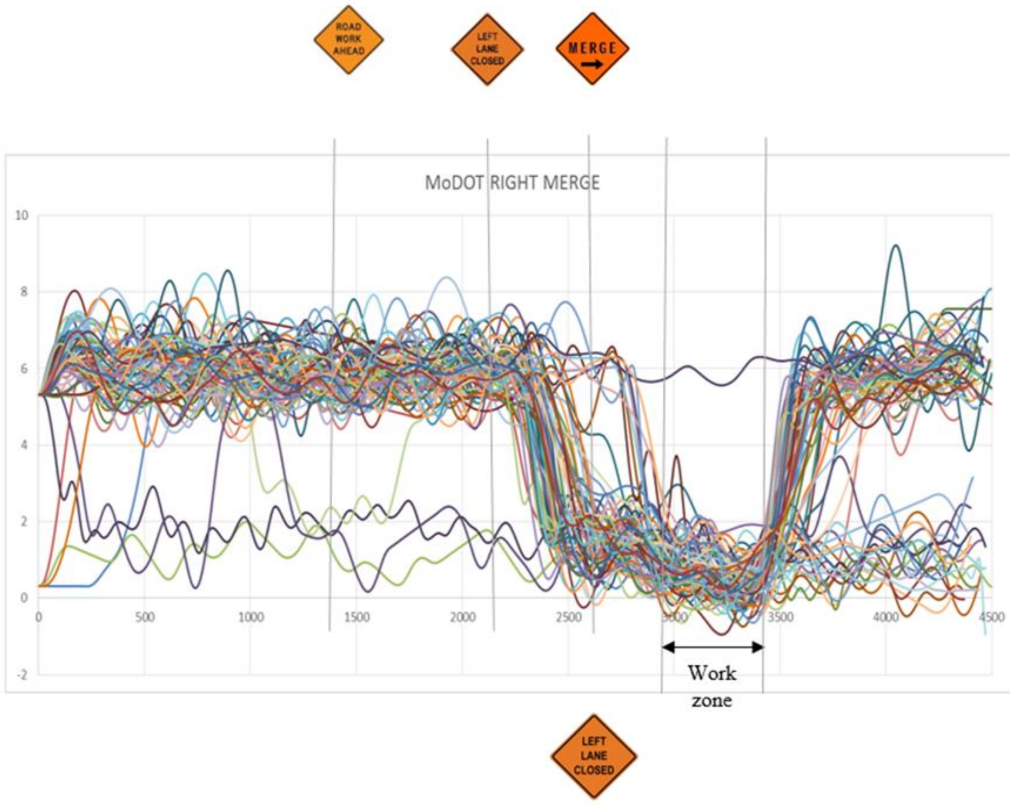

Figure 3.15. Driving path of 75 drivers for MoDOT alternate right merge

Almost all of the drivers have merged to the Right lane in this scenario before 2900 feet i.e. start of the work zone. One driver is spotted to have driven through the work zone as observed in the graph between 2900 and 3300 feet at x > 4. This observation indicates a better response from drivers to the Missouri alternate merge Right signage. Different zones of merging are observed for the merge right scenario when compared to the merge left scenario. This is expected because of the different starting positions of drivers. Hence a new classification of merge zones is required for developing the probability density plots.

3.5.2. Dynamic Distribution of Drivers– Evolution of Probability Density. From the observed driving patterns for MUTCD Right merge scenario, the figures indicate the existence of 5 different zones through which the driving segments can be classified. Table 3.8 describes the various zonal classifications of 75 drivers for MUTCD merge right scenarios.

Based on the different zones, Kernel density plots are obtained to explore the distribution of drivers.

From Figure 3.16., for zone Z_{A1}, at $y = 50$ feet, all drivers are on the right lane. At $y = 100$ feet the KDE indicates a similar pattern as observed previously. At $y = 260$ feet, the KDE clearly has two modes, but like a mixture of two densities with large overlap. The KDE indicates a group of drivers merging to the left lane at that y-location. The single group of drivers at the beginning of this zone split into two groups very soon.

For zone Z_{N1}, the three KDEs are similar in that they all have two modes, indicating a mixture of two distributions. The KDE is relatively stable during this lengthy zone, indicating most drivers kept on their own lane. But the mode on the right lane increases at y=2250 feet (towards the end of this zone), indicating that some drivers started to merge to the right lane.

For zone Z_{A2}, all KDEs have two modes, but the mode on the left lane decreases and the mode on the right lane increases. The dynamic of the KDE within this short zone indicates that a number of drivers merged to the right lane and more drivers were on the right lane than on the left in this zone.

Table 3.8. Zone descriptions for MUTCD right merge scenario

Zone	**Y range [ft.]**	**Description**	**Sample Y-locations [ft.]**
Z_{A1}	[0, 400]	A large group of drivers switch lanes immediately	50, 100, 260
Z_{N1}	[400, 2000]	Most drivers follow a straight path	400, 1250, 2000
Z_{A2}	[2000, 2700]	A second large group of drivers move from the left lane to the right lane by reacting the merge signs	2200, 2400, 2600
Z_{N2}	[2800, 3400]	Most drivers follow a straight path on the right lane	2900, 3100, 3300
Z_{A3}	[3400,4600]	A large group of drivers change to the left lane immediately after the work zone	3400, 3500, 3800

For zone Z_{N2}, the mode on the left lane diminishes rapidly from y = 2900 feet until y=3300 .This tells that at y = 2900 feet, almost all drivers were on the right lane i.e. at the start of the work zone.

For zone Z_{A3}, The KDE at y = 3800 feet shows an even distribution indicating that a large group of drivers chose to merge to the left lane at the end of the work zone. Within zone Z_{A1} one observes the largest change of driver distribution on the two lanes, followed by zone Z_{A2} and Z_{A3} where slightly significant changes are seen. In zone Z_{N1} the driver distribution on the two lanes are relatively stable.

An important observation from the density plots of MUTCD right merge is the similar patterns of driver behavior at the start of simulation in comparison to left merge scenarios.

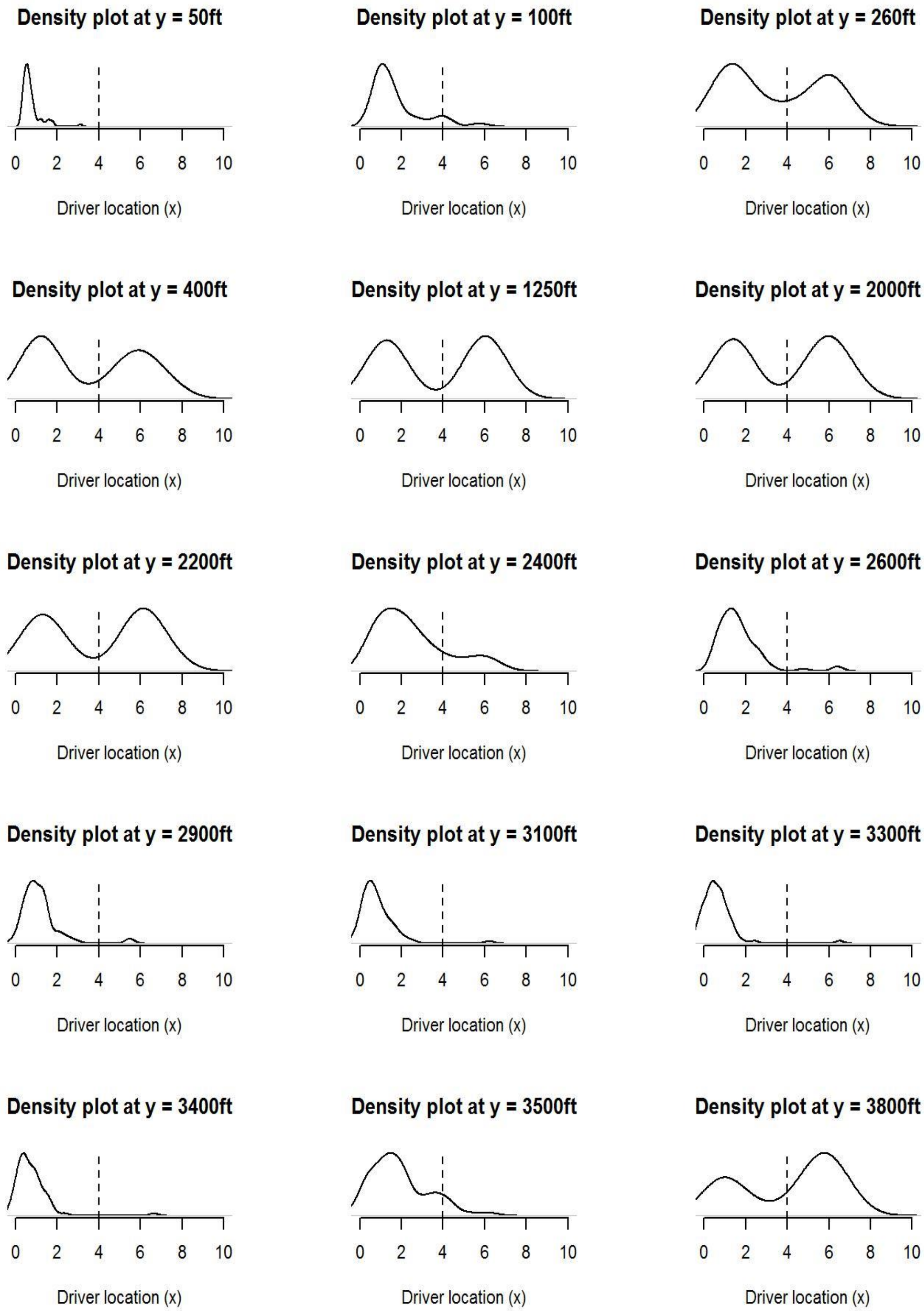

Figure 3.16. Density distribution for MUTCD right merge

Table 3.9 summarizes the zone descriptions for Missouri alternate right merge scenario. Two active merge zones and one neutral zone are observed.

Table 3.9. Zone descriptions for Missouri alternate right merge scenario

Zone	**Y range [ft.]**	**Description**	**Sample Y-locations [ft.]**
Z_{N1}	[0, 2000]	A large group of drivers remain on the same lane. Neutral zone	50, 400, 1800
Z_{A1}	[2000, 2900]	Majority of the drivers change from left to right lane after reacting the work zone signs	2200, 2400, 2900
Z_{A2}	[2900, 4000]	A second large group of drivers move from the left lane to the right lane by reacting the merge signs	3200, 3400, 3600

From Figure 3.17., for zone Z_{N1}, almost all drivers are on the left lane and this distribution is constant throughout the zone indicating a neutral zone. For zone Z_{A1}, the three KDEs are varying, indicating that the drivers actively merge during this zone. At y = 2200, the distribution shows that all of the drivers are concentrated on the left lane but at y = 2900, the distribution rapidly concentrates the drivers on the right lane. This observation indicates that the majority of drivers reacted to the work zone signage and merged to the right lane.

The driving patterns observed for the Missouri alternate right merge scenario is slightly different from the patterns obtained for MUTCD right merge.

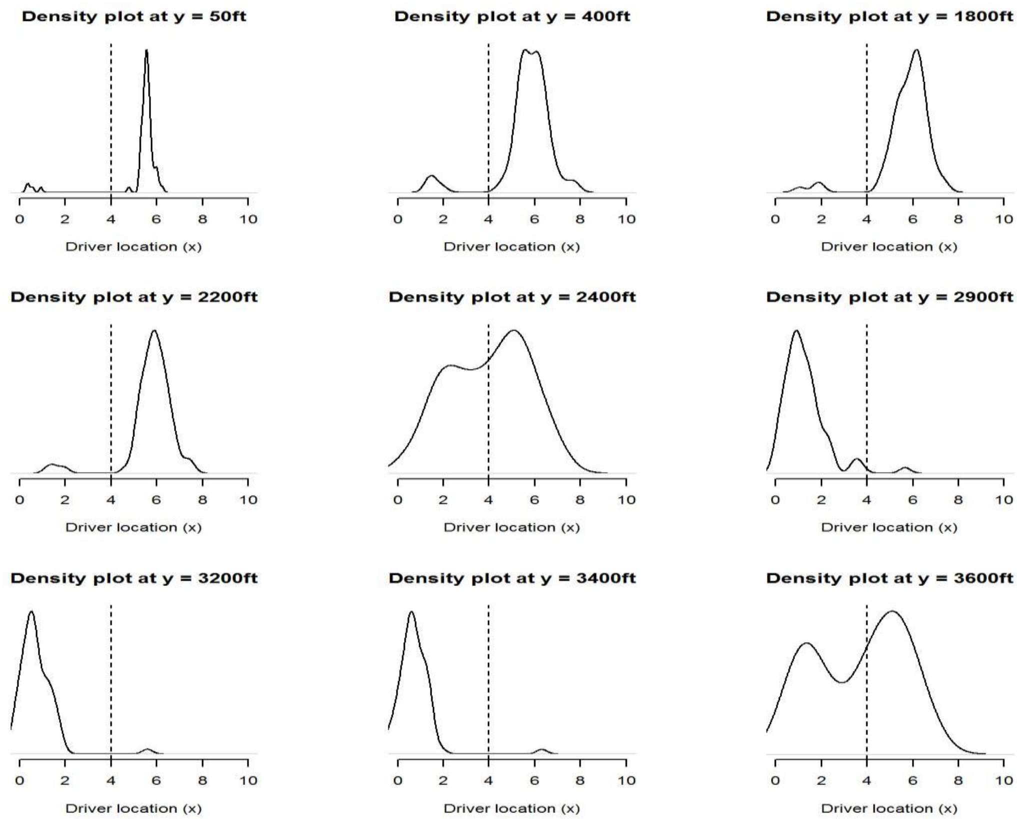

Figure 3.17. Density distribution for Missouri alternate right merge

For zone Z_{A2}, we observe similarity in the modes at y = 3200 and y = 3400 as this region is within the work zone and all of the drivers are on the right lane. At y = 3600, an even distribution is observed and the mode on the left lane increases and the mode on the right lane decreases. The dynamic of the KDE within this zone indicates that a number of drivers merged to the left lane immediately at the end of the work zone.

3.5.3. Classification of Drivers. Classification of drivers based on the merge positions for both the merge right configurations are done to understand and establish interesting driving patterns. This enables in extracting useful features.

From Table 3.10., observe that almost half of the drivers chose to change their lane and half the drivers chose to remain on the same lane (right lane) from the beginning to the end of the simulation for the MUTCD right merge configuration. Two high risk drivers are identified, Driver ID- 20 and 38 that drove through the work zone and hence classified under failed simulation.

Table 3.10. Classification of drivers for MUTCD right merge

Group	Description	No. of Drivers in Group	Sample Drivers in group
A	Changed to left lane and then to right lane	38	1,2,4,5,7,9
B	Did not change lane	35	3, 8, 10, 11, 25, 26
Failed	Failed simulation- Drove through work Zone	2	20 , 38

For the Missouri Alternate right merge scenario, a distinct pattern is observed during the merge positions for few set of drivers. Majority of the drivers merge to the right lane much before the work zone starts but a few set of drivers merge extremely late, just before the start of the work zone. We try to distinguish between these 2 set of drivers by conducting cluster analysis.

Group A.1- These set of drivers merge to the Right lane when they spot the 1st merge sign, i.e. before y = 2667 feet.

Group A.2- These set of drivers merge to the Right lane when they spot the 2nd merge sign, i.e. after y = 2667 feet.

Table 3.11 summarizes the group distribution of drivers for the Missouri alternate right merge.

Table 3.11. Classification of drivers for Missouri alternate right merge

Group	Description	No. of Drivers in Group	Sample Drivers in group
A.1	Merged to the right lane early (Early merge)	66	1,2,4,5,7,9
A.2	Merged to the right lane late (late merge)	8	10,11,36,40,41,50,68,73
Failed	Failed simulation- Drove through work Zone	1	64

For the Missouri alternate merge right case, 1 high risk driver is observed, driver ID- 64 that drove through the work zone. Characterization of the two different merge groups A.1 and A.2 are done to analyze the distribution amongst the age group and gender. Figure 3.18 compares the two groups with the original age distribution of 75 participants for the Missouri alternate right merge.

Higher percentages (37.5 %) of drivers in the age group of 18-24 are part of group A.2. One may infer that drivers in this age group preferred merging late.

Figure 3.19 illustrates the characterization of drivers in the two groups based on gender.

From Figure 3.19., it is clearly evident that a higher percentage (75%) of males preferred to merge late while the distribution of female drivers is nearly equal to the distribution of female drivers that preferred the early merge.

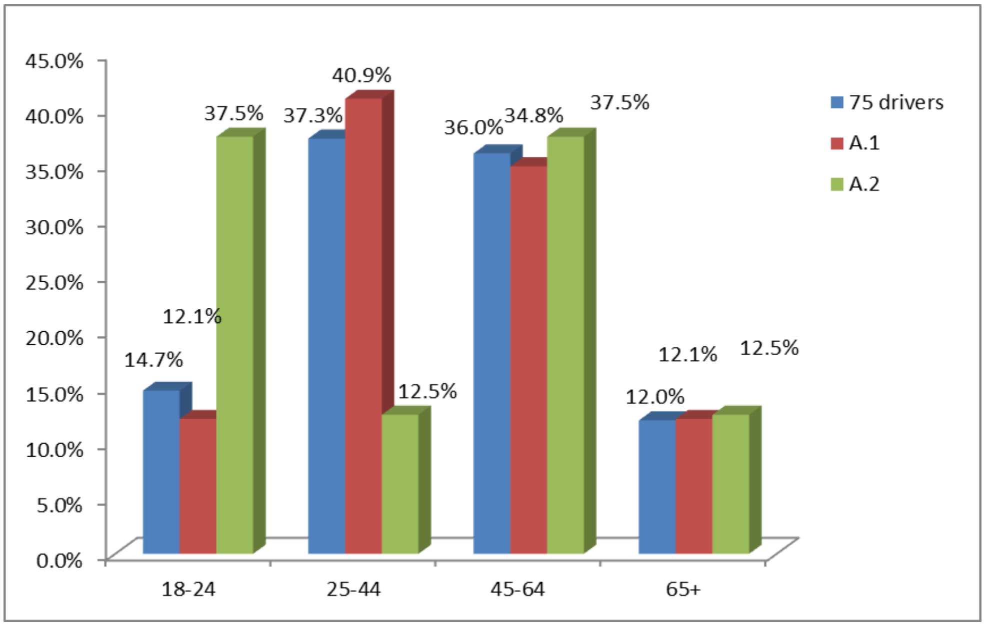

Figure 3.18. Characterization of groups A.1 and A.2 based on age for Missouri alternate right merge

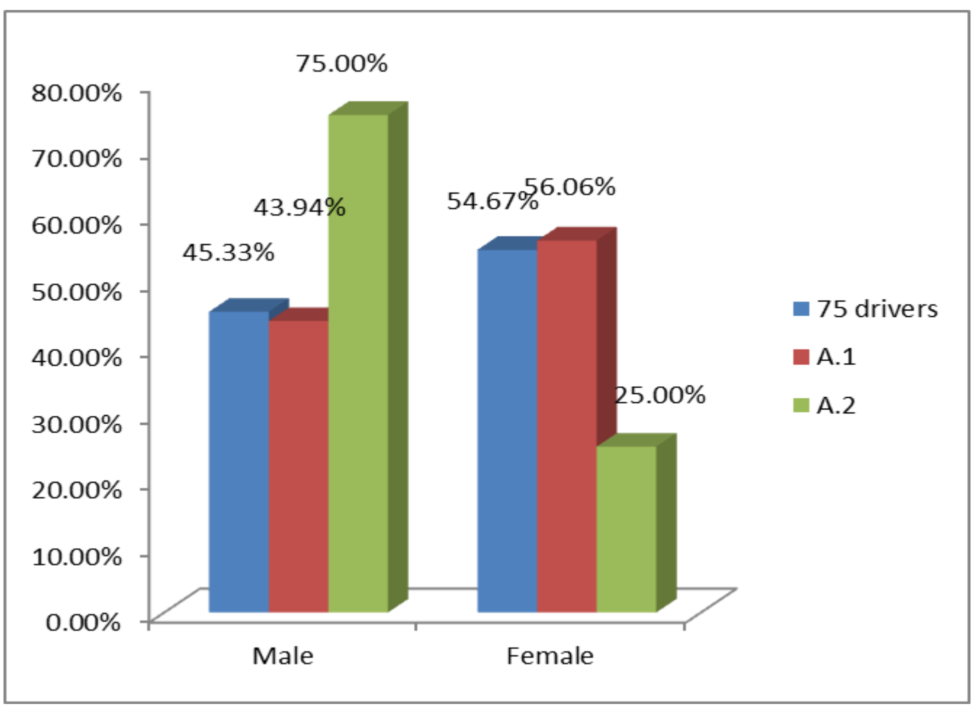

Figure 3.19. Characterization of groups A.1 and A.2 based on gender

3.5.4. Characterization of High Risk Drivers. Table 3.12 summarizes the number of high risk drivers that entered the work zone.

Table 3.12. Characterization of high risk drivers for right merge configuration

"High-risk" drivers who entered the work zone		
	MUTCD Merge Right (2 drivers)	**Missouri alternate right merge (1 driver)**
participant ID	20, 38	64

Driver 20 is male and falls in the age group of 25- 44 years old. Driver 38 who is observed to briefly enter the work zone is female and in the age group of 65 +. Driver 64 in the alternate merge right scenario is female and falls in the age group of 45- 64.

3.6. SUMMARY OF MAJOR FINDINGS OF RIGHT MERGE SCENARIO

Based on purely the number of high risk drivers for both merge right scenario, there is negligible difference between the two configurations. Due to the varying starting positions of drivers for the two scenarios, a number of drivers (35 in total) did not change lanes for the MUTCD right merge scenario and sample size for analysis is reduced due to this difference. There exist two distinct merge patterns for Missouri alternate right merge scenario. Both the sign configurations provide better results in terms of driver behavior as more number of drivers reacted to the road signs evident from the visual analysis.

3.7. COMPARISON BETWEEN RIGHT AND LEFT MERGE SCENARIOS

Comparisons between right merge and left merge configurations are discussed in the following sections.

3.7.1. MUTCD Left vs Right Merge. MUTCD Merge Right shows better driver reaction to the work zone signage compared to MUTCD Merge Left. A total of 17 high risk drivers are observed for merge left scenario compared to 2 high risk drivers for merge right. One of the factors influencing this varying behavior for the two merge scenarios is practice during the simulation. All drivers started with driving for the MUTCD Merge Left scenario and as drivers got better accustomed to the simulator, we observe better results for MUTCD merge right.

3.7.2. Missouri Alternate Left vs Right Merge. Missouri Alternate Merge Left and Merge Right show similar characteristics in terms of driver response to the different work zone. Both cases yielded 1 high risk driver for the entire simulation. Missouri Alternate Merge Right shows two distinct patterns of driver’s reaction to the sign configurations. Two groups of drivers emerged that merged to the right either by reacting to the 1st merge sign configuration or to the 2nd merge sign configuration. This observation aids in concluding that more number of drivers (8 in total) reacted to the Missouri Alternate sign in the right merge scenario.

4. RESULTS AND CONCLUSION

4.1. RESULTS

Data analyses of driving patterns were conducted for 75 participants with varying demographic background. The driving patterns observed in each of the four merge scenarios- MUTCD merge left, MUTCD merge right, Missouri Alternate merge left and Missouri Alternate merge right showed interesting patterns.

Based on purely the high risk drivers, MUTCD merge left had 17 drivers that were significant for the analysis and one may conclude that the performance of drivers in this scenario were not on par with the driving characteristics attributed to the other three scenarios. 41.18% and 29.18% of high risk drivers are in the age group of 25-44 and 65+ respectively. Therefore, a higher percentage of high risk drivers are present in 25-44 and 65+ age segments. 64.71% of high risk drivers are male drivers and hence, a higher percentage of male drivers are present.

There could be a number of reasons for the portrayal of "Risky" behavior among drivers. The first and foremost reason could be the amount of time or experience the driver gained during practice with the driving simulator. Although the sequence of scenarios undertaken by participants was in random order, there were a number of drivers that started with the MUTCD left merge scenario. Therefore, with limited experience or practice for the 1st scenario, the risky participants may have failed to understand the nature of simulation, sign positions and other features of the driving simulator.

One cannot conclude with enough evidence that the performance of the MUTCD sign is better over the Missouri alternate sign or vice versa since the risky drivers for one scenario drove normally in the other.

Another important finding during the analysis of driving patterns is the emergence of different driving characteristics for each scenario. Majority of drivers preferred to merge immediately at the beginning of a simulation and continue driving on the same lane until the end. A number of drivers also merged upon noticing the work zone sign configurations and their driving behavior is of particular interest.

There exist two sets of driving patterns for the Missouri Alternate right merge scenario as observed in the analysis. Table 3.11 shows the classification of drivers into early merge group and late merge group based on the merge positions. The early merge group A.1 had 66 drivers and the late merge group A.2 had 8 drivers. It is interesting to note that 37.5 % of the drivers that preferred to merge late (group A2) are within the age group of 18-24 and 75 % of late mergers are male.

4.2. CONCLUSIONS

Apart from the distinct observation of two different merge patterns for the Missouri alternate merge right configuration; a significant difference in the performance of sign configurations does not exist for the right merge scenario. The numbers of high risk drivers are comparable for both the right merge cases and significant evidence is not present to prove the effectiveness of one sign over the other for this scenario.

Missouri alternate left merge configuration provides better results as a clear switch configuration. There is significant evidence to prove that Missouri alternate sign configuration is better than the MUTCD sign configuration for the Left merge scenario based on the number of high risk drivers and hence, a possible interpretation for the unsafe or outlying driver behavior in the MUTCD left merge scenario could be the presence of confusing or unclear road signs on the freeway but this variation may be due to driver inexperience during the simulation.

Simulator study is shown to be a feasible approach and provides meaningful results for understanding driver's behavior and characterization.

4.3. FUTURE WORK

The promising results obtained in the driving simulator prove that the use of simulation can be a healthy approach for analyzing the effectiveness of different traffic signage. This approach is safe, cost effective and can be programmed to varying traffic conditions without external hindrance. Varying amounts of traffic can be programmed into the simulator to obtain a more real-time experience of driving on the road.

Based on the results obtained, this study builds a foundation for important future research. A further extension of research can be made to study the effectiveness of signs for 3 way lanes or multiple lanes. This extension may prove useful to clearly understand the performance of the sign configuration when there are more than one lane options available for merging.

Theoretically, this study can be used to model automatic feature extraction of drivers and resampling from limited simulation data. These features are used in today's driverless car technologies as more and more automobile manufacturers are exploring the possibilities of understanding human driving behavior to implement them in computer driven machines. The use of cyber physical systems in transportation is a growing trend and results obtained in this research can be explored further and deeper to understand the true nature of humans behind the wheel.

APPENDIX

Sample codes used in performing the data analysis are described in this appendix. The codes generated for MUTCD left merge scenario is shown and similar set of codes are used for analysis of the three other scenarios. The code used is illustrated in "*italics*". Text following # is meant to be read as comments describing the function of code and not the actual code.

P1 = read.csv("mutcd leftD1.csv") # Read file containing driver 1 data

class(P1)

names(P1)

head(P1)

Xloc = P1[1:118,23] # defines x set of locations from the data set

Yloc = P1[1:118,24] # defines y set of locations from the data set

plot1 = plot(Yloc,Xloc,type = "b") # plots a graph of y vs x

xout = seq(from = 0,to = 4560, by = 10) # defines a set of y index from 0 to 4560 to generate y interpolations

int1 = spline(Yloc,Xloc,xout = xout) # interpolates x locations with respect to y locations

par(mfrow=c(1,1))

plot(xout,int1$y) # plots a graph containing interpolated y vs x locations.

write.csv(int1$y,file="D1.csv") # writes a file containing interpolated set of x and y locations

Similar set of codes are used for interpolating x and y locations of 75 drivers. The following codes are used to generate density curves for MUTCD left merge scenario. The segments are described in the following range.

Segment 1 - 0 to 280 feet

Segment 2 - 400 to 2250 feet

Segment 3 - 2300 to 2850 feet

Segment 4 - 2900 - 4300 feet

Visual1

head(Visual1)

jpeg("density plot of drivers.jpg", width = 7, height = 8, units = "in", pointsize = 12, quality = 75, bg = "white", res = 200) # creates a jpeg file containing density plots

par(mfrow=c(4,3))

{

xden50 = t(Visual1[6,2:76]) # driver locations at y = 50 ft

density(xden50)

plot(density(xden50),xlim=c(0,10),bty="n",main = "Density plot at y = 50ft",xlab = "Driver location (x)",yaxt="n",ylab = "") # plots the density distribution graph at y=50

abline(v=4,lty=2)

xden100 = t(Visual1[11,2:76]) # driver locations at y = 100 ft

density(xden100)

plot(density(xden100),xlim=c(0,10),bty="n",main = "Density plot at y = 100ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

abline(v=4,lty=2)

xden260 = t(Visual1[27,2:76]) # driver locations at y = 260 ft

plot(density(xden260),xlim=c(0,10),bty="n",main = "Density plot at y = 260ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

abline(v=4,lty=2)

xden400 = t(Visual1[41,2:76]) # driver locations at y = 400 ft

plot(density(xden400),xlim=c(0,10),bty="n",main = "Density plot at y = 400ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

abline(v=4,lty=2)

xden1250 = t(Visual1[126,2:76]) # driver locations at y = 1250 ft *plot(density(xden1250),xlim=c(0,10),bty="n",main = "Density plot at y = 1250ft",xlab = "Driver location (x)",yaxt="n",ylab = "")*

abline(v=4,lty=2)

xden2250 = t(Visual1[226,2:76]) # driver locations at y = 2250 ft

plot(density(xden2250),xlim=c(0,10),bty="n",main = "Density plot at y = 2250ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

abline(v=4,lty=2)

xden2300 = t(Visual1[231,2:76]) # driver locations at y = 2300 ft

plot(density(xden2300),xlim=c(0,10),bty="n",main = "Density plot at y = 2300ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

abline(v=4,lty=2)

xden2400 = t(Visual1[241,2:76]) # driver locations at y = 2400 ft

plot(density(xden2400),xlim=c(0,10),bty="n",main = "Density plot at y = 2400ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

abline(v=4,lty=2)

xden2600 = t(Visual1[261,2:76]) # driver locations at y = 2600 ft

plot(density(xden2600),xlim=c(0,10),bty="n",main = "Density plot at y = 2600ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

```
abline(v=4,lty=2)

xden2900 = t(Visual1[291,2:76])  # driver locations at y = 2900 ft

plot(density(xden2900),xlim=c(0,10),bty="n",main = "Density plot at y = 2900ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

abline(v=4,lty=2)

xden3600 = t(Visual1[361,2:76])  # driver locations at y = 3600 ft

plot(density(xden3600),xlim=c(0,10),bty="n",main = "Density plot at y = 3600ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

abline(v=4,lty=2)

xden4000 = t(Visual1[401,2:76])  # driver locations at y = 4000 ft

plot(density(xden4000),xlim=c(0,10),bty="n",main = "Density plot at y = 4000ft",xlab = "Driver location (x)",yaxt="n",ylab = "")

abline(v=4,lty=2)

}

graphics.off()
```

The following code is used to determine the merge (lane switch) positions of 75 drivers. The code used to determine merge position of driver 1 is presented. Similar set of codes are used to determine the merge positions for 74 drivers.

Driver 1 position during first switch

X1 = Visual1$X1[1:457] # defines set of x positions from the data set for driver 1

Y1 = Visual1$Y[1:457] # defines set of y position from the data set for driver 1

min(Y1[X1>=4]) # function used to determine the first point of lane switch from right to left lane.

#Driver 1 position during second switch

A1 = switch2$X1[20:432] # defines set of x positions from the data set for driver 1 after the first lane switch has occurred.

B1 = switch2$Y[20:432] # defines set of y positions from the data set for driver 1 after the first lane switch has occurred.

min(B1[A1<=4]) # function used to determine the second point of lane switch from left to right lane.

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VITA

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Hari quit his job to pursue his Master's Degree in Engineering Management and got accepted into Missouri University of Science and Technology (formerly University of Missouri, Rolla) during the fall of 2015 where he received an opportunity to work as a Graduate Research Assistant under Dr. Ruwen Qin. He conducted research on driving pattern identification and driver's behavior modeling. Hari received the outstanding Graduate Research Award which was awarded by the Department of Engineering Management and Systems Engineering at Missouri S&T in April 2016 for his work. Hari graduated with his M.S. in Engineering Management from Missouri University of Science and Technology in December of 2016.