The Effect of Roadside Vegetation and Clear Zone Design on Driver Behavior

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

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Abstract

Roadside vegetation provides a myriad of environmental and psychological benefits to drivers. Research has shown that, although natural landscapes cause less stress and frustration to the driver, the same vegetation may increase the severity of run-off-the-road crashes. This study evaluates the relationship between clear zone design and the presence of roadside vegetation on driver speed, lateral positioning, and drivers' visual scan patterns. A driving simulator was utilized to test six combinations of clear zone sizes and roadside vegetation densities. Participants' driving performance was measured throughout the virtual drive. While there were no statistically significant differences between drivers' speeds, the speed trends that were found correlate to statistically significant observations in previous research, further validating the effect of clear zone size on driver speed. Along left curves, drivers drove closer to the centerline when there were trees near the edge of the road. Based upon the recorded drivers' eye movements, the horizontal scan pattern did not significantly change between combinations, suggesting that drivers use their peripheral vision to monitor potential hazards.

1 Introduction

Natural environments within the roadway network have been found to have many positive implications, such as reduced stress, decreased road rage, and alleviated depression [1, 2, 3]. While trees provide numerous psychological and environmental benefits, significant risk is imposed on drivers when trees are placed within proximity to the traveled way. Fixed-object crashes are some of the most severe crashes, and with respect to trees in particular, 46% of collisions with trees are fatal [4].

A primary cause for this high fatality rate is the presence of trees along high-speed rural roads. Due to the high cost of removal, trees are often present within the clear zone, thus increasing the likelihood of a fixed-object collision in the event of a run-off-the-road crash. Additionally, the presence of trees in the clear zone may affect drivers' visual scan patterns, leading to the driver's inability to detect potential hazards such as wildlife. As described by the American Association of State Highway and Transportation Officials (AASHTO), the clear zone is a design element on both local and collector roads and is intended to provide a recovery area for errant vehicles. It should be a minimum of 2.1 m and 3 m (7 and 10 ft) on roads with and without a curb, respectively [5].

Previous studies have examined to some extent the effect that clear zone size and vegetation density have on vehicle speeds and lane position. In 2014, a study by Fitzpatrick et al. utilized a static evaluation in addition to field observations to investigate the effect that clear zone size and vegetation density had on driver speeds and lane positioning. It was found that drivers selected lower speeds in the static evaluation in scenarios with small clear zones. In field observations, this was confirmed, and additionally, drivers drove closer to edge of the road in large clear zones [**Error! Reference source not found.**]. The researchers acknowledged that a field or driving simulator study would be needed to further validate a relationship to vehicle speed. More recently, Calvi [**Error! Reference source not found.**] conducted such a simulator study where the size of the clear zone and spacing of roadside trees were varied. Calvi found that drivers statistically significantly reduced their speeds and moved toward the center of the lane when trees were close to the road. The spacing of trees did not affect driver speeds but did influence lane positioning; drivers moved away from the edge of the road as tree spacing decreased. He concluded that further studies were warranted to investigate different roadside tree configurations, road alignment geometries, and vegetation types [**Error! Reference source not found.**]. Additionally, drivers' visual scan patterns as a function of clear zone size and vegetation density were not studied in the two studies, or in any other previous research.

Other studies have focused on roadside vegetation without considering the clear zone. A comparison of suburban and urban streets via a driving simulator demonstrated a mean speed reduction of 4.86 kph (3.02 mph) when trees were present along the suburban landscape [**Error! Reference source not found.**, **Error! Reference source not found.**]. Additionally, suburban roadways were perceived to be the safest by participants in a follow-up survey, and the presence of trees aided drivers with sensing the edge of the road. A driving simulator study conducted in 2010 demonstrated no change in lateral position when trees were close to the edge of the road, with and without guard rails [**Error! Reference source not found.**]. This observation indicates that drivers did not view trees as hazardous due to the lack of danger presented in a virtual drive, leading the researchers to conclude that a field study would be needed for validation. However, as a means of validating speed selection in the simulator environment, a study comparing driving simulator versus field data speeds on identical routes with a common set of drivers showed no significant differences in the actual and perceived speeds of drivers [**Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.**].

The current study employed a full-scale driving simulator study and expanded upon existing literature by examining drivers' visual scan patterns in varied clear zone/roadside vegetation density configurations. The controlled laboratory settings allowed for the consistent manipulation of critical variables as well as the direct measure of dependent measures. More specifically, driver speeds and lateral positions as well as driver eye movement were captured in an effort to validate previous studies.

2 Methodology

An experimental design was developed based upon existing literature to further the knowledge of the effect of roadside vegetation placement on roadway safety. The following section outlines the research tasks that were employed to address the objectives of this study. Statistical differences were primarily determined using a 1-way ANOVA test. However, as appropriate, a paired *t*-test or a chi-squared test was utilized. Values with a calculated $p \leq 0.05$ were considered to be statistically significant. All error bars presented throughout the analysis represent 95% confidence interval values. The primary independent variables were clear zone size and roadside vegetation density, which translated into dependent measures of driver speed, lateral position and visual scan patterns.

2.1 Driving Simulator Experimental Design

The driving simulator setup includes a fully equipped 1996 Saturn sedan and three screens subtending 135 degrees horizontally. At a resolution of 1024 x 768 pixels and at a frequency of 60Hz, the virtual environment is projected on each screen through a network of four advanced Realtime Technologies (RTI) simulator servers. High-end multimedia video chips were used to parallel-process the images projected to each of the three screens. The participant sits in the driver's seat and operates the controls, just as he or she would in a normal car. A Dolby surround system consisting of side speakers and two subwoofers located under the hood of the car provide realistic wind, road, and other vehicle noises with appropriate direction, intensity, and Doppler shift. The driving simulator is depicted in Figure 2.1.

Figure 2.1 – Driving simulator at Arbella Insurance Human Performance Lab, University of Massachusetts Amherst

Two vegetation densities and three clear zone sizes were utilized to create six unique combinations, which were constructed using RTI's SimCreator© software. These six corresponded to the combinations used by Fitzpatrick et al. [**Error! Reference source not found.**], which were presented in a static evaluation. Vegetation density was either medium or dense. Three levels of clear zone width were used. The small clear zone had trees in close proximity to the edge of the roadway. In the medium clear zone combinations, trees were located approximately two meters away from the edge of the traveled way, and in the large clear zone combinations, trees were six meters from the edge of the traveled way. Cross sections of the six experimental combinations are depicted in Figure 2.2.

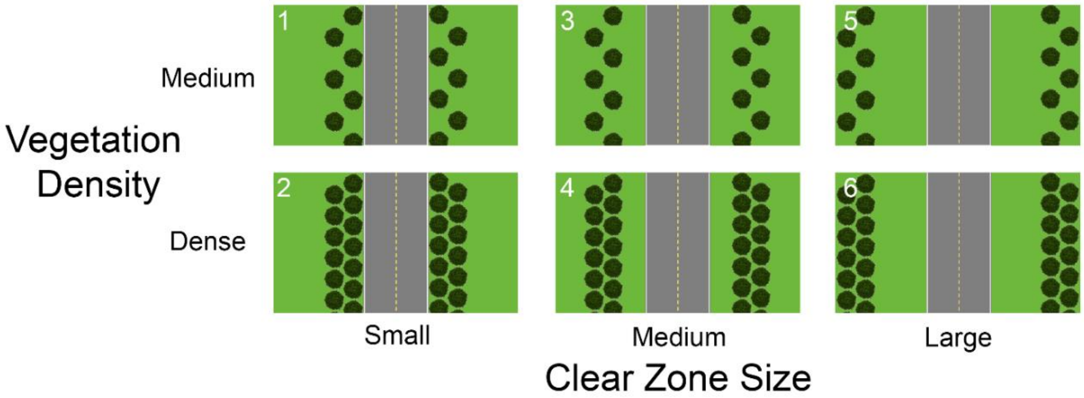

Figure 2.2 – Cross sections of the six clear zone size/vegetation combinations traversed by drivers in the virtual drive

Each virtual drive consisted of six segments, each containing a different clear zone size/vegetation density module. Each module consisted of eight subsegments as follows: four tangent sections, two right curves, and two left curves. A 35 mile per hour speed limit sign (56.3 kph) was placed at the beginning of each segment. Experimental segments were separated by two transition tiles and a control intersection to help keep drivers alert. Data was collected continuously throughout the drive; however, eight primary locations were selected for data comparisons. The eight fixed analysis locations were located at the midpoint for each subsegment as presented in Figure 2.3.

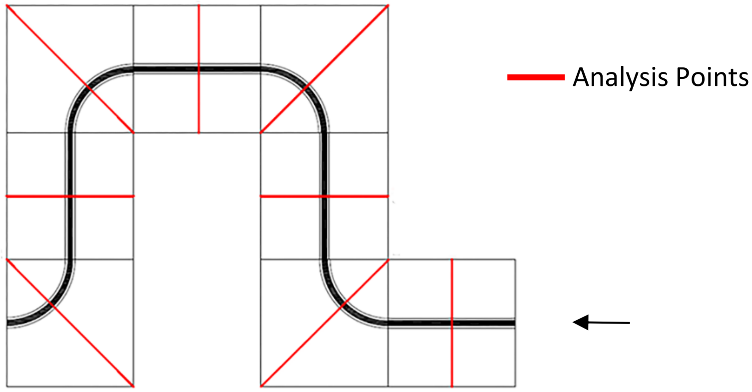

Figure 2.3 – Plan view of a module for each clear zone/vegetation density combination

To eliminate any effect that the order of the combinations may have had on driver speeds, a Latin square design was used. By this logic, each clear zone distance/vegetation density combination appears once in every row and column, and as such varies the order of presentation across drivers. Altogether, six unique virtual worlds were created, each consisting of six consecutive segments with varying modules. The specific order of combinations for each of the six drives is shown in Table 2.1.

Table 2.1 – Latin square design to vary presentation order

Drive	Segment					
	#1	#2	#3	#4	#5	#6
A	2	3	4	6	1	5
B	5	1	6	4	3	2
C	3	2	1	5	6	4
D	4	6	3	2	5	1
E	6	5	2	1	4	3
F	1	4	5	3	2	6

Module	Clear Zone Size / Vegetation Density
1	Small / Medium
2	Small / Dense
3	Medium / Medium
4	Medium / Dense
5	Large / Medium
6	Large / Dense

2.2 2.2 Participant Demographics and Procedures

Twenty-four drivers from the greater Amherst, Massachusetts, area were recruited as paid simulator participants. Twelve males and twelve females drove each of the drive combinations. Participant ages ranged from 21 to 38 years old with an average age of 25.6 years (SD = 3.6 years). The average driving experience was 8.5 years. One driver experienced discomfort during the simulator drive and had to withdraw from the study, resulting in a final sample of 23 drivers. All procedures including informed consent, payment, and participant recruitment followed Protocol ID#: 2013-1588 as approved by the Institutional Review Board (IRB) of the University of Massachusetts.

2.3 Eye Tracking Capture and Analysis

The Applied Science Laboratories Mobile Eye is an ultra-lightweight and portable head-mounted eye tracker system and was used to monitor eye movements of the driver. The eye tracker records the position of the eye point of gaze at 30 Hz. The eye tracker has a visual angle range of 50 degrees in the horizontal direction and 40 degrees in the vertical direction. The system's accuracy is 0.5 degrees of visual angle [14].

Accurate eye tracker data was captured from a representative sample of the 23 participants. Full eye tracking data collection was not conducted, in part due to the robust nature of the data analysis process, coupled with the consistent output data necessitating less data needed to achieve sufficient statistical power.

From the collected eye tracker data, the coordinates of the driver's focus were captured. By plotting the y-coordinate versus time, the number of glances at the speedometer could be quantified. An example of this process is shown in Figure 2.4.

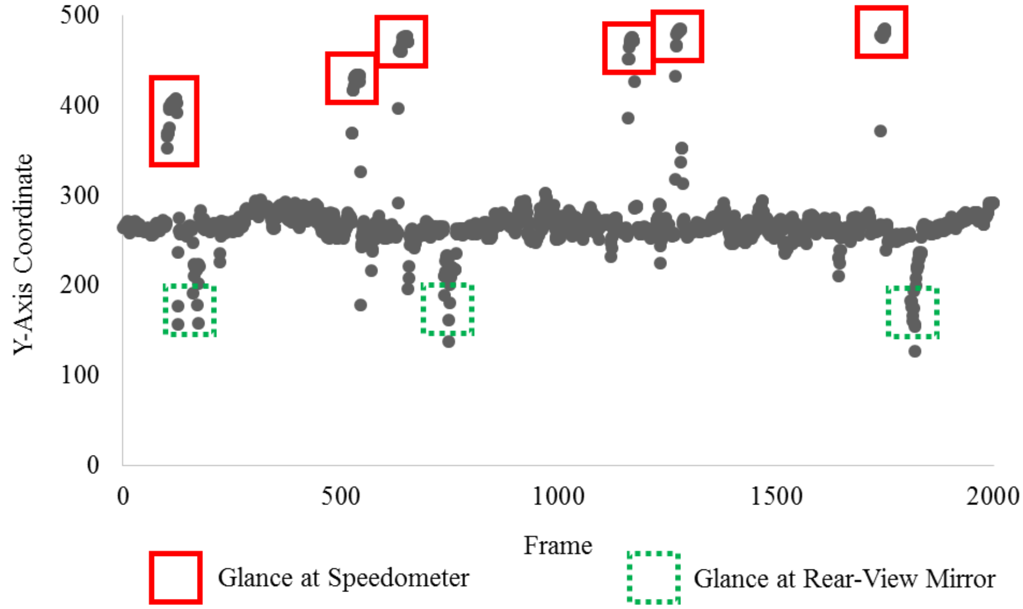

Figure 2.4 – Example graph showing how the number of glances at the speedometer was determined for each segment

To analyze the horizontal scan pattern, a video software, Kinovea ©, was utilized in order to track drivers' scan pattern. Kinovea was selected because it allows a customizable grid to be superimposed on the video. This allowed for a consistent format for completing comparisons between drivers. As shown in **Error! Reference source not found.**, the travel lane was overlaid by four boxes with each box corresponding to one meter in width. The grid was extended to the side of the road to quantify how far drivers scanned depending on the clear zone size/vegetation density combination. Glances to the left of the centerline were not tracked because it was difficult to determine if glances to the left were due to the presence of oncoming traffic or simply locating the forward roadway. Finally, only tangent segments were analyzed using the eye tracking data because drivers tended to track the edge line when navigating right curves and track the centerline when navigating left curves. Both of these analyses are outside the scope of this study.

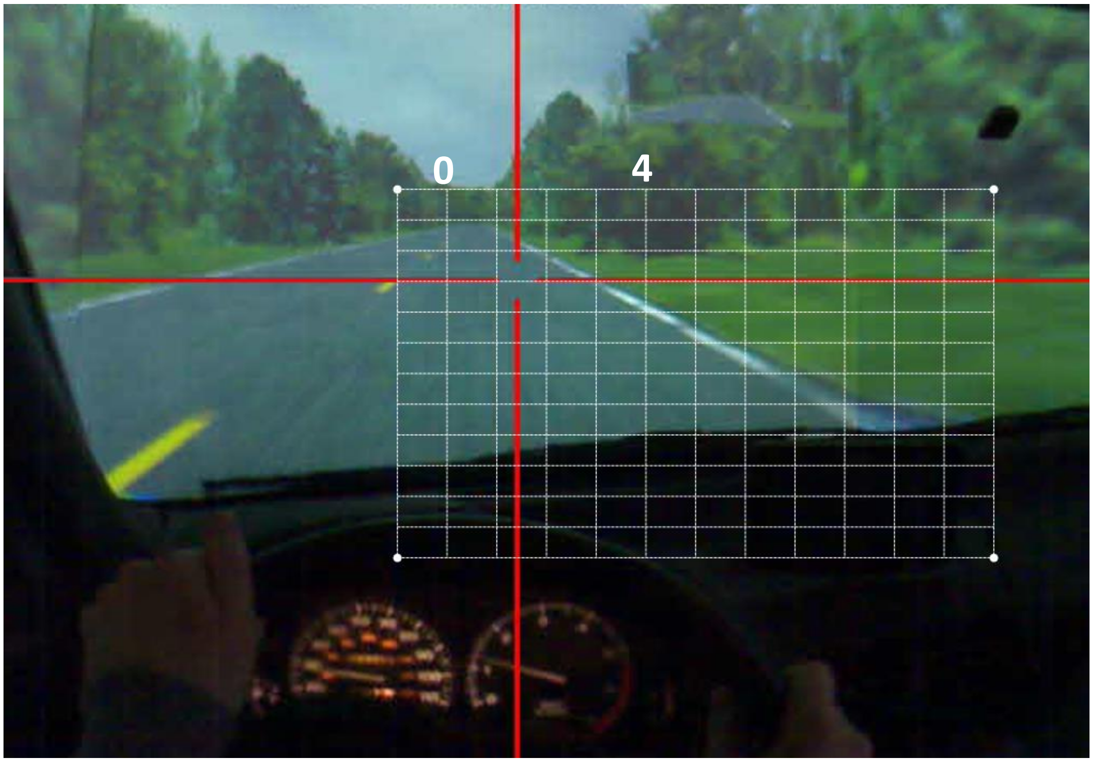

Figure 2.5 – Superimposed grid used to measure the driver's eye movement (red crosshairs)

3 Results and Discussion

Three primary metrics were used to evaluate drivers' responses to the different clear zone size/vegetation density combinations: speed, lateral position, and visual scan pattern. This section presents the findings from the driving simulator study.

3.1 Speed Selection

Participants were instructed to drive as they normally would. As shown previously in Figure 2.3, driver speeds were captured at eight points within each segment comprising four data collection points along tangent sections and two data collection points along both right and left curves. The average speeds for the 23 drivers in each of the six clear zone size/vegetation density combinations are presented in Figure 3.1**Error! Reference source not found.**.

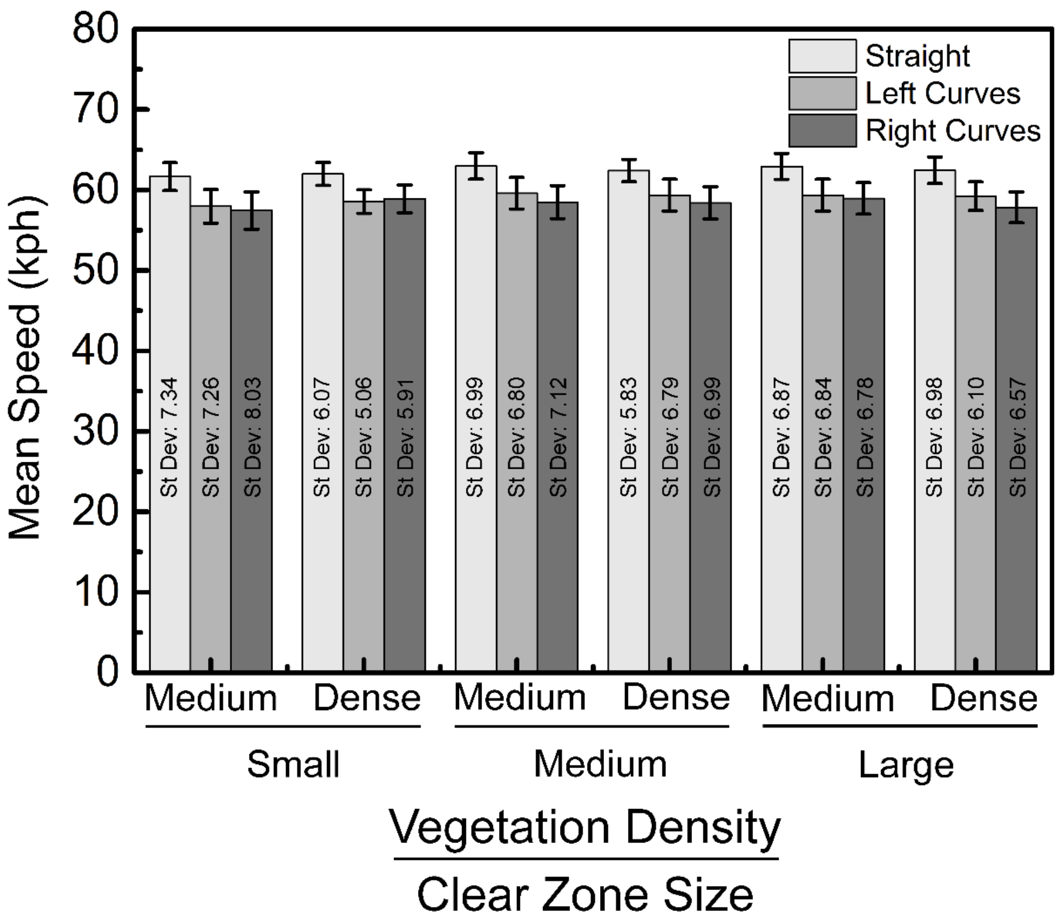

Figure 3.1 – Mean speeds at the data analysis points for straight segments, left curves and right curves

There were no statistically significant differences in speed observed between the different combinations for the straight, right curve, or left curve analysis points. There are a variety of possible reasons that no statistically significant speed differences were observed. One possibility is that drivers were not afraid of running off the road because they were in a safe simulated environment. Another potential influence could have been the 35 mile per hour (56.3 kph) speed limit signs at the beginning of each segment. These signs were included in the virtual environment in order to increase the realism of the environment. However, the speed limit signs may have been detrimental to the study because the eye tracking data described in the next section showed that drivers paid consistent attention to their speed throughout the drive.

While no statistically significant differences were observed between the experimental scenarios, several noteworthy trends emerged when completing a within-subjects analysis of speed. Table 3.1 investigates each driver's speed in each of the six clear zone size/vegetation density combinations and ranks each combination from fastest (rank = 6) to slowest (rank = 1). For example, 35% of drivers had their slowest speed (rank = 1) occur in the small clear zone/medium vegetation combination, whereas only 9% of drivers had their fastest speed (rank=6) occur in that same combination.

Table 3.1 – Percentage of drivers at each ranking within each combination

Rank	Clear Zone Size/Vegetation Density Combination					
	Small		Medium		Large	
	Medium	Dense	Medium	Dense	Medium	Dense
6 Fastest	9%	13%	22%	13%	17%	26%
↓	17%	13%	*26%	13%	*22%	9%
	4%	26%	9%	22%	*22%	17%
	22%	4%	13%	13%	17%	*30%
	13%	13%	22%	*26%	13%	13%
1 Slowest	*35%	*30%	9%	13%	9%	4%
Average Rank	1.83	2.17	2.87	2.35	2.87	2.91

Note: (*) indicates the most frequent ranking for each combination. The last row shows the overall average rank for each combination.

A noticeable trend is observed with the highest percentages of slow speeds occurring in the small clear zone combinations. Thirty-five percent of drivers had their slowest speed occur in the small clear zone with medium vegetation density and 30% in the small clear zone and dense vegetation. This is in stark contrast to only 9% and 13% of drivers having their fastest speed occur in these combinations, respectively. This trend is seen again when looking at the large clear zone combinations where 17% and 26% of drivers had their *fastest* speed occur in medium and dense vegetation, respectively. Only 9% and 4% of drivers had their *slowest* speeds occur in these same combinations. The overall average rank, with one being the slowest and six being the fastest, for each combination suggests that the clear zone size may have had an effect on driver speeds. This trend matches both the field observations from Fitzpatrick et al. (2014) and the driving simulator study by Calvi (2015), both of which showed statistically significant decreases in speed as the size of the clear zone decreased.

3.2 Visual Scan Pattern

Accurate eye tracking data was captured for nine drivers. Using the methodology described in **Error! Reference source not found.**, the number of glances at the speedometer was quantified for each of the six clear zone size/vegetation density combinations. It was hypothesized that drivers may pay more attention to their speed in different combinations; however, this was not the case, as shown in Table 3.2. While there were statistically significant differences in the number of glances between drivers, there were no statistically significant differences between clear zone size/vegetation density combinations. The average number of glances, approximately 9.5 for each combination, correlates with a glance at the speedometer roughly every 20 seconds, as each segment took an average of 100 seconds to traverse.

Table 3.2 – Number of glances at the speedometer

Subject	Clear Zone Size/Vegetation Density Combination					
	Small		Medium		Large	
	Medium	Dense	Medium	Dense	Medium	Dense
2	20	14	12	19	23	19
5	16	11	10	14	14	20
6	6	8	11	8	9	9
7	7	12	15	8	3	7
8	10	10	11	15	10	11
9	6	3	4	3	4	8
11	8	4	6	7	9	7
12	5	5	9	6	7	4
18	12	9	5	6	7	3
Average	10.0	8.4	9.2	9.6	9.6	9.8
St Dev	5.1	3.8	3.6	5.2	6.0	6.0

As described in **Error! Reference source not found.**, drivers' horizontal scan patterns during straight segments were analyzed. It was hypothesized that drivers would scan a wider field of view when the clear zone size increased. However, drivers almost exclusively fixated between the centerline and the edge line, as shown in Figure 3.2.

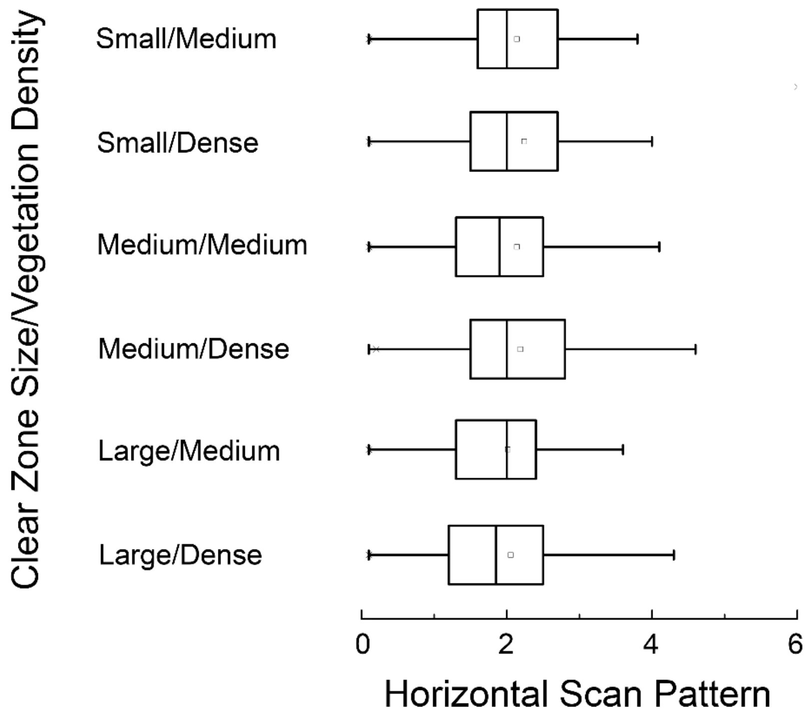

Figure 3.2 – Horizontal scan pattern for each combination with zero corresponding to the centerline and four corresponding to the right edge line

The lack of an easily explained horizontal scan pattern could be the result of three potential factors: drivers using their peripheral vision to watch for hazards in the clear zone, drivers not feeling the need to scan the clear zone due to a low perceived risk of a hazard materializing, or drivers wearing the eye tracker, which hindered head movement. Further eye tracking studies are warranted because these results show that drivers are using their peripheral vision to scan the clear zone. A future study could explore drivers' ability to anticipate and react to hazards, such as wildlife, as the roadside environment is varied.

3.3 Lane Positioning

In addition to drivers' speeds and eye tracking movement, their lane positioning was also captured throughout the drive. There were no statistically significant differences in lane positioning during tangent segments, as shown in Figure 3.3. However, when navigating left curves, drivers drove almost a foot further from the edge of the road when the clear zone was small than in other combinations, a statistically significant difference, shown in Table 3.3. This finding validates the previous field observations conducted by Fitzpatrick et al. [**Error! Reference source not found.**].

Table 3.3 – Average lane position

Roadway Geometry	Clear Zone Size/Vegetation Density Combination		
	Small	Medium	Large

	Medium	Dense	Medium	Dense	Medium	Dense
Straight	-0.11	-0.17	-0.09	-0.07	-0.10	-0.10
Left Curves	-0.30*	-0.26*	-0.10	-0.01^	-0.02^	-0.03^
Right Curves	0.45	0.47	0.37	0.51	0.39	0.38

Units: center of virtual vehicle's distance from center of the travel lane (m), negative value is left of center and positive value is right of center.

*indicates statistical difference between values marked with a ^.

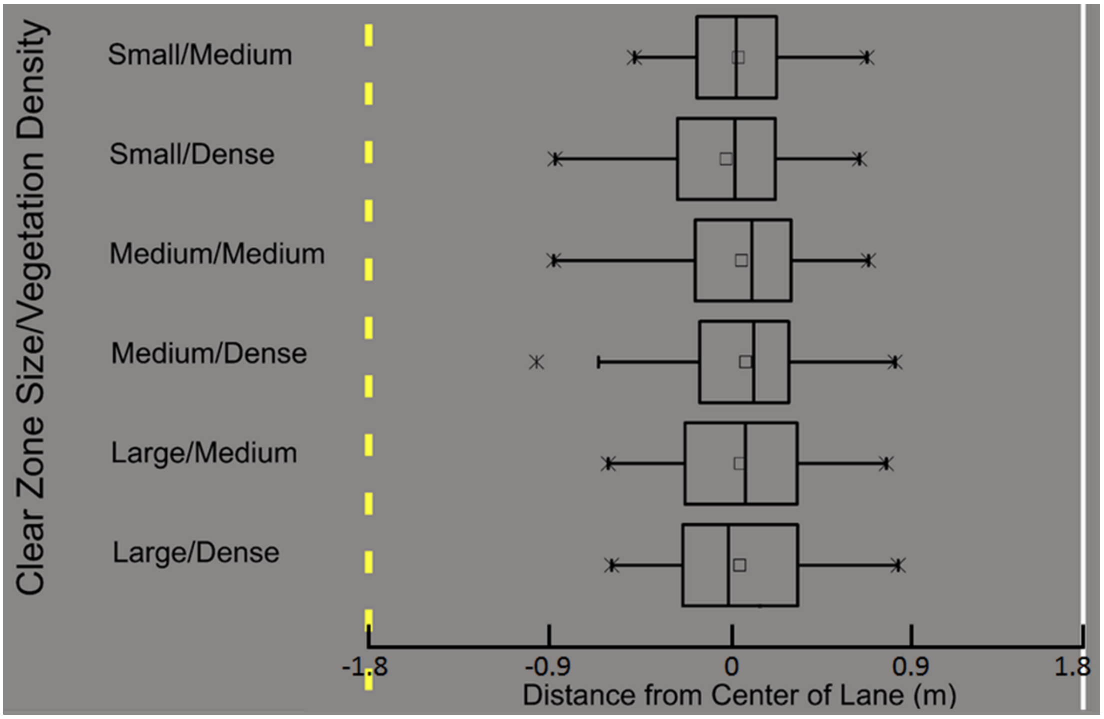

Figure 3.3 – Lane position of the center of vehicle during tangent sections (figure is to scale)

While no statistically significant differences in lane positioning were observed along tangent segments, this is likely due to the lack of danger present to drivers in a driving simulator environment. Field observations, such as the data collected by Fitzpatrick et al. [**Error! Reference source not found.**] are perhaps a better indicator of drivers' lane positioning due to the actual risk imposed by roadside trees. Additionally, none of the 23 participants had driven in the simulator before, meaning they were not familiar with the vehicle's position within the lane like they would be with their personal vehicles.

4 Conclusions

This research investigated the effect of clear zone size and surrounding vegetation density on driver performance by conducting a driving simulator experiment with 23 paid participants with an average age of 25.6 and 8.5 years of driving experience on average. Drivers traversed a ten-minute drive that consisted of six segments. Three clear zone sizes ranging from 0 to 6 meters were used in conjunction with two vegetation densities, dense and medium, to make a total of six clear zone size/vegetation density combinations.

There were no statistically significant differences in speeds between the six combinations for straight, left curve, or right curve sections. This lack of statistical significance could have been due to speed limit signs affecting participants' speed behavior. To investigate the effect that the speed limit signs had on the results, two future studies are recommended. The first would use the same simulated environment without the presence of speed limit signs, and the second would use the same simulated environment and obscure the speedometer from drivers so that they do not know how fast they are driving. Of note, a comparison of drivers' speed within each combination observed herein resulted in a trend that was similar to previous observed speeds in the field; however, isolation of the specific variables that contribute to the resulting speed selection is warranted.

Clear zone size did cause drivers to move toward the center of the road when navigating left curves, again validating the correlation between field observations and driving simulation. There were, however, no statistically significant differences in lane positioning on straight or right curve sections.

Eye tracking data showed that the average driver glanced at the speedometer approximately ten times per section, or once every 20 seconds, indicating that the presence of speed limit signs and the fear of enforcement affected speeds. Eye tracking data also showed that drivers scan from the centerline of the road to the edge line and that drivers' horizontal scan pattern did not significantly change as the clear zone size increased or as the vegetation became denser. This lack of statistical significance is in and of itself significant, as it suggests that drivers tended to rely on their peripheral vision to scan for hazards in the clear zone.

Acknowledgments

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