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Effect of Vehicle Color and Background Visibility for Improving Safety on Rural Kansas Highways

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In this research, a stopped vehicle was simulated at a rural intersection in Kansas, where a large number of crashes have occurred. Various vehicles with different colors approaching from eastbound and westbound directions under different daytime light conditions were shown to participants. Response times of participants to identify the approaching vehicles were measured for each vehicle color under different conditions. The collected data were analyzed using an Analysis of Variance (ANOVA) test to determine whether there is a difference between the mean response times to various vehicle colors moving in the same direction and the same daytime light condition, and the same vehicle color moving in the same direction and several daytime light conditions. A Least Significant Difference (LSD) test was then used to identify which vehicle colors or daytime light conditions are different from the others using Statistical Package for the Social Sciences (SPSS) statistical software.

ANOVA test results showed no significant difference between vehicle colors for (a) morning, eastbound direction and (b) mid-day, westbound direction, while there is a significant difference between response times to vehicle colors for (c) mid-day, eastbound direction and (d) evening, westbound direction. The ANOVA test results for various daytime light conditions showed no difference between response times to (a) black, eastbound vehicles. However, response times to (b) black, westbound vehicles, (c) red, eastbound vehicles, and (d) white, eastbound vehicles were impacted by daytime light conditions. Moreover, the results of the LSD test for mid-day, eastbound direction showed no difference between red and black vehicles. On the other hand, the LSD test showed all vehicle colors have different response times in evening, westbound direction. For daytime light conditions comparison, LSD test results showed black, westbound vehicles in mid-day have a shorter response time compared to the evening time period. Red, eastbound vehicles in morning have shorter response time compared to mid-day. Also, white, eastbound vehicles in the morning have shorter response time compared to mid-day.

Considering the aforementioned results of data analysis, findings of this research do not conclude that the differences between the response times to colors are consistent, meaning a specific color does not stand out above the others. Despite differing lighting conditions where some colors were slightly more recognizable, the difference is not uniformly significant. Based on the results of this study, there is not enough evidence to determine that the elevated number of crashes at the study intersection is due to camouflaging of vehicles due to coloring, and no other immediate cause can be identified.

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Final Report

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Abstract

The effect of vehicle color on crash involvement has been an interesting topic for several decades; however, the effect of a vehicle's color on its visibility to drivers has not been studied in detail, especially at rural intersections. There has been some speculation that the combination of vehicle color and background environment can cause a camouflage effect on a vehicle's visibility for drivers stopped at an intersection.

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Chapter 1: Introduction

1.1 Background and Problem Statement

Rural areas typically experience higher levels of highway safety concerns, especially at intersections. Kansas has many such intersections where there are considerable numbers of crashes leading to significant economic loss.

For example, the locals refer to the intersection of US-281 and US-50 in Stafford County, Kansas, as “Hell’s Crossing.” The title reflects the reputation of the crossroads known as a location of frequent motor vehicle crashes. Between the years 2008 and 2012, 43 crashes occurred at or near the intersection of these two highways. Many of these crashes occurred within a short distance of the actual intersection itself. While only one crash resulted in a fatality, 15 others involved injuries to persons and 27 resulted in property damage.

Figure 1.1: Stafford County, Kansas
Source: Stafford County, Kansas (n.d.)

According to the crash reports of several two-vehicle accidents at the intersection, after stopping along the intersecting highway, one of the drivers claimed that they did not see the vehicle traveling on the main highway, although the driver reported looking at the roadway. In one case, at the intersection of US-50 and US-281 in Stafford County where numerous accidents occurred, a young woman who drove a passenger vehicle had a collision with a semi-truck after she stopped at the stop sign and reportedly looked both ways onto the main roadway. The driver claimed the coloring of the semi-truck blended into the background.

Stafford County is a rural county in the south central part of Kansas. The county has a total area of 795 square miles. The 2010 United States Census reported a county population of 4,437. This same report showed a median age of these residents as 41 years old, and a median family income of $38,235 or a per capita income of $16,409. The county is divided into 21 townships with St. John as the county seat (United States Census Bureau, 1990, 2000, 2010).

US-50 is the primary east-west highway serving the southwest, central, and northeastern parts of the state. US-281 is a north-south highway running through Kansas and extending through six states, from the Mexican border in Texas to the Canadian border in North Dakota. The intersection of these two highways is the only intersection of major highways within Stafford County.

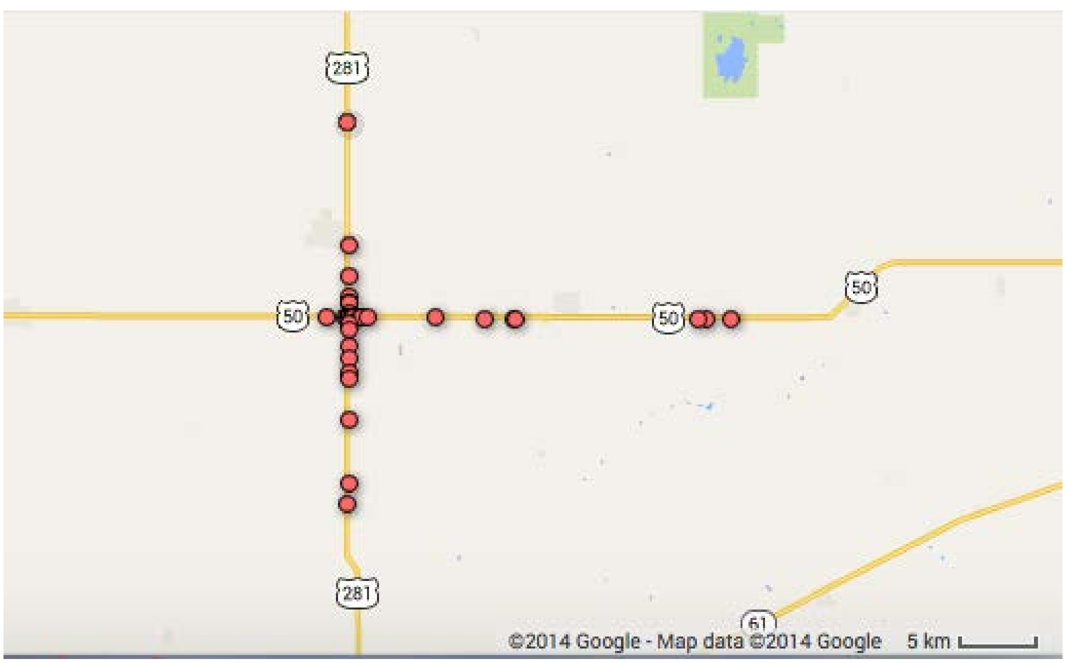

Figure 1.2: Map of Crash Locations
Source: Google

Of the 43 crashes occurring between 2008 and 2012 at or near the intersection of US-50 and US-281, 19 crashes were reported as occurring on US-281, while 24 were reported as occurring on US-50. A review of the crash distribution across months of the year from 2008 to

2012, as shown in Figure 1.3, reveals that the most frequent month for a crash to occur is November, when 14 percent of all crashes have occurred, followed by June and September, when 11.6 percent of all crashes occurred during each month. The months of January, March, July, and August each show the lowest percentage of crashes with 4.7 percent each. The monthly average for crashes at the site is 3.58.

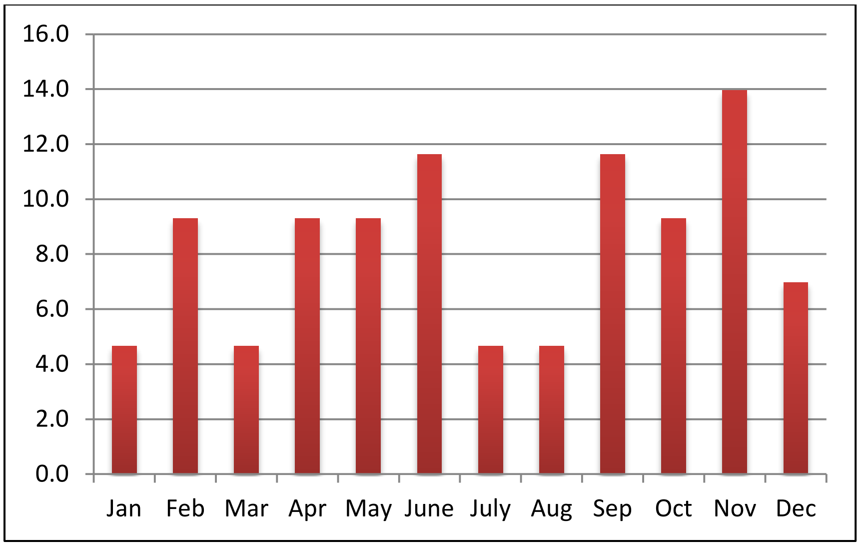

Figure 1.3: Percentage of Crashes by Month

However, even more revealing is the trend illustrated in Figure 1.4 that indicates an increased frequency of crashes each year since 2010 and the highest frequency of the five years considered in this research, with 11 crashes taking place in 2012.

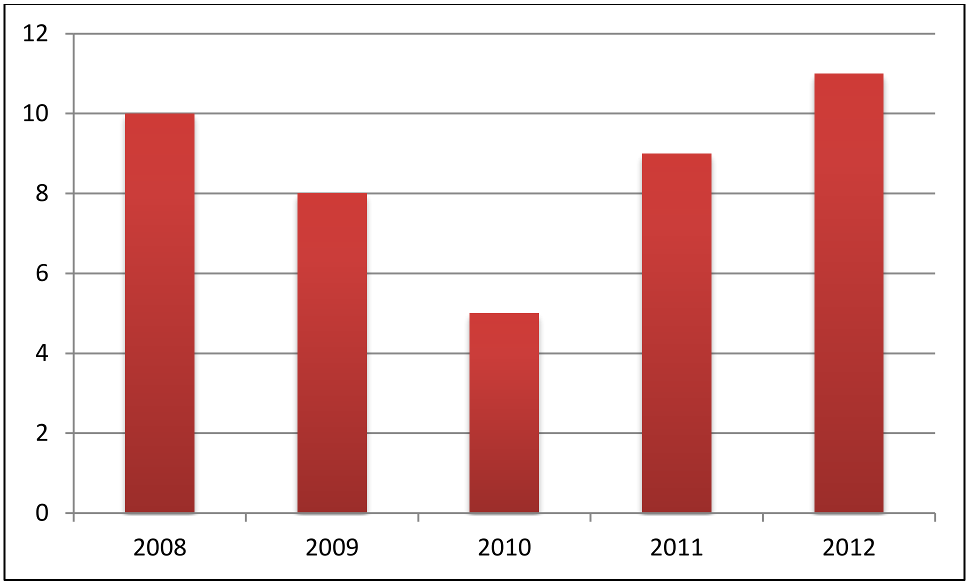

Figure 1.4: Crash Distribution by Year

Figure 1.5 shows the collision diagram of the studied intersection by considering crash data from 2008 to 2012. Appendix A provides collision diagrams of each study year separately, in addition to legend of symbols. Only 13 out of 43 identified crashes during the five year period are intersection-related crashes. Twenty crashes were animal-related crashes, and 14 crashes were multi-vehicle crashes.

Some speculation has arisen concerning the effect of vehicle color on its visibility within a rural environment, in effect camouflaging the vehicle in the surroundings. It is the general perception that such a camouflaging effect would likely impact the number of crashes on any rural highway intersection similar to the one at US-50 and US-281. This project is intended to study the topic in a more quantitative manner and see whether such an effect exists due to visibility.

1.2 Objectives

The main objective of this study is to evaluate the effect of vehicle color on its visibility, as it is seen by stopped drivers at an intersection, where a considerably high number of crashes have taken place. In addition, the effect of daytime light conditions (morning, mid-day, and evening) and two different directions of travel (eastbound and westbound) are investigated to identify whether those factors affect visibility.

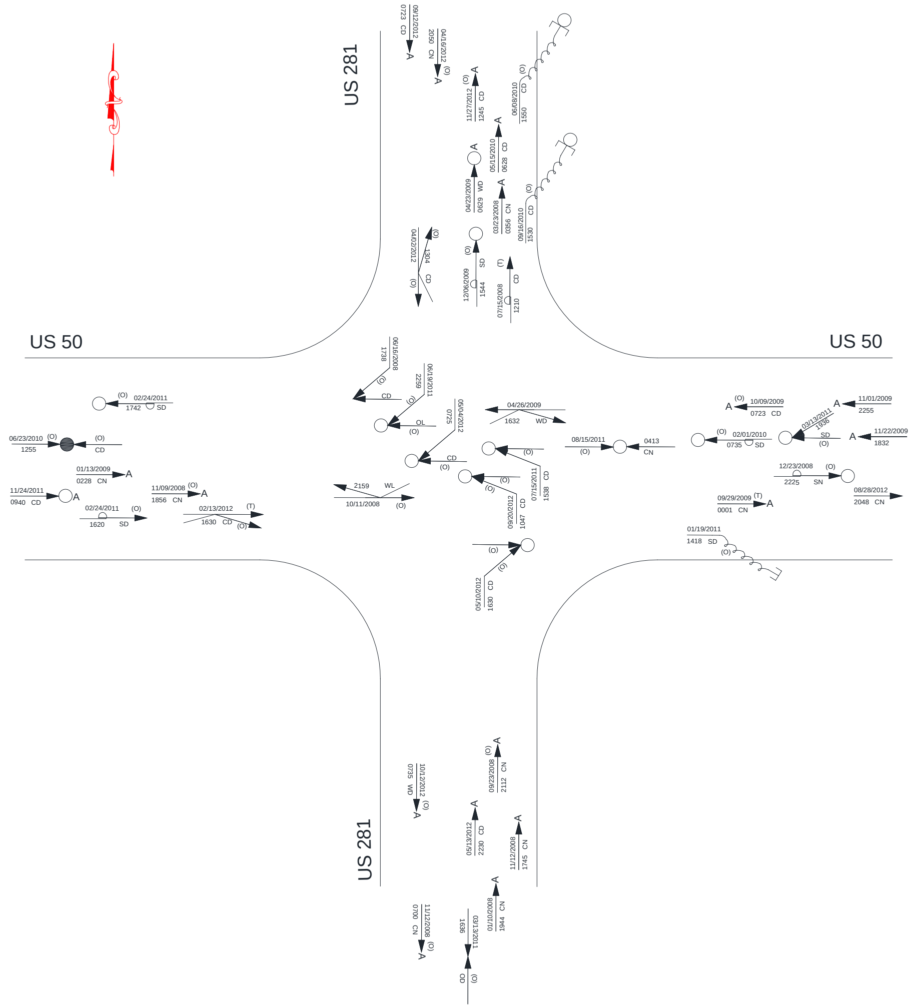

Figure 1.5: Collision Diagram of US-50 and US-281 Highways Intersection for Years 2008 to 2012

1.3 Research Design

Though research of this type could be carried out over a long period of time, comparing different weather seasons and other factors, due to the time limitations this research was more simplified in an effort to produce initial results fitting of the deadline required. Six primary tasks were identified as necessary in order to provide this report.

An in-depth review of literature using various databases across multiple disciplines was carried out to identify any useful findings relevant to the research topic. Video clips were then recorded from a stationary location using a video camera placed at a location near the junction of US-50 and US-281 in Stafford County, Kansas, during early October 2014. The weather was clear and sunny, with high visibility. Vehicles were recorded while traveling at average speeds and different directions from two miles away. Video clips were then played to a number of respondents through a large television screen at close range in an attempt to simulate the respondent being in a stopped vehicle. Respondents indicated the point at which they saw the approaching vehicle by pressing a button on a timer and stopping the clock. The research team then recorded the time. Respondents were also asked to complete a short questionnaire regarding their eyesight and other demographic factors, such as age, gender, eye health, driving history, etc. This information was used to analyze the results of the vehicle observation test based on demographic information. Responses were compared with respect to vehicle color and background visibility in an attempt to determine whether any possible differences of distance perception exist.

1.4 Outline of the Report

All tasks related to the project activities, including findings, have been documented and provided in this report. Chapter 1 presents background details and the introduction. A summary of the previous studies conducted on related topics are presented in Chapter 2. Chapter 3 presents the methodology utilized in this study to study the effect of vehicle color on visibility, whereas Chapter 4 presents the results of the data analysis. Finally, Chapter 5 summarizes conclusions and recommendations.

Chapter 2: Literature Review

The color of vehicles has become an interesting topic from a transportation safety point-of-view, due to the perception of a correlation between crash occurrence and vehicle color when more than one vehicle is involved in a crash. This chapter discusses past studies addressing the effect of vehicle color on crash occurrence.

Some research has been done on whether the color of vehicles can cause them to stand out or blend into their surroundings. This research has primarily focused on urban settings. Some of this research dates as far back as the 1950s and has provided various results. In 1969, R.A. Nathan made several suggestions for vehicle coloring, specifically for semi-trucks, that have yet to become required by law. Among his observations, he included “A vehicle's coloring, especially the rear-end, can have an important effect upon its visibility. The coloring of a vehicle can also serve other motorists as an aid in judging its size, distance and relative speed” (Nathan, 1969).

Other researchers studying the safety of vehicle coloring have determined that “no single vehicle color was found to be significantly safer or riskier than white, the baseline color” (Owusu-Ansah, 2010). Still others have determined that “A considerably high number of drivers are in lack of optimal visual acuity. Refractive errors in drivers may impair traffic security” (Erdoðan et al., 2011). The study found nearly a quarter of heavy vehicle drivers had some type of vision disorder.

2.1 Color of Vehicles Involved in Crashes

Various studies have been conducted investigating the relationship between vehicle color and crash occurrence. However, the results are conflicting, reaching opposing conclusions in different studies.

Lardelli-Claret et al. (2002) studied crashes from 1993 to 1999 in which one of the drivers committed an infraction. They used a paired case-control study from the Spanish database of traffic crashes. Traffic violators were used as the control group and the other drivers as the case group. Comparing various colors against white color, these researchers concluded light colors, including white and yellow, were associated with a slightly lower risk of being passively involved in a crash. The colors of vehicles in their study included white and yellow as light colors, as well as blue, beige, grey, brown, orange, black, red, and green.

Furness et al. (2003) investigated the effect of vehicle color on the risk of serious injury from a crash using a population-based case control study designed to identify and quantify modifiable risk factors in the Auckland region of New Zealand. The researchers studied 571 serious injury crashes and fatal crashes between April 1998 and June 1999. Also, 588 randomly selected drivers were used as controls. The most prevalent colors were white, black, grey, red, and silver in the studied region. Researchers found a significant reduction in the risk of serious injury in silver vehicles compared to white vehicles in both the univariate analysis and multivariate analysis. According to this research, silver vehicles were about 50 percent less likely to be involved in a crash resulting in serious injury than white vehicles.

Newstead and D'Elia (2010) studied the relationship between vehicle accidents and the vehicle's color in Victoria and West Australia. The researchers investigated 17 colors for vehicles: black, blue, brown, cream, fawn, gold, green, grey, maroon, mauve, orange, pink, purple, red, silver, yellow, and white. Two light conditions were considered, consisting of daylight condition and combined dawn and dusk conditions. According to their research for the daylight condition, black, grey, silver, red, and blue vehicles had the highest crash risks in descending order. Moreover, for the dusk and dawn condition, black and silver vehicles had the highest risk in descending order at 5 percent significance level. Grey vehicles had a high crash risk with p-value of 0.0574. Table 2.1 shows the vehicle colors with higher crash risks for the two studied conditions.

Table 2.1: Vehicle Colors with Higher Crash Risks in Victoria and West Australia

Daylight Condition			Dawn or Dusk Conditions		
Color	**Increase in crash risk**	**p-value**	**Color**	**Increase in crash risk**	**p-value**
Black	12 percent	<0.05	Black (P<0.05)	47 percent	<0.05
Grey	11 percent	<0.05	Silver (P<0.05)	15 percent	<0.05
Silver	10 percent	<0.05	Grey (P=0.0574)	25 percent	0.0574
Red	7 percent	<0.05			
Blue	7 percent	<0.05			

Source: Newstead & D'Elia, 2010

Covey (2009) investigated the problematic intersection of US-53 and County Trunk Highway V in Wisconsin. According to his research, the most popular colors of vehicles sold in the U.S. in 2003 in ascending order are: silver, white, black, red, medium/dark grey, brown, blue, and green. The researcher used the collected and recorded crash data for 51 crashes occurring at the study intersection from 1994 to 2007. The researcher compared the color of involved vehicles in crashes at the studied intersection to the percentage of vehicle colors in the U.S. Covey concluded that brown, blue, and green vehicles are in a higher percentage of crashes at the study intersection than the average number of those same colors sold in the U.S. In addition, silver, white, and grey vehicles are less likely than the average sold to be in crashes at the study intersection.

2.2 Approaches to Data Analysis

Deery and Fildes (1999) studied 198 novice drivers aged 16 to 19 who completed a self-report questionnaire. They used cluster analysis to analyze the results of the study. They used measures and variables in six groups: driving style, driving record, attitudes, alcohol use, other drug use, and demographic variables. They analyzed attitude and alcohol use measures with separate one-way Multivariate Analysis of Variance (MANOVA).

Mourant, Ahmad, Jaeger, and Lin (2007) investigated the effect of high and low optic flow on the performance of 30 drivers who were asked to drive a driving simulator at two different speeds, 30 and 60 mph, and in various geometric fields of view at 25, 55, or 85 visual degrees. They implemented a three-factor 2*2*3 experimental design for factors including: the specified speed (30 or 60 mph), optic flow (low or high), and geometric field of view (25, 55, or 85 degrees). A three-factor Analysis of Variance (ANOVA) was used to analyze the results.

Cantin, Lavallière, Simoneau, and Teasdale (2009) studied the effect of age on reaction times of various groups, including older drivers, in a simulator. They designed the experiment in a way that the participants drove a simulated car as their primary tasks and responded to an auditory stimulus as their secondary tasks with verbal responses. They tested three hypotheses: 1) more complex maneuvers impose more mental workload on drivers, 2) all driving context imposes higher mental workload on older drivers, and 3) more complex tasks impose greater mental workload on older drivers. Ten male younger drivers (between 20 and 31 years old) and 10 older drivers (between 65 and 75 years old) were selected. The researcher checked the mental and physical situation of participants through some tests and questionnaires. ANOVA test was used to analyze groups (young and elderly) and driving contexts (baseline, driving on straight road, stopping at intersections, and overtaking maneuvers). For each of the contexts (straight, intersection, or overtaking maneuver), one-way ANOVA was used separately and groups were compared.

Lucidi et al. (2010) studied 1,008 young novice drivers between 18 and 23 years old in Italy with valid driving licenses. They utilized various measures and variables in the study, including personality measures, driving related measures, attitudes toward traffic rules, accident risk perception, and driving behavior using a designed questionnaire. To conduct the statistical analysis, the researchers used cluster analysis from “classify” package of Statistical Package for the Social Sciences (SPSS) software.

Chapter 3: Methodology

This study evaluated the effect of vehicle color on its visibility to understand whether there is a safety concern arising from any possible camouflaging with the surroundings. Methodology utilized in studying the topic is explained in this chapter. The methodology consisted of data recording at the selected intersection, experimentation, and data analysis.

3.1 Location Details

The intersection of US-50 and US-281 is a two-way stop controlled intersection located in south central Kansas, as shown in Figure 3.1. This intersection, known as “Hell’s Crossing” by the locals, is a typical rural intersection with US-50 running east and west with no stop signs or warning lights as it intersects with US-281. US-281 runs north and south and is controlled by stop signs with flashing lights. Transverse rumble strips are also in place to warn drivers of the upcoming stop. On the southwest corner of the intersection is a state yard with outbuildings and a paved parking/service lot. The southeast corner has a farm field, as do the northeast and northwest corners. Both US-50 and US-281 are two-lane highways with posted speed limits of 65 miles per hour. Additionally, both highways feature signage at the intersection, notifying drivers of the specific intersection as well as informational and directional signage for upcoming locations on the roadway. Photographs of the location follow in Figures 3.1 through 3.7.

Figure 3.1: Satellite View of US-50/US-281 Intersection
Source: Google

Figure 3.2: Overhead View of US-50/US-281 Intersection
Source: Google

Figure 3.3: US-281 – Northbound
Source: Google

Figure 3.4: US-281 – Southbound
Source: Google

Figure 3.5: US-281 – Southbound
Source: Google

Figure 3.6: US-50 – Eastbound
Source: Google

Figure 3.7: US-50 – Westbound
Source: Google

3.2 Video Recording and Editing

Traffic at the intersection of US-50 and US-281 in Stafford County, Kansas, was video recorded between sunrise and sundown concentrating on three-hour blocks of time (7:00 a.m. to 10:00 a.m., 11:00 a.m. to 2:00 p.m., and 3:00 p.m. to 6:00 p.m.) in an attempt to best represent the changing lighting and conditions of the day. Traffic was recorded as vehicles approached the intersection from both eastbound and westbound directions during the three different time blocks, which are identified in this study as morning, mid-day, and evening daytime lighting conditions. This approach provided a satisfactory way of capturing the changing lighting conditions throughout the day. Figure 3.8 shows the locations of installed cameras at the study intersection.

Video clips were then brought back to the lab for review, where it was determined to use clips with similar styles of vehicles of different colors. Red, black, and white were the most prevalent vehicle colors and, as such, those were chosen as the main test colors. Beige and light blue were also included in the test videos so that the respondents would not be paying any particular attention to the tested colors. It was determined that video clips featuring semi-trucks, vehicles with headlights on, or vehicles with high amounts of chrome would not be used, as they were likely to be identified easily as a result of these features and not necessarily as a result of their color. All of the video clips were the same in length and each direction was shot from the same angle. After reviewing all clips, 13 video clips fitting all criteria were identified as suitable to be used in the experimentation portion of the study.

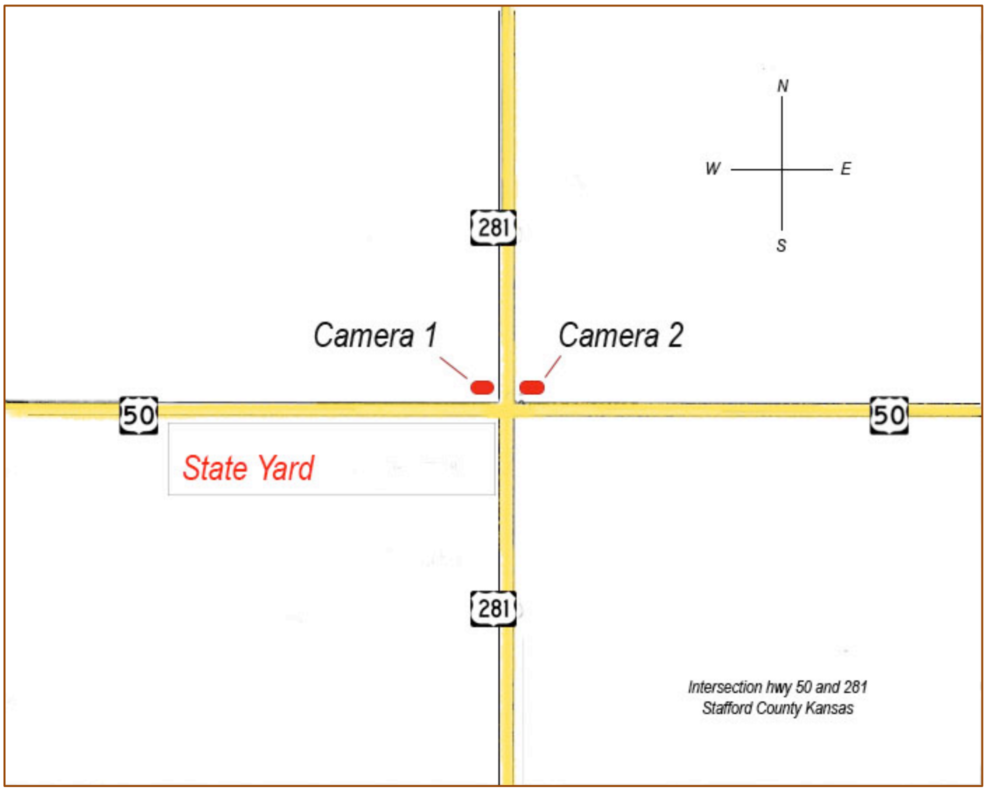

Figure 3.8: Camera Locations at the Intersection

3.3 Experimental Data Collection

To collect data, participants were asked by the researchers if they had a few minutes to spare for an experiment concerning highway safety on the rural highways of Kansas. Upon entering the laboratory, participants were asked to complete a brief questionnaire to collect demographic data (see Appendix B). Participants were then asked to sit at the test station, which consisted of a large-screen television and a steering wheel console to better simulate the driving experience. Experimental setup is shown in Figures 3.9 and 3.10. Participants were shown a series of 13 video clips of oncoming vehicles recorded at different times of day and were instructed to press a button attached to a timer as soon as they recognized the oncoming vehicle. The 13 video clips were shown in random order so no single participant was exposed to the same sequence. When the participant reacted and stopped the timer, the researcher recorded the data, reset the timer, and cued the next clip. The entire process took between 7 to 10 minutes, depending on the participant.

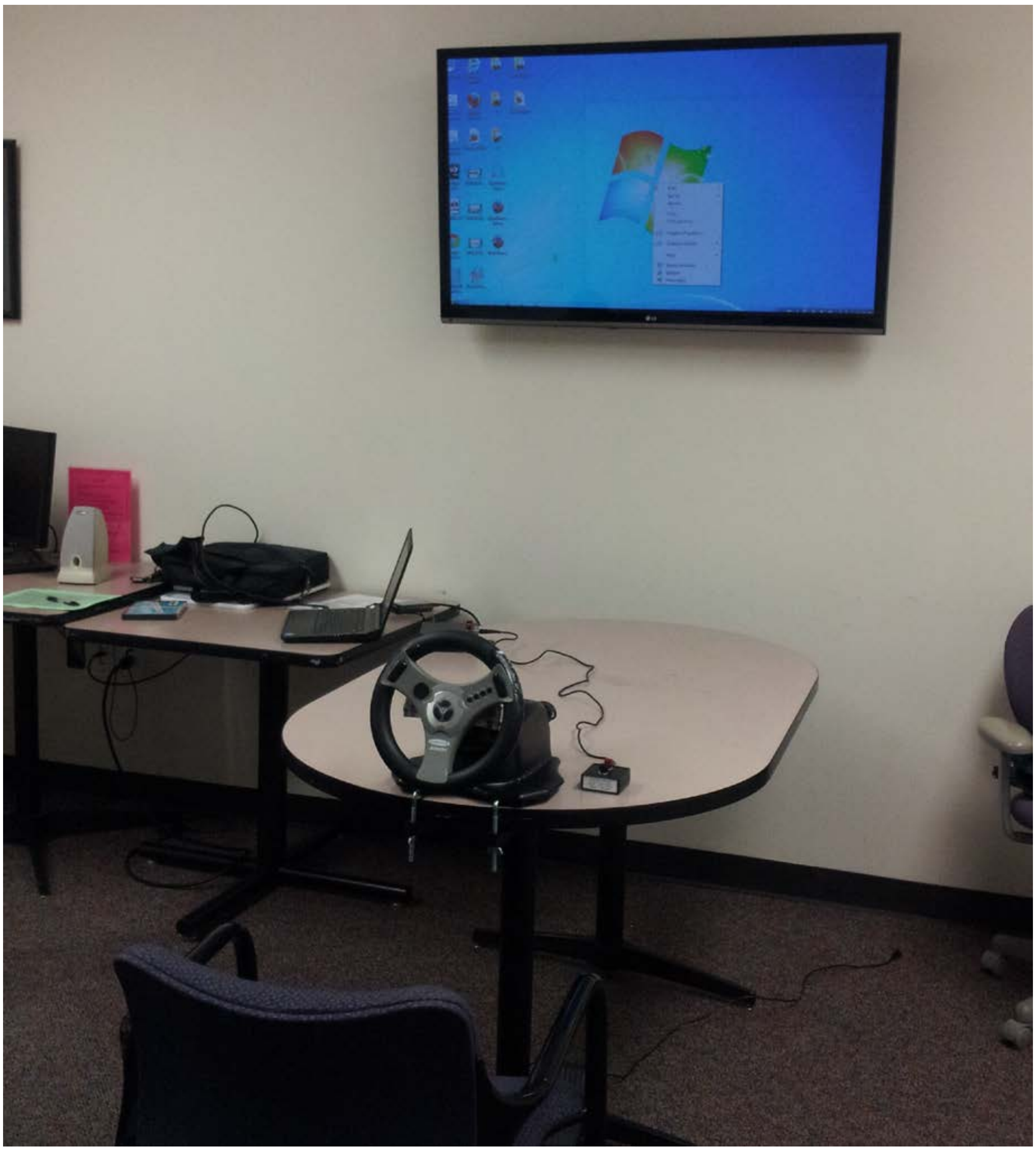

Figure 3.9: Experimental Data Collection Setup

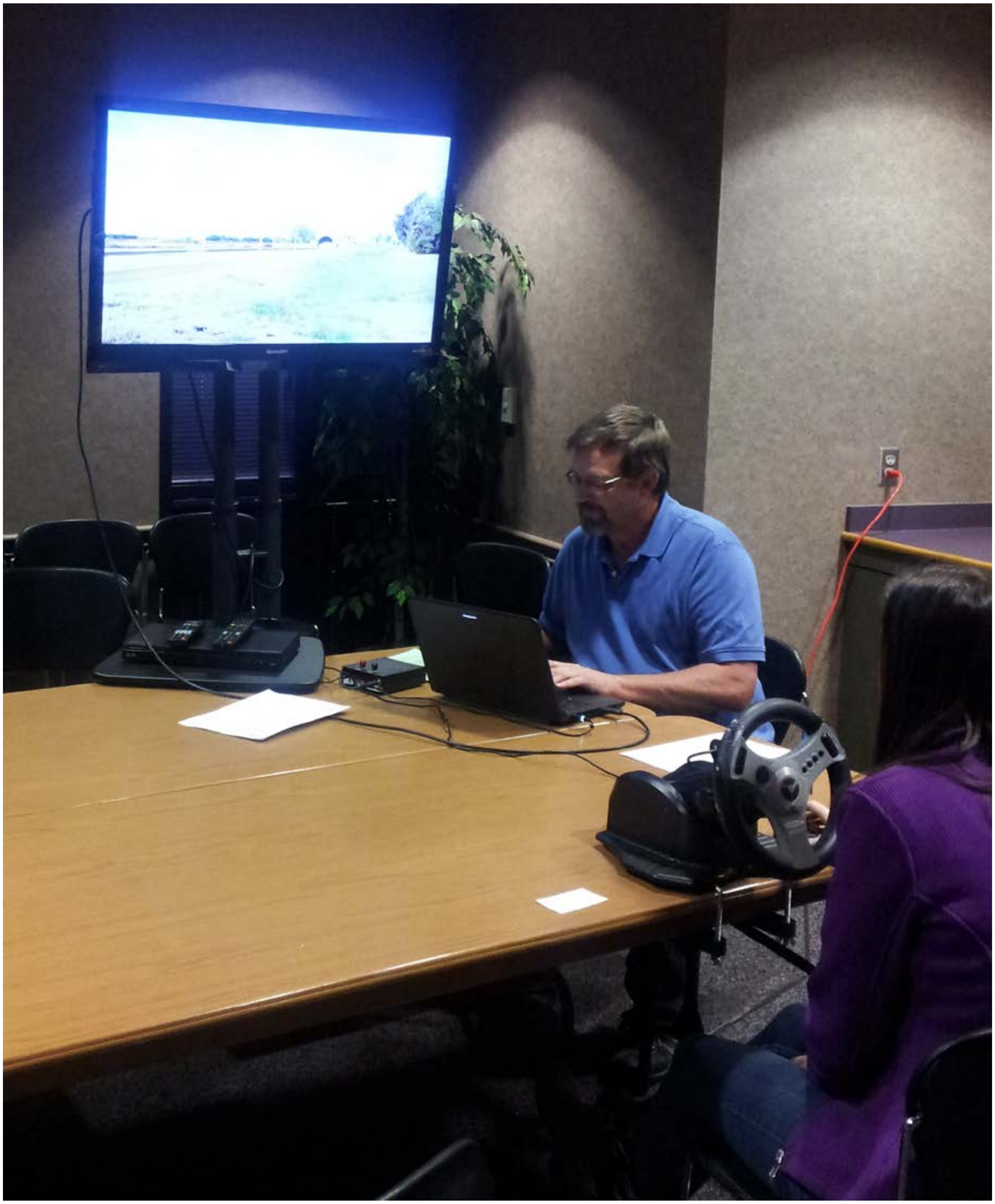

Figure 3.10: Experimental Data Collection Setup with Researcher and Participant

3.4 Characteristics of Respondents

For this study, the research sample of participants was recruited on a volunteer basis from the population of a large Midwestern university. This population was chosen primarily because they closely represent the age of the individuals involved in some of the most recent accidents occurring at the intersection of US-50 and US-281. This sampling was also a convenience sampling of the most available source of participants.

A total of 150 participants contributed to this study (N=150). For demographic purposes, researchers asked participants to complete a six-item questionnaire to ascertain age, gender, if participants wore corrective lenses, general eye health, if and from where they were a licensed driver, and their years of driving experience. The results of these questions are identified in the tables below.

Question 1: Age. The participants were asked to self-identify which age group they fit into. Figure 3.11 shows that 80 percent of the participants were between the ages of 18 and 24, 11.3 percent were between the ages of 25 and 34, 6 percent were between the ages of 35 and 44, 0.6 percent were between the ages of 45 and 54, 0.6 percent were between the ages of 55 and 64, and 1.3 percent were aged 65 years or older.

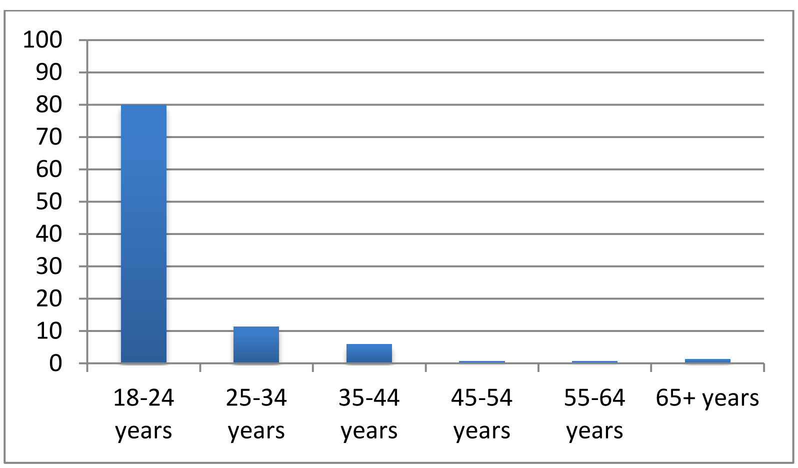

Figure 3.11: Age Group Distribution of Respondents

1. Age groups: 18 to 24 (N=120), 25 to 34 (N=17), 35 to 44 (N=9), 45 to 54 (N=1), 55 to 64 (N=1), and 65+ (N=2), where N is the sample size.
2. Gender: Female (N=64), Male (N=86).

Question 2: Gender. Participants were asked to identify their gender. The ratio of female to male volunteers is represented in Figure 3.12 with 42.7 percent of females to 57.3 percent males.

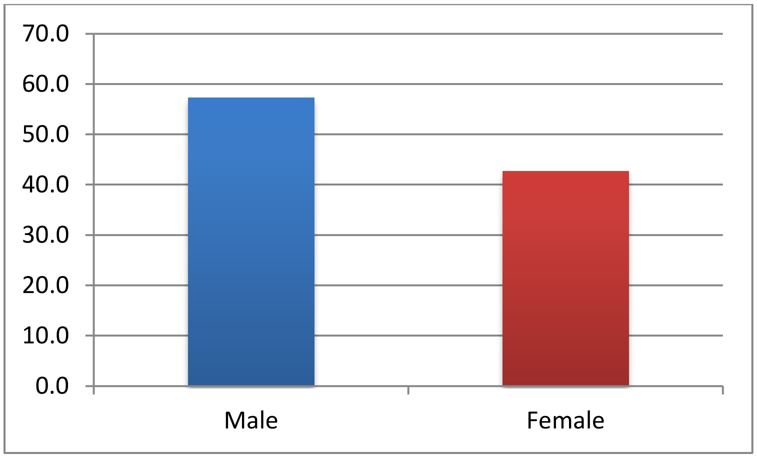

Figure 3.12: Gender Distribution of Respondents

3. Corrective lenses: (N=82), Yes (N=68)

Question 3: Corrective lenses. Participants were asked if they wore corrective lenses. Figure 3.13 illustrates 54 percent did not wear corrective lenses and 46 percent did use some form of corrective lens either while driving or for everyday use. No specific information was asked regarding the type of corrective lenses used.

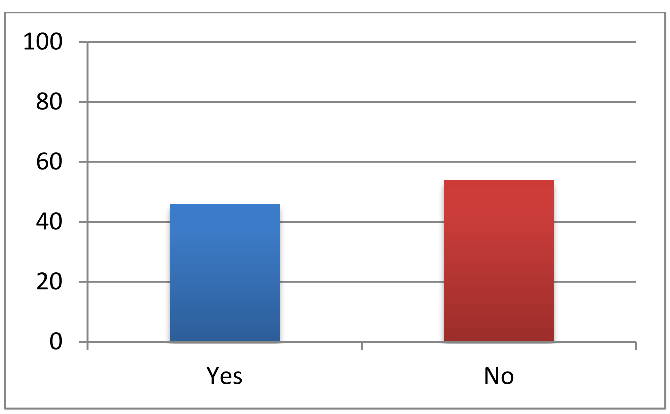

Figure 3.13: Corrective Lens Usage Percentages

4. Eyesight: No problems (N=75), Farsighted (N=15), Nearsighted (N=60). Among the nearsighted participants, two were colorblind; one had amblyopia and one was partially blind in one eye.

Question 4: Problems with eyesight. Participants were asked to describe any problems they may have with their eyesight. The results of this question are demonstrated in Figure 3.14. Of the participants, 50 percent reported they had no problems with their eyesight, 10 percent reported they were farsighted, and 40 percent reported they were nearsighted. Of the 40 percent nearsighted participants, 1.6 percent reported they were nearsighted with amblyopia and 1.6 percent reported nearsightedness with one eye partially blind.

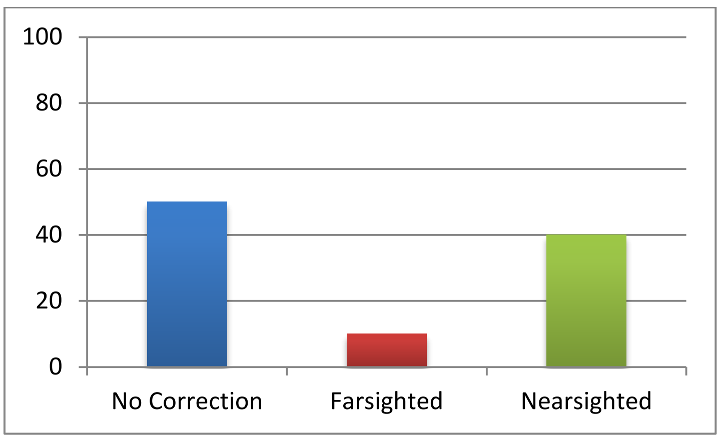

Figure 3.14: Eyesight Distribution of Respondents

5. Licensed Drivers: USA (N=139), International (N=5), No license (N=6).

Question 5: Valid driver's license. Participants were asked if they had a valid driver's license at the time of the data collection. Figure 3.15 illustrates that 93 percent were in possession of a driver's license issued in the United States, 3 percent were in possession of a driver's license issued internationally, and the remaining 4 percent were unlicensed.

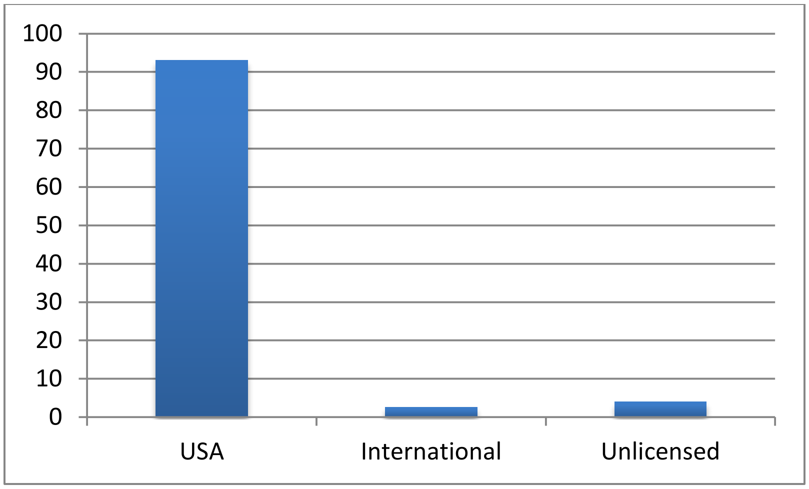

Figure 3.15: Driver's License of Respondents

6. Years Driving: 0 to 10 (N=138), 11 to 20 (N=5), 12 to 30 (N=4), 30+ (N=3).

Question 6: Years of driving experience. Participants were asked how many years they had been driving. Figure 3.16 illustrates 61.3 percent reported they had been driving for five years or less, 31.3 percent reported they had been driving six to 10 years, 0.6 percent had been driving for 11 to 15 years, 2.6 percent had been driving for 16 to 20 years, 1.3 percent had been driving for 21 to 25 years, 1.3 percent had been driving for 26 to 30 years, and the remaining 2 percent had been driving for 31 years or more.

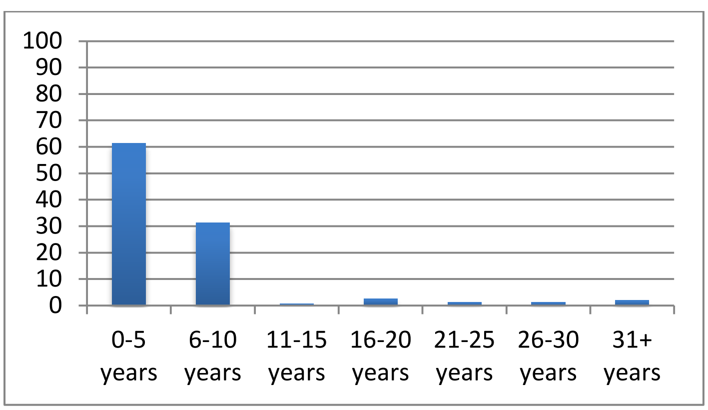

Figure 3.16: Driving Experience of Respondents

As expected, there is a direct correlation between the age of the drivers and the years of driving experience. Furthermore, the majority of drivers were licensed in the U.S. and had no vision correction.

3.5 Data Analysis Methodology

Analysis of Variance (ANOVA), developed by Sir Ronald Fisher, is a generalized t-test used to identify the differences between more than two groups. However, to compare two groups, the results of ANOVA and t-test must be completely the same. The ANOVA test relies on F-statistic or F-test. In ANOVA, three sums of squares are needed in order to compare the data: the total sum of squares, the sum of squares between groups, and the sum of squares within groups. These values can be calculated using Equation 3.1 through Equation 3.3.

$$SST = \sum_{j=1}^{n}\sum_{i}^{N_j}(x_i^2) - \frac{\left[\sum_{j=1}^{n}\sum_{i=1}^{N_j} x_i\right]^2}{N_T}$$ **Equation 3.1**

$$SSB = \sum_{j=1}^{n}\frac{\left(\sum_{i=1}^{N_j} x_i\right)^2}{N_j} - \frac{\left[\sum_{j=1}^{n}\sum_{i=1}^{N_j} x_i\right]^2}{N_T}$$ **Equation 3.2**

$$SSW = \sum_{j=1}^{n}\left(\sum_{i}^{N_j}(x_i^2) - \frac{\left(\sum_{i=1}^{N_j} x_i\right)^2}{N_j}\right)$$ **Equation 3.3**

In which:

SST: total sum of squares,
SSB: sum of squares between groups,
SSW: sum of squares within groups,
n: number of groups,
N_j: number of observations or studied variables in group j,
N_T: total number of observations or variables in all of the groups,
x_i: the value of ith variable or observation,
i: number of variable or observation varies from 1 to N_j, and
j: number of group varies from 1 to j.

There is also a relationship between total sum of squares, sum of squares between groups, and sum of squares within groups as illustrated in Equation 3.4.

$$SST = SSB + SSW \qquad \textbf{Equation 3.4}$$

Degree of freedom for sum of squares between and sum of squares within groups can be calculated according to Equation 3.5 and Equation 3.6, respectively.

$$df_B = n - 1 \qquad \textbf{Equation 3.5}$$

$$df_W = N_T - 1 \qquad \textbf{Equation 3.6}$$

Also mean squares for between and within groups are calculated according to Equation 3.7 and Equation 3.8, respectively.

$$MS_B = \frac{SSB}{df_B} \qquad \textbf{Equation 3.7}$$

$$MS_W = \frac{SSW}{df_W} \qquad \textbf{Equation 3.8}$$

F-ratio is calculated as Equation 3.9 and must be compared to F-critical, which can be obtained from particular tables considering the degrees of freedom for between and within groups and the expected significance level.

$$F = \frac{MSB}{MSW} \qquad \textbf{Equation 3.9}$$

The p-value, that is, the probability of obtaining a test statistic as extreme or more extreme results, assuming the null hypothesis is true, can be calculated and compared to the significance level. Statistical software packages such as Statistical Analysis System (SAS) and SPSS calculate the F-ratio as well as the p-value in ANOVA test. Thus, instead of comparing F-ratio with F-critical, p-value of the model can be compared to the significance level (Kuehl, 2000).

The Least Significant Difference (LSD) test is a pairwise comparison technique developed by Ronald Fisher in 1935 to compute the smallest significant difference between two means. It is used most frequently when an ANOVA hypothesis is rejected. The LSD is essentially a set of individual t-tests differentiated only by the calculation of standard deviation. Different from a standard t-test, Fisher's test increases the power of the test by calculating the pooled standard deviation from all data groups. The LSD test does not correct for multiple comparisons (Hayter, 1986).

Chapter 4: Data Analysis and Results

This chapter discusses the analysis of data collected in this study and their associated results. Analysis was carried out by direction (east/west), color of vehicle (beige, black, light blue, light grey, red, and white), and daytime light condition (morning, mid-day, and evening). The ANOVA method was used to determine whether the vehicle color or daytime light condition influences the visibility. An LSD test was utilized to determine which vehicle color is different from the other colors or what daytime light condition is different from the other daytime light conditions.

Collected data were analyzed using two different analysis methods: (1) Groups of vehicle colors were compared utilizing ANOVA, and (2) Effect of daytime lighting conditions was investigated using the LSD test.

4.1 Comparison of Response Times for Different Vehicle Colors at Same Direction and Daytime Light Condition

In order to investigate whether vehicle color influences the visibility of the vehicle, response times of participants were compared against different vehicle colors using ANOVA as the statistical analysis approach. The ANOVA examined the difference of the mean of response times for each group of vehicle color. ANOVA was also used to compare vehicle colors of each direction and each daytime light condition, using videos recorded of various colors for two directions and three daytime lighting conditions. As illustrated in Table 4.1, four groups of vehicle color comparisons were selected:

- Morning, eastbound vehicle colors of black, red, and white.
- Mid-day, eastbound vehicle colors of black, light grey, red, and white.
- Mid-day, westbound vehicle colors of beige and black.
- Evening, westbound vehicle colors of black, red, and white.

Table 4.1: Summary of Video Clips Based on Time of Day, Direction, and Vehicle Color

Direction / Daytime	Eastbound	Westbound
Morning	Black, Red, White	___*
Mid-Day	Black, Light Grey, Red, White	Beige, Black
Evening	Light Blue	Black, Red, White

*No suitable video clips were available for morning westbound traffic.

4.1.1 Morning Eastbound Vehicle Colors of Black, Red, and White

Table 4.2 shows the results of the ANOVA test for black, red, and white vehicles in morning, eastbound direction. The values of the F-statistic and p-values in the table for the corrected model should be considered in interpreting the results. The corrected model has a p-value of 0.51 that is much greater than the significance level ($\alpha=0.05$), which means there is no significant evidence to conclude that there is a statistical difference between response times for black, red, and white vehicles in the morning in the eastbound direction. In other words, vehicle color has not affected the response times for the morning, eastbound direction.

Table 4.2: ANOVA Test Results to Compare Response Times of Black, Red, and White Vehicles for Morning, Eastbound Direction

Source	Type III Sum of Squares	Degree of Freedom	Mean Square	F Statistic	p-value
Corrected Model	19.43	2	9.72	0.68	0.51
Intercept	9415.85	1	9415.85	657.38	0.00
Color	19.43	2	9.72	0.68	0.51
Error	6402.55	447	14.32		
Total	15837.84	450			
Corrected Total	6421.98	449			

4.1.2 Mid-Day Eastbound Vehicle Colors of Black, Light Grey, Red, and White

Table 4.3 outlines the results of the ANOVA test for black, light grey, red, and white vehicles for mid-day, eastbound direction. This p-value is less than the significance level (α=0.05), therefore, it can be concluded that the mean response time of at least one of the vehicle colors is significantly different from the others.

Table 4.3: ANOVA Test Results to Compare Response Times of Black, Red, White, and Light Grey Vehicles for Mid-Day, Eastbound Direction

Source	Type III Sum of Squares	Degree of Freedom	Mean Square	F Statistic	p-value
Corrected Model	2229.70	3	743.24	38.52	0.00
Intercept	15879.84	1	15879.84	823.00	0.00
Color	2229.70	3	743.24	38.52	0.00
Error	11499.81	596	19.30		
Total	29609.35	600			
Corrected Total	13729.51	599			

4.1.3 Mid-Day Westbound Vehicle Colors of Beige and Black

Table 4.4 shows the results of the ANOVA test for beige and black vehicles for mid-day, westbound traffic. Considering that the p-value of 0.34 is greater than the significance level (α=0.05), any difference between response times and vehicle colors for mid-day lighting condition and westbound direction cannot be determined. In other words, for mid-day, westbound direction, the vehicle color does not influence the response times of the participants.

Table 4.4: ANOVA Test Results to Compare Response Times of Beige and Black Vehicles for Mid-Day, Westbound Direction

Source	Type III Sum of Squares	Degree of Freedom	Mean Square	F Statistic	p-value
Corrected Model	5.63	1	5.63	0.90	0.34
Intercept	2369.95	1	2369.95	380.53	0.00
Color	5.63	1	5.63	0.90	0.34
Error	1855.97	298	6.23		
Total	4231.55	300			
Corrected Total	1861.60	299			

4.1.4 Evening Westbound Vehicle Colors of Black, Red, and White

For the evening westbound direction, three vehicle colors were considered: black, red, and white. Table 4.5 shows the results of the ANOVA test for these vehicle colors. The p-value of 0.00 in the corrected model is less than the selected significance level (0.05), meaning that the mean response time of at least one of the vehicle colors is different from the others.

Considering the ANOVA test results of each of the color groups, it cannot be concluded that there are differences between the response times of participants due to vehicle color for (1) morning, eastbound direction, or (2) mid-day, westbound direction. However, for (1) mid-day, eastbound direction, and (2) evening, westbound direction, the response times are affected by the vehicle color. Table 4.6 summarizes the results of the vehicle color comparisons.

Table 4.5: ANOVA Test Results to Compare Response Times of Black, Red, and White Vehicles for Evening, Westbound Direction

Source	Type III Sum of Squares	Degree of Freedom	Mean Square	F Statistic	p-value
Corrected Model	1659.02	2	829.51	50.66	0.00
Intercept	13266.14	1	13266.14	810.22	0.00
Color	1659.02	2	829.51	50.66	0.00
Error	7318.94	447	16.37		
Total	22244.10	450			
Corrected Total	8977.96	449			

Table 4.6: Summary of Vehicle Color Comparison for Directions and Daytime Light Conditions

Comparison	Significant
Morning, eastbound direction, black, red, and white vehicles	No
Mid-day, eastbound direction, black, light grey, red, and white vehicles	Yes
Mid-day, westbound direction, beige and black vehicles	No
Evening, westbound direction, black, red, and white vehicles	Yes

4.2 Identifying Which Vehicle Color is Different

The results of the ANOVA test showed whether the mean response times were different from each other or not. To identify response times of one vehicle color compared to other colors, an LSD test was used. When the F-statistic value is significant or the p-value is less than the significance level (usually α=0.05 in the ANOVA test), the LSD test can be utilized to conduct pairwise comparison (Williams & Abdi, 2010). As shown in the previous section, mid-day, eastbound direction and evening, westbound direction satisfied this requirement and accordingly, the LSD test was carried out for those two comparisons.

Table 4.7 shows the comparisons of black, light grey, red, and white vehicles for mid-day, eastbound direction using the LSD test. In the first column, the base vehicle color is determined and in the second column, the other colors compared to the base vehicle color are given. The third column shows the differences of the response times of base color to the other colors. The p-value provides the pairwise comparison between the mean response times of the base vehicle color to the other vehicle colors. When the p-value is less than a significance level of $\alpha=0.05$, it means the response times of two compared vehicle colors are statistically different at the 5 percent significance level. The value of the mean difference is positive if the mean response times from the base vehicle color are greater than the compared vehicle color, and is negative when the mean response times from the base color are less than the mean response times of the compared color. According to the p-values, there is no significant difference between the mean response times of black and red vehicles. Every other color is significantly different, which means the mean response times of the black and red vehicles are statistically different from the response times of the white and light grey vehicles in mid-day light condition in eastbound direction. Also, comparing the mean response times of white and light grey vehicles indicates that there is significant difference between the mean response times.

Considering the mean differences in Table 4.7, it can be concluded that the red and black vehicles have shorter response times compared to white and light grey vehicles. In addition, the mean response time for a white vehicle is less than the mean response time for a light grey vehicle. In other words, red and black vehicles have shorter response times followed by the mean response time of white vehicles, and light grey vehicles have the longest response times in the mid-day, eastbound direction.

Table 4.7: Comparison of the Response Times of Black, Red, White, and Light Grey Vehicles for Mid-Day, Eastbound Using LSD Test

(I) COLOR	(J) COLOR	Mean Difference (I-J)	Std. Error	p-value	95 percent Confidence Interval for Difference	
					Lower Bound	Upper Bound
BLACK	RED	0.80	0.51	0.12	-0.20	1.79
	WHITE	-2.37*	0.51	0.00	-3.37	-1.38
	LIGHT GREY	-4.07*	0.51	0.00	-5.07	-3.08
RED	BLACK	-0.80	0.51	0.12	-1.79	0.20
	WHITE	-3.17*	0.51	0.00	-4.16	-2.17
	LIGHT GREY	-4.87*	0.51	0.00	-5.86	-3.87
WHITE	BLACK	2.37*	0.51	0.00	1.38	3.37
	RED	3.17*	0.51	0.00	2.17	4.16
	LIGHT GREY	-1.70*	0.51	0.00	-2.70	-0.70
LIGHT GREY	BLACK	4.07*	0.51	0.00	3.08	5.07
	RED	4.87*	0.51	0.00	3.87	5.86
	WHITE	1.70*	0.51	0.00	.71	2.70

*The mean difference is significant at the .05 level.

Table 4.8 shows the comparisons of black, red, and white colors' response times for the evening, westbound direction. Considering p-values, the mean response time of each vehicle color in evening, westbound is statistically different from the other colors' response times. According to the results shown in Table 4.8, the mean response time of the red vehicle is the shortest. The longest mean response time is the black color for the evening, westbound condition.

Table 4.8: Comparison of the Response Times of Black, Red, and White Vehicles for Evening, Westbound Using LSD Test

(I) COLOR	(J) COLOR	Mean Difference (I-J)	Std. Error	p-value	95 percent Confidence Interval for Difference	
					Lower Bound	Upper Bound
BLACK	RED	4.68*	0.47	0.00	3.76	5.60
	WHITE	1.93*	0.47	0.00	1.01	2.85
RED	BLACK	-4.68*	0.47	0.00	-5.60	-3.76
	WHITE	-2.75*	0.47	0.00	-3.67	-1.83
WHITE	BLACK	-1.93*	0.47	0.00	-2.85	-1.01
	RED	2.75*	0.47	0.00	1.83	3.67

*The mean difference is significant at the .05 level

Results of the LSD test showed no difference between the mean response times of red and black vehicles for mid-day eastbound direction. However, response times of both red and black vehicles are statistically different from white and light grey vehicles. The mean response times of white and light grey vehicles are also statistically different. Red and black vehicles have the shortest response times, followed by response times of white vehicles. The light grey vehicle in the mid-day, eastbound direction had the longest response time.

For the evening, westbound direction, mean response times of the black, red, and white vehicles are significantly different from each other. Red, white, and black have increasing mean response times, respectively. The variance of the longest and shortest mean response times of the LSD test is less than 4.7 seconds.

4.3 Comparison of Response Times Under Different Lighting Conditions

The effect of daytime light condition on the vehicle visibility was investigated by comparing the response times for the same vehicle color during different times of day, hence different daytime light conditions. In order to compare the mean response times for a specific vehicle color in a particular direction and various daytime light conditions, an ANOVA test was used and the mean response times were compared. ANOVA tests and pairwise comparisons were conducted for three colors, black, red, and white, for different daytime light conditions on eastbound and westbound as follows:

- Black vehicles, eastbound direction for morning and mid-day light conditions.
- Black vehicles, westbound direction for mid-day and evening light conditions.
- Red vehicles, eastbound direction for morning and mid-day light conditions.
- White vehicles, eastbound direction for morning and mid-day light conditions.

Table 4.9 shows the results of the ANOVA test for black, eastbound vehicles during morning and mid-day light conditions. The p-value of the corrected model is greater than the selected significance level (0.05), which means that vehicle color does not affect the response time for black, eastbound vehicles under morning and mid-day light conditions.

Table 4.9: ANOVA Test Results to Compare Response Times of Black Eastbound Vehicles for Morning and Mid-Day Light Conditions

Source	Type III Sum of Squares	Degree of Freedom	Mean Square	F Statistic	p-value
Corrected Model	44.22	1	44.22	3.34	0.07
Intercept	5082.77	1	5082.77	383.95	0.00
Daytime	44.22	1	44.22	3.34	0.07
Error	3944.95	298	13.24		
Total	9071.93	300			
Corrected Total	3989.17	299			

Table 4.10 shows the results of the ANOVA test for black, westbound vehicles for mid-day and evening light conditions. The p-value of the corrected model is less than the selected

significance level (0.05), which means that the mean response times of black, westbound vehicles for mid-day and evening light conditions are significantly different.

Table 4.10: ANOVA Test Results to Compare Response Times of Black Westbound Vehicles for Mid-Day and Evening Light Conditions

Source	Type III Sum of Squares	Degree of Freedom	Mean Square	F Statistic	p-value
Corrected Model	1646.29	1	1646.29	91.76	0.00
Intercept	8395.97	1	8395.97	467.97	0.00
Daytime	1646.29	1	1646.29	91.76	0.00
Error	5346.50	298	17.94		
Total	15388.76	300			
Corrected Total	6992.79	299			

Table 4.11 shows the results of the ANOVA test for red, eastbound vehicles for morning and mid-day conditions. The p-value of the corrected model is less than the selected significance level (0.05), implying that the mean response times of red, eastbound vehicles for morning and mid-day light conditions are significantly different.

Table 4.11: ANOVA Test Results to Compare Response Times of Red Eastbound Vehicles for Morning and Mid-Day Light Conditions

Source	Type III Sum of Squares	Degree of Freedom	Mean Square	F Statistic	p-value
Corrected Model	152.88	1	152.88	14.35	0.00
Intercept	3999.52	1	3999.52	375.52	0.00
Daytime	152.88	1	152.88	14.35	0.00
Error	3173.86	298	10.65		
Total	7326.27	300			
Corrected Total	3326.74	299			

Table 4.12 shows the results of the ANOVA test for white, eastbound vehicles for morning and mid-day conditions. The p-value of the corrected model is less than the selected significance level (0.05), implying that the mean response times of white, eastbound vehicles for morning and mid-day light conditions are significantly different.

Table 4.12: ANOVA Test Results to Compare Response Times of White Eastbound Vehicles for Morning and Mid-Day Light Conditions

Source	Type III Sum of Squares	Degree of Freedom	Mean Square	F Statistic	p-value
Corrected Model	116.39	1	116.39	7.11	0.01
Intercept	9010.87	1	9010.87	550.38	0.00
Daytime	116.39	1	116.39	7.11	0.01
Error	4878.93	298	16.37		
Total	14006.19	300			
Corrected Total	4995.32	299			

The ANOVA tests reveal that the daytime light conditions significantly influence the mean response times for same vehicle color on same direction except black, eastbound vehicles. To investigate the differences of the mean response times, the LSD test was utilized. Table 4.13 shows the results of the LSD test between the mean response times for black, westbound vehicles during mid-day and evening light conditions. Mean differences indicate that the response time of a black vehicle at mid-day is 4.69 seconds less than the response time of a black vehicle in the evening.

Table 4.13: Comparison of Response Times of Black Westbound Vehicles for Mid-Day and Evening Light Conditions Using LSD Test

(I) DAYTIME	(J) DAYTIME	Mean Difference (I-J)	Std. Error	p-value	95 percent Confidence Interval for Difference	
					Lower Bound	Upper Bound
Mid-Day	Evening	-4.69*	0.49	0.00	-5.65	-3.72
Evening	Mid-Day	4.69*	0.49	0.00	3.72	5.65

*The mean difference is significant at the .05 level.

Table 4.14 shows the LSD test results for red, eastbound vehicles for morning and mid-day. The difference between the mean response times is 1.43 seconds.

Table 4.14: Comparison of Response Times of Red Eastbound Vehicles in Morning and Mid-Day Light Conditions Using LSD Test

(I) DAYTIME	(J) DAYTIME	Mean Difference (I-J)	Std. Error	p-value	95 percent Confidence Interval for Difference	
					Lower Bound	Upper Bound
Morning	Mid-Day	1.43*	0.38	0.00	0.69	2.17
Mid-Day	Morning	-1.43*	0.38	0.00	-2.17	-0.69

*The mean difference is significant at the .05 level.

Table 4.15 shows the LSD test results for the white, eastbound vehicles for morning and mid-day light conditions. The mean difference indicates that participants recognized the white vehicle in the morning light condition 1.25 seconds earlier than the white vehicle in the mid-day light condition.

Table 4.15: Comparison of Response Times of White Eastbound Vehicles in Morning and Mid-Day Light Conditions Using LSD Test

(I) DAYTIME	(J) DAYTIME	Mean Difference (I-J)	Std. Error	p-value	95 percent Confidence Interval for Difference	
					Lower Bound	Upper Bound
Morning	Mid-Day	-1.25*	0.47	0. 01	-2.17	-0.33
Mid-Day	Morning	1.25*	0.47	0. 01	0.33	2.17

*The mean difference is significant at the .05 level.

The mean response times for black, red, and white eastbound vehicles were investigated in morning and mid-day light conditions. The mean response time was not statistically different for black vehicles; however, the mean response times of red and white vehicles were statistically different. Moreover, the mean response time of black, westbound vehicles was statistically different for the mid-day and evening light conditions.

Chapter 5: Summary and Conclusions

5.1 Conclusions

As with previous researchers studying similar data, this research team concludes that vehicle color has no significant effect on response times for vehicle recognition. This study shows that one single color does not stand out above the others. Despite differing lighting conditions where some colors were slightly more recognizable, the difference is not uniformly significant.

The intersection of US-50 and US-281 has experienced regular and increased frequency of vehicle crashes. However, based on the results of this study, there is not enough evidence to determine that these crashes are due to camouflaging of vehicle coloring, and no other immediate cause can be identified. As a result, it is recommended further research be conducted in an attempt to determine the cause of the increased frequency of crashes at this site.

5.2 Discussion

Research of vehicle color in this study was not a fully controlled experiment allowing for all other variables to be constant. Additional technical concerns that may have limited some variables did not function as planned.

For example, editing of video recordings could not be completed due to the limitations of the technology available. Video recording was attempted two different times. During the first attempt, researchers used a control vehicle, a white midsize sedan driven up and down US-50 at different speeds to maintain a single variable. The concept was to use this vehicle as a standard and then to digitally change the color of this vehicle using video editing software. The color change proved to be problematic in that, although researchers could in fact change the color of the vehicle when it was in close proximity to the camera and filling more of the field of view, the color change would not hold when the vehicle was further away and became more pixelated. After many attempts at editing and using a number of different video postproduction tools, the research team determined to reshoot the videos using everyday traffic for the test. While this approach required no editing of the video clips, it also introduced the variable of different makes and models of test vehicles.

Furthermore, technological tools required for in-depth analysis of this type of research were not available to the research team. Tools such as driving simulators, eye-tracking equipment and software, and advanced video techniques will enhance the efforts of future research for this topic.

5.3 Limitations

A number of limitations reduced the data of this research. As noted above, research of this type could involve several months or even years in order to collect all the needed data. This study was limited to five months from beginning approvals to final report. As a result, it was not possible to test different backgrounds and pavement marking conditions.

In addition to the limited time, data collection was also limited to the specific vehicles traveling the highway on the particular day that the researchers were on location. As a result, the color of the vehicles included in the study was not equally distributed into the various driving scenarios.

Furthermore, the study used a convenience sampling of respondents from a population on a university campus. Although a diversity of age was attempted, as expected of such a sample, the majority of respondents were within the younger age group of 18-24. Along with the disproportionate age distribution of respondents, researchers had to rely on the good-hearted nature of respondents to volunteer for participation in the study. The only reward offered was a coupon showing the participation of a subject, with the possibility that an instructor might offer extra credit for the students' participation. Many respondents did not find the participation coupon of interest or value in exchange for their time commitment.

Similar to other studies of this type, this research was limited by vehicle color classifications. As stated by Newstead and D'Elia (2007), "vehicle colours cover an almost infinite spectrum of hues and saturations. Due to pragmatic requirements, vehicle registers are forced to record these into a fixed number of discrete classifications" (p. 11). Such was true in this study; variations to color tones could not be controlled, resulting in highly varied identified vehicle colors within a classification.

This study also researched only a single location. More complete research of this type would have to include multiple locations with similar crash records, similar geometric characteristics, and similar traffic control. Different recordings made under different seasons would also allow testing the effects under different backgrounds and pavement conditions. Each of these scenarios will improve the reliability of the research results and findings.

5.4 Delimitations

In addition to researching the specific location, this study was limited to daylight hours. Specifically the research data was collected during three different time frames (7:00 a.m. to 10:00 a.m., 11:00 a.m. to 2:00 p.m., and 3:00 p.m. to 6:00 p.m.) in an attempt to capture the different light conditions as they changed throughout the day.

Further restrictions were put on the experiment by the research team, limiting vehicles presented to the participants to those without headlights on or large amounts of reflective surfaces such as chrome grilles. Semi-trucks were also omitted from the experiment.

Researchers also limited data collection to a location on a university campus because of the opportunity for reaching higher numbers of potential respondents.

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Appendix A: Collision Diagrams for Studied Years

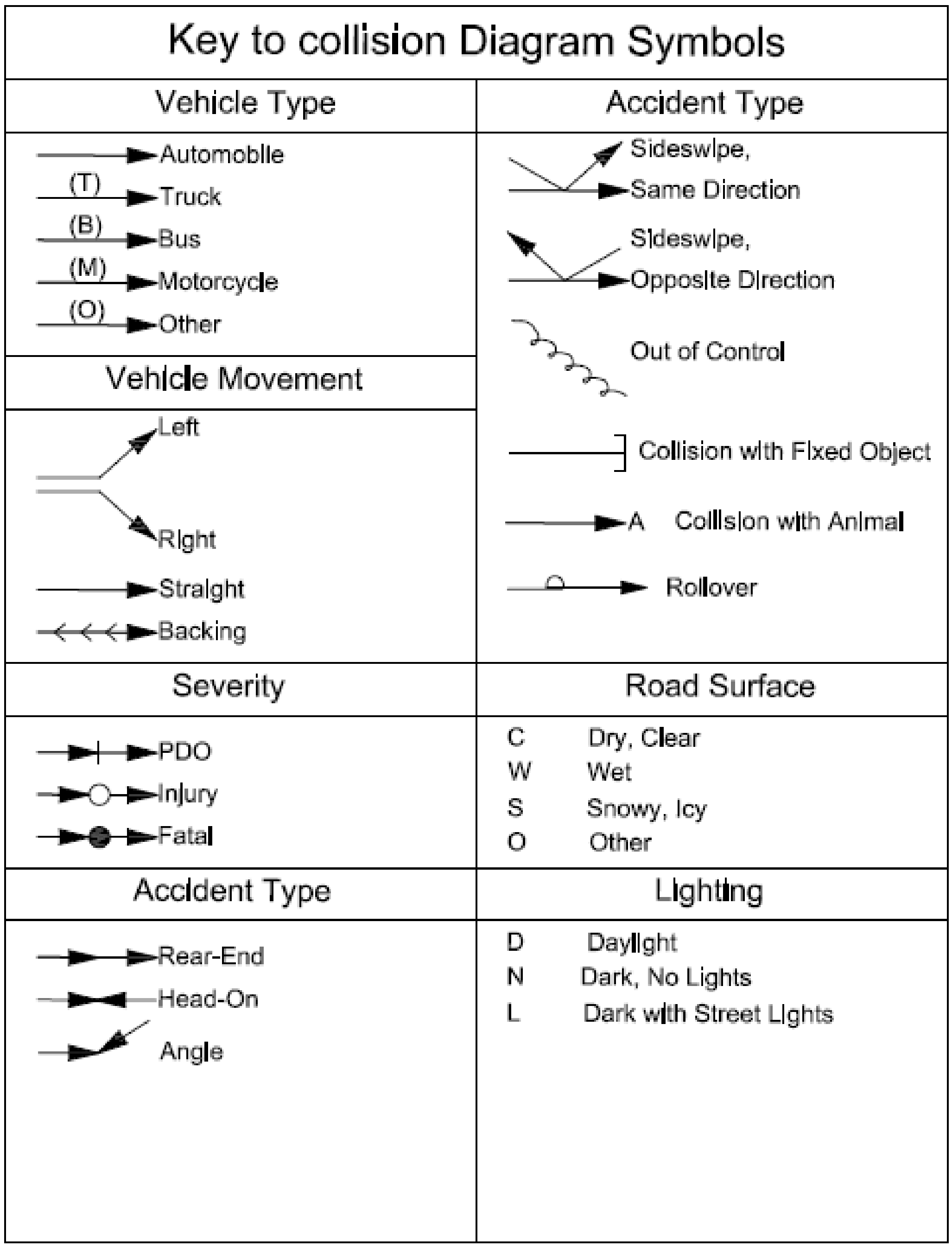

Figure A.1: Legend of Collision Diagrams

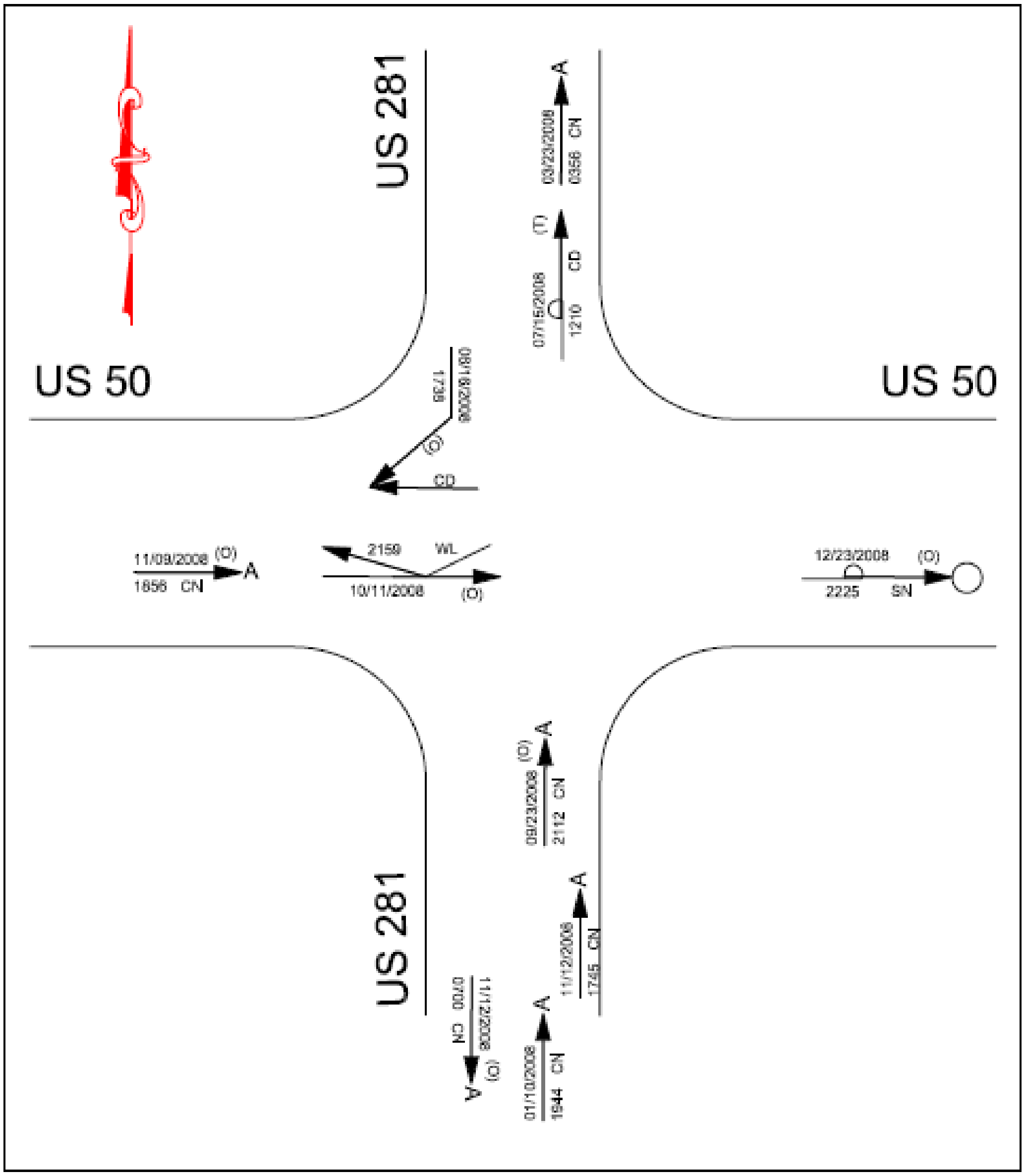

Figure A.2: Collision Diagram of 2008

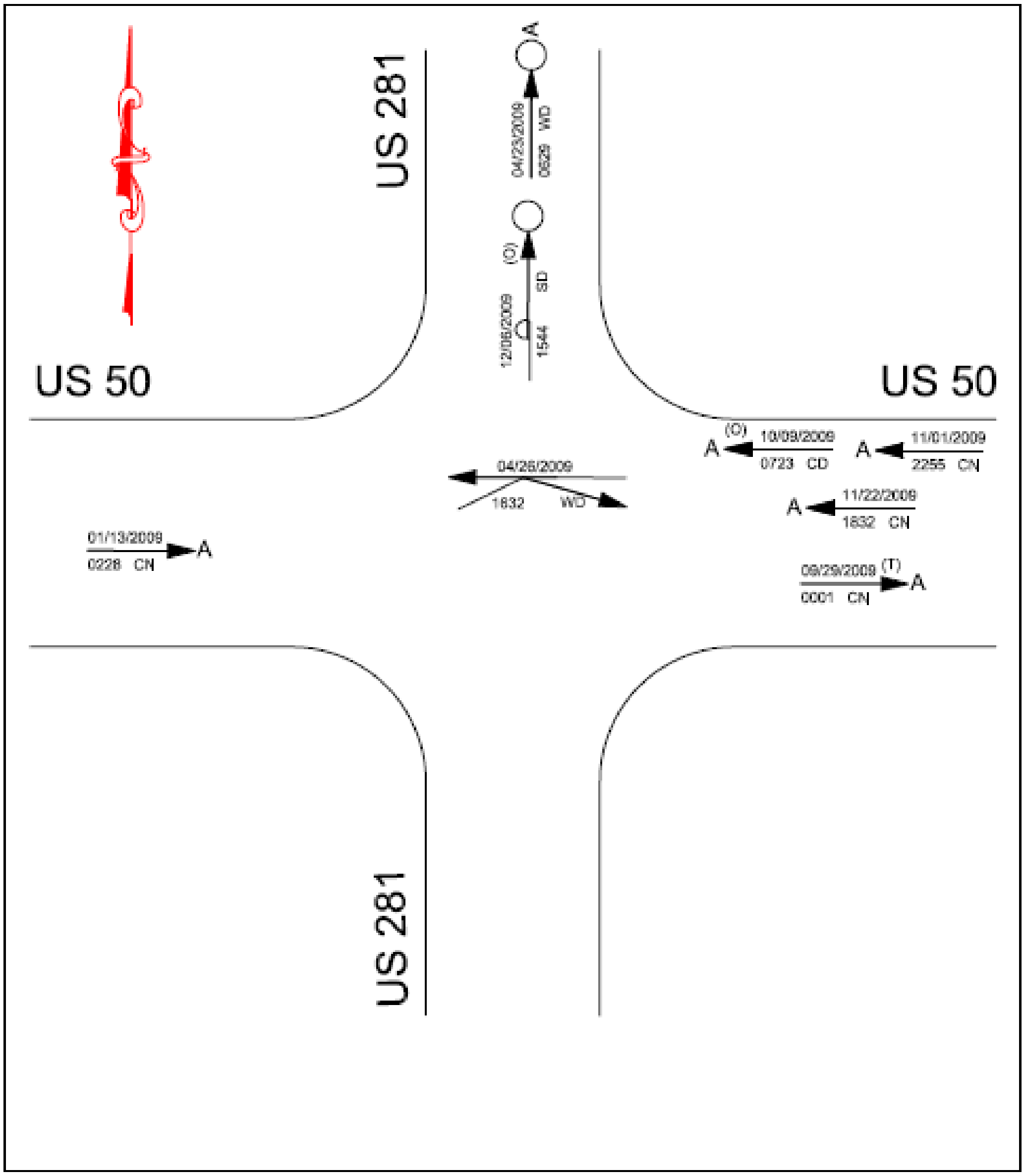

Figure A.3: Collision Diagram of 2009

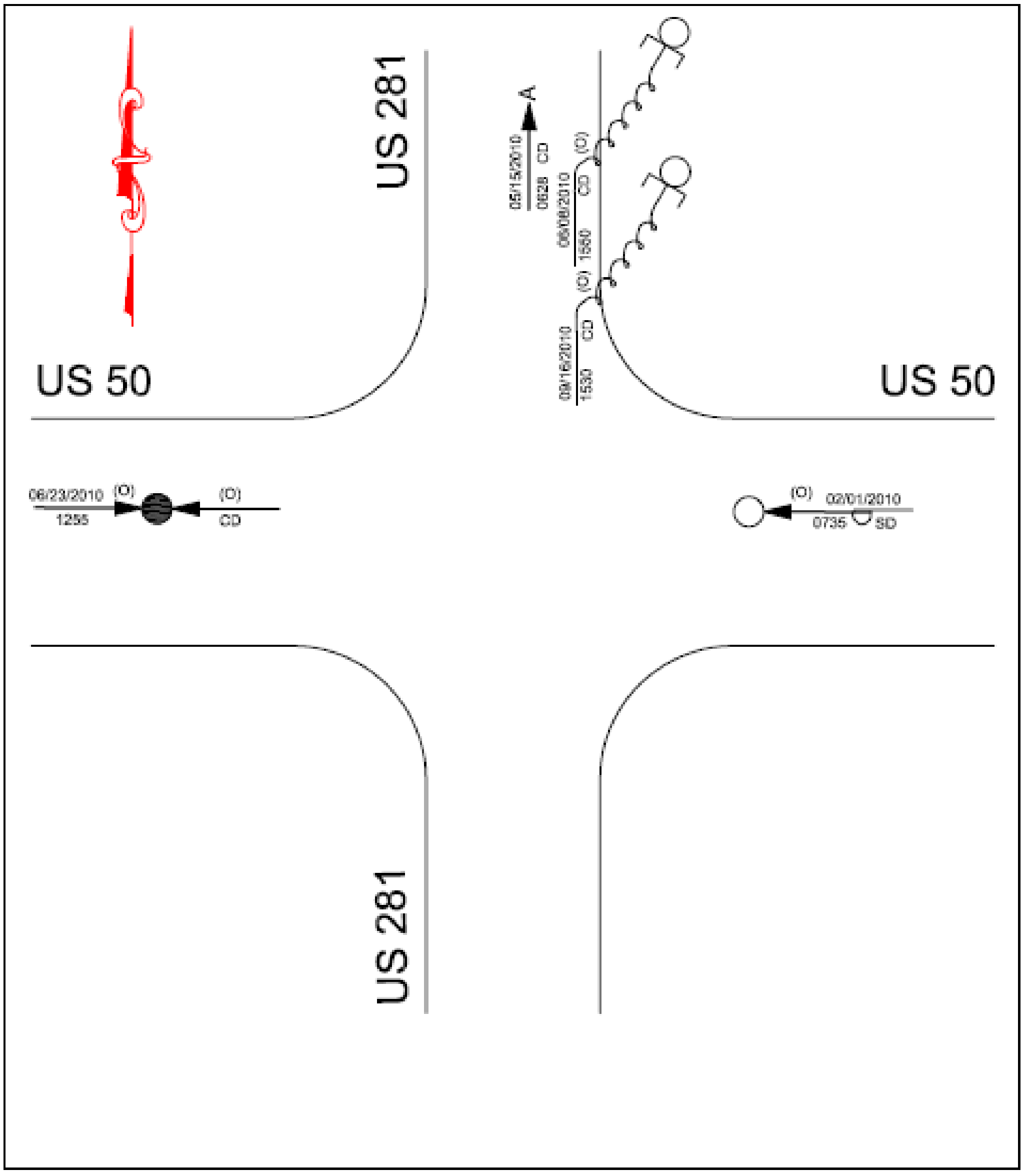

Figure A.4: Collision Diagram of 2010

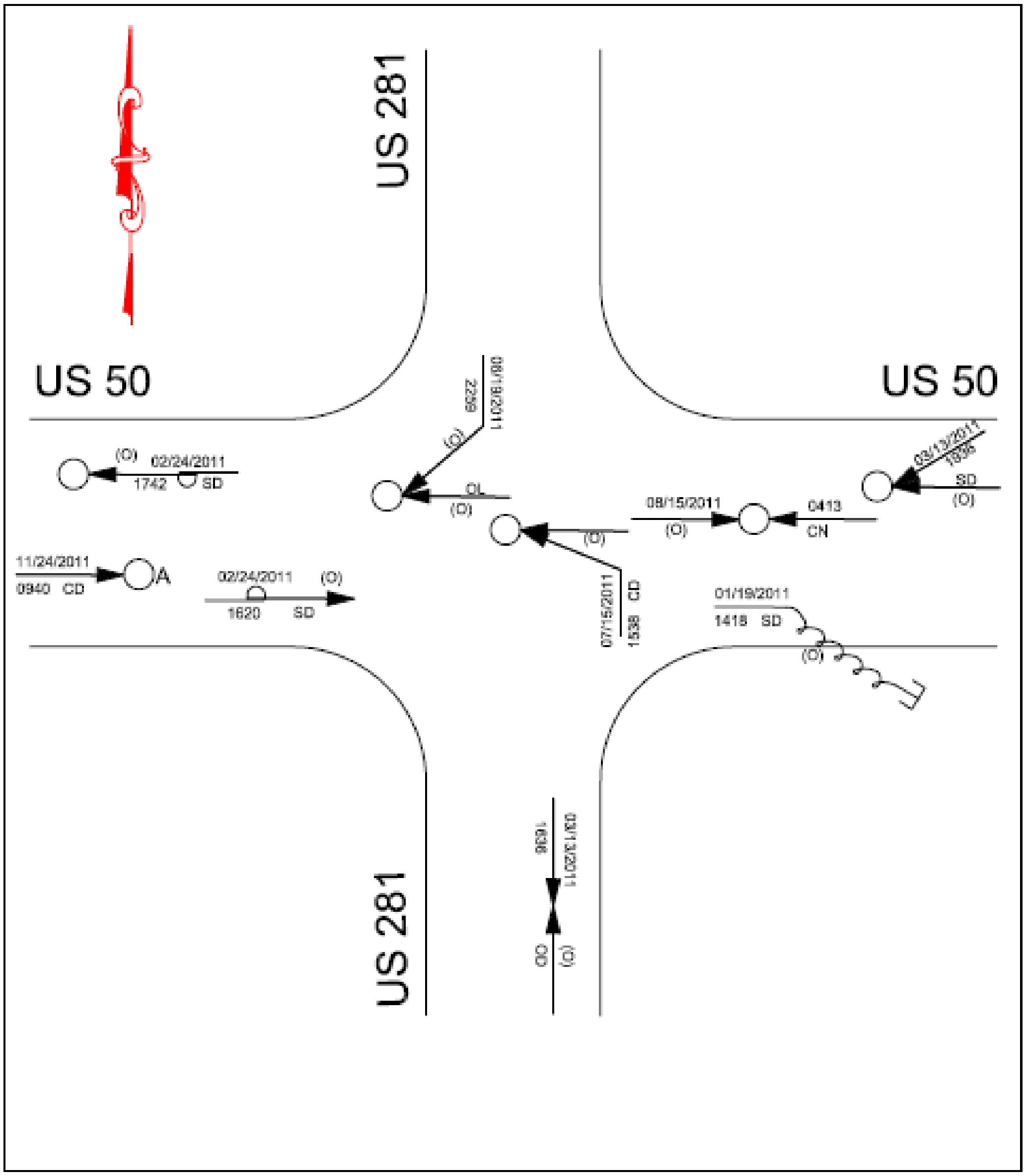

Figure A.5: Collision Diagram of 2011

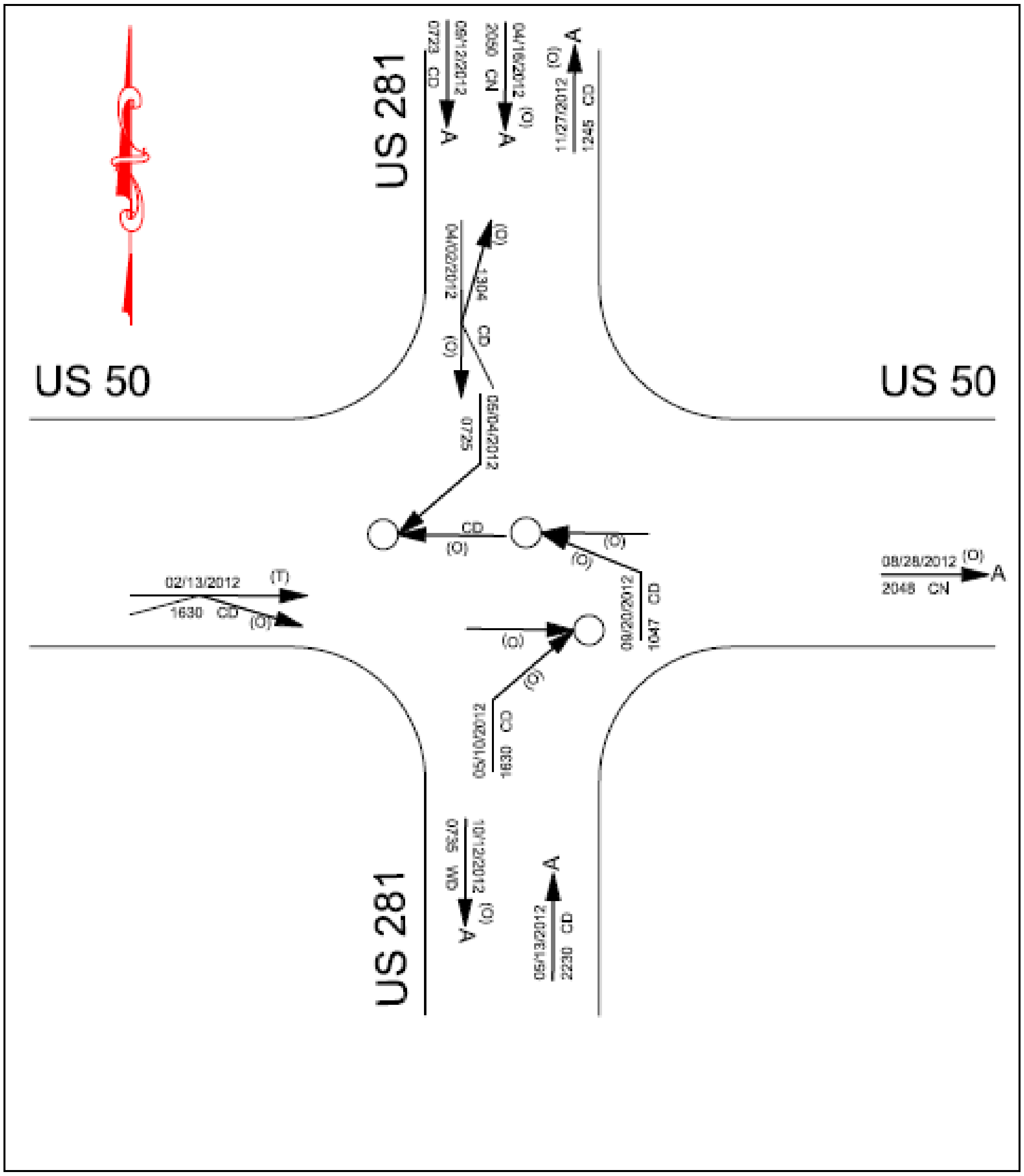

Figure A.6: Collision Diagram of 2012

Appendix B: Information Collection Questionnaire

Thank you for your participation in this research project. Please answer the following questions as completely and truthfully as possible. *Your participation in this study will be kept completely confidential – no information will be gathered that will identify you.*

I. What is your gender?
- ☐ Male
- ☐ Female

II. What is your age?
- ☐ Under 18
- ☐ 18-24
- ☐ 25-34
- ☐ 35-44
- ☐ 45-54
- ☐ 55-65
- ☐ 65 +

III. How many years have you held a valid driver's license? _____________

IV. In what state are you licensed to drive? ___________________________

V. Have you ever had your license revoked for any reason? ☐ Yes ☐ No

VI. Do you wear corrective lenses (glasses or contacts)? ☐ Yes ☐ No

Are you: ______ Nearsighted or _ Farsighted?

VII. Do you have any other conditions that affect your vision (i.e. color blindness, tunnel vision, etc.)? ☐ Yes ☐ No

If Yes, please specify: ____

VIII. What percentage of your driving is done in the following settings:

- ☐ Urban/Suburban
- ☐ Rural
- ☐ Off-road

Should you have any questions or concerns about your participation in this study, you may contact the principle investigator, Dr. Sunanda Dissanayake, KSU Department of Civil Engineering, 785-532-1540, sunanda@ksu.edu.


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