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The Effect of Roadside Elements on Driver Behavior and Run-Off-the-Road Crash Severity

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THE EFFECT OF ROADSIDE ELEMENTS ON DRIVER BEHAVIOR AND RUN-OFF-THE-ROAD CRASH SEVERITY

A Thesis Presented

by

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ABSTRACT

THE EFFECT OF ROADSIDE ELEMENTS ON DRIVER BEHAVIOR AND RUN-OFF-THE-ROAD CRASH SEVERITY

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Roadside vegetation provides numerous environmental and psychological benefits to drivers. Previous studies have shown that natural landscapes can effectively lower crash rates and cause less stress and frustration to the driver. However, run-off-the-road crashes resulting in a collision with a tree are twice as likely to result in a fatality, thus reinforcing the need to examine the placement of vegetation within the clear zone, defined herein as a flat unobstructed area for errant vehicles to recover. This study explores the relationship between the size of the clear zone and the presence of roadside vegetation on selected driver attributes, including both driver speed and lateral positioning. To evaluate the effect on the driver speed selection process, a static evaluation was employed. Completed by more than 100 drivers, the static evaluation was utilized to gather speed selections on both real and virtual roads containing four combinations of clear zone size and roadside vegetation density. Additionally, field data was collected to validate the findings of the static evaluation and to determine the extent to which roadside vegetation impacts driving attributes. When presented with a large clear zone, drivers positioned the vehicle further from the edge of the road as the vegetation density increased. Furthermore, the speeds observed in the field correlated with the speeds that participants selected when watching a video of the same road. Finally, the UMassSafe Traffic Safety Data Warehouse was utilized to link crash and roadway data, allowing for an in-depth analysis of run-off-the-road (ROR) crash severity. The results of this study further demonstrate the nature of the relationship between clear zone design and driver behavior. Additionally, the results provide information regarding improved clear zone design practices that may translate into improved roadway safety.

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CHAPTER 1

INTRODUCTION

Due to increasing levels in the built environment, opportunities to preserve the natural environment are critical. Studies on climate change have shed light on the critical role trees play within the environment with regards to mitigating negative impacts. Specifically, trees have the ability to reduce heat islands by providing shade, leading to lower pavement temperatures and decreased emissions (1). Positive psychological implications, such as reduced stress, decreased road rage, alleviated depression and expedited recovery from injuries have been associated with natural environments.

While trees provide psychological and environmental benefits, they pose a potential risk to drivers when placed within proximity to the traveled way. Approximately 1.9 percent of all crashes are with fixed objects such as trees and 46 percent of these crashes are fatal (1). Although there is research that describes both the positive and negative aspects of natural vegetation along the roadside, there is a need to further understand the impacts on driver performance. Additionally, there is a need to investigate the correlation between the built environment and run-off-the-road crashes. The research conducted within this thesis outlines a methodology that was employed to evaluate the effects of roadside elements on driver performance as well as an analysis of run-off-the-road crashes. The corresponding results, included herein provide describe the nature of the relationship between roadside vegetation and select driver attributes.

1.1 Problem Statement

As described within the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and*

Streets (Green Book), the clear zone is a design element on both local and collector roads and is intended to provide a recovery area for errant vehicles (2). The AASHTO Green Book stipulates that the clear zone located on roads with or without a curb should be a minimum of 7 and 10 ft, respectively (2). Implementation of the clear zone may often present a challenge as it may require the roadway builder to purchase additional right of way and to remove trees.

The efficacy of the clear zone remains a bit ambiguous within the literature as past studies show contradicting results with regard to roadside elements. The natural environment seems to produce psychological benefits on drivers, yet trees were shown to increase the severity of run-off-the-road crashes. Analysis on the benefits and hazards of vegetation placed within the clear zone has not been fully investigated, thus there is a need for an improved understanding as to how elements placed within the clear zone impact the related driver behavior. Specifically, there is a need to compare the frequency and severity of crashes on roads with adequate clear zones versus roads with roadside trees. Lastly, there is a need to evaluate and understand the specific impacts of trees within the clear zone on driver behavior.

1.2 Research Hypotheses and Objectives

Based upon the identified problem statement, the overarching goal of this thesis research was to evaluate the impacts resulting from the presence of trees within close proximity to the traveled way. Within the framework of this overarching goal, a series of research objectives and corresponding hypotheses were developed as outlined in the following section.

Objective 1: Understand the effect that roadside vegetation density has on vehicle speeds. The first hypothesis is that the density of trees along the roadside will have a measurable effect on operating speeds. When trees are more thickly settled, drivers may perceive a faster operating speed or feel unsafe, and in turn reduce their speed. The second hypothesis is that vehicle speeds observed in the real world will be similar to the speeds surveyed during the static evaluation.

Objective 2: Understand how the size of the clear zone affects driver behavior. It is hypothesized that a smaller clear zone may cause drivers to position their vehicle further from the edge of the road or accept lower operating speeds in fear of running off the road.

Objective 3: Determine the effect that various roadway environmental elements have on drivers' speed selection. It is hypothesized that participants will not rate vegetation density as influential to their speed selection because it is a roadway element that is only subconsciously noticed.

Objective 4: Utilize crash data to investigate run-off-the-road crashes and the patterns associated with their severity. It is hypothesized that a direct correlation will exist between the severity of run-off-the-road crashes and the type of roadside elements involved during the crash.

1.3 Scope

While there are many factors that are believed to influence operating speeds, the scope of this study focused solely upon roadside elements, and most specifically upon roadside vegetation. Other variables such as traffic volumes, road conditions, weather conditions and functional classification were held constant or not considered as variables.

Additionally, the scope of the crash data analysis component was limited to Massachusetts run-off-the-road crashes occurring between 2007 and 2010. Other types of crashes were examined for comparison purposes but the focus was on run-off-road crashes.

CHAPTER 2

BACKGROUND

Concepts relating to both roadside vegetation and run off the road safety have been the focus of a myriad of research efforts. The published literature was studied to identify previous research that is related to the topics presented within this thesis. More specifically, the research review focused upon three primary topics: the psychological effects that natural environments have on people in general, driver behavioral studies and crash data analyses. The literature reviewed, while broad in topics, makes a good portrayal of the benefits and consequences of roadside trees.

2.1 Psychological Effect of Trees

A recent study was conducted by the Kentucky Transportation Center at University of Kentucky and had participants watch a virtual simulation online of different roadway types (3). Some roads were in an urban setting while others were rural. They varied the roadway width, clear zone width, surrounding plant intensity and barrier type. After the subjects went through a roadway scenario they were asked to rate their discomfort on a ten point scale. The study found that discomfort increases as vegetation becomes more intense and increased with narrower roadways. The researchers hypothesized that an increase in discomfort could correlate to reduced vehicle speeds as drivers have a lower sense of security. The researchers concluded that "it would be useful to run a direction validation test, eliciting data for each scenario in a five-axis simulator and comparing these data with response data gathered using the online visualization method. (3)"

A paper published in *Environment and Behavior* tried to address the question of "can highway vegetation mitigate automobile driver frustration?" (4) To answer this question, 106 people watched a video of a drive down one of three highway corridors. The subjects were asked to solve an unsolvable anagram; the researchers would measure their level of anger and their frustration tolerance, or how long they kept trying before giving up.

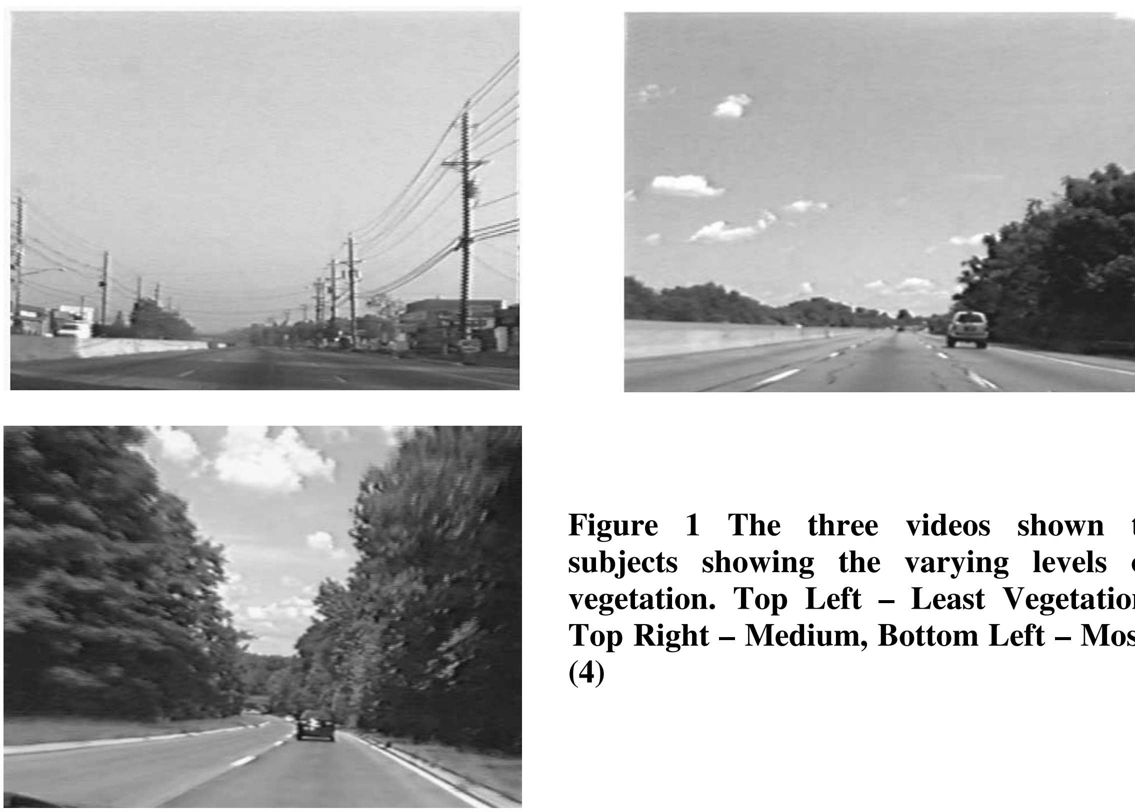


Figure 1 The three videos shown to subjects showing the varying levels of vegetation. Top Left – Least Vegetation, Top Right – Medium, Bottom Left – Most. (4)

The researchers found that the videos had no effect on how angry the subjects got from failing to solve the anagram. However, the researchers did find that the people who viewed the videos with more vegetation had a higher tolerance for frustration as more time was spent trying to solve the anagram before giving up. The researchers mention that this finding is significant because it means vegetation can reduce the chances of road rage occuring.

A study conducted in 2003 attempted to determine what made a stretch of road more or less preferable for pedestrians (5). To do so, three types of walking behavior were first identified: walking to commute, walking for health reasons, or walking for 'spiritual or relaxation purposes.' The researcher then asked people to respond to a questionaire asking the reasons why they walk, and what they did or did not like about the road they were walking along. Common responses for positive attributes were greenery, grass, and road was well maintained. These factors also showed up when they were not present along the stretch of road. In the end the author summarized that "it is clear that greenery/grass/landscape appears to be fairly significant … when walking for spiritual renewal or stress relief." (5)

A team of researchers from Texas A&M studied the effects that roadside environments had on stress recovery and immunization (6). They subjected people to a mild stressor and then had them watch a video of a simulated drive with varying levels of greenery. Subjects were again subjected to another mild stressor. After that stressor, the experimenters measured their blood pressure. As expected, the researchers found that the subjects who viewed the videos of more natural settings had less elevated blood pressures than the other groups.

2.2 Crash Data Analyses

In Seattle on SR-99, the city converted two-way left turn lanes into landscaped medians with left turn/U-turn pockets, among other improvements. Researchers from the Washington State DOT analyzed three years of crash data before and after the change (7). The study found a decrease in crash rates but an increase in crash severity; however, neither finding was statistically significant. The authors noted that 32 trees had to be replaced in the three year analysis period and while collisions with trees were generally property damage only (PDO) crashes, "concern does exist that as tree width and strength grow over time, tree crash severity may increase." (7)

In Texas, Researchers examined ten sites that had recently undergone landscape improvements (8). These landscape improvements included interchange, roadside and median landscaping as well as roadside planting. The crash rate significantly decreased at 8 of the 10 sites studied and increased slightly at the other two. The authors identified the reason for the increase was due to the sites being complex grade separated interchanges which require a higher number of roadside vertical objects, such as columns and road signs. A 71% decrease of tree collisions was observed which was attributed largely to one of the ten sites. The researchers concluded that "landscape along the roadside is having a positive effect on driver behavior and perception." (8)

Five roads were studied in Toronto, Canada that had recently undergone landscape improvements. Crash frequency and severity were observed for three years before the improvements and three years after the improvements had been made (9). The researchers found that there was between a 5 and 20 percent reduction in crash rate and severity as a result of the changes. The authors say that their research "indicates a possible correlation between greening and reduction in mid-block accident frequency and severity." (9)

A researcher from Georgia Institute of Technology studied five years of crash data from Colonial Drive in Orlando, Florida (10). He did so to challenge the assertion that "the wider the clear zone, the safer it will be." A "livable" section of the road was compared with a section that adhered to the more conservative design standards. Through analysis of the crash data, he found that livable streets had 10.7 percent fewer crashes and 23.6 percent fewer injurious crashes. A summary of the roadway characteristics can be found in Table 1.

Table 1 Design Characteristics of Livable and Comparison Sections of Colonial Drive from *Safe Streets, Livable Streets*. (10)

Characteristic	Livable section	Comparison section
Length (miles)	0.9	0.9
Average daily traffic (vehicles)	47,000	46,000
Posted speed limit (mph)	40	45
Lanes	4 x 11 ft.	4 x 12.5 ft.
Median	10 ft. painted	10 ft. painted
Shoulder	6.5 ft. parking lane	5 ft. paved shoulder ± 15 ft. runout zone
Avg. crashes per intersection	21	19
Mean age of at-fault driver	28	27

Researchers at Caltrans and California Polytechnic State University studied six years of crash data on 29 different sections of road, of which 19 had trees in the median (11). They only included crashes that occurred on the side of the road containing the median as they wanted to see what effect the trees had on frequency and severity. A significant finding was that large trees in medians were associated with more collisions and increased severity. However, the authors acknowledged that some of this association was statistically weak. Lower speeds and larger side clearances were not found to reduce frequency and severity of crashes with median trees contrary to what might be intuitively believed.

A study completed in 2003 compared the safety of freeways to parkways, which are roads which are generally divided by a landscaped median and have medium to high speeds (12). The study attempted to compare roads that had similar characteristics in terms of average daily traffic, average speed, and types of drivers. The main performance indicators that were used were fatal accident rate (FAR) and accident cost (AC). The study found that parkways had a lower FAR as well as a lower AC. Run-off-the-road crashes were more common on parkways but the authors deduced that this was due to elements that make up freeways, such as concrete barriers and guardrails which inhibit run-off-the-road crashes. The authors admit that "this current study does not allow conclusions about any specific landscape elements or settings that may be contributing to the decrease in collisions and accidents." (12) This paper identifies an area prime for further researchers, the study of how each individual landscape element affects driver performance. Such a study could possibly be conducted in a driving simulator.

A 2006 study analyzed national crash data in an attempt to quantify the effect that urban trees had on traffic safety which was measured by crash incidence and severity (13). The reasoning for undertaking this project is that "circumstances of tree crashes in urban settings are not well understood." (13) In addition to learning about the patterns of crashes with trees, the researches wanted to look at the difference in collisions based on if the area was urban or rural. A relevant finding from the analysis was that collisions with trees made up 1.9% of all crashes and crashes in rural areas result in a higher rate of injurious crashes than in urban areas and fixed object collisions were more frequent in rural areas than urban areas. An interesting observation was made when they were describing trees as technology, "Western European countries have lower crash injury rates despite less support of tree removal due to aesthetic and environmental reasons." (13) The article concludes with the statistic that 80 percent of the US population lives in urban areas and there is a need for better informed road design.

Five years of crash data were studied for a two lane undivided roadway in New Hampshire (14). The researchers wanted to build a model that identified statistically significant factors predicting the probability of crashes and injury crashes. They wanted to use this model to perform a risk assessment in the area for which the model was developed. One relevant finding was that adding sidewalks to a section of the road made it safer not only for the pedestrians but also for drivers.

Andrew Zeigler analyzed 500 vehicle-tree accidents in Michigan in an attempt to provide recommendations to state and local road authorities (15). He found that often times the driver is intoxicated or is not familiar with the road. He observed that vehicle-tree accidents usually occur along a winding rural road and that "no single feature of the road environment accounts for all the accidents that occur." Like many engineers before him, Zeigler suggests tree removal as an alternative for addressing environmental and safety issues.

A literature review in 2007 focused on the benefits that trees have on communities while balancing the risk they present to motorists (1). Early in the paper, they talk about how urban trees can be a cost effective approach for urban cities to meet environmental standards. Part of this effect is that emissions increase with respect to air temperature, and trees that shade pavement can reduce asphalt temperatures by 36° F which can reduce air temperatures by 7° F. The authors also cited the statistic that 1.9 percent of all accidents were collisions with trees but they mention that 46 percent of these collisions were fatal. Due to the way police reports are written, it is hard to study the effect that vegetation has on crash rates as this detail is rarely noted by the officer(s) on the scene. Among many suggestions, the authors call for "improved data collection concerning vegetation" and "before-and-after studies to assess consequences of installing or removing street and median trees." (1)

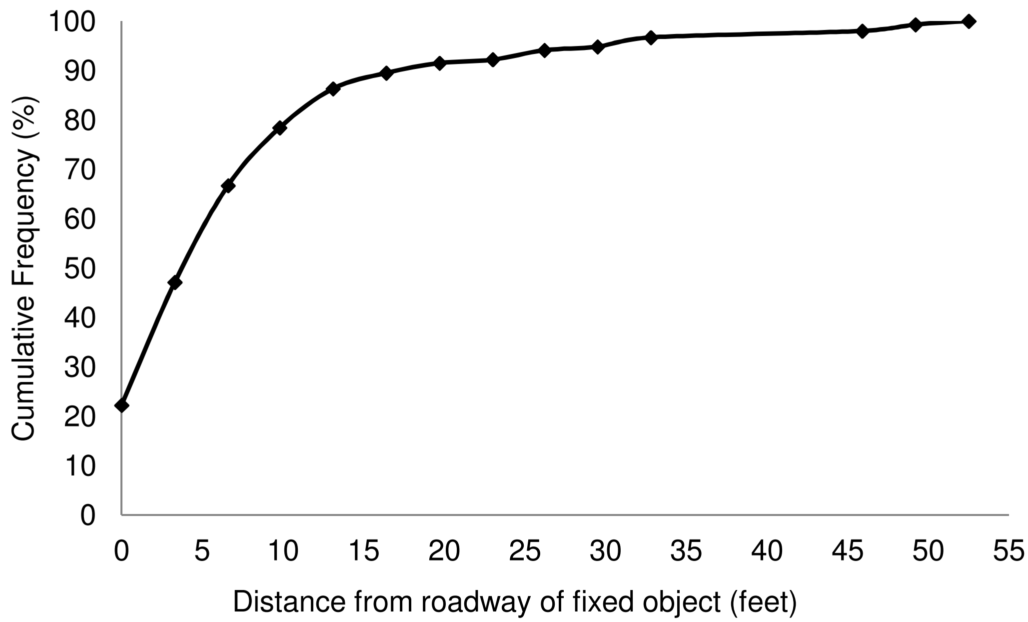


Figure 2 90% of fatal ROR accidents in Australia occurred from collisions with fixed objects less than 20 feet away from the roadway. (1)

2.3 Behavioral Studies

Several studies that have focused upon driver behavior are of relative importance to the work conducted within this thesis. This section outlines several of these studies which have focused on driver behavior.

Researchers from China, collaborating with the Texas Department of Transportation examined the relationship between roadside stimuli and driver fatigue (16). In the experiment, 12 subjects drove in a driving simulator down a two-way two-lane road. Along the road they varied the amount of “roadside stimuli.” For the majority of the drive, there would be no significant roadside elements; then every 1, 5, 10 or 40 kilometers there would be a section of roadside trees. The researchers used average heart rate as a measure of driver fatigue as prior research indicated that heart rate was a good indicator of judging driving load. The study found that drivers were least affected by dense stimuli as they became acclimated to it, the optimal spacing of stimuli to keep drivers alert was found to be between 5 and 10 kilometers. The study demonstrates that roadside elements do affect drivers physiologically and demonstrates a need for more research to determine if this physiological change affects driver performance.

Researchers in Italy used a driving simulator to test six different conditions involving guard rails and shoulders along the road (17). They had their subjects drive through one of the six different conditions and they measured their speeds and lateral position along different parts of the drive which included a left and right curve as well as a straight section. They found that when a shoulder was present drivers went significantly faster at 17 of the 42 points at which they were measuring. There was no significant change at the other measurement points. The subjects also drove nearer to the edge at 33 of 42 points when a shoulder was present. The guardrail had no significant effect on speed. An interesting finding from this study was that when no guard rail was present near trees, drivers did not change their position in the travel lane. The researchers concluded that this implied that the drivers did not perceive the nearby trees as a risk, but they also acknowledged that this may change in real life when actual physical harm is possible.

A project from the Texas Transportation Institute used a driving simulator to test the effect that roadside trees had on drivers' perception of safety as well as sense of edge; or how well they can distinguish the road from surrounding land uses (18) (19). In the experiment, 31 participants drove through four different scenarios, an urban setting with and without roadway trees and a rural setting with and without roadway trees. The participants were then asked to rate their sense of safety and sense of edge. Throughout the experiment, the vehicle speed was also captured. The researchers found that suburban streets with trees were perceived as safest and urban streets without trees were perceived as least safe. A mean speed reduction of 3.02 miles per hour was observed when trees were present along the suburban landscape. The presence of trees also helped drivers with sensing the edge of the road. The authors summarized by saying that street trees may provide positive safety benefits and "further study with a larger sample size is warranted." (18) (19)

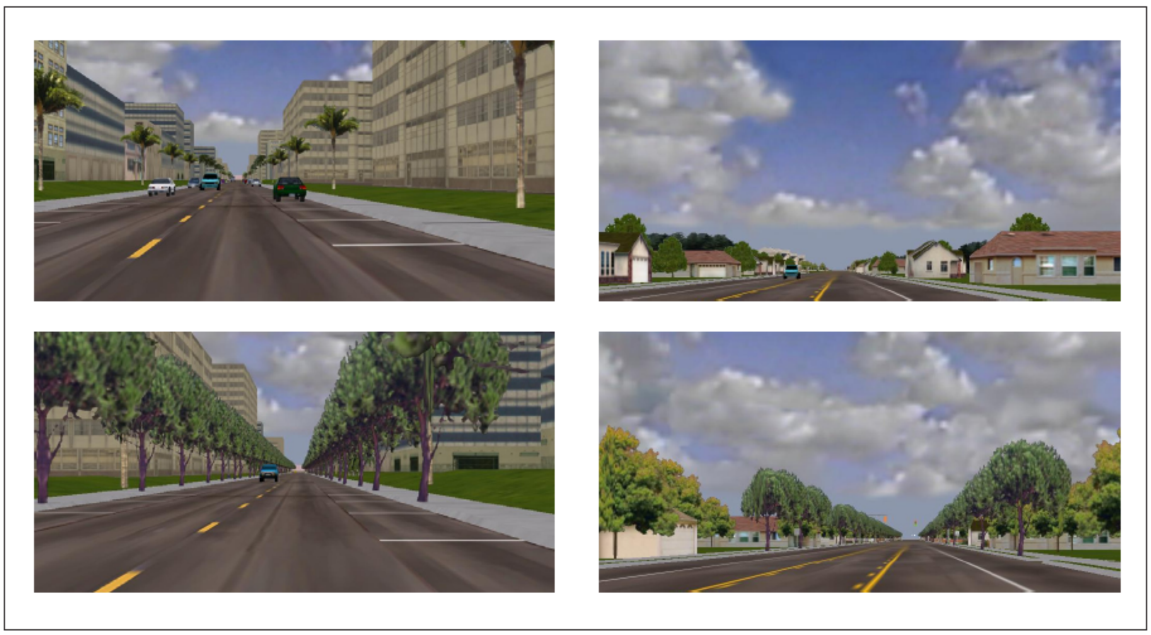


Figure 3 Four different scenarios drivers encountered in *The Street Tree Effect.* (19)

Researchers from the University of Minnesota used a driving simulator to test various changes to the roadway, such as the installation of lighting poles, lighter colored pavements and shrubs on medians and shoulders (20). They had 32 participants (16 male, 16 female) drive through 8 different combinations of their variables. The researchers collected the speeds of the drivers as well as their position in the lane. They concluded that “landscape treatments indeed had an effect on driver behavior, but the effect was markedly inconsistent.” (20)

Ewing and Dumbaugh reviewed literature regarding which factors cause crashes in general (21). Their objective was to identify when, where and why traffic collisions occurred. After their review they were able to make two interesting statements; “the traffic environments of dense urban areas appear to be safer than the lower-volume environments of the suburbs” and “less-‘forgiving’ design treatments - such as narrow lanes, traffic-calming measures, and street trees close to the roadway - appear to enhance a roadway’s safety performance.” (21) The reasoning given for this second observation is that less-forgiving designs provide drivers with a distinct idea of where the edge of the roadway is while providing them with a clear sense of what a safe travel speed is. The authors conclude their review by stating that there has been little research done on understanding why pre-crash behaviors occur based on the environment in which they occur.

Researchers from University of Massachusetts – Amherst used a driving simulator, real drivers and a static evaluation to study the difference in perceived speed versus actual speed. (22-24) The key findings were that speeds perceived by drivers in the field were similar to the speeds perceived while driving in a replicated driving simulator environment. The static evaluation, while only consisting of images and not videos, examined the extent to which pavement markings, functional classifications and barriers had on driver’s speed selection.

CHAPTER 3

METHODOLOGY

A series of research tasks were developed based upon the existing literature and the documented needs for further research. An experimental design was created to evaluate the effects of clear zone size and roadside vegetation on driver behavior and run of the road crash severity. The following section outlines the research tasks that were employed to address the objectives and evaluate the established hypotheses.

3.1 Literature Review

The initial task of the thesis research was a literature review. This task was initialized at the onset of the study and continued through the thesis process. Any research regarding roadside elements in the clear zone or the clear zone in general was studied. An added emphasis of this task was to identify research which has been conducted using a driving simulator and identify its strengths and weaknesses in order to build off of it. The results of this literature review were presented previously in Chapter 2 and are integrated into the remaining sections as appropriate.

3.2 Static Evaluation

A static evaluation was developed using Adobe Captivate 6. The purpose was to evaluate how roadside vegetation and clear zone size affect drivers' speed selection.

3.2.1 Static Evaluation Development

The static evaluation consisted of two main elements. The first involved showing participants a video of either a real or virtual drive and asking them to input the speed they would select on the given road. The participants were asked to not input how fast the surrounding traffic was travelling at, what they thought the speed limit should be or the speed at which they thought the video was captured. The second element asked participants to rate, using a Likert scale, how strongly various factors, which are displayed in Table 2, affect their speed selection.

Table 2 Factors Included within Assessment of Driver Speed Selection Process

Lane Width	Presence of Vehicles Following You	Presence of Guard Rails/Barriers	Pedestrian Activity
Posted Speed Limit	Weather	Known Presence of Police Enforcement	Internal Distractors (Radio, Cell phone, GPS, etc.)
Shoulder Width/Type	Time of Day	Density of Roadside Vegetation	Intersection Frequency
Presence of Oncoming Vehicles	Presence of Passengers	Proximity of Roadside Objects	Pavement Quality

3.2.2 Development of Simulated Environments

Four virtual environments were developed using Realtime Technologies Inc. (RTI) driving simulation platform software. The virtual environments were designed for the driver simulator located in the Arbella Insurance Human Performance Lab at University of Massachusetts Amherst. The environments consist of varying levels of roadside stimuli and clear zone size, Figure 4.

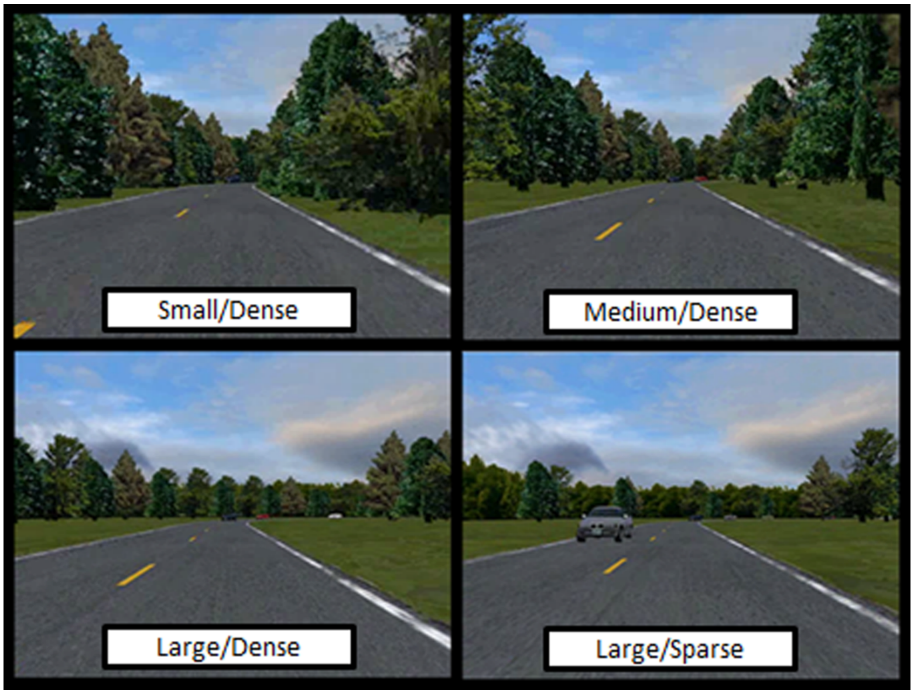


Figure 4 Driving simulator scenarios depicting different clear zone size/vegetation density combinations shown to participants during the static evaluation.

3.2.3 Field Video Capture

Field video was captured in Amherst, Pelham and Belchertown on a clear Sunday morning when the surrounding traffic was extremely sparse. A camera was mounted on a tripod and held out of a moon roof at an angle that mimicked the viewpoint of the driving simulator videos. While the speed limit of the selected roads varied, a concerted effort was made to drive at a constant speed, around 40 mph, during video capture so that the static evaluation results were not skewed. Figure 5 depicts the route taken and labels the points of video capture and Table 3 outlines the specific clear zone/roadside vegetation configuration of each location.

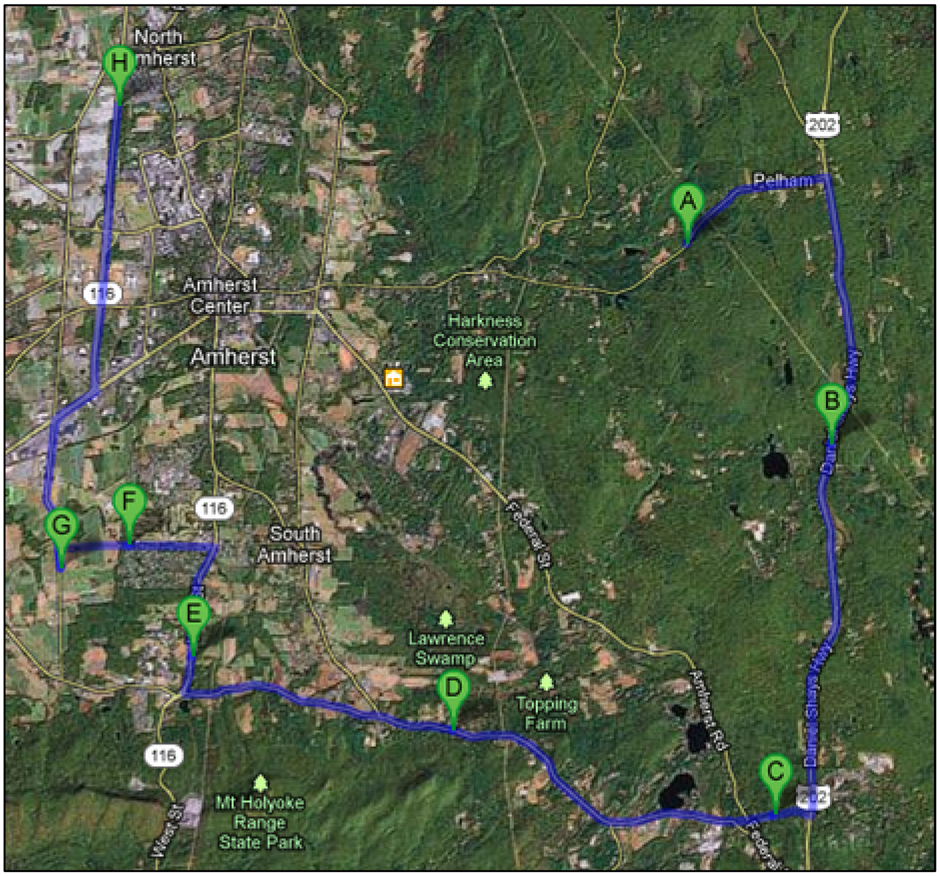


Figure 5 The route taken during field video capture and the locations of the clear zone/vegetation combinations.

Table 3 Clear Zone Size and Vegetation Densities Associated with Figure 5.

Point	Clear Zone Size	Vegetation Density
A	Medium	Dense
B	Large	Dense
C	Small	Dense
D	Medium	Dense
E	Large	Sparse
F	Small	Dense
G	Large	Sparse
H	Large	Dense

3.3 Real World Validation of Static Evaluation Results

Eight segments of roads were identified as having similar configurations to the videos used in the static evaluation and selected for field data collection. Along these roads, at least 39 vehicle speeds were captured. Vehicle positioning was observed as well using a video camera. It was hypothesized that the results of this field analysis would mimic the results found in the static evaluation.

3.3.1 Field Validation Observation Spots

Two locations for each clear zone/vegetation density combination were selected in the surrounding area resulting in observations at eight different sites. Table 4 presents the eight locations that were selected for the field validation of the driving simulator study. At two locations, multiple observations took place concurrently at different spots on the road where the roadside conditions changed.

Table 4 Locations of the Field Validation Observation Spots

Location	Clear Zone Size	Vegetation Density	Sample Size	Speed Limit (mph)	Lane Width (ft)
Amherst Rd - Pelham	Small	Dense	51	40	10
Pomeroy Ln – Amherst	Small	Dense	40	35	12
Feeding Hills Rd – Westfield	Medium	Dense	82	40	11
Bay Road – Amherst	Medium	Dense	39	40	12
Route 202 SB - Belchertown	Large	Dense	47	50	12
Route 9 SB – Amherst	Large	Dense	53	50	12
West St – Amherst	Large	Sparse	57	40	12
Route 9 SB – Amherst	Large	Sparse	53	50	12

3.3.2 Standard Data Collection Method

At each location, a tripod was set up to collect video of the oncoming direction of traffic for the purpose of obtaining lateral positioning. A LiDAR speed gun, graciously on loan from the Massachusetts State Police, was used to collect vehicle speeds. When possible, video and speeds were captured from the inside of a vehicle for the purpose of being inconspicuous to the drivers. In other locations, such placement of a vehicle was not possible, Figure 6. While at each location, the posted speed limit and lane widths were noted for data analysis.

Figure 6 A setup where video could not be obtained from the inside of a vehicle.

3.3.3 Linked Site Data Collection

At two locations, two observers were utilized to capture data at two different points along the road, each with a different clear zone/vegetation density. The purpose of a linked observation was to eliminate variables such as speed limit, lane width, shoulder type and driver demographics.

3.3.4 Data Analysis Technique

Vehicle speeds were spoken into the camera so they could be transcribed later. Lateral positions were obtained by using a transparency and VLC media player to gauge where a vehicle was positioned on the road. Figure 7 displays how lateral positions were obtained from the collected video data.

Figure 7 Computerized portrayal of the lateral positioning analysis.

3.4 Crash Data Analysis

In accordance with objective four, the UMass Safety Data Warehouse was utilized to investigate the patterns and trends associated with run-off-the-road crashes, Figure 8. The Data Warehouse in combination with the MassDOT roadway inventory provided information on the details of all crashes that occurred within the Commonwealth of Massachusetts between 2007 and 2010.

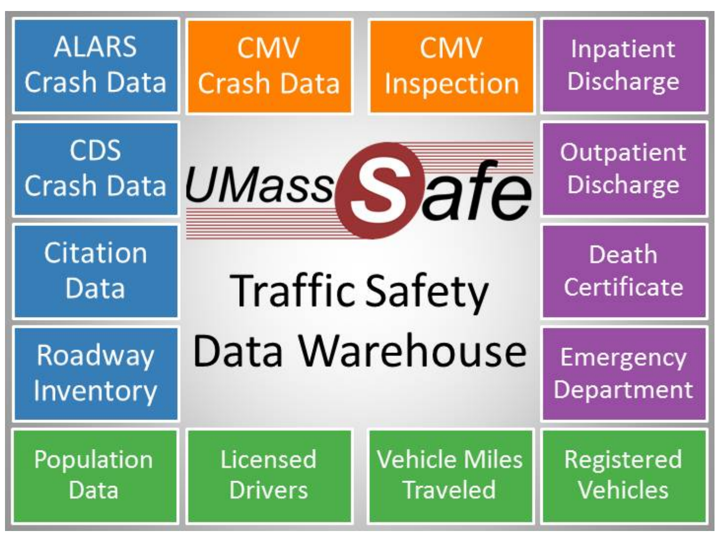


Figure 8 UMass Safety Data Warehouse.

3.4.1 Filtering of Run-off-the-road Crashes from All Crashes

To analyze the severity and trends associated with run-off-the-road crashes, a methodology for defining these crashes had to first be developed. Figure 9 displays a flow chart of how a run-off-the-road crash was defined from the crash data.

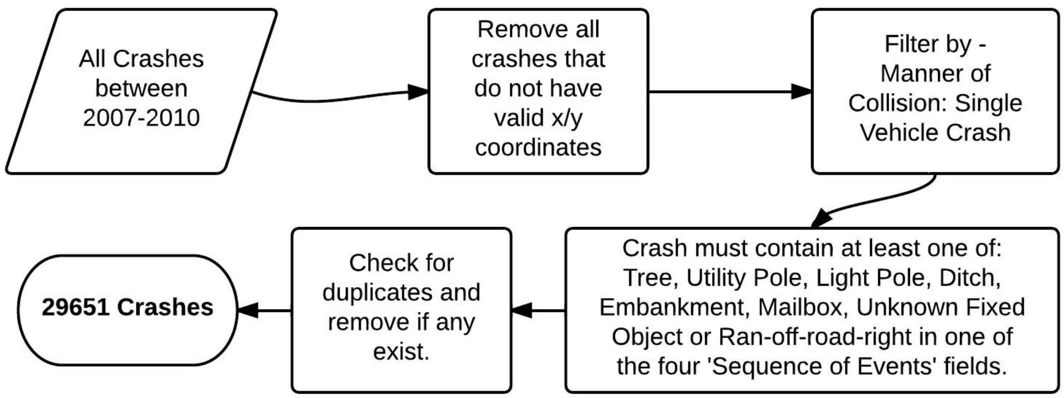


Figure 9 Flow chart of methodology to isolate run-off-the-road crashes.

Crashes without valid x and y coordinates were removed for the purpose of ensuring data quality and that all crashes could be geolocated. A total of 29,651 crashes from the years 2007 to 2010 were obtained, ensuring an adequate sample size for multi-variable comparisons.

3.4.2 Software used for Analysis and Plotting of Crash Data

Microsoft Access was utilized to link each individual crash with the MassDOT roadway inventory using the unique identifier for the roadway ID. Then the pivot table feature in Microsoft Excel was used to investigate the data. Next, Minitab 16 was used to perform the statistical testing. Finally, graphs were generated using OriginPro 8.6.

CHAPTER 4

FINDINGS AND RESULTS

The objectives and hypotheses are presented in Table 5 and are addressed in the following chapter. Vehicle speed and lateral positioning were the primary metrics used to evaluated drivers' response within the static evaluation and in the field. This chapter presents the crash data analysis and the results from both phases of the experiment.

Table 5 Objectives and Hypotheses

	Objective	Hypotheses
1	Understand the effect that roadside vegetation density has on vehicle speeds	(A) The density of trees along the roadside will have a measurable effect on operating speeds (B) Speeds observed in the real world will be similar to the speeds surveyed during the static evaluation.
2	Understand how the size of the clear zone affects driver behavior.	(A) A smaller clear zone may cause drivers to position their vehicle further from the edge of the road (B) A smaller clear zone may cause drivers to accept lower operating speeds in fear of running off the road.
3	Determine the effect that various roadway environment elements have on driver's speed selection.	(A) Participants will not rate vegetation density as influential to their speed selection
4	Utilize crash data to investigate run-off-the-road crashes.	(A) A direct correlation will exist between the severity of run-off-the-road crashes and the type of roadside elements involved during the crash.

The first section of this chapter provides the results of the static validation and the following sections describe the results of the field data validation and the crash data analysis, respectively. The main focus of the analysis was to evaluate driver behavior in the four different clear zone/vegetation density combinations selected.

4.1 Static Evaluation

100 participants participated in an online static evaluation of their speed selection based on roadway characteristics. While demographic data was not collected, the sample did consist of males and females, of varying ages and geographic locations in the United States. Participants were asked to choose the speed they would drive after watching either 1 of 9 real world videos, or 1 of 4 driving simulator videos. After the videos, they were asked how strongly 16 roadway environment factors affect their speed choice.

4.1.1 Factors Influencing Speed

Participants were asked to rate 16 aspects of the driving environment on the magnitude that each one affects their speed choice while driving. The participants were given five options: *Very Little, Little, Neutral, Strongly and Very Strongly*. For analysis purposes, the response options were given a numerical value of 1 to 5 (lowest to highest). Table 6 presents an ordered list of the results with factors listed from most influential to least influential.

Table 6 Ranking of Static Evaluation Factors Influencing Speed

Factor Influencing Speed	Average Rating
Known Presence of Police Enforcement	4.28
Pedestrian Activity	4.25
Weather	4.25
Pavement Quality	3.91
Intersection Frequency	3.91
Proximity of Roadside Objects	3.83
Lane Width	3.78
Posted Speed Limit	3.76
Shoulder Width/Type	3.68
Time of Day	3.51
Presence of Oncoming Vehicles	3.45
Presence of Guard Rails/Barriers	3.27

Presence of Vehicles Following You	3.27
Presence of Passengers	3.22
Density of Roadside Vegetation	3.16
Internal Distractors (Cell Phone, Radio, etc.)	2.98

Known police enforcement was narrowly rated as the most influential factor influencing speed followed by pedestrian activity and weather. Participants selected internal distractors, such as cell phones and radios, as the least influential on their speed selection.

The standard deviation of each factor as calculated to investigate the extent to which variability existed within the responses. Table 7 displays an ordered list of the 16 factors from most variability to least. Density of roadside vegetation, one of the primary foci of this thesis research, displayed the most variability while rating very low as an influencing factor on speed choice. This supported the prediction of Hypothesis 3A that drivers would not consciously think that roadside vegetation affects their operating speed. Weather and pedestrian activity had the least variability and both were near the top of the list of most influential. Proximity of roadside objects, the other primary foci, had a low variability and scored in the upper middle of the pack with a score correlating with “Strongly”.

Table 7 Standard Deviations from the Static Evaluation Ranked from Most Variability to Least

Factor Influencing Speed	Standard Deviation
Density of Roadside Vegetation	1.13
Presence of Passengers	1.06
Internal Distractors	1.01
Time of Day	1.00
Presence of Oncoming Vehicles	1.00
Presence of Vehicles Following You	0.94
Posted Speed Limit	0.93
Known Presence of Police Enforcement	0.93

Presence of Guard Rails/Barriers	0.93
Shoulder Width/Type	0.91
Pavement Quality	0.83
Proximity of Roadside Objects	0.82
Lane Width	0.77
Intersection Frequency	0.73
Pedestrian Activity	0.69
Weather	0.64

The influence of *Density of Roadside Vegetation* on speed choice was compared to the influence of the other 15 choices, Table 8. Despite being ranked as the second least influential of the 16 factors, roadside vegetation density was still ranked as more influential than each other factor by at least 6 percent of respondents. 51 percent of respondents indicated that the proximity of roadside objects was more influential to their speed choice while 41 percent said that they had equal effects.

Table 8 Comparison of Responses for *Density of Roadside Vegetation* versus Other Speed Influencing Factors

	Density of Roadside Vegetation		
Factor Influencing Speed	>	=	≥
Internal Distractors	39	30	**69**
Presence of Guard Rails/Barriers	34	33	**67**
Presence of Passengers	33	32	**65**
Presence of Vehicles Following You	28	35	**63**
Shoulder Width/Type	19	38	**57**
Time of Day	24	31	**55**
Presence of Oncoming Vehicles	29	24	**53**
Lane Width	17	34	**51**
Proximity of Roadside Objects	8	41	**49**
Posted Speed Limit	21	25	**46**
Pavement Quality	13	31	**44**
Intersection Frequency	13	30	**43**
Known Presence of Police Enforcement	8	22	**30**
Pedestrian Activity	6	23	**29**
Weather	7	21	**28**

4.1.2 Speed Decisions

1300 speed choices were collected in response to nine real world videos and four driving simulator videos. The maximum speed selected was 90 mph, which was omitted from the data analysis because it was an extreme outlier. When omitting that value, the next highest speed was 75 mph. The lowest speed selected was 20 mph and 45 mph was the most commonly selected speed. Lastly, the median speed that participants chose was also 45 mph.

4.1.2.1 Speed Decisions from Simulator Videos

Four different driving simulator videos were shown to participants throughout the static evaluation. Drives with dense vegetation and small, medium and large clear zones were presented along with a drive with sparse vegetation and a large clear zone. Figure 10 presents the average speeds that participants selected after watching the four videos of the simulated drive. While the drives with large clear zones presented higher averages than the medium and small clear zones, these differences were not statistically significant.

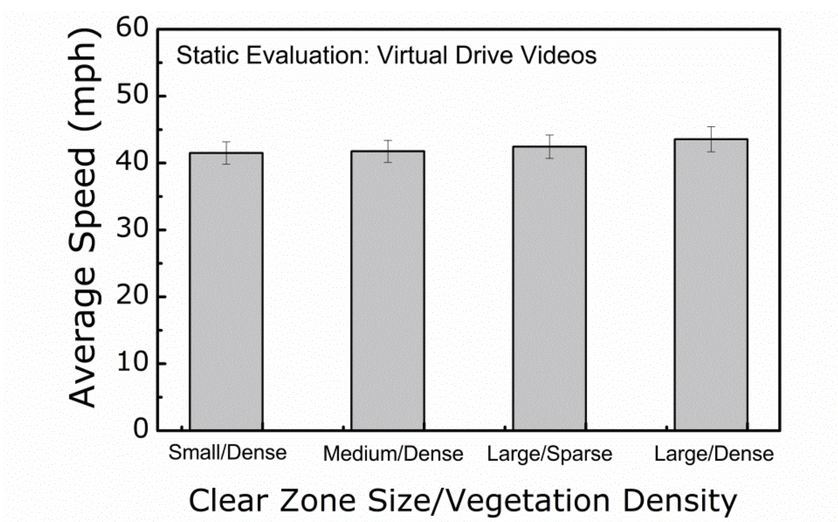


Figure 10 Average speed selected after watching the four driving simulator drives.

4.1.2.2 Speed Decisions from Real World Videos

Nine different videos captured from real roads were presented to participants. Participants responded with an average speed of 41.9 mph for roads with small clear zones and dense vegetation, Figure 11. The videos of a medium clear zone and dense vegetation elicited an average speed of 44.4 mph from participants. Within the large clear zone videos, the dense and sparse vegetation elicited responses of 52.9 mph and 48.7 mph, respectively. The difference in average speed was statistically significant between each combination. The results from the static evaluation supported Hypothesis 2B as participants did, in fact, select a lower speed than for the small and medium clear zones. Hypothesis 1A was not supported as participants were not affected by roadside vegetation as higher speeds were selected on roadways with dense vegetation than roadways with sparse vegetation.

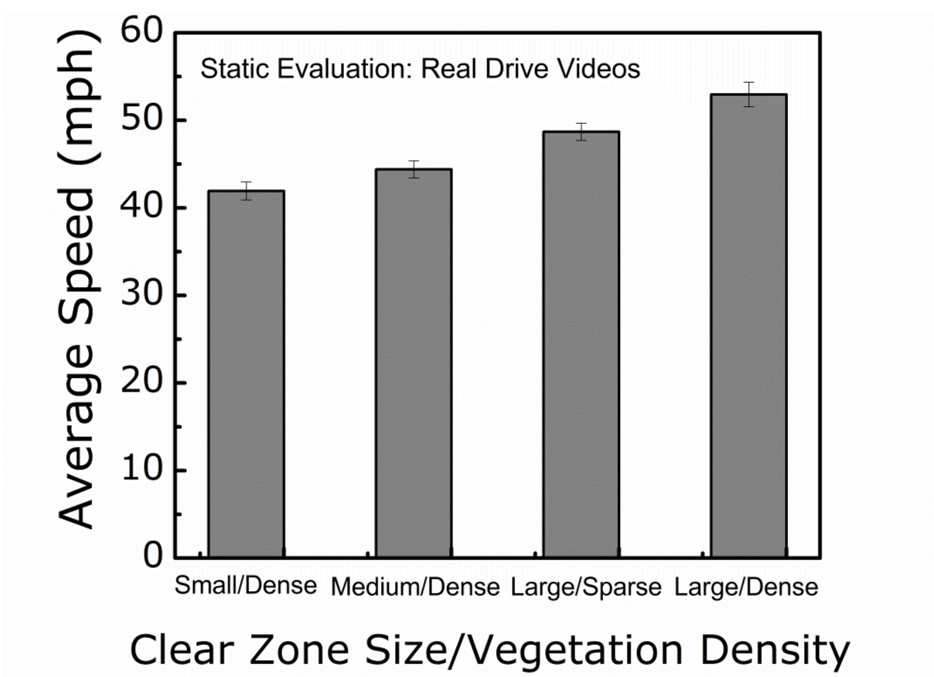


Figure 11 Average speed selected after watching the nine videos of real drives.

4.1.2.3 The Effect of Utility Poles within Close Proximity of the Roadway

One location used within the evaluation presented an interesting opportunity to investigate the effect that utility poles within close proximity of roadway has on speed selection. Figure 12 depicts the scenario that participants were presented with during the static evaluation.

Figure 12 Static evaluation scenario with directional utility pole presence.

In one direction there is an open field with absolutely nothing posing a hazard to vehicles running off the road. In the other direction, utility poles are approximately four feet from the edge of the road spaced approximately 150 feet apart. When presented with the video of the road with no utility poles, participants responded with an average speed of 50.0 mph. When utility poles were in close proximity of the roadway, participants selected a speed two miles per hour lower, a statistically significant difference (paired t-test, p=0.003). The individual responses of the 100 responses were examined for the utility pole scenario, Table 9. 36 percent of respondents indicated that they would select a lower speed on the road with the utility poles. 49 percent selected the same speed for both scenarios and only 15 percent of respondents selected a higher speed when utility poles were present.

Table 9 Within Subjects Speed Comparison Measuring the Effect of Utility Poles on Speed Choice

Response Type	Percentage of Respondents	Average Speed on Road w/o Poles (mph)	Average Speed on Road w/ Poles (mph)	Difference (mph)
Higher Speed with no Utility Poles	36	54.6	45.6	9
Equal Speed	49	48.9	48.9	0
Lower Speed with no Utility Poles	15	43.0	50.9	-7.9

4.2 Validation of Static Evaluation Findings

Eight locations were selected for analysis based on their clear zone size and adjacent vegetation density. Due to the differences in lane widths and posted speed limits, the lateral positions and speeds were normalized to compare different locations. 12 foot lanes and 40 mph speed limits were used as the baseline as they were the most commonly found at the observation sites. The equations below detail the normalization process:

$$Observed\ Lateral\ Position * \frac{12}{Lane\ Width} = Normalized\ Lane\ Width$$

$$Observed\ Speed * \frac{40}{Posted\ Speed\ Limit} = Normalized\ Speed$$

The percent of drivers violating the speed limit was an additional measure that was used to compare speeds across different locations.

4.2.1 Speed Results

To negate the effect that higher speed limits had on vehicle speeds, the results were normalized as previously described. Figure 13 displays the averaged normalized speeds across the four combinations of clear zone and vegetation density. Small clear zone/dense vegetation roads had similar normalized speeds to roads with a large/sparse configuration. Medium/dense and large/dense road configurations both had significantly lower normalized average speeds. The percent of drivers violating the speed limit was also examined as another measure to evaluate the speeding tendencies of the road. The percentage of observed drivers violating the speed limit was strongly correlated with the average speed observed. The findings of the field data collection did not support Hypothesis 1A or 2B as normalized speeds were extremely similar for the four clear zone/vegetation density combinations.

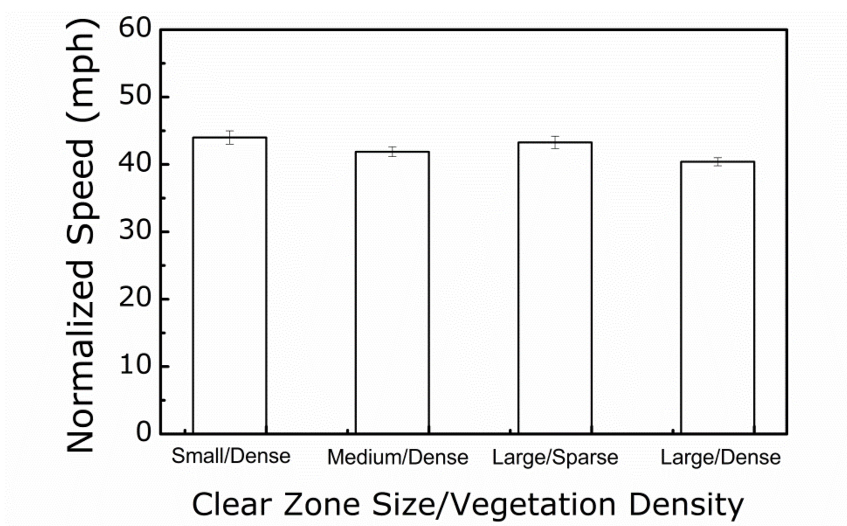


Figure 13 Average normalized speeds from the field study

4.2.2 Lateral Positioning

Lateral positioning of vehicles was captured using video data and is presented in Figure 14. With the exception of small clear zones, drivers positioned their vehicle closer to the edge of the road as the proximity of roadside objects decreased which supports Hypothesis 2A.

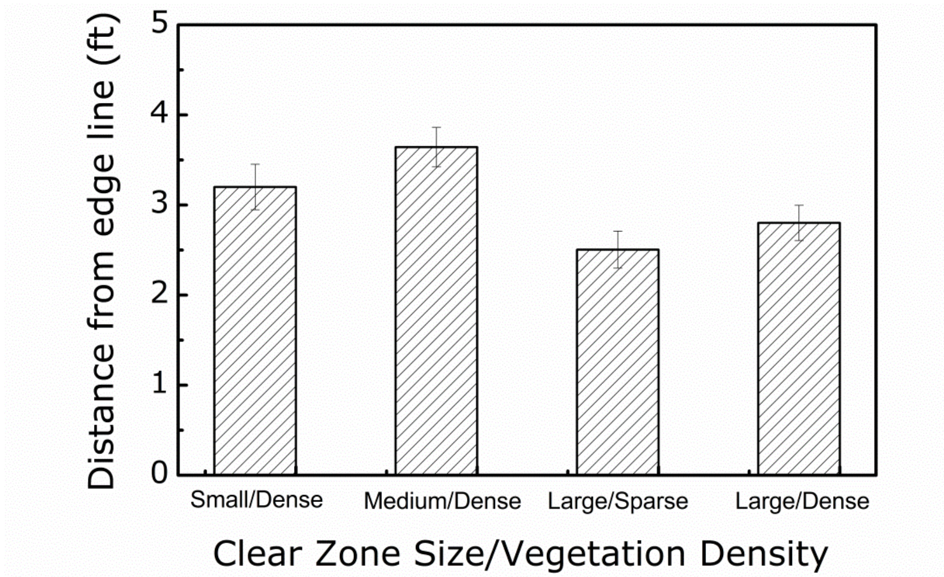


Figure 14 Average normalized lateral positions measured by the distance in feet from the edge line.

4.2.3 Similar Location as Static Evaluation

Four locations which were featured in the static evaluation were studied in the field as well. Each of the four clear zone/vegetation density combinations were represented during the field validation, Figure 15. Two of the locations – Bay Road and West St – exhibited speeds statistically similar to what participants indicated during the static evaluation. Pomeroy Lane, a road with a small clear zone and dense vegetation, had lower speeds than in the static evaluation. Route 202, a densely vegetated road with a large clear zone, had higher speeds in the field than respondents indicated during the static evaluation. Hypothesis 1B, which states that "speeds observed in the real world will be similar to the speeds surveyed during the static evaluation," was supported as two of the locations exhibited statistically similar speeds and the other two locations had average speeds in the same range as were selected during the static evaluation.

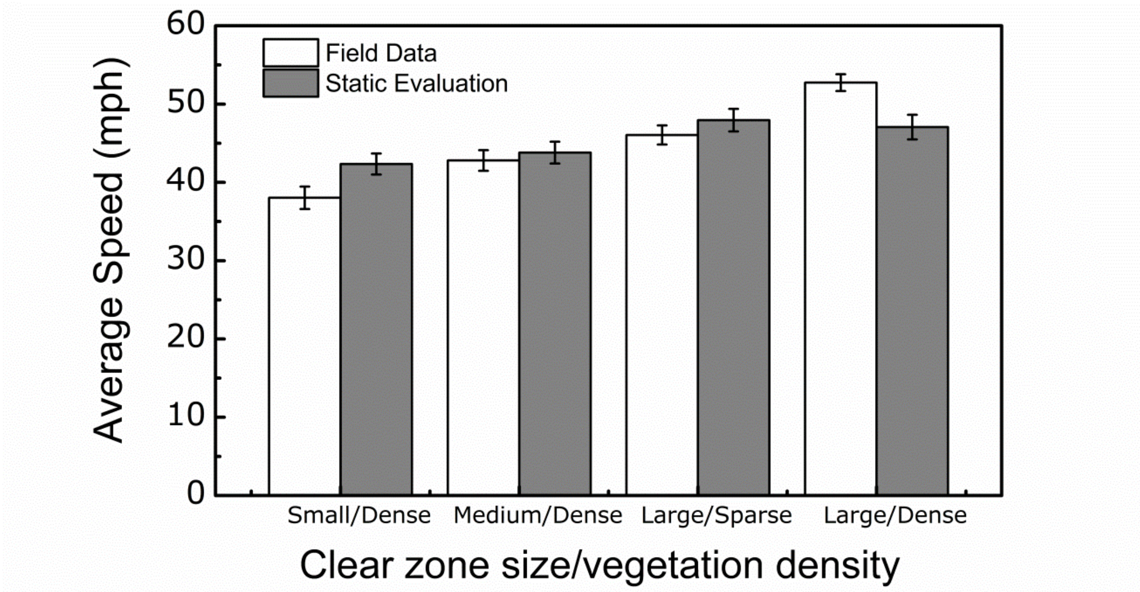


Figure 15 Average speeds of the four locations studied in both the static evaluation and field validation.

4.2.4 Linked Locations

Two locations were observed as a pair for the purpose of removing all external variables such as differences in speed limits, shoulder types, lane widths and driver demographics. In the case of one scenario the road transitioned from a medium clear zone to a large clear zone, all the while having dense vegetation density, Figure 16. While in the medium clear zone, drivers positioned their vehicle 4.4 feet from the edge of the road and while in the large clear zone drivers were a half foot closer to the edge of the road. Drivers reduced their speed by 2.7 miles per hour when transitioning from the medium to large clear zone. Both differences were statistically significant.

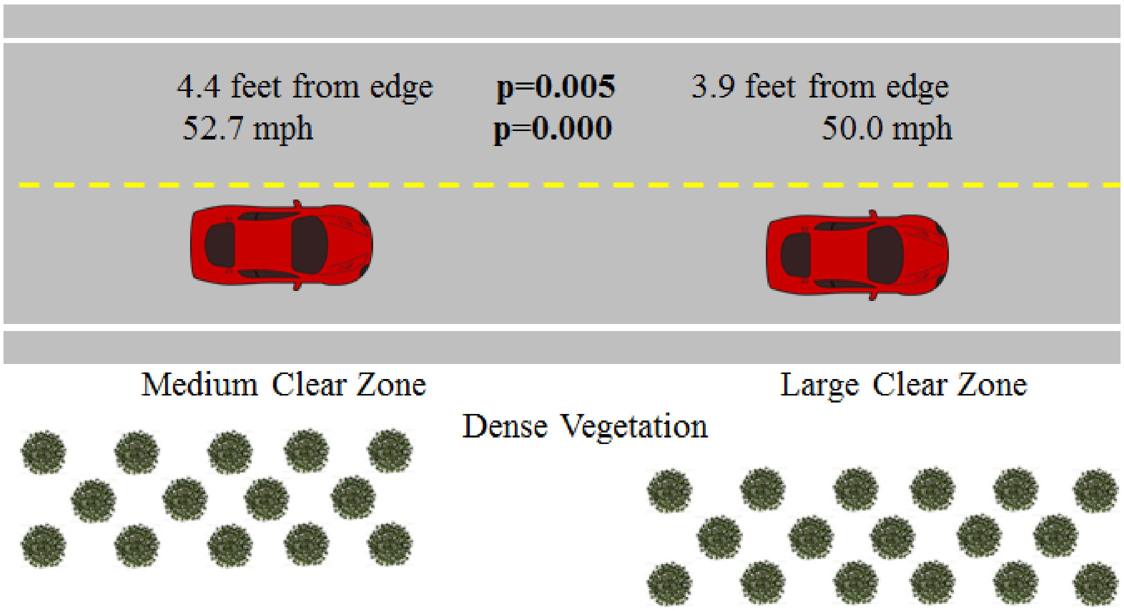


Figure 16 Linked location on Route 202 Southbound in Belchertown, MA

Route 9 in Amherst, MA was another location which was studied as a linked observation. The road transitioned from sparse vegetation to dense vegetation all the while having a large clear zone, Figure 17. When vegetation was present, drivers positioned their vehicle statistically significantly further from the edge of the road. The difference in speed between the two vegetation densities was not statistically significant.

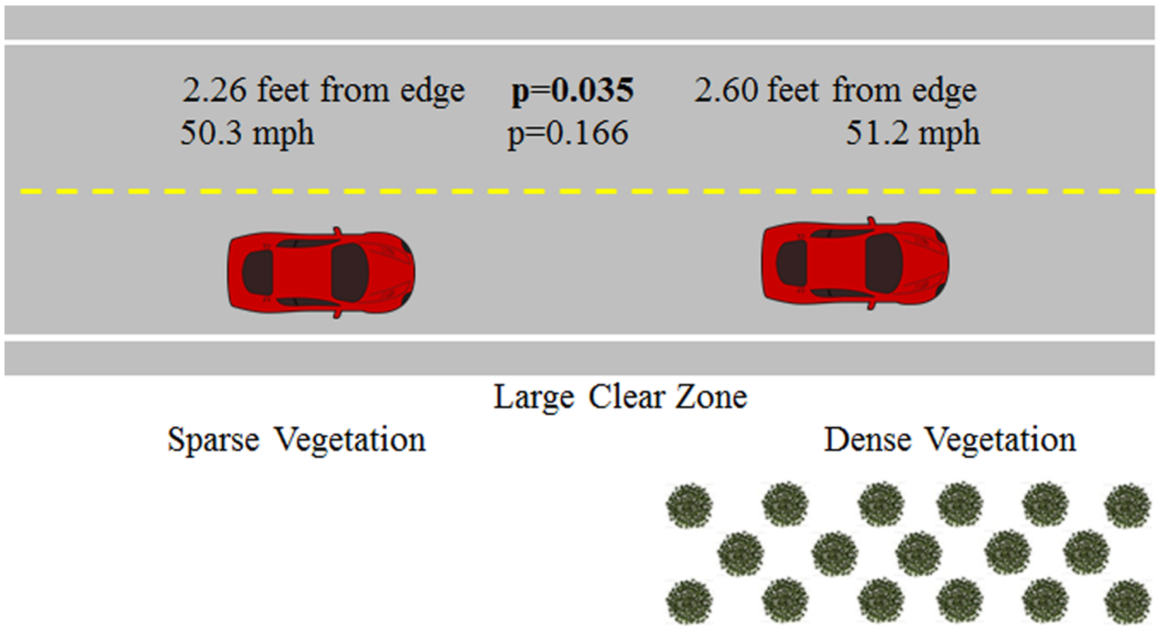


Figure 17 Linked location on Route 9 in Amherst, MA

4.3 Crash Data Analysis

The UMass Safety Data Warehouse was utilized to investigate the patterns and trends associated with run-off-the-road crashes. The crashes were grouped into three categories for the purpose of analysis. Fatal Injury and Non-fatal injury - Incapacitating crashes were grouped as "Serious". Non-fatal injury – Non-Incapacitating and Non-fatal injury – Possible were grouped as "Minor". No Injury crashes were labeled as "Property Damage Only". Crashes with injury statuses of: "Not Applicable", "Not Reported", "Reported by Invalid", and "Unknown" were not included in the analyses as no conclusion could be drawn regarding the crash severity.

4.3.1 Gender and Time of day

The differences between crash injury rates for males and females during both night and day were quantified and are shown in Figure 18. Run-off-the-crashes, which occurred during the night, had a higher chance of serious than those that occurred during the day, though the difference is narrowly insignificant (p=0.06). Male drivers were found to have a higher rate of Property Damage Only crashes than female drivers for both day and night driving.

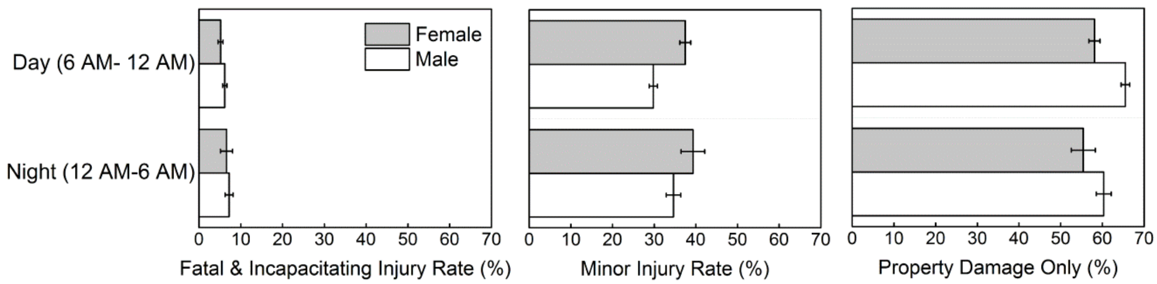


Figure 18 ROR injury rates as a function of both gender and time of day.

A chi-squared test was used to example the statistical significance for the data corresponding to Figure 18**.** There were no statistical differences when comparing injury severities of crashes involving females, Table 10**.** The difference in serious injury crashes for night versus day for both males and females was narrowly statistically insignificant (p=0.06).

Table 10 P-Values from Chi-squared Test Associated with Data Displayed in Figure 18

	Serious	**Minor**	**No Injury**
Female: Night vs. Day	0.06	0.31	0.06
Male: Night vs. Day	0.06	0.00	0.00
Day: Male vs. Female	0.02	0.00	0.00
Night: Male vs. Female	0.52	0.00	0.01

*Statistical significance indicated by a P-value ≤ 0.05 and a shaded box.

Men experience a higher serious injury rate than females during the day (p=0.02). Men likely experience a serious injury rate due to their riskier driving behavior and excessive speeding. Crashes at night probably result in more fatalities because drivers do not have the sight distance to avoid hazards in comparison to driving during the day. Also, alcohol is more likely to play a factor in the occurrence of these nighttime crashes.

4.3.2 Driver Age

The severity of run-off-the-road crashes was also investigated with respect to the age of the driver, Figure 19. It was found that crashes involving older drivers (60+ years of age) were more likely to result in a serious injury than crashes with younger (<22 years of age) or middle age (23-59 years of age) drivers. Older drivers were also more likely to sustain minor injuries than young and middle age drivers.

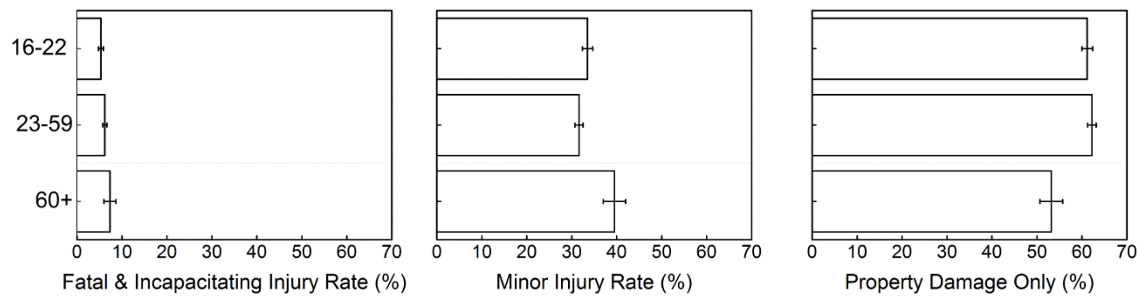


Figure 19 ROR injury rates versus driver age.

Table 11 P-Values from Chi-squared Test Associated with Data Displayed in Figure 19.

	Serious	**Minor**	**No Injury**
Young vs. Old	0.00	0.00	0.00
Young vs. Middle	0.02	0.01	0.18
Middle vs. Old	0.09	0.00	0.00

*Statistical significance indicated by a P-value ≤ 0.05 and a shaded box.

While it can be concluded that the severity of these crashes is higher when it involves an older driver, no conclusions can be drawn regarding the frequency of these crashes as there is no reliable data source which can describe the vehicle miles travelled (VMT) for each age group. A similar trend is seen when comparing the fatality rate with both gender and age of the driver, Figure 20. Middle aged male drivers had statistically higher serious crash rates when compared to females from the same age group. Young males and females both were statistically less likely to sustain serious injuries from a ROR crash than older drivers. All statistical comparisons can be seen in Table 12.

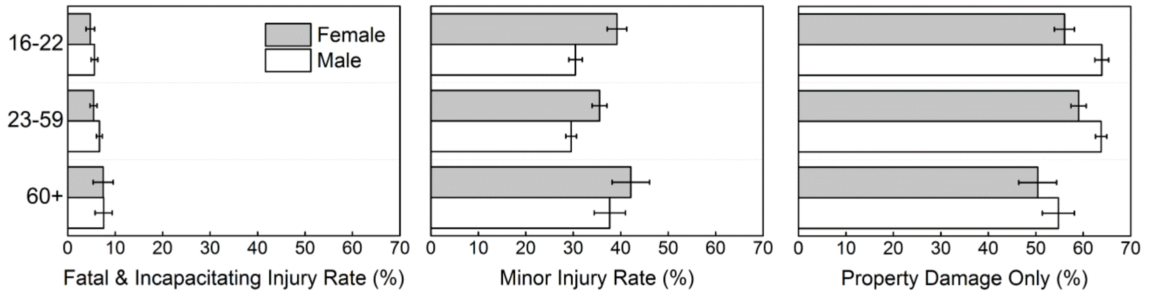


Figure 20 Crash injury rates as a function of both driver age and gender.

Table 12 P-Values from Chi-squared Test Associated with Data Displayed in Figure 20.

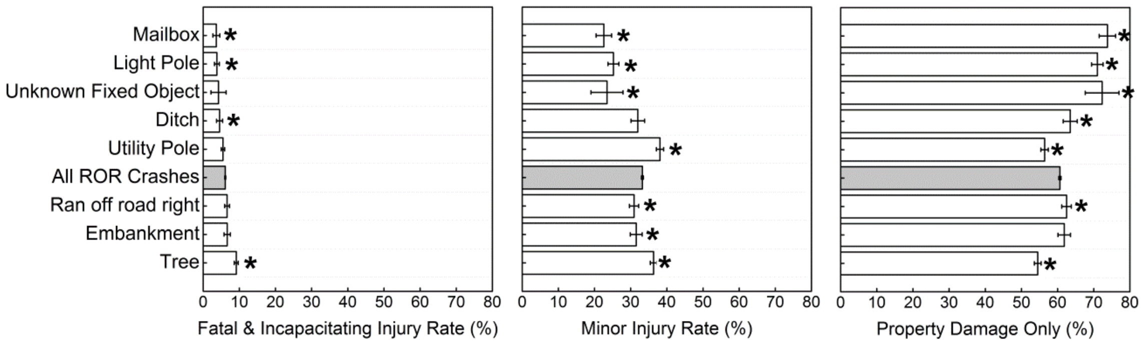
	Serious	**Minor**	**PDO**
Female: Young vs. Old	0.01	0.20	0.01
Female: Young vs. Middle	0.26	0.01	0.03
Female: Middle vs. Old	0.05	0.00	0.00
Male: Young vs. Old	0.03	0.00	0.00
Male: Young vs. Middle	0.03	0.32	0.89
Male: Middle vs. Old	0.34	0.00	0.00
Young: Male vs. Female	0.14	0.00	0.00
Middle: Male vs. Female	0.02	0.00	0.00
Old: Male vs. Female	0.94	0.09	0.11

*Statistical significance indicated by a P-value ≤ 0.05 and a shaded box.

4.3.3 Most Harmful Roadside Objects

For the purpose of influencing roadside design, it is important to investigate the level of harm each level of harm each roadside object presents. To determine the harmfulness of each roadside object, the crash roadside object, the crash injury rates for eight ROR indicators were determined by their presence within one of presence within one of the four possible "sequences of events," [a]A statistically significant difference (*) when compared to all run of the road crashes (grey) was achieved for P<0.05.

Figure 21. These fatality rates were then compared with the fatal accident rate for all ROR crashes. When a collision with a tree occurs, the chance of a serious injury is statistically higher (p = 0.00) supporting Hypothesis 4A. It was also found that collisions with light poles, ditches and mailboxes have a statistically lower chance of a serious injury when compared with the serious injury rate of all ROR crashes.



[a]A statistically significant difference (*) when compared to all run of the road crashes (grey) was achieved for P<0.05.

Figure 21 Crash injury rates for various run off the road crash indicators present in one of the four possible sequences of events within a crash report.

4.3.4 Guardrails

Collisions with guard rails, a common barrier placed alongside roadways to prevent ROR crashes, were examined to evaluate their effectiveness. ROR guard rail crashes (Figure 22) demonstrated a higher serious injury rate in comparison with ROR crashes not involving a guard rail. However, this comparison is not significant (p=0.14).

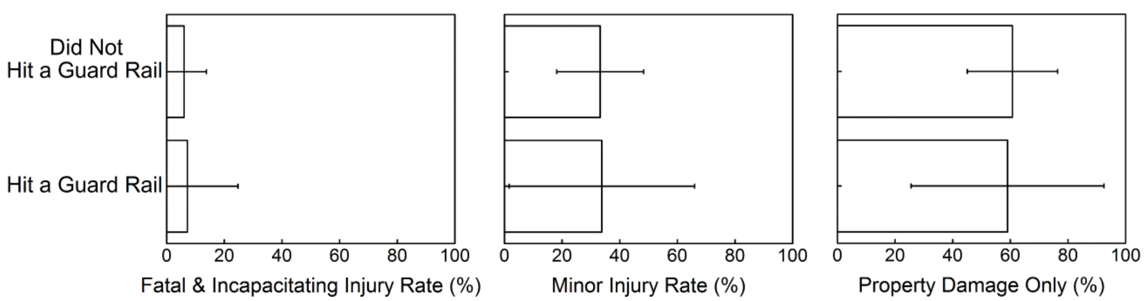


Figure 22 The effect of hitting a guard rail on ROR crash severity.

4.3.5 Speed Limit and Shoulder Width

The severity of ROR crashes was analyzed as a function of the posted speed limit as speeding is one of the factors that increase the severity of ROR crashes, Figure 23. For posted speed limits ranging from 20 to 65 mph, an upward trend was observed reaching serious injury rates of approximately 9 percent. A similar was trend was seen for minor injuries, as the speed limit increased, so did the chance of a minor injury. The chance of a PDO crash occurring decreased as the speed limit increased.

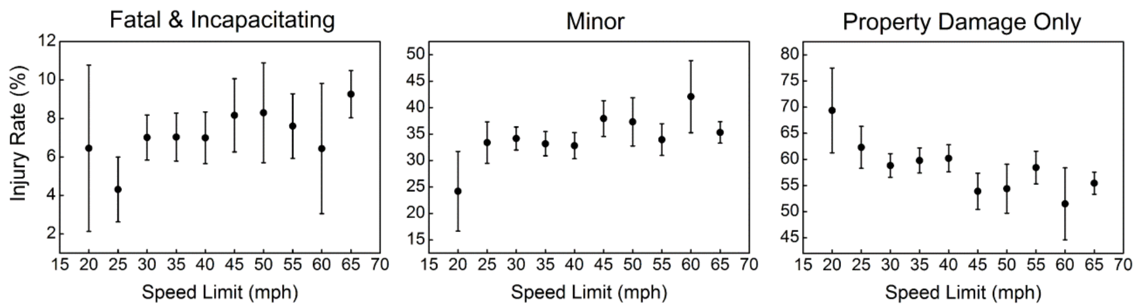


Figure 23 Posted speed limit versus crash injury rate.

The width of the right shoulder for three speed groups was compared to the crash severity to determine if the extra room allowed drivers to regain control and lower the severity of the crash, Figure 24. However, very few statistical differences were observed. A large right shoulder (10+ feet) results in a higher serious injury rate than a 0-4 foot shoulder for roads with a speed limit of 40-50 mph.

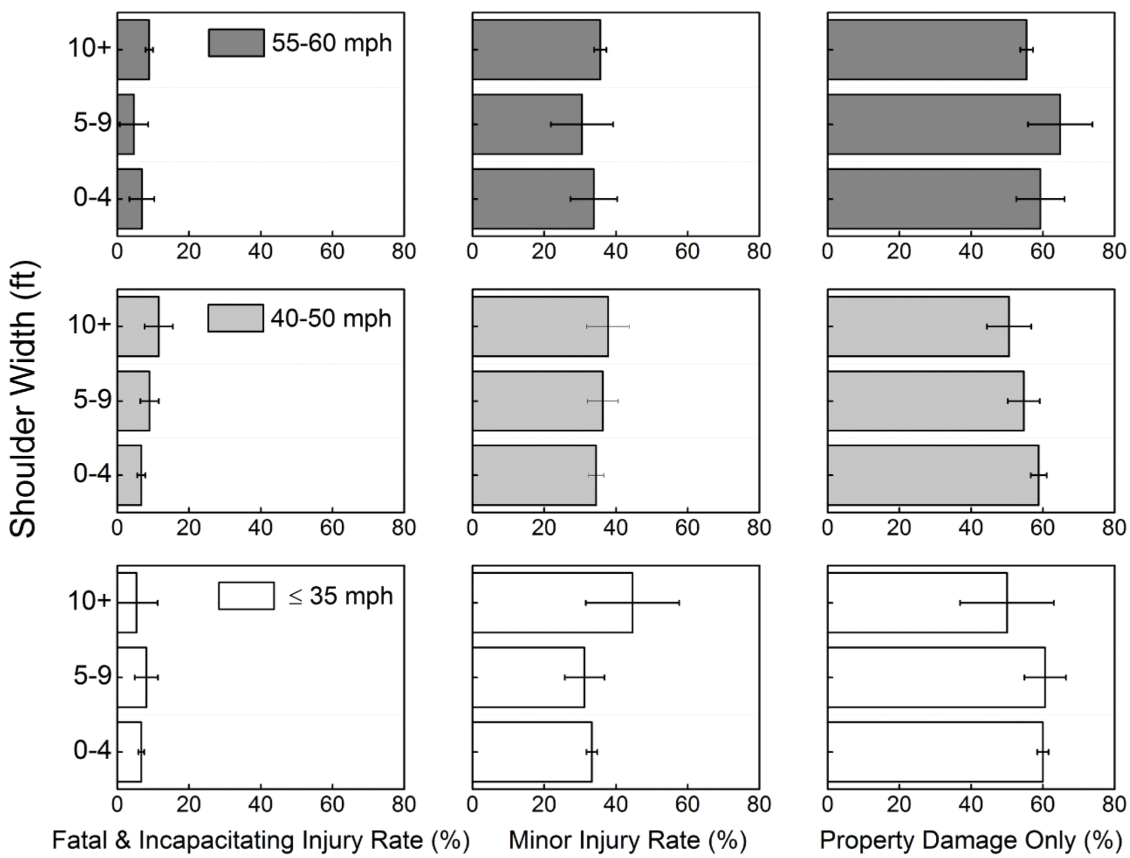


Figure 24 Crash injury rates as a function of the size of the right shoulder and posted speed limit.

4.3.6 County

The serious and minor injury rates were also compared at the county level versus the state average to see if different regions experienced different patterns regarding run-off-the-road crashes. 9 of the 14 counties experience serious injury rates that are not statistically different from the overall serious injury rate. However, five counties have statistically significant differences. Middlesex County, home of approximately 25 percent of Massachusetts' population and the 23rd most populated county in the nation, has a ROR serious injury rate of only 6.1 percent. Suffolk County however, the county which houses Boston, has a ROR fatal accident rate of 8.6 percent. The other three differences are displayed in Figure 25.

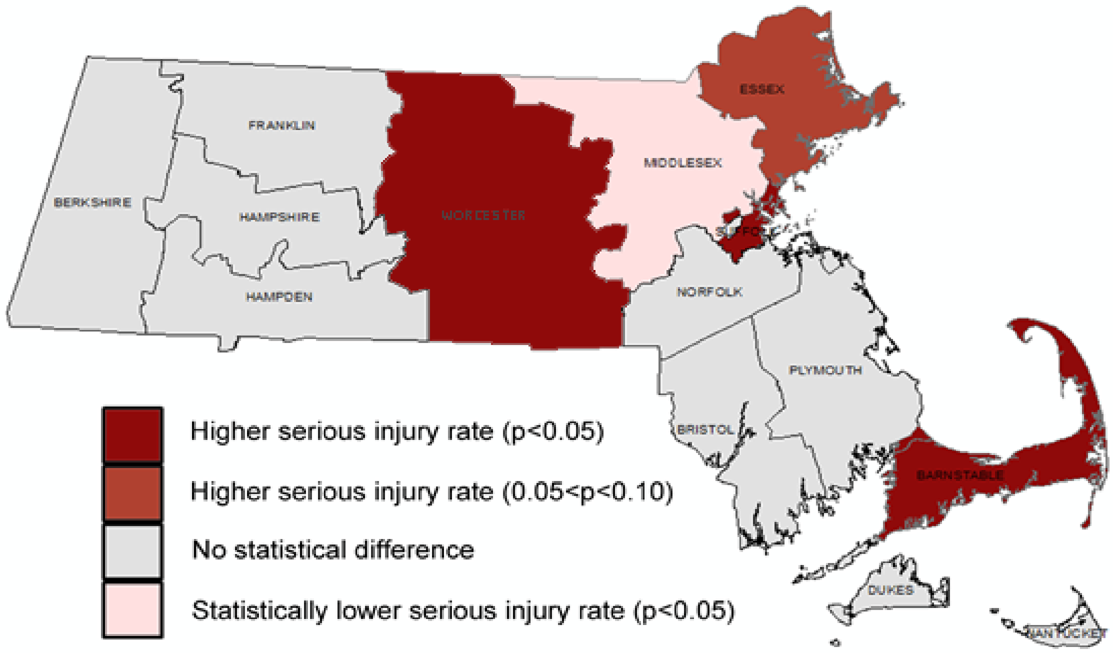


Figure 25 County map of run off the road serious injury rates as compared to the statewide average.

Minor injury rates were also compared for the 14 Massachusetts counties, Figure 26. Again, Middlesex County experienced injury rates lower than the state injury rate. For minor injuries, Suffolk County does not show any significant difference from the state rate. Worcester, Plymouth, Bristol and Barnstable counties all have minor injury rates higher than the state average.

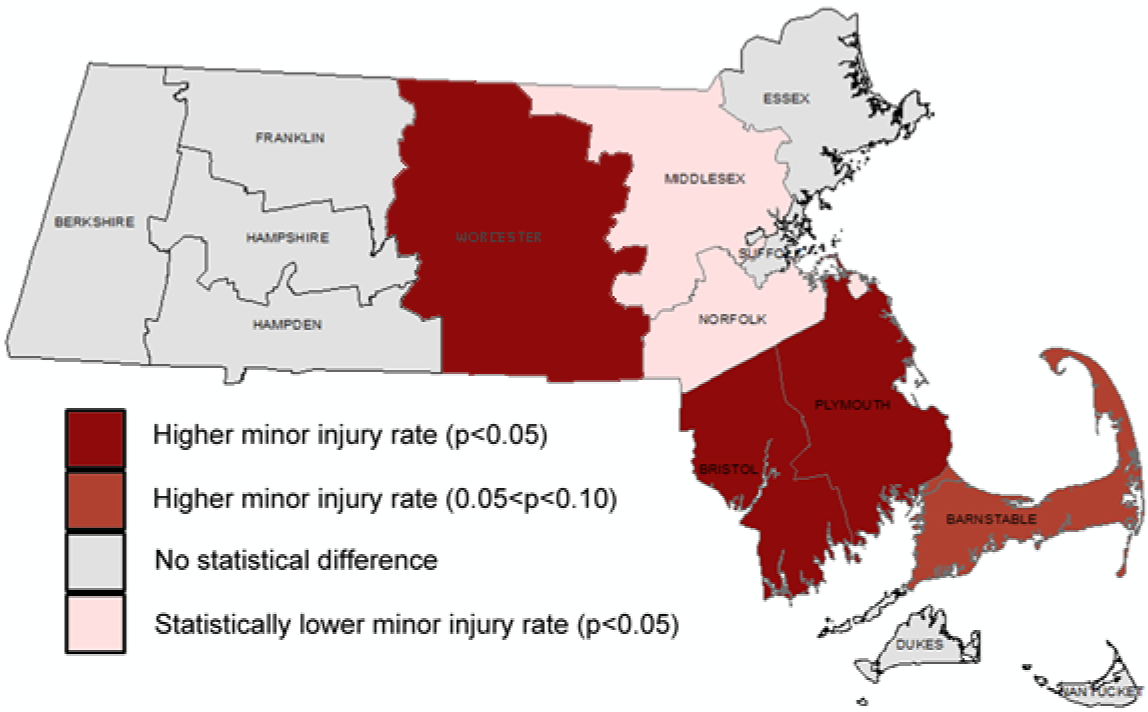


Figure 26 County map of run off the road minor injury rates as compared to the statewide average.

CHAPTER 5

DISCUSSION

5.1 Static Evaluation

A total of 100 participants, all of whom were licensed drivers, participated in the static evaluation. This type of evaluation allowed for insight into the driver's mindset as they determined their operating speed for each video of a real road or driving simulator scenario. The benefits of an evaluation distributed via internet were a large sample size and a wide geographic distribution. The following section discusses the results and findings documented in the previous chapter.

5.1.1 Simulation Videos

Drivers were presented with four driving simulator videos where the size of clear zone and density of roadside vegetation varied. It was hypothesized that the small clear zone and dense vegetation would cause drivers to select a slower speed than when presented with trees sparse and a large clear zone. However, the average speeds selected by participants did not vary as expected between the four driving simulator videos. Statistically, the same speed was chosen for each simulator video. The results are not supported by field validation concluding that either participants did not have enough time to assess the conditions from the 10 second clip or they did not feel fully immersed because of the low quality video. Thus, this should be considered as a preliminary investigation into speed-related driving simulator environments and should be explored further when better software is available to capture more realistic driving simulator drives.

5.1.2 Real World Videos

Drivers were shown nine videos of roadways with the same clear zone/vegetation density scenarios as the four driving simulator drives. When subjects were presented with dense trees close to the road, they selected statistically lower speeds than when the trees were further from the road. An abnormally high average speed was selected in the large clear zone/dense vegetation video combination. This spike in speed can be attributed to at least 12 foot wide lanes and large, paved shoulders on the road whereas in the large clear zone/sparse vegetation video combination, shoulders were either gravely or non-existent. Since participants rated lane width and shoulder width/type as 'Strongly affect their speed choice,' the abnormally high average speed in large clear zone/dense vegetation video combination was likely influenced by shoulder width/type. Overall, the results determined from real world videos captured during the static evaluation were as hypothesized.

The case study involving utility poles in close proximity to the road was enlightening as it confirmed that drivers change their speed when roadside objects are in close proximity to the roadway. Utility poles pose a large hazard in the case of run-off-the-road crashes so it is comforting that drivers are aware and do take caution.

5.1.3 Limitations of Static Evaluation

While an online static evaluation has many advantages such as large sample size and wide geographic distribution, it lacks the level of immersion that driving creates and many variables cannot be held constant as could be in a driving simulator. Best efforts were made to choose similar roads but often times the speed limit, lane width, shoulder type and shoulder width varied.

5.2 Validation of Static Evaluation Findings

Ideally, locations could have been found where there was a constant speed limit, constant lane widths and similar shoulder widths/types. However, this was not possible so the speeds and lateral positions had to be normalized for comparison.

5.2.1 Observed Speeds

The locations with small clear zones and dense vegetation had the highest normalized speeds but also had the highest percentage of drivers violating the posted speed limit, nearly 75 percent. For roads with medium and large clear zones containing dense roadside vegetation, only ~60 percent and ~50 percent of drivers were speeding, respectively. The roads with large clear zones and sparse vegetation also had high normalized speeds and a high percentage of speeders. This may be explained by the fact that speed limits are placed abnormally low on densely vegetated roads with small clear zones for the purpose of safety.

5.2.2 Lateral Positioning and Linked Locations

The lateral positioning of vehicles was captured for vehicles traveling along roads where either the vegetation density changes for a constant clear zone or where the clear zone changes but the vegetation density is held constant. As the vegetation density increased for a large clear zone, driver positioned their vehicles further from the edge of the road. With the exception of small clear zones, drivers positioned their vehicle closer to the edge of the road as the proximity of roadside objects decreased. The exception of small clear zones with dense vegetation could be due to oncoming vehicles. Drivers might have felt trapped and positioned their vehicle closer to the edge to gain extra space. Additionally, one of the small clear zone roads, Amherst Rd in Pelham, has 10 foot lanes which could cause drivers to be extra cautious with regard to oncoming vehicles. While best efforts were made to ensure uniformity, shoulders varied from location to location and could have influenced lateral positioning. Drivers might have changed their positioning based on the quality and size of the shoulder in addition to the size of clear zone and density of roadside vegetation.

5.2.3 Similar Location as Static Evaluation

Speeds were captured on four of the same roads presented in the static evaluation. For medium clear zone/dense vegetation and large clear zone/spare vegetation combinations, static evaluation participants chose a speed statistically the same as observed in the field.

However, drivers who encountered small clear zones with dense vegetation drove at statistically lower speeds than static evaluation participants chose. Drivers immersed on a road with a high density of trees may make an unconscious decision to drive slower due to the high rate of visual flow in the surrounding environment. This level of immersion while driving cannot be replicated by viewing video clips.

A statistical difference was seen between drivers and static evaluation participants for the road with a large clear zone and dense vegetation. Static evaluation participants stated slower speeds than observed field speeds. The ability to gauge the size of a clear zone from a video versus while driving could explain this difference. These differences could be furthered explored by replicating the road scenarios in a driving simulator in order to hold all other variables constant.

5.2.4 Limitations of Field Validation

The original intent was to separate the vegetation density into dense, moderate and sparse designations. While in the field, defining a site as having dense vegetation or moderate vegetation is very subjective. Defining the clear zone size is much easier but still presents a challenge as the clear zone often changes along the same segment of roadway. While there were many locations with sparse or dense trees, locations with consistent moderate vegetation density were challenging to identify. For improved accuracy, the final analysis did not include sites with "moderate" vegetation density.

5.3 Crash Data Analysis

29,651 run-off-the-road crashes occurring in Massachusetts from 2007 to 2010 were analyzed. While it was possible to investigate the outcome and locations of each crash, it was not possible to determine a cause of each crash. Many conclusions were made regarding the injury rates of ROR crashes. Unfortunately, the frequency at which these crashes occur within demographic subset as accurate Vehicles Mile Traveled (VMT) data is not available. Conclusions could have been drawn using Registry of Motor Vehicle (RMV) data on the number of licensed drivers. However, those conclusions would be skewed as not all people with a driver's license drive the same amount. For example, somebody living in urban Boston may only drive once a week whereas somebody living in northwestern Massachusetts may have to drive 25+ miles per day.

5.3.1 Gender and Time of Day

While there were no significant differences for serious and minor injury rates between night and day for women, men more were likely to sustain a minor injury when they were involved in a run-off-the-road at night. Men have been proven to engage in riskier driving behavior such as speeding or drunk driving, these risky behaviors become more frequent at night and when there are fewer drivers on the road. It was expected that there would be a significant rise in serious injury rates at night, but the difference was narrowly not statistically significant for both males and females (p=0.06).

Males also were likely to experience no injury and only property damage whereas females were more likely to sustain minor injuries as a result of ROR crashes. Societal pressures may play a role as in males may be more likely to refuse medical treatment for minor injuries whereas females would not feel this societal pressure.

5.3.2 Driver Age

Younger drivers (16-22) and middle aged drivers (23-59) had similar serious and minor injury rates when involved in a ROR crash. This was unsurprising as the injury rate does not take into account the frequency of these types of crashes but rather the outcome when they occur.

Older drivers were more likely to sustain serious injuries than younger drivers and more likely than younger and middle aged drivers to sustain minor injuries. The ability of the body to recover from injuries is the likely the cause of this difference. As the body ages, it loses its ability to overcome traumatic events. Additionally, reaction times increase as you get older. When a ROR crash, a younger or middle aged driver may be able to steer or hit the brakes a little sooner lessening the severity of the crash.

5.3.3 Most Harmful Roadside Objects

The injury rates of every roadside object which may be struck during a run-off-the-road crash was compared to the overall ROR crash injury rate. The results from this analysis confirmed the initial hypothesis that roadside trees were extremely dangerous to drivers. 10 percent of crashes involving a tree resulted in a serious injury. Conversely, only 55 percent of crashes involving a tree only involved property damage. It is safe to conclude that trees are the most harmful roadside object. The second most harmful roadside would most likely be utility poles. While the chance of a serious injury is not significantly higher for utility pole crashes, the chance of a minor injury is significantly greater.

The common factor for utility poles and trees is that they are both immovable objects. Most utility poles are at least 18 inches in diameter and roadside trees can vary from anywhere from 4 to 24+ inches in diameter. While the data was not available within the UMass Safety Data Warehouse, it is likely that the severity of the crash increases as the diameter of the fixed object increases. This speculation is supported by the fact that mailboxes and light poles, each having smaller diameters and constructed of more frangible materials, have statistically lower serious and minor injury rates.

5.3.4 Guardrails

It was difficult to evaluate the efficacy of guardrails in lessening the severity of run-off-the-road crashes as it is rare that a ROR crash still occurs after a collision with a guard rail. The primary of purpose of rigid roadside barriers is to keep drivers from leaving the roadway and guard rails seem to do just that. While not within the scope of this thesis research, an in depth analysis of guardrails could determine how well they prevent ROR crashes from occurring, this is discussed further in the Future Work section.

5.3.3 Speed Limit and Shoulder Width

Expectedly, the serious and minor injury rates increased as the posted speed limit increased. While it would be very informative to know the speed at which every ROR crash occurred, a thorough and costly investigation at the site of each crash would be required. It is likely that the severity of the crash increases as the driver's speed increases. An interesting comparison would be whether the absolute speed at which the crash occurred or the amount over the speed limit the crash occurred more greatly affected the severity. An example of this type of study would involve a comparison of a crash at 70 mph on an interstate and a crash at 55 mph on a windy rural road to see which would be more dangerous.

Injury rates were also investigated with respect to the shoulder width at constant speeds. Findings demonstrated that shoulder width was more likely to have an effect on the frequency of these crashes rather than influencing the severity.

5.3.4 County

Finally, ROR injury rates were compared across the 14 counties in Massachusetts. While counties are not an ideal way to geographically group crashes, they can provide a generalized idea as to the crash patterns in the area. Suffolk County, the most urban county in Massachusetts had a serious injury rate of 8.5%, which was significantly higher than the state rate. A comparison between crash severity and seat belt usage demonstrated that Worcester County, one of the highest observed seat belt usage rates during the annual Massachusetts Safety Belt Usage Observation Study (22), had the highest serious and minor injury rates in the state. Bristol County, which had one of the lowest belt usage rates, had a serious injury rate around the state average and a minor injury rate statistically lower than the state average. Therefore, it appears that belt usage does not appear to be a strong factor in determining the severity of ROR crashes.

CHAPTER 6

CONCLUSIONS

This research investigated the effect of clear zone size and surrounding vegetation on driver behavior using an online static evaluation, a field validation of the static evaluation findings and a crash data analysis, which focused on run-off-the-road crashes in Massachusetts. The results and discussion presented in the previous chapters resulted in a number of conclusions, which are outlined within this chapter.

6.1 Static Evaluation

The online static evaluation included 100 participants who selected speeds based on roadway characteristics. After watching 13 short videos and selecting an operating speed for each road, the participants were asked to rate how strongly roadway environment factors affected their speed choice. The results are as follows:

- Respondents selected speeds that were statistically similar for the four driving simulation video clips despite the differences in clear zone size and vegetation density.
- Responses for real world videos showed as the size of the clear zone increased, so did the speed at which respondents said they would travel.
- When utility poles were in close proximity of the roadway, the average speed selected was 2 miles per hour lower than the exact same road without utility poles.

- The known presence of police enforcement was rated as the most influential on respondents' speed choice. Proximity of roadside objects was rated as having a "strong" influence whereas roadside vegetation density was rated as having a "neutral" effect.

6.2 Validation of Static Evaluation Findings

Eight locations containing similar roadside configurations as depicted in the static evaluation were studied in the field to see if real drivers exhibited similar behavior as respondents indicated. Video data was captured to see if the presence of trees affected the lateral positioning of vehicles on the roadway. The data collected in the field indicated the following:

- Two of the four locations studied in the field and featured in the static evaluation had statistically similar speeds as what respondents indicated. One location had lower speeds and the last location had higher speeds.
- With the exception of roads with small clear zones, vehicles drove closer to the edge as the clear zone size increased. It was hypothesized that narrower lanes on the roads with a small clear zone may have caused the exception.
- At the two linked locations with multiple observers, drivers positioned their vehicle farther from the edge line as vegetation density increased for a constant clear zone and decreased their distance from the edge line as clear zone size increased for constant vegetation density.

6.3 Crash Data Analysis

The UMass Safety Data Warehouse was utilized to investigate the patterns and trends associated with 29,651 run-off-the-road crashes occurring in Massachusetts from 2007 to 2010. The key crash data analysis findings are as follows:

- While the difference in the severity of crashes occurring at night vs. day was not significant, the data would suggest that nighttime ROR crashes are more serious in nature.
- Men are more likely to escape injury during ROR crashes but this difference may be due to a reporting bias.
- Older drivers are more likely than younger and middle aged drivers to sustain serious or minor injuries during a ROR crash.
- The injury severity of ROR crashes does not correlate on a regional level to the seat belt usage rate observed by UMass Safe during Summer 2012.

6.4 Future Work

Despite the findings and conclusion of this research, additional research questions remain. Some of the future research that is recommended include a validation of the field data collected, a full scale driving simulator study and a thorough investigation of the efficacy of guardrails at preventing ROR crashing. Each of these are briefly expanded upon in the following sections.

6.4.1 Validation of Field Data Collection Methodology

In order to ensure that the presence of a camera and observer had minimal effects on driver behavior, one or two locations should be observed a second time. In the future, a camera could be mounted on a utility pole and the lane could be chalked 100 feet apart.

Speeds would be obtained not by direct observation, but by analyzing the video frame-by-frame.

6.4.2 Full Scale Driving Simulator Study Using Developed Scenarios

A full scale driving simulator study could investigate the effect of subconscious decisions on speed selection. Scenarios similar to those in the static evaluation could be used to see if drivers selected speeds similar to those reported in the evaluation. This study would garner more insight on which factors affect subconscious speed related decisions. As discussed in section 5.2.1, a driving simulator would allow for the classification of roadside vegetation density into dense, moderate and sparse rather than just dense and sparse. Lastly, a driving simulator study could also examine the effect that roadside vegetation has on lateral positioning and these data could be compared to the data collected during the field validation.

6.4.3 Investigate the Efficacy of Guardrails at Preventing ROR Crashes

While ROR collisions with guardrails were examined in terms of injury severity, a separate analysis could investigate how effective guardrails are at preventing ROR from occurring. A secondary analysis would be to determine whether prevention of run-off-the-road crashes would always results in less serious injuries.

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