Assessing the effects of work zone configurations on drivers' visual attention

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ASSESSING THE EFFECTS OF WORK ZONE CONFIGURATIONS ON DRIVERS’ VISUAL ATTENTION

A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science

in

The Department of Mechanical and Industrial Engineering

by

Karthi Punniaraj
B.E., Anna University, 2007
May 2014
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<table>
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<td>CLM</td>
<td>Conventional Lane Merge</td>
</tr>
<tr>
<td>JLM</td>
<td>Joint Lane Merge</td>
</tr>
<tr>
<td>DOTD</td>
<td>Department of Transportation and Development</td>
</tr>
<tr>
<td>MUTCD</td>
<td>Manual on Uniform Traffic Control Devices</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>CH75</td>
<td>Conventional Lane Merge, High traffic density, Warning sign placement distance reduced by 25%</td>
</tr>
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<td>CH100</td>
<td>Conventional Lane Merge, High traffic density, Warning sign placement distance as per standard</td>
</tr>
<tr>
<td>CH125</td>
<td>Conventional Lane Merge, High traffic density, Warning sign placement distance increased by 25%</td>
</tr>
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<td>ANOVA</td>
<td>Analysis of variance</td>
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ABSTRACT

This study assessed the effects of two different work zone configurations on driver’s visual attention by eye movement monitoring. A driving simulator study was conducted with thirty participants. Variations in traffic density and warning sign placement distance were added to the merge configurations to simulate the real time situation. A 2 x 2 x 3 within-subjects factorial design was used for this research. The independent variables used in this study were (1) merge configuration [(i) Conventional Lane Merge (CLM) and (ii) Joint Lane Merge (JLM)], (2) traffic density [(i) high and (ii) low] and (3) distance between traffic signs [(i) standard distance, (ii) 25% reduction from standard and (iii) 25% increase from standard]. The dependent variable used for this study was the total number of eye movements (gaze) of the participants towards the three mirrors (rear view, left side view and right side view), and towards ‘other areas’ such as dash board, warning signs, environment, and other vehicles etc., were analyzed.

Results from the research show that, the total number of gazes at mirrors and ‘other areas’ in CLM and JLM are nearly the same and they are not significantly different (p value: >0.05). Changes in traffic density and sign placement distances have a significant effect on number of gazes at mirrors and ‘other areas’ (p value: <0.05). Gender and driving experience have a significant effect on number of gazes at mirrors, but not at ‘other areas’. Reducing the sign placement distances by 25% from the standard distances does not show any significant effect on the number of gazes at mirrors, however it shows an increase in the number of gazes at ‘other areas’ by nearly 11.6%. An increase in sign placement distances by 25% from the standard distances, show an increase in number of gazes at mirrors by nearly 16.9%, while it does not show any significant effect on the number of gazes at the ‘other areas’.
CHAPTER 1: INTRODUCTION

One of the major factors that contribute to economic development and primary position of the United States in the global economy is the pervasive and high-quality transportation system (Milenković, 2012). In order to construct and maintain such a huge transportation system, the United States Department of Transportation faces challenges on a continuous basis (Bureau of Transportation Statistics, 2012). In 2011 highway transportation comprised nearly 88% of the total transportation miles (highway, air, and rail) in the United States. United States had nearly 6,586,610 km of roads in 2012, which was the most kilometers of roads in the world (Central Intelligence Agency, 2014). Most of the U.S. highways and freeways are aging, which need proper maintenance, rehabilitation, and upgrading to provide safe maneuvering to the motorists. A road cannot be used for a lifetime without periodic maintenance and rehabilitation. Under normal conditions, the life span of asphalt pavement is approximately 16 years. Due to drastic increase in number of road users, the lifespan has been reduced to 8-12 years (Lomax et al., 2013). Every year 3.7 billion hours and 2.3 billion gallons of fuel are wasted in traffic jams. Nearly 23,745 miles of federal-aid roadway improvement projects were underway annually from 1997 to 2001 (FHWA, 2001). Nearly 40% of urban highways in the U.S. are congested and a motorist passes a construction zone approximately every 100 miles (ASCE, 2013; Ullman et al., 2008). Records show that 24% of non recurring delays occur due to work zones. In order to perform road maintenance, the traffic flow cannot be stopped for a long time. As a result, lane merge concepts have evolved over years to maintain the traffic flow near work zones without disturbing the maintenance activities. Work zones negatively affect and create disturbance to the regular traffic flow (Akepati & Dissanayake, 2011). Apart from reduced road traffic volume, construction zones also affect motorists’ safety. Drivers in a work zone encounter complex array of warning signs, barrels, pylons, construction equipment and machines which can
create hazards for motorists. It was estimated that at any time during the peak summer 2001, there were nearly 3,110 work zones on the National Highway System (NHS) (Wunderlich & Hardesty, 2003). Nearly 20,876 miles of roadways and 12.8% of the 163,734 miles of NHS-designated roadways contribute to the total number of work zones mentioned above (Wunderlich & Hardesty, 2003). Additionally, it was estimated that there was a loss of over 60 million vehicles of capacity per day (Wunderlich & Hardesty, 2003). At work zones, crash rate increases by 20-30% (Ullman et al., 2008). Thus it is essential to properly guide motorists in work zones.

While driving, motorists continuously gather information from roadways through warning signs, navigation systems, actions of other vehicles on the road, etc. In order to obtain visual information about possible relevant changes in traffic situations, it is assumed that motorists gaze at the three rear view mirrors (Pastor et al., 2006). The chances that the motorist will go off the road or not respond to a speed change warning or not notice a turn, occurs when the motorist’s ability to detect the immediate surroundings decreases (Wertheim, 1978). Directly measuring drivers’ attention is not possible, as this is not a manifest variable. Past research identified a few representative variables that include number of gazes at rear view mirrors, duration of gaze at different areas, frequency of transiting their visual fields to a specific direction, etc, (Wong & Huang, 2013).

This study is an extension of a previous research conducted by the author, which was sponsored by the U.S. Department of Transportation, University Transportation Centers Program (UTC). The previous study was focused on the effects of changes in merge configuration, traffic density and the distance between traffic signs in the advance warning zone on three driving parameters, namely braking force, speed, and travel time, and drivers’ perceived workload (Punniaraj et al., 2014; Shakouri et al., 2014). Both of the studies were conducted on the same merge types (CLM and JLM) with same independent variables like
the present research, but with different dependent variables. The present research focuses on total number of visual gaze at the three mirrors (rear view, left side view and right side view) of a car. Additionally, number of gazes at ‘other areas’ such as dashboard, warning signs, environment, other vehicles, etc., are grouped together for analysis.

1.1 Rationale

Driving is a complex task that requires continuous attention to the traffic situations and demands quick reaction to safely maneuver vehicle through the situations. The main causes of traffic accidents are drivers’ inattentiveness and distractions (Pastor et al., 2006). Understanding the causes of accidents in freeways and implementing preventive measures are the major concern of the United States Department of Transportation. Motorist’s inattentiveness and adequate maneuvers can avoid majority of accidents on road (Nabatilan et al., 2012; Wong et al., 2010). Among these, driver’s inattentiveness is critical factor that leads to crashes in most of the cases (Brown et al., 2000; Chan et al., 2010; Mcknight & Mcknight, 2003; Olson et al., 2009; Underwood, 2007). Driving is a skill based activity that demands continuous attentions of the drivers, and to change and adjust their behavior accordingly. In most of the cases, before maneuvering, drivers look ahead through the windshield for possible hazards on their way (Levin, 2009; Nabatilan, 2007; Salvucci & Liu, 2002; Underwood, 2007; Underwood et al., 2002; Underwood et al., 2003). Attention of the driver diverts to adjacent lane during a lane change (Salvucci & Liu, 2002; Underwood et al., 2003) and to both sides during travel through an intersection (Summala et al., 1996). When drivers divert their attention from their frontal area, their awareness regarding safety considerations ahead decreases (Brown et al., 2000).

In order to look at the two sides of the road and situations behind the vehicle, the motorists use rear view mirrors. Frequency of mirror-gazing is an indicator of a person’s (driver) attentiveness (Brookhuis et al., 1991; Poole & Ball, 2005; Recarte & Nunes, 2003).
Thus, when the number of times a driver gaze at any of the three mirrors (rear view, left side view and right side view) in a period is known, we may get an indication of the driver attentiveness in that period. Using mirror gazing frequency as an indicator is very reliable, as this task is intrinsic and not derived from the performance of a secondary task. Visual attention pattern of the drivers varies with change in surrounding such as traffic density, lane merges, construction zones, number of lanes, etc (Recarte & Nunes, 2003; Robinson et al., 1972).

Analysis of visual attention on rear view mirrors is carried out in many studies in different road conditions. One such analysis that captures the visual attention frequency in conventional roadway and motorway was conducted by Pastor et al. (2006). Misallocation of visual attention has been considered as one of the major causes of crashes on highways (Brown et al., 2000; Chan et al., 2010; Underwood et al., 2003; Wong & Huang, 2011). Results from Poole and Ball (2005) show that the eye movement tracking will provide an indication of where a person pays attention. A similar study is carried out in this research, where the visual attention is studied in two different merge configurations. The research questions that led to this research were: in which merge configuration does the motorist gaze more at rear view mirror? If the number of mirror gaze is more, does that mean the driver pays more attention or more confused with the situation? Which other area does the motorists pay attention during a lane merge? These are few questions related to driving attention that many researchers have been studying over the recent past. Results of those researches are interpreted mainly based on psychological and human factors point of view. This study also follows similar kind of interpretation of the results.

1.2 Objectives and Boundaries of Study

The major objective of the study was to identify in which of the two merge configurations (CLM and JLM), does the motorist gaze at the mirrors (rear view, left side
view and right side view) more often. In addition, this study aimed to identify number of gazes on ‘other areas’ such as dashboard, warning signs, environment, other vehicles, etc., which are grouped together and analyzed.

Boundaries of the study are listed below:

- This is a driving simulator study that concentrates on assessing the effect of two different work zones on drivers' visual attention. The results of this study will show that, which merge configuration demands more visual attention.
- Since the purpose was to count the number of times the participants gaze at the three mirrors, eye tracking device was not used. Direct observation of participant’s videos was followed to obtain the data. Similar procedure was followed by Bach et al. (2008).
- This study does not analyze other driving variables like brake, acceleration, speed etc.
- Age range of the participants was between 20 to 30 years, and the participants are only from a student’s population.
CHAPTER 2: LITERATURE REVIEW

A literature survey was conducted on merging strategies and researches on eye tracking methodologies in driving applications, in order to provide an overview of past studies related to this field. As the present study focused only on number of eye movements and not the gaze duration, gaze path, pursuit, etc., the literature survey does not elaborate on those areas. This study used videos of the participants, and the eye movements were directly observed by the researcher.

2.1 Merging Strategies

2.1.1 Conventional Merge

The conventional lane merge design (CLM) specified in the MUTCD (U.S. Department of Transportation, 2009), is the most commonly used design in the U.S. and seeks to guide drivers from the closed lane to the open lane safely. Under the CLM configuration, when two lanes merge into one lane, vehicles in the open lane are given the right of way, while those in the closed lane are expected to move into the open lane before the two lanes merge (Figure 1). Vehicles in the open lane are given the opportunity to continue to move into the work zone area without stopping, but vehicles in the closed lane may have to slow down or stop if the merging gaps in the open lane are limited (Rayaprolu, 2010). However, the safety of this merging configuration is only effective in low to moderate traffic densities (Ishak et al., 2012). Some advantages of the CLM in the U.S. are its widespread usage and drivers’ familiarity with the incorporated traffic signs. However, increased potential for rear end and side swipe crashes and longer queue lengths in high traffic density are the drawbacks of this merge (Ishak et al., 2012).
2.1.2 Early Merge

Early merge aims at providing enough response time for drivers approaching a merge by means of placing warning signs in advance of the taper (McCoy & Pesti, 2001). Early merge is divided into static early merge and dynamic early merge. In static early merge, drivers are informed about the upcoming lane closure by advance “LANE CLOSED” signs placed nearly 1.5 miles before the taper. Also, lane reduction signs are placed 1500 ft. before the taper, followed by flashing arrow panels at the beginning of the taper. This type of lane merge is suitable when demand is below capacity but fails as congestion develops due to speed variation between lanes as drivers in the closing lane tend to pass those in the open lane. Contrary to static early merge where sign distance intervals are fixed, the signs in dynamic early merge are responsive to real time traffic measurements (Figure 2). When stopped vehicles are detected by sonic detectors near the signs, a signal is transmitted to the nearest upstream sign. Signs in dynamic early merge are placed at either 0.25-0.5 mile intervals upstream of the lane closure. When the signal is received by a sign, it alerts the drivers by showing a “DO NOT PASS” message. Another difference between early static and
dynamic merge is the incorporation of beacon lights in dynamic merge. The lights are deactivated once a stopped queue is no longer detected.

![Dynamic Early Merge Design Layout](image)

**Figure 2 - Dynamic Early Merge Design Layout (McCoy & Pesti, 2001)**

Early merge strategies may be successful in reducing the number of forced merges in the transition area, however, travel times during high traffic density may increase (Rouphail & Tiawari, 1985). Tarko et al. (1998) found that using early dynamic merge strategies increased the size of queues and length of merging zones due to the reduction of speed in the open lane, especially during high traffic. McCoy and Pesti (2001) found a smooth merging behavior in low traffic with the dynamic early merge, but abrupt decelerations and large queue lengths during high traffic led to a reduction in throughput. Early merge strategies potentially can reduce traffic volume. However, as with the CLM, its efficiency declines in high traffic density, and chances of accidents and aggressive driving increase.

### 2.1.3 Late Merge

The late merge strategy was proposed to reduce aggressive driving behavior between motorists in the closed and open lanes (McCoy & Pesti, 2001) (Figure 3). In this strategy
vehicles are encouraged to stay in their lanes until they reach the merge section. As like the early merge strategy, late merge is also divided into static late merge and dynamic late merge. The concept behind the late merge is to encourage drivers to use both lanes until a specified merging point. Once vehicles reach the merging point, those in the closed lane merge with vehicles in the open lane in an alternating pattern. Typically, a “Use Both Lanes to Merge Point” sign is placed approximately 1.5 mile (2.4 km) in advance of the taper.

![Figure 3 - Late Merge Design Layout (Pesti et al., 1999)](image)

Several researchers studied the efficacy of late merge configuration in terms of traffic flow characteristics and safety in work zones. Beacher et al. (2005) compared the CLM and static late merge configurations and found that except for positive response from drivers towards static late merge, no significant difference in throughput compared to the CLM was found. Similarly, Kang et al. (2006) concluded that the behavior of the dynamic late merge strategy is analogous to the CLM in unsaturated traffic densities. According to McCoy and Pesti (2001) forced merges in the late merge strategy was 75% lower than CLM at high densities. Forced merges occur when there is not enough space between vehicles in the closed lane and open lane and as a result, the vehicles in the closed lane attempt to merge with evasive maneuvers. The result also showed 30% fewer lane straddles at densities below 25 vehicles per mile. Finally, a study by Grillo et al. (2008) found that the dynamic late merge configuration is more effective on highways with moderate to heavy congestion prior to construction work zones. As a result, benefits of the late merge lie in its application in high
volume traffic. It reduces rear end crashes and creates shorter queues. However, compliance of drivers to this new strategy is low which creates hazards in low volume traffic (Beacher et al., 2005).

2.1.4 Zipping

An alternate merging strategy called “zipping signs” is used in the Netherlands, Belgium and Germany (Figure 4). In this strategy, during congested periods, vehicles in the open lane permit adjacent vehicles to merge in an alternating pattern until the congested period ends.

![Figure 4 - Zipper Sign (Risten) in the Netherlands](image)

Dijker and Bovy (1998) studied the performance of zipping strategy in the Netherlands, and found that compared to other configurations, zipping maneuvers do not affect throughputs in the zipping strategy. In the United States, the Connecticut Department of Transportation proposed a test sign similar to the zipping sign (Feldblum et al., 2005). This sign was the result of two surveys that showed it was the statistically best understood sign among 6 proposed signs (Figure 5). This test sign was used in the field along with the W 4-2 sign and the results showed that the test sign had statistically increased the desirable number of merges from 56% to 66% and reduced the undesirable merges from 9% to 5%. One
advantage of this merging strategy is that speed is better maintained as motorists travel through the merging area (Idewu, 2006). This experimental sign is used in JLM configuration.

![Figure 5 - MUTCD W4-2 (b) Experimental Merge Sign](image)

**2.1.5 Always Close Right Lane**

This strategy, which is commonly used in Arkansas, advocates for closing the right lane at all times. Drivers who are familiar with the rules know ahead of time which lane is ending. Once the first merge is completed, drivers are channeled to the appropriate side of construction. Although the effects of this type of strategy are not well documented, one study showed that the crash rate in always close right lane configuration was 46% lower than the CLM (Schrock & McClure, 2009). This configuration creates less confusion on which lane is closed and may reduce the number of sideswipe crashes. It is widely recognized that when congestion develops and queues form at the approach to work zones, the risk of crashes increases, especially on major highways where speeds are high and drivers are accustomed to unencumbered travel. Additionally, the problem can be compounded by limited sight distance and roadway curvature. As a result, in high traffic density, increased back-of-queue crash at lane closures in always close right lane strategy presents a very serious safety condition.
2.1.6 Joint Merge

The crash analysis results of work zone areas show that the rate of crashes in advance warning areas where drivers usually perform their merging maneuvers is higher compared to other parts of the road (Bureau of Transportation Statistics, 2011). Therefore, the Joint Lane Merge (JLM) configuration was proposed as an alternative to the CLM configuration (Idewu, 2006; Idewu & Wolshon, 2010) with more emphasis on the configuration of the transition area. In the JLM configuration (Figure 6) motorists in both lanes have equal right of way, as opposed to CLM where only the open lane has the right of way. The JLM configuration is divided into five distinct zones as shown in Figure 6.

![Figure 6 - Joint Lane Merge Configuration Layout](image)

The advance warning zone in the JLM is typically a mile long and compared to the CLM includes more traffic signs to inform drivers about the upcoming road conditions. At the end of the advance warning zone, two flashing arrow signs are placed on both sides of the road, suggesting that vehicles should merge by taking alternating turns over the transition area. The transition zone is divided into three sections. In the first section, both lanes are tapered from the full lane width (typically 12 ft) to nearly 6 ft to form a single lane of 12 ft. In the second section, vehicles merge to the center line, and in the third section vehicles are
guided by the flashing arrow sign either to the right or left lane, depending on the open lane in the work zone area. The activity and termination areas in the JLM configuration are identical to those in the CLM configuration.

Several studies evaluated the operational efficiency of joint merge. Idewu and Wolshon (2010) conducted a field study to evaluate the effects of the JLM on traffic in a controlled work zone in Louisiana. The comparison of merging speed between the JLM and CLM showed no significant difference at volumes ranging from 600 to 1,200 vehicles per hour (vph). However, the experimental results did suggest that drivers going through the JLM were more cautious in their merging maneuvers. Ishak et al. (2012) examined and compared the safety performance of the conventional lane merge configuration with joint merge in terms of uncomfortable decelerations and speed variance by using a microscopic simulation model (VISSIM). Results showed that in most simulation scenarios, for the advance warning zone, the CLM configuration exhibited lower frequency of uncomfortable decelerations as opposed to the JLM configuration. However, for low flow rate of 500 vph, no significant differences were detected. For the transition area, in most scenarios with low to moderate flow rates (500–1500 vph) the JLM configuration had less frequent rate of uncomfortable decelerations and therefore was considered safer than the CLM configuration. In another study, Rayaprolu et al. (2013) compared performance measures in terms of total throughput and average delay time between CLM and JLM. Their results showed that at low levels of demand (500 and 1000 vph) both configurations had similar operational performance in terms of throughput and average delay time. At high levels of demand, the JLM had significantly higher throughput and shorter delays than the CLM. Open literature regarding lane merge configuration is replete with studies focusing on the operational aspects of merge configurations like operating speed, throughput, delays, etc. Despite efforts to modify merge configurations and improve work zone safety, the high rate of crashes and fatalities in work
zone areas are still unacceptable which indicates that the current safety measures and applied policies are deficient in reducing risky driving behavior (Hirsch, 2003; Mayhew, 2007).

Studies show that drivers’ behavior contributes significantly to 90–95% of crashes (Evans, 2004) in which, risky and aggressive driving appears to be the dominant human factor (Reason et al., 1990). Researchers have tried to explain the relationship between individual differences on risk taking behavior with accident involvement (Ulleberg & Rundmo, 2003). Drivers with risky driving behavior frequently speed and change lanes aggressively, fail to give way to other vehicles or pedestrians and ignore traffic control signs (Weng & Meng, 2012). Many researchers found that risky behavior on roads is influenced by gender. In one study, Yagil (1998) reported that male drivers, particularly younger individuals, are more likely to disobey traffic rules. Furthermore, the results showed that male drivers perceive traffic violations as less dangerous as do females. Chliaoutakis et al. (2002) used previous driving violations and irritability as factors for predicting aggressive driving. The latter factor was more rampant among young drivers who easily lose their temper and express their anger by showing reckless driving. Chen (2009) studied the relationships between personality factors, attitudes toward traffic safety and risky driving behaviors among young Taiwanese motorcyclists. His findings show that attitudes toward traffic safety are directly associated with risky driving behaviors and traffic safety. Moreover, personality traits are indirectly mediated by traffic safety attitudes and also are found to influence risky driving behaviors.

2.2 Eye Tracking Researches

Most of the information that a driver receives while driving is with his visual capability and thus the driving task is best suited to the application of eye tracking methods (Sivak, 1996). Eye movement measurement was performed in a real driving situation by Mourant and Rockwell (1972). The experiment was carried out in the urban and freeways
which consisted of left and right turns and lane changes. Results from their study show that novice drivers gaze fewer number of times towards the rear and side mirrors than experienced drivers. Cohen and Studach (1977) studied the eye movements of drivers while driving around curves which show similar comparison among experienced and novice drivers. Followed by that, there were many related researches that tested the effect of driving experience on eye movements using actual driving setting (Crundall & Underwood, 1998; Underwood et al., 2003). Video filming of driving were performed for eye tracking studies (Underwood et al., 2002; Underwood et al., 2003).

Drivers must pay continuous attention to multiple information sources to make necessary informed decisions and drive safely (Wong & Huang, 2011). Incomplete or unwanted information will divert the attention of the drivers (Brown et al., 2000; Chan et al., 2010; Underwood et al., 2003; Wong & Huang, 2011). With visual sense and ability motorists gather information and process it to take decisions. Psychological studies on driver behavior have increased over the past few years that focus mainly on driving safety (Nabatilan, 2007; Nabatilan et al., 2012). It is a common consideration among the researches that an accident occurs when the motorist diverts attention from the point of interest that demands attention (Chan et al., 2010; Olson et al., 2009). Perceptual capabilities, careful assessment of acquired information and attention are the three factors that are most essential in all the driving situations (Nabatilan et al., 2012). Eye movement measurements are usually carried out through fixations, duration, and saccades that has provided researches with many insights into the behavioral aspect of information processing in a dynamic scene (Nabatilan et al., 2012).

2.3 Eye Tracking Methods

Video cameras, capturing the drivers eye movements and interactions, were used as a method to evaluate driver attention and driving behavior in a study conducted by Bach et al.
(2008). Driver’s field of view, face of the participant, interaction with the system and steering wheel/system setup was captured using four cameras. In their research, two investigators reviewed 48 videos separately and finally compared the results to merge as single list of data. Average of the two data (from two investigators) plus a constant based on sampling were considered as the final data. Where there was a disagreement between the two investigators, a third author reviewed the data. Similar method was followed in the present study to obtain number of gazes at mirrors and ‘other areas’.

Decoding human information is made possible with recent technological advancement that identifies important characteristics of visual allocation strategy while performing complex driving tasks. A brief summary of driving related researches involving human factors engineering are provided in Underwood (2004). According to that study eye tracking methods may be classified based on eye tracking algorithms, method of measurements, diagnostic, or interactive research. A hierarchy of eye tracking methods was provided by Duchowski (2003), which is shown in Figure 7.

![Hierarchy of Eye Tracking Applications](image)

Figure 7 - Hierarchy of Eye Tracking Applications (Duchowski, 2003)

Interactive eye tracking method was used by Ward et al. (2000) and Fang et al. (2013) in their researches. These types of eye tracking studies are used mostly in visually-mediated applications, where the device includes various input tools. As the name implies,
these system interacts or responds with the user through a human computer interaction systems. With the users gaze, words are typed in the system, using word processing techniques. This method involves probabilistic techniques to anticipate the next letter or word. On the other hand Diagnostic studies record the eye movement to assess the user’s attention patterns in a given scenario. McCarley (2004) used diagnostic method for visual scanning, Recarte and Nunes (2000) used diagnostic method to assess verbal and spatial imagery tasks and Dukic (2005) used for button location and eccentricity studies.

In summary, there are various researches to improve the traffic situations near a construction zone, from which new merging concepts are evolving. To test the effectiveness of the new merge types, driving simulator based studies are used. Once the merge configuration is tested for its effectiveness in the driving simulator studies, it is subjected to a field study to evaluate the results obtained from the simulator studies. In both the studies, eye tracking methods are being used for identifying driver’s behavior, distractions, attention, etc. The present study tests the effect of two merge types on drivers’ visual attention using a driving simulator. Eye movements of the participants / drivers are counted by watching the videos of each scenario.
CHAPTER 3: METHODOLOGY

3.1 Background

The videos of the participants driving through the merge configurations were available from the previous study. In order to utilize the available data, this study aimed at tracking the eye movement of the participants. Finding the gaze duration, gaze patterns, area of interest (AOI), point-of-regard, scan path, etc., was not possible obtain from the videos. Counting the number of gazes at mirrors and ‘other areas’ was possible from those videos. Similar method was followed by Bach et al. (2008) in their study for evaluating driver attention and driving behavior. Based on the findings from literature, number of gazes on mirror is a representative variable for driver’s attention (Brown et al., 2000; Chan et al., 2010; Konstantopoulou et al., 2010; Poole & Ball, 2005) Hence this study aimed to obtain the total number of gazes of the participants towards the three mirrors (rear view, left view and right view) of a car. Additionally, total number of eye movements towards ‘other areas’ such as dash board, warning signs, environment, other vehicles etc., is analyzed. Direct observation of participant’s videos was made to obtain the data.

3.2 Participation in the Study

Thirty students from Louisiana state university were selected using convenience sampling method to participate in the study. The sample size was decided based on power analysis from a pilot study. This estimation concurs with previous researches that are very similar and involved eye tracking (Crundall & Underwood, 1998; Hayashi et al., 2005; Nabatilan et al., 2012). All participants were either graduate or undergraduate students of Louisiana State University (LSU) and participated in the experiment on a voluntary basis. Twenty two male and eight female participants were selected with the age ranging between 20 to 30 years with the median of 4.5 years of driving experience. The criterion for inclusion was having a valid driving license and a minimum of one year driving experience. The results
of self-reported questionnaire regarding driving experience showed that out of 30 participants, two of them were involved in an accident previously and 10 of them had violated road regulations resulting in ticket in the past 12 months. Participants who took part in the study indicated that they are in good general health prior to the experiment. They also stated good familiarity with standard American road signs. A brief explanation about the project was given to the participants and they were provided with an informed consent form that explained the benefits and risks involved in the research (APPENDIX 1). Demographic information form was given to the participants to collect gender and total years of driving experience data (APPENDIX 2). Participants were instructed to rest or quit at any point during the experiment, if they felt signs of motion related sickness. All thirty students participated in the twelve scenarios. Two to three minutes of break was given between each scenario, and a break of five minutes was given after the completion of first six scenarios. Data obtained only for seven female and 21 male students. Seven out of thirty participants were wearing glasses. Two male participants’ data were removed from the research, since the two participants were wearing cap that did not allow viewing the eye movements of those participants.

3.3 Resource Used for the Experiment

The study was conducted in Patrick F. Taylor Hall (PFT) located on Louisiana State University (LSU), Baton Rouge campus. Driving simulator equipped with a full size ford sedan vehicle located in PFT hall was used to perform this research (Figure 8 and Figure 9). Researchers involved in this research completed the National Institute of Health (NIH) online human subjects training (APPENDIX 3). Further to that, “Application for approval of projects which Use human subjects” was completed and approval obtained from Institutional Review Board (IRB) of LSU.
An on road high-fidelity driving simulator manufactured by Realtime Technologies Inc., Baton Rouge, LA (Realtime Technologies Inc, 2013) was used in this study to simulate driving experience through the construction zones. The simulator is a turn-key system that
can be used for automotive related researches, training and for new product development programs. The simulator features a full size Ford Focus body (minus the wheels) with technologically-advanced software and series of cameras, projectors and screens. The driving simulator provides multi-channel audio/visual systems with 180° display, full-width automobile cab including windshield, driver and passenger seats, center console and dash, full instrumentation, control loaded steering, braking and acceleration. It is equipped with a one linear degree-of-freedom motion base, providing realistic motion cues to the driver, and was surrounded by four screens showing front, rear, left and right views.

The simulator can be scaled up to six degree of freedom base, which are three rotational degrees of freedom (roll, pitch, yaw) and three translational or linear degrees of freedom (surge, heave, sway). The side-mirrors consisted of two LCDs, which showed the rear view of the road. There were three cameras inside and one camera outside the car to record drivers’ eye movement, foot position on accelerator and gas pedals, steering wheel and ambient traffic flow. This driving simulator has a library of residential, urban, rural, commercial, industrial, highway, intersection and traffic signal control; autonomous, interactive ambient traffic; extensive, interactive scripted vehicle activity; variable roadway friction and weather effects; and data collection definition. User can create their desired environment as the software is capable of customized designing. The startup and shut down procedures of the driving simulator is provided in APPENDIX 4.

For this study, videos captured from the eye movement tracking camera was used and total number of times the participants gaze at each mirror (rear view, left view and right view) and ‘other areas’ were identified. Similar method was followed in a study conducted by Bach et al. (2008). The video capturing software of the simulator that was used in this study is called data distillery, which displayed videos, captured in all the four cameras on the same screen (Figure 10). The video from the software is compatible with windows media player.
3.4 Experimental Design

The objective of the study was to identify in which of the two merge configurations (CLM and JLM), does the motorist gaze at the mirrors (rear view, left view and right view) more often. In addition to that, this study aimed to identify number of gazes on ‘other areas’ such as dashboard, other objects, warning signs etc which were grouped together and analyzed. In order to achieve the objectives a 2 x 2 x 3 factorial within-subjects design, was chosen, which yielded 12 scenarios to be tested. Table 1 shows the twelve different scenarios and levels for this experiment. High density consisted of fifty-five vehicles and the low density consisted of twenty seven vehicles on the driving environment. Maximum number of vehicles that the software can generate is fifty five. The freeway was designed in such a way that there were two lanes for each direction.

Figure 10 - Snapshot of Eye Tracking Video
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<th>Low traffic density</th>
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<td>25% increase</td>
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(C: Conventional, J: Joint, H: High, L: Low, 75: 25% reduction from standard, 100: as per standard, 125: 25% increase from standard.)

Fifty five vehicles were equally distributed to both direction of the traffic for low density scenario, which resulted in 26-27 vehicles on one direction. For high traffic density scenario the traffic on the opposite direction to the driver was cut off and thus the total number of vehicle in the driving direction was fifty five. All the vehicles gets recreated once the vehicle crosses the designed freeway length (6000 meters) that ensured presence of traffic on the freeway until completion of a scenario.

3.4.1 Independent Variables

Merge configurations (CLM or JLM) were the two major variables or groups used for comparison. Two different traffic densities were tested to simulate the real situation. High and low traffic densities were used to test the two extreme cases. In addition, three levels of sign distance in the advance warning zone were used. The standard distances shown in Figure 11 and Figure 12 were multiplied by 0.75 and 1.25 to decrease or increase the distances between the signs by 25%, respectively. Thus the independent variables were Merge configurations (2 levels), Traffic density (2 levels) and Warning sign placement distance (3 levels).
3.4.2 Dependent Variables

There are two dependent variables for this study. Total number of times the participants gaze at each mirror (Rear view, Left view and right view). Additionally participant’s number of gazes at ‘other areas’ such as dashboard, warning signs, environment, other vehicles, etc., was counted during data collection process and it is analyzed. Direct
observation of the videos was used to count the number of times the participants gaze at each mirror and ‘other areas’ similar to the study by Bach et al. (2008).

3.4.3 Hypothesis

The hypothesis predicted that there would be a significant difference in total number of gazes at mirrors between CLM and JLM configurations.

H0 : Total number of gazes at rear view mirrors and ‘other areas’ in CLM is equal to total number of gazes at rear view mirrors and ‘other areas’ in JLM.

H1 : Total number of gazes at rear view mirrors and ‘other areas’ in CLM is not equal to total number of gazes at rear view mirrors and ‘other areas’ in JLM.

3.5 Experimental Procedure

Prior to participation in the study, simulation related sickness of the participant was assessed, using a motion sickness assessment questionnaire (APPENDIX 5), in order to determine if a participant was fit for the experiment. Participants, who were prone to motion sickness, were excluded from the study. Also the motion related sickness was assessed between every two scenarios. There were two participants in this study who were eliminated because of experiencing motion related sickness during first few scenarios of the experiment. Participants became familiar with the experiments and the simulator through a trial run. Once the trial run was completed, the participants were subjected to a total of twelve scenarios, which was completely randomized based on Latin square design as shown in Table 2 (Dénes & Keedwell, 1991; Hinkelmann & Kempthorne, 2008). Each scenario took approximately two minutes to complete. Using data acquisition software, the driving related data was captured. The data capturing rate was close to 60 data points per second. Videos of the participants were captured using the four cameras. From the videos, number of times the subjects gaze at rear view mirrors and ‘other areas’ were counted.
The area of gazing was determined by setting a standard using a controlled subject. The controlled subject was instructed to gaze at mirrors and ‘other areas’ in all commonly possible ways. Figure 13 to Figure 16 shows the snapshot of possible ways that the participants can gaze at rear view mirror, left side view mirror, right side view mirror, dashboard, warning signs, environment, inside the vehicle and other vehicles.

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Figure 13 - Control Subject Gazing at Rear View Mirror

Figure 14 - Control Subject Gazing at Left Side View Mirror
3.6 Modeling of the Driving Environment

Twelve work-zone scenarios as explained in experimental design section were designed based on an interstate freeway driving environment. The route comprised of 3.7 mile (6km) long four lane divided freeway with a construction zone located on the right lane. All scenarios had a speed limit of 70 mph (112km/h). Work zones were designed with a speed limit of 50 mph (80 km/h). The signs presented speed and distance in United States customary units. A speed limit sign of 70 mph was set at the start of each scenario. A large stop sign was placed at a point where the participants were asked to stop. After the participants stopped the car and came to complete halt, the simulation was stopped. The traffic density was manipulated by the driving simulator.
The CLM and JLM layout consists of five different zones as shown in Figure 11 and Figure 12. These zones are (1) advance warning zone, (2) transition zone, (3) buffer, (4) work zone and (5) termination zone. The advance warning zone is typically a mile long and is primarily used to inform the motorists of what to expect ahead as they approach the work zone area. When redirection of the driver's normal path is required, traffic must be channelized from the normal path to a new path. This redirection is done in the transition area. The buffer space is an optional feature in the activity area that separates traffic flow from the work activity or a potentially hazardous area and provides recovery space for an errant vehicle. The work zone is an area of roadway where the work takes place. It is composed of the work space and the traffic space, and may contain one or more buffer spaces. The termination area is used to return traffic to the normal traffic path. The termination area extends from the downstream end of the work area to the END ROAD WORK signs, if posted.

The two lane merges and its environment for driving were modeled in the driving simulator. The designed model was projected onto the screen using Sim Vista software (Realtime Technologies Inc, 2013). Conventional merge and Joint merge were designed in the software with the specifications shown in Figure 11 and Figure 12. Barrel models were used to isolate the construction zone. Warning signs were used before the merging point to alert the drivers.

Internet scene assembler software from Realtime technology was used to design the two merge configuration which was based on Java programming ("Parallel Graphics," 2013). In the software there are readily available roads of different types, driving environments, trees, buildings, traffic signals, barrels, pylons, construction vehicles, people, etc (Figure 17). Three 2000 meters long freeway roads were placed next to each other to model a total of 6
km freeway road. Construction zones were designed using the standard barrels that were available in the software.

Figure 17 - Construction Zone Layout Model of the Driving Simulator

Models of vehicles, gravels, stores etc were obtained from the standard templates of the software and scaled to the requirements. These objects are referred as static objects in the software. To manure the vehicle to one lane in the merge zone, Java programming was used. Path identifiers were placed in each barrel and a defined path was programmed by
3.7 Data Collection Methods

This study was based on direct observation of the participant’s eye movement from the video that was captured by the simulator. Eye movement towards rear view mirror, side view mirror, left view mirror, and ‘other areas’ were counted separately. Data collection started when the video started and ended after the participants crossed the last barrel (end of work zone). Data obtained from the research is provided in APPENDIX 7. On random sampling basis nearly 30% of the data (108 videos) were cross verified by three different students from different departments of LSU (Civil engineering, Industrial engineering and Electrical engineering). Before verifying process all the three students were explained about the process of obtaining data from the videos and control subject snapshots were shown and explained. One best sample of each gaze type of the participants was also shown to the verifier (Figure 18 to Figure 23). The verifiers watched the videos and counted the eye movements in line with the controlled subject’s snapshots and data were recorded in a format similar to APPENDIX 7. Where the difference in the total count of each mirror or dashboard or others were found, researcher checked the video again with the verifier and errors were identified. There were only 6 videos out of 108 videos that had minor differences in the total count. Thus the data in this research may contain nearly 5% error (6 out of 108). Duration of a gaze was not recorded in this study. If a participant gazes at rear view mirror for a long time, and diverts his eye to dashboard, one count for rear view mirror and one count for dashboard was considered. In other words, number of eye movements away from the frontal driving view was counted.
Figure 18 - Participants Gazing at Frontal Driving View

Figure 19 - Participants Gazing at Rear View Mirror

Figure 20 - Participants Gazing at Left Side View Mirror
Figure 21 - Participants Gazing at Right Side View Mirror

Figure 22 - Participants Gazing at Dashboard

Figure 23 - Participants Gazing at ‘Other Areas’
3.8 Data Analysis Method

ANOVA analysis was performed to test the difference in means of the two major groups (CLM and JLM) for total number of gazes at the three rear view mirrors and at the ‘other areas’. This research consists of three independent variables and two dependent variables. Analysis of variance (ANOVA) is performed to compare all the twelve scenarios in order to test the main effects and the interaction effects. Performing twelve different t-test will increase the error in the test results and also reduces the reliability of the results (Freund et al., 2010). Co-variables such as gender and years of driving experience were tested in the ANOVA. ANOVA results for number of gazes at mirrors, and ‘other areas’ are discussed in next chapter.
CHAPTER 4: RESULTS

The results are shown in two sections namely, ANOVA results for participants gazing at mirrors and ANOVA results for participants gazing at ‘other areas’. Bar charts with error bars are used to illustrate the difference between the means CLM and JLM pairs. Test was performed in IBM SPSS Statistics, version 21. In all the cases 95% confidence interval and significance level (alpha value) of 0.05 was used unless specified.

4.1 ANOVA Results for Number of Gazes at Mirrors

Analysis of variance procedure can be used when the experiment has one dependent variable and one or more factors and/or variables. The factor variables divide the population into groups. Hypothesis about the effects of factors / variables on the means of various groupings of single dependent variable can be tested using ANOVA procedure (Freund et al., 2010). In this study, merge type, traffic density and sign placement distance were considered as fixed factors and total number of times the participants gaze at mirror and ‘other areas’ were considered as dependent variable. Additionally gender and years of driving experience were considered as covariates for the analysis. For the main effects, Bonferroni adjustment is used to calculate confidence interval. Levene’s inferential statistics was used to assess the equality of variances for different groups. Null hypothesis of Levene’s test assumes that the variances of population from which different samples are drawn are equal (Levene, 1960). The p-value of Levene's test for gaze at mirrors and ‘other areas’ are found to be more than 0.05, which show that the differences in sample variances are likely to have occurred based on random sampling from a population with equal variances. Thus, the null hypothesis of equal variances is accepted and it is concluded that there is no difference between the variances in the population.

Test between subjects show that the total number of gazes at mirrors is not significantly different between the merge type CLM and JLM (p value: 0.705). Number of
gazes at mirrors on different traffic density and different sign placement distances are significantly different (p value: 0.001 and p value: 0.002). This show that change in traffic density and sign placement distance affect the total number of gazes at mirrors. Number of gazes at mirrors is positively correlated with the traffic density, which means when the traffic density increases the number of gazes at mirrors increases and vice versa. Similarly co-variables such as gender and driving experience is found to be significant (p value: 0.001 and p value: 0.003) and influence the total number of gazes at mirror. All the interactions were not significantly different from each other (p value: > 0.6). Since the interactions are not significant, only the main effects are compared (type II SS). Additionally, a TUKEY’s Honestly Significant Difference (HSD) post HOC test was performed for the sign placement distance that show that sign placement distance of “75% of standard” and “standard” are not significance (p value: 0.804). But the sign placement distance “125% of standard” and “100% as per standard” is significantly different (p value: 0.026). This means that, reducing the sign placement distances by 25% from the standard distances does not significantly affect the number of gazes at mirrors. However, an increase in sign placement distances by 25% from the standard distances results an increase in number of gazes at mirrors by 16.9%. Significant difference exists between sign placement distance “125% of standard” and “75% as per standard” for total number of gazes at mirrors (p value: 0.04). Number of gazes at mirrors while driving on “125% of standard” sign distance is nearly 20.6 % more compared to driving on “75% as per standard” sign distance. Average number of gazes on two merge situation is compared in Figure 24.
Figure 24 - Average Number of Gazes at All the Mirrors.

Total number of gazes at all the mirrors is plotted in a bar chart for all the participants, in pairs of CLM and JLM (Figure 25 to Figure 30). Figure 25 shows the total number of gazes at all the three mirrors in H75 combination. In CH75 scenario, 18 participants out of 28 gazed more often at the mirrors, than the total gazes in JH75 scenario.

Figure 25 - Total Number of Gazes at the Mirrors in H75 Combination

- Figure 26: In CH100 scenario, 11 participants out of 28, gazed more often at the mirrors, than the total gaze in JH100 scenario.
• Figure 27: In CH125 scenario, 10 participants out of 28 gazed more often at the mirrors, than the total gazes in JH125 scenario.

![Figure 26 - Total Number of Gazes at the Mirrors in H100 Combination](image)

Figure 26 - Total Number of Gazes at the Mirrors in H100 Combination

![Figure 27 - Total Number of Gazes at the Mirrors in H125 Combination](image)

Figure 27 - Total Number of Gazes at the Mirrors in H125 Combination

• Figure 28: In CL75 scenario, 13 participants out of 28 gazed more often at the mirrors, than the total gazes in JL75 scenario.

![Figure 28 - Total Number of Gazes at the Mirrors in H125 Combination](image)

Figure 28 - Total Number of Gazes at the Mirrors in H125 Combination
- Figure 29: In CL100 scenario, 13 participants out of 28 gazed more often at the mirrors, than the total gazes in JL100 scenario.

- Figure 30: In CL125 scenario, only 13 participants out of 28 gazed more often at the mirrors, than the total gazes in JL125 scenario.
4.2 ANOVA Results for Number of Gazes at ‘Other Areas’

Test between subjects show that the total number of gazes at ‘other areas’ is not significantly different between the merge type CLM and JLM (p value: 0.534). Number of gazes at ‘other areas’ on different traffic density and different sign placement distances are significantly different (p value: 0.001 and p value: 0.000). This show that change in traffic density and sign placement distance affect the total number of gazes at ‘other areas’. Number of gazes at ‘other areas’ are negatively correlated with the traffic density, which means when the traffic density increases the number of gazes at ‘other areas’ decreases and vice versa. Co-variables such as gender and driving experience are not significant (p value: 0.738 and p value: 0.654) and does not influence the total number of gazes at ‘other areas’. All the interactions are significantly different from each other (p value > 0.4). Since the interactions are not significant, only the main effects are compared (type II SS). Additionally, a TUKEY’s Honestly Significant Difference (HSD) post HOC test was performed for the sign placement distance that show that sign placement distance of “75% of standard” and “standard” are close to significance (p value: 0.052). But the sign placement distance “125% of standard” and “100% as per standard” is not significantly different (p value: 0.073). This means that,
reducing the sign placement distances by 25% from the standard distances show slightly significant effect on the number of gazes at ‘other areas’ (decrease by 11.6 %). However, an increase in sign placement distances by 25% from the standard distances does not show an increase or decrease in number of gazes at ‘other areas’. Highly significant difference exists between sign placement distance “125% of standard” and “75% as per standard” for total number of gazes at ‘other areas’ (p value: 0.000). Number of gazes at ‘other areas’ while driving on “125% of standard” sign distance is nearly 20.7 % more compared to driving on “75% as per standard” sign distance. Average number of gazes on two merge situation is compared in Figure 31.

![Figure 31 - Average Number of Gazes at ‘Other Areas’](image)

Total number of gazes at ‘other areas’ is plotted in a bar chart for all the participants, in pairs of CLM and JLM (Figure 32 to Figure 37). Figure 32 shows the total number of gazes at ‘other areas’ in H75 combination. In CH75 scenario, 14 participants out of 28 gazed more often at ‘other areas’, than the total gazes in JH75 scenario.
Figure 32 - Total Number of Gazes at the ‘Other Areas’ in H75 Combination

- Figure 33: In CH100 scenario, 12 participants out of 28, gazed more often at the ‘other areas’, than the total gaze in JH100 scenario.

- Figure 34: In CH125 scenario, 15 participants out of 28 gazed more often at the ‘other areas’, than the total gazes in JH125 scenario.

Figure 33 - Total Number of Gazes at the ‘Other Areas’ in H100 Combination
Figure 34 - Total Number of Gazes at the ‘Other Areas’ in H125 Combination

- Figure 35: In CL75 scenario, 13 participants out of 28 gazed more often at the ‘other areas’, than the total gazes in JL75 scenario.

- Figure 36: In CL100 scenario, 9 participants out of 28 gazed more often at the ‘other areas’, than the total gazes in JL100 scenario.

- Figure 37: In CL125 scenario, only 16 participants out of 28 gazed more often at the ‘other areas’, than the total gazes in JL125 scenario.

Figure 35 - Total Number of Gazes at the ‘Other Areas’ in L75 Combination
Figure 36 - Total Number of Gazes at the ‘Other Areas’ in L100 Combination

Figure 37 - Total Number of Gazes at the ‘Other Areas’ in L125 Combination
CHAPTER 5: DISCUSSION AND CONCLUSION

This research was conducted based on the idea that motorists obtain visual information about changes in traffic by gazing at the three mirrors (rear view, left view and right view). Driving behavior of the motorists depends on the visual information that the motorist obtain from the mirrors. Thus, the research hypothesized that frequency or number of times a motorist gaze at the mirrors in a given driving situation, is a good behavioral indicator of drivers visual attention (Brookhuis et al., 1991; Pastor et al., 2006; Poole & Ball, 2005).

In the present study, total number of eye movements towards all the three mirrors (rear view, left view and right view) and ‘other areas’ like dashboard, warning signs, other vehicles, environment, inside the vehicle etc., were counted while the motorists drove through two types of lane merge configurations in a driving simulator. With the videos captured during the experiment, the eye movements were observed and recorded. Similar method of data collection was followed by Bach et al. (2008) in their research to evaluate driver attention and driving behavior. The null hypothesis of this research was that, total number of gazes at mirrors and ‘other areas’ in CLM is equal to the total number of gazes at mirrors and ‘other areas’ in JLM. Alternate hypothesis was defined as the total number of gazes at mirrors and ‘other areas’ in CLM is equal to the total number of gazes at mirrors and ‘other areas’ in JLM. Results from the research show that, the total number of gazes at mirrors and ‘other areas’ in CLM and JLM are nearly the same and they are not significantly different (p value: >0.05). Changes in traffic density and sign placement distances have a significant effect on number of gazes at mirrors and ‘other areas’ (p value: <0.05). With increase in traffic density, number of gazes at mirrors and ‘other area’ increases. Gender and driving experience have a significant effect on number of gazes at mirrors, but not at ‘other areas’. Reducing the sign placement distances by 25% from the standard distances does not
show any significant effect on the number of gazes at mirrors, however it shows an increase in the number of gazes at ‘other areas’ by nearly 11.6%. An increase in sign placement distances by 25% from the standard distances, show an increase in number of gazes at mirrors by nearly 16.9%, while it does not show any significant effect on the number of gazes at the ‘other areas’. Number of gazes at mirrors and ‘other areas’ increase by 20.6% with increase in sign placement distance from ‘75% of standard’ to ‘125% of standard’.

Researches on JLM configuration in comparison with CLM configuration showed that, JLM outperforms CLM in various aspects such as; increased traffic flow, reduced lane changes, evenly balanced lane volume, more safer, less throughput time and less delays (Idewu, 2006; Idewu & Wolshon, 2010; Ishak et al., 2012; Rayaprolu et al., 2013). The base research from which this present study is extended, showed that JLM requires lower braking force, less mental demand, less temporal demand, less effort and lower frustration levels (Punniaraj et al., 2014; Shakouri et al., 2014). JLM configuration requires higher travel time compared to CLM, because of its design (Punniaraj et al., 2014).

Apart from the increased driving distance, mental workload of the drivers is another major factor that may affect frequency of gazing. It is found that increase in mental workload decreases the gazing frequency and vice versa (Recarte & Nunes, 2003). Since the mental workload is less in JLM compared to CLM, it could be inferred that the participants gazed at mirrors and ‘other areas’ in order to pay more attention and were not confused with a new merge type (JLM) (Shakouri et al., 2014). Post HOC analysis of ANOVA for the present study also confirms the results of previous researches. Result shows that, number of gazes at mirror increase, with increase in warning sign placement distance. With increase in warning sign placement distance, the mental workload decreases compared to decreasing the warning sign placement (Shakouri et al., 2014). Thus with decreased workload, the mirror gazing frequency increases. On the other hand, higher number of gazes at ‘other areas’ compared to
number of gazes at mirrors is possibly due to more mental workload that made participants to gaze at dashboard and other vehicles to be more cautious (Yagil, 1998).

In addition to the previously stated reasons, number of gazes in JLM could be affected due to other reasons such as: the participants familiarity with a new merge type, were attempting to match the speed of other cars, were following alternate merging patterns, more number of warning signs were used etc. However, in the CLM, all the participants were very familiar with the merge type and warning signs. But considering the experimental design, each participant drove through all merge scenarios. Unfamiliarity with JLM configuration can occur for the first time the participants encounter JLM scenario. In rest of the five scenario of JLM type, participants would have experienced JLM at least once. Hence familiarity with the merge configuration may not be a reason for slightly higher number of gazes in few JLM scenarios.

In conclusion, this driving simulator study shows that, JLM configuration demands equal amount of visual attention compared to CLM configuration. Based on previous studies on JLM configurations and the results from the present study, it seems that JLM outperforms CLM in almost all the cases. In order to say which merge configuration is better than the other, effects on visual attention and various other variables such as brake, acceleration, traffic flow, driver distractions, etc., should be tested in a field study. Based on the results of the field study, advantages and disadvantages of each result need to be weighed and decision on selection should be made. The results of this study develop a better understanding of how the two merge type’s affects the visual attention of motorists. Small sample size and selected age group of participants in this research limits to generalize the results. These results could become the basis for future field study with more number of participants.
5.1 Future Recommendations

- The results of this study need to be evaluated in a field study with an eye tracking device. Field study may include participants of different age group, the two merges in different environments such as rainy day, night, windy conditions, etc.

- Effects due to modification in the design of CLM configurations such as increase in transition zone, additional warning signs etc., could be tested.

- Effects due to modification of the contents of warning signs could be tested.

- Drivers’ distractions such as cell phones, songs, passenger communications, etc., could be tested in the two merge types.

- Effect of alcohol level on decision making in the two merge configurations could be tested.
REFERENCES


Lomax, T., Schrank, D., & Eisele, B. (2013). Inconsistent traffic conditions forcing texas commuters to allow even more extra time. *Texas A&M Transportation Institute*.


Rayaprolu, P. (2010). Operational And Safety Assessment Of Joint And Conventional Lane Merge Configurations For Freeway Work Zones, Louisiana State University, USA.


APPENDIX 1. INFORMED CONSENT FORM

**Risks/Discomforts**
The only risk is the chances of getting motion sickness. The tasks have been designed to fall within the normal job performance for a good driving condition, so the potential physical or mental discomfort is not expected to be any greater than that, after a typical video game. Participants are encouraged to inform the investigators or the co-investigators, if motion sickness is felt.

**Right to Refuse:** At any time during the experiment, you have the right to not participate or withdraw from the study. There will be no penalties for withdrawal.

**Privacy:**
Other than as set forth above, participant identity will remain confidential unless disclosure is legally compelled.
Results of the study may be published, but no names or identifying information will be included in the publication.

**Financial Information:** There is no financial benefit for the participants.

**Removal:** You are expected to comply with the investigator’s instructions. If you fail to comply, you will be removed by an investigator from the experiment.

**Signatures:** The study has been discussed with me and all my questions have been answered. I may direct additional questions regarding study specifics to the investigators. If I have questions about participant’s rights or other concerns, I can contact Robert C. Mathews, Chairman, Institutional Review Board, (225) 578-8692. I agree to participate in the study described above and acknowledge the investigator’s obligation to provide me with a signed copy of the consent form.

_______________________________________              ________________
Participant Signature                                                                     Date

________________________________________
Print name

Do not write anything in the box below

Participants ID
APPENDIX 2. DEMOGRAPHIC INFORMATION FORM

Participant id __________________

Date of Experiment _____________  Time of Experiment ______________

**Instruction:** Please fill an appropriate box for each question.

1. Gender         [ ] Male       [ ] Female

2. Age           [ ] <20        [ ] 20-29        [ ] 30-39        [ ] 40-49        [ ] ≥50

3. How long have you had your driving license? _____________

4. How long have you been driving?
   - [ ] <1
   - [ ] 1-5
   - [ ] 5-9
   - [ ] ≥10

5. Estimate the number of miles you drive per year _____________

6. During the past year (12 months) have you been involved in any accidents?
   - [ ] Yes
   - [ ] No

7. If yes, how many accidents _____________

8. During the past year (12 months) have you had any traffic violations?
   - [ ] Yes
   - [ ] No

9. If yes, how many violations _____________

10. How often do you talk on your cell phone when you drive?
    - [ ] Never
    - [ ] Sometimes
    - [ ] Always

11. How often do you text message when you drive?
    - [ ] Never
    - [ ] Sometimes
    - [ ] Always
APPENDIX 3. NIH HUMAN SUBJECTS TRAINING CERTIFICATE

Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that Karthy Punniaraj successfully completed the NIH Web-based training course "Protecting Human Research Participants".

Date of completion: 08/23/2012

Certification Number: 987565
APPENDIX 4. SIMULATOR STARTUP AND SHUT DOWN PROCEDURES

Driving Simulator Startup Procedure

Following steps were followed for driving simulator startup

1. Turn ON monitors
   a. Operator’s station monitors (Plug strip on back of desk)
   b. SimObserver monitors (Plug strip underneath table and then use monitor on buttons)
2. If RTI computers are OFF, start up all computers by using switch on front panel (Start with top computer and work towards bottom of rack)
3. Inspect cab for any equipment or personal items left from previous day or run
4. Turn ON power to cab and motion base (1 power strip by right screen)
5. Turn ON A/C unit near the door (ON / OFF button on the top). Set to 73. Set cab fan to 3.
6. Check both E-stops are in proper position – Push In, Twist out
7. Check key in vehicle is in run position and both front windows are down.
8. Calibrate steering system
   a. On Host computer double click on LSU Steering Calibration and the program will start.
   b. The steering wheel will turn slowly to the right hitting hard stop, then it will return to the center position (Check progress that steering wheel is rotating).
   c. Once the calibration is complete, press any key to continue message appears in the command window. Press any key and the window closes.
9. Turn ON projectors (Use plug at rear of vehicle located on left side of rear screen)
10. Check motion base for movement. Check to make sure centering bolt is removed.
11. Check that power light is ON on the motion base amp under rear of vehicle on driver’s side.
12. Turn ON sound system
   a. Switch ON the “sound system control unit” located in front of the vehicle subwoofer.
   b. Blue light glows. Red light goes OFF.
   c. Adjust volume to level marked on front of the unit (5 bar is the normal setting).
13. Switch ON camera power strip located in the cabinet.
15. Test operation of simulator by running a scenario from the operator console either using SimCreator or the experimenter’s interface.
16. Stop SimCreator. Simulator is ready to use.
Driving Simulator Shutdown Procedure

Following steps were followed for driving simulator lab shutdown

1. Turn OFF projectors (Unplug cord on rear wall. Do not start projectors for 20 minutes after shutting down)
2. Close SimCreator, if running.
3. Close SimObserver.
4. Turn OFF sound system.
5. Turn OFF power switches to cab (Power strip in front of right screen).
6. Turn OFF computer if required.
   a. The computers are built to run 24/7. Some facilities prefer to shut off computers at end of the day.
   b. In case of shut down, use the windows interface or by toggling the switches on the front of the units.
7. Turn OFF the monitors.
8. Turn OFF the camera power strip in the cabinet.
9. Turn OFF the A/C unit behind the left screen.
APPENDIX 5. MOTION SICKNESS ASSESSMENT QUESTIONNAIRE

Participant id _________________
Date of Experiment ____________  Time of Experiment _______________
Test # _____________________
Please take your time and answer the question carefully. Should you have any questions please don’t hesitate to contact us at kpunni1@lsu.edu or call 225-349-6755.

Directions:

Please read the symptoms provided in the table below and mark any that apply. You can show the severity of the symptom by marking the corresponding number. Zero means you don’t have that symptom and as the number goes up the severity increases proportionally.

<table>
<thead>
<tr>
<th>Motion Sickness Assessment Questionnaire (MSAQ)</th>
<th>Not at all</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
<td>Do you feel ....</td>
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<tr>
<td>Sick to stomach</td>
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<tr>
<td>Faint-like</td>
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<tr>
<td>Annoyed/irritated</td>
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<tr>
<td>Sweaty</td>
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<tr>
<td>Queasy</td>
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<tr>
<td>Lightheaded</td>
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<tr>
<td>Drowsy</td>
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<tr>
<td>Clammy/cold sweat</td>
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<tr>
<td>Disoriented</td>
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<tr>
<td>Nauseated</td>
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<td>Hot/warm</td>
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<tr>
<td>Dizzy</td>
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<tr>
<td>Like I am spinning</td>
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<tr>
<td>As if I might vomit</td>
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<tr>
<td>Uneasy</td>
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</tbody>
</table>
APPENDIX 6. JAVA SCRIPTS FOR MODIFYING TRAFFIC FLOW

Program to Define Path, Speed and Traffic Density

```javascript
this.onInitialize = function() {
    Scenario.Subject.passed=false;

    Scenario.PathLane1.onLeave = function(entity){
        entity.resetBehavior(ALL_BEHAVIOR);
        entity.setDesiredLane(1);
    }

    Scenario.PathLane2.onLeave = function(entity) {
        entity.resetBehavior(ALL_BEHAVIOR);
        entity.setDesiredLane(2);
    }
}

this.onEnter = function(entity) {
    if(entity.isSubject())
    {
        Scenario.Subject.passed=true;
        // Turn off traffic other than what is already there
        Scenario.setAmbientTrafficDensity(0.0001);
    }
    if(!entity.isSubject())
    {
        entity.setDesiredLane(1);
        entity.setVelocity(RAMP,45*MPH_TO_MPS,5.0);

        if(entity.getLane()==1)
            entity.traverse(Scenario.PathLane1, TRAVERSE_JOIN);
        if(entity.getLane()==2)
            entity.traverse(Scenario.PathLane2, TRAVERSE_JOIN);
    }
}
```
Program to Define Reduced Speed in Construction Zone

this.onEnter = function(entity) {
    // Executes at the start of the time sensor
    if(!entity.isSubject())
    {
        entity.setDesiredVelocity(VELOCITY_FIXED,45*MPH_TO_MPS);
    }
}

this.onActivate = function() {
    // Executes each time step of the sensor
}

this.onLeave = function() {
    // Executes when the time sensor expires
}

Programming of Time Sensor to Regulate the Traffic

this.onEnter = function(entity) {
}

this.onActivate = function() {
    // Executes each time step of the sensor
    var vel=Scenario.Subject.getVelocity();
    if(vel>45*MPH_TO_MPS)
    vel=45*MPH_TO_MPS;
    if(Scenario.Subject.passed)
    {
        for(i=0;i<52;i++)
        {
            if((Scenario["Vehicle"+i].getCoordinateY()<Scenario.Subject.getCoordinateY())
            &&(Scenario["Vehicle"+i].getCoordinateX()>0.0)
            &&(Scenario["Vehicle"+i].getCurrentTraversal()!=null))
                Scenario["Vehicle"+i].setVelocity(vel);
        }
    }
}

this.onLeave = function() {
    // Executes when the time sensor expires
}
APPENDIX 7. EXPERIMENTAL DATA

Data for CH75, CH100 and CH125

<table>
<thead>
<tr>
<th>Participant</th>
<th>Gender</th>
<th>Yrs of Exp</th>
<th>CH75</th>
<th>CH100</th>
<th>CH125</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rear Left</td>
<td>Right</td>
<td>DB</td>
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<td>1</td>
<td>M</td>
<td>1</td>
<td>13</td>
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<td>0</td>
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<td>2</td>
<td>M</td>
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<td>M</td>
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<td>M</td>
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<td>24</td>
<td>10</td>
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<td>6</td>
<td>M</td>
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<td>16</td>
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<td>7</td>
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<td>5</td>
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<td>2</td>
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<td>9</td>
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<td>11</td>
<td>M</td>
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<td>4</td>
<td>1</td>
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<td>12</td>
<td>F</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>13</td>
<td>M</td>
<td>3</td>
<td>19</td>
<td>0</td>
<td>3</td>
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<td>14</td>
<td>F</td>
<td>3</td>
<td>4</td>
<td>7</td>
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VITA

Karthi Punniaraj is a native from Tiruchirappalli, Tamilnadu, India. Karthy received his undergraduate degree in Mechanical Engineering from Anna University in 2007. In August 2012, Karthy enrolled in Masters of Science in Industrial Engineering program at LSU. His five years of industrial experience in India and his passion for people led him to focus his degree in Human Factors. He is expected to graduate in May 2014. His interests also include Lean Manufacturing processes, Quality and six-sigma and Project management and its implementation in an automotive industry.