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Study of Seat-belt Usage in Nevada & Driver's Performance

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STUDY OF SEAT-BELT USAGE & DRIVER’S PERFORMANCE

by

Atul Sancheti

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science in Engineering - Electrical Engineering

Department of Electrical & Computer Engineering
Howard R. Hughes College of Engineering
The Graduate College

University of Nevada, Las Vegas
December 2013
THE GRADUATE COLLEGE

We recommend the thesis prepared under our supervision by

Atul Sancheti

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Study of Seat-belt Usage in Nevada & Driver’s Performance

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December 2013
ABSTRACT

STUDY OF SEAT-BELT USAGE IN NEVADA & DRIVER’S PERFORMANCE

by

Atul Sancheti

Dr. Pushkin Kachroo, Examination Committee Chair
Professor of Electrical & Computer Engineering
University of Nevada, Las Vegas

According to the Centers for Disease Control (CDC), motor vehicle incidents has been reported to be the leading cause of the accidental deaths in the United States accounting for more than 42,000 deaths every year. Distracted driving and Driving under influence (DUI) are the major contributors to these roadway crashes. Moreover, drivers fatigue and drowsiness behind the wheel is another important factor contributing to the high fatality rate. These factors results in significant decline in the driver’s abilities of perception, recognition and vehicle control.

It has also been reported by National Highway Traffic Safety Administration (NHTSA) estimated that about 292,471 lives of passenger vehicle occupants age 5 and older were saved because of proper seat-belt use in such crashes from 1975 through 2011. Out of these about 11,949 lives were saved in 2011. According to an estimate provided by NHTSA, if all passenger vehicle occupants wore seat-belts an additional 3,384 would
have been saved in 2011. Thus it is important to spread awareness about such accidents in the field of active safety research.

This thesis looks at the driver’s seat-belt usage in Nevada for 2012 and also studies driver’s performance behind the wheel under various distractions and impairments on the driver. This has been primarily done to focus on the driver’s attitude towards road safety. By conducting a seat-belt usage survey across Nevada in the year 2012, we have captured seat-belt usage across gender, age groups, ethnicity, vehicle types, state of registration, road types and in different counties. This data was further provided to NHTSA to focus primarily on the areas with low seat-belt usage during the Click it or Ticket (CIOT) mobilization campaign. Another aspect of the research work was to study driver’s performance behind the wheel under various impairments and distractions induced on the driver. This study has been conducted in a laboratory environment to avoid any potential dangers to anyone associated with the study. A driver was provided with a cell phone to text and talk while driving on a driving simulator located at Transportation research Center (TRC). Moreover, to induce a similar effect as alcohol, a driver was provided with fatal vision goggles with varying Blood Alcohol Concentration (BAC) while the driver’s road performance was recorded on the simulator.
ACKNOWLEDGEMENTS

I would like to express my sincere thanks and gratitude to my advisor Dr. Pushkin Kachroo for inspiring, motivating and guiding me throughout my research. I am also grateful to my committee members Dr. Masha Wilson, Dr. Amei Amei and Dr. Ebrahim Saberinia for their insightful remarks.

I would also like to take this opportunity to show my gratitude and appreciation towards my parents Mr. Pramod Kumar Sancheti, Mrs. Sunita Sancheti, my brother Ashwin Sancheti and my entire family for being there and showing their love and support throughout the course of my research. Their constant enthusiasm and quest to know about my research motivated me to work more effectively and efficiently towards my goal.

I am also grateful to the support and motivation provided by my friends Anuj Nayyar, Himanshu Verma, Pratik Verma, Puneet Lakhanpal, Romesh Khaddar, Sergio Contreras, Shaurya Agarwal and Sourabh Srom during this journey. Last but not the least, I would like to thank to all the participants who helped me during the course of this study.
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CHAPTER 1

INTRODUCTION

1.1 Overview

Motor vehicle crashes are the leading factors for the number of death in the United States [1]. Every year thousands of people die and gets critically injured in these crashes. Several safety awareness campaigns have been deployed throughout the United States to spread awareness and educate people about the possible ways to reduce the number of fatalities in such crashes. In spite of these awareness campaigns, number of severe injuries and fatalities and the overall number of such accidents is a stark reality. According to an estimate provided by NHTSA, in 2011 29 percent of passenger car occupants and 33 percents of light truck occupants involved in fatal crashes were unrestrained. Also, it has been reported that in fatal crashes, 77 percent of passenger vehicle occupants who were totally ejected from vehicles were killed. Seat-belts are very effective in preventing total ejections. This has been re-iterated by the fact that only 1 percent of the occupants reported to have been using restraints were totally ejected which is a relatively lesser percentage than 31 percent of the unrestrained occupants [5].

Figure 1.1 shows the overall yearly fatalities in the United States from 2001-2010. According to Fatality Analysis Reporting System (FARS) following factors have been
mainly associated with the majority of these crashes. These are:-

- Alcohol Induced Crashes
- Distraction Induced Crashes
- Drowsiness/ Fatigue Induced Crashes

1.1.1 Alcohol Induced Crashes

A driver is said to be impaired by alcohol when his/her blood alcohol concentration (BAC) is 0.08 grams per deciliter (g/dL) or more. Any fatal crash resulting due to a driver with a BAC of 0.08 or more is referred to as alcohol impaired driving crash.
and such fatalities are termed as alcohol impaired driving fatalities [2]. In 2010, 10,228 people died in alcohol impaired driving crashes, thereby accounting for 31 percent of the total motor vehicle fatalities in the United States. Figure 1.2 shows the distribution for alcohol impaired fatalities from 2001-2010 in the United States. Moreover in recent years around 1.5 million drivers have been arrested for driving under the influence of alcohol which is way beyond the number of people arrested for other crimes such as theft or vandalism. It is evident from these statistics that despite of various educational and regulatory measures adopted by local, state and federal governments alcohol induced driving crashes continues to be a public safety issue.

![Figure 1.2: Yearly Fatalities in Alcohol Impaired Motor Vehicle Crashes](image-url)

Figure 1.2: Yearly Fatalities in Alcohol Impaired Motor Vehicle Crashes
1.1.2 Distraction Induced Crashes

As we are making progress in educating more and more people about using seat-belts while driving and not to drive under the influence, newer and more dangerous avenues have come into picture. According to National Highway Traffic Safety Administration (NHTSA), distracted driving accounted for 5,474 deaths and 448,000 injuries in 2009. In addition to this, the percentage of deaths reported due to distracted driving has increased from 10 percent in 2005 to 16 percent in 2009. Any task that diverts drivers attention from the primary task of navigating the vehicle is termed as distraction. Various forms of distraction have been identified such as texting; using cellphones, eating, reading etc. are the most reported ones.

Among these various sources of distraction, cellphones are accounted as the leading distracting factor. According to the National Occupant Protection Use Survey (NOPUS) conducted by NHTSA, the percentage of drivers holding cellphones to their ears was around 5 percent in 2010. Figure 1.3 shows the percentage of handheld cellphone use from 2002-2010 [3]. Moreover according to the behavioral research conducted in Carnegie Mellon University around 37% of the brain activity is reduced by using a cellphone [4]. Hence it is important to educate people about the evils of distracted driving and to come up with a system to generate a warning signal whenever a driver is getting distracted.
1.1.3 Drowsiness/ Fatigue Induced Crashes

According to NHTSA, approximately 100,000 crashes are caused by drowsiness/fatigue impaired driving every year. Moreover around 71,000 people are severely injured and about 1,500 people die in these accidents. Although the awareness about driving under the influence and the need to buckle-up are important and are being spread through various media campaigns, the dangers of driving while feeling drowsy or fatigued are still very under appreciated. According to a survey conducted by National Sleep Foundation (NSF), 32% of the participants reported that they have driven drowsy at least once per month. In addition, 36% of the drivers have nodded off or fallen asleep behind the wheel. It has also been reported that being awake for
18 hours or more leaves one at the same level of risk for a crash as a person with a BAC of 0.08.

The above mentioned factors results in significant decline in the drivers abilities of perception, recognition and vehicle control. Thus it is an important aspect to study drivers performance and behavior induced due to the above mentioned circumstances in the field of active safety research.

1.2 Thesis Contribution

The objective of this thesis is to study the Daytime Seat-belt usage in Nevada. The sampling methodology for seat-belt survey was based on the average fatalities in last 5 years. This was changed from the earlier used population based sampling methodology. This was done to remove bias induced by highly populated area in calculation of seat-belt usage. Also, it was done to focus the attention towards the area with high crash fatalities.

Another aspect of the thesis focus on studying driver’s performance in different environments such as driving while texting, driving while talking on the cell phone, driving with induced blood alcohol concentrations. This study was performed in a simulated laboratory environment with a virtual driving scenario created on a driving simulator. To induce the alcohol impairment on a driver, fatal vision goggles were used. To study the effects of distractions, a cell phone was used and driver’s driving performance while texting and talking on the cell phone was recorded.
1.3 Thesis Structure

This thesis is structured in two sections. Section I covers the Daytime Seat-belt Usage in Nevada for 2012. This section explains in detail the sampling methodology used and the procedure followed for conducting a statewide seat-belt survey. In addition, it also describes the results obtained from the seat-belt survey. Chapter 2 gives a brief introduction to the sampling technique used for selecting survey sites for the seat-belt survey. Chapter 3 explains the data collection strategy followed during the survey to collect the seat-belt usage data across Nevada. Chapter 4 explains in brief about the data analysis procedures followed to estimate the seat-belt usage. This chapter also explains the non-response adjustment and sampling weight to be distributed across each site. Chapter 5 summarizes the seat-belt usage result for Daytime Seat-belt Usage Survey 2012 in Nevada across various categories such as gender, age, ethnicity, vehicle type, vehicle’s state of registration, road types and county where the survey was conducted.

Section II covers the study of driver’s performance behind the wheel across various distractions and influences on the driver. The performance of the driver is compared amongst different scenarios and also compared to the driving without any of the induced distractions and influence on the driver. Chapter 6 provides an insight to the previous research done to study driver’s performance with different types of distractions. Chapter 7 explains about the experimental setup used for this study. Chapter 8 describes the analysis performed on the obtained data from this study. The analysis includes basic statistical analysis, frequency based analysis and entropy analysis to
study the randomness of data obtained in different scenarios.

Chapter 9 concludes combining results from both sections and the areas which can be explored further.
SECTION I: SEAT-BELT USAGE
CHAPTER 2

SAMPLING METHODOLOGY

The Nevada Department of Public Safety (DPS) Office of Traffic Safety (OTS) contracted with the Transportation Research Center (TRC) at the University of Nevada, Las Vegas (UNLV) to design the Statewide Seat Belt Use Survey Methodology for Nevada. The sampling methodology used earlier was based on the population distribution across counties. According to the Part 1340 - Uniform Criteria for State Observational Surveys of Seat Belt Use provided by National Highway Traffic Safety Administration (NHTSA), average fatality distribution across the counties was to be used as a parameter for the first stage sampling. This is done to remove the unintended bias in seat belt use rates introduced due to the population based criterion. Moreover, this would enable the states to focus more on areas with traffic safety concerns.

2.1 Sample Design

A stratified multistage design, in which counties are PSUs, road segments are SSUs, followed by time segment, road direction, lane, and vehicles selection is followed to select the observation site. All passenger vehicles with a gross vehicle weight up to 10,000 pounds will be included in the survey. This includes small commercial
vehicles. The target population of this methodology includes all drivers and right-front passengers of all passenger vehicles that travel on all roads within the state boundary from 7 a.m. to 6 p.m. in all days of the calendar year.

2.1.1 County Sampling Frame

According to the Uniform Criterion 1340 [8] average fatality index in the state should be considered as a factor for inclusion or exclusion of counties. States have the option to use either last 3, 4 or 5 years of the average fatality data provided by NHTSA. This data is available through NHTSA’s Fatality Analysis Reporting System (FARS) [7]. Table 2.1 lists the 5-year average fatality counts based on FARS data for the counties in Nevada.

Table 2.1: List of Counties in Nevada by Fatality (Source: NHTSA [11])

<table>
<thead>
<tr>
<th>County</th>
<th>Average Fatality Count</th>
<th>Fatality %</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark</td>
<td>228</td>
<td>63.2%</td>
<td>63.2%</td>
</tr>
<tr>
<td>Washoe</td>
<td>33</td>
<td>9.1%</td>
<td>72.3%</td>
</tr>
<tr>
<td>Nye</td>
<td>20.4</td>
<td>5.7%</td>
<td>78.0%</td>
</tr>
<tr>
<td>Elko</td>
<td>16.8</td>
<td>4.7%</td>
<td>82.7%</td>
</tr>
<tr>
<td>Lyon</td>
<td>8.8</td>
<td>2.4%</td>
<td>85.1%</td>
</tr>
<tr>
<td>Douglas</td>
<td>8.4</td>
<td>2.3%</td>
<td>87.4%</td>
</tr>
</tbody>
</table>

continued on next page
<table>
<thead>
<tr>
<th>County</th>
<th>Average Fatality Count</th>
<th>Fatality %</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humboldt</td>
<td>8.4</td>
<td>2.3%</td>
<td>89.7%</td>
</tr>
<tr>
<td>Churchill</td>
<td>6.2</td>
<td>1.7%</td>
<td>91.4%</td>
</tr>
<tr>
<td>White Pine</td>
<td>6.2</td>
<td>1.7%</td>
<td>93.1%</td>
</tr>
<tr>
<td>Lincoln</td>
<td>5.6</td>
<td>1.6%</td>
<td>94.7%</td>
</tr>
<tr>
<td>Carson City</td>
<td>5</td>
<td>1.4%</td>
<td>96.1%</td>
</tr>
<tr>
<td>Pershing</td>
<td>3.4</td>
<td>0.9%</td>
<td>97.0%</td>
</tr>
<tr>
<td>Esmeralda</td>
<td>2.8</td>
<td>0.8%</td>
<td>97.8%</td>
</tr>
<tr>
<td>Lander</td>
<td>2.6</td>
<td>0.7%</td>
<td>98.5%</td>
</tr>
<tr>
<td>Mineral</td>
<td>2</td>
<td>0.6%</td>
<td>99.1%</td>
</tr>
<tr>
<td>Storey</td>
<td>2</td>
<td>0.6%</td>
<td>99.7%</td>
</tr>
<tr>
<td>Eureka</td>
<td>1.3</td>
<td>0.3%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Under Criterion 1340.5.a.1, a state may exclude counties comprising up to 15 percent of their passenger vehicle occupant fatalities. A state may select any combination of counties while employing this exclusion. Thus the state of Nevada chooses the top five counties in table 2.1 accounting for 85 percent of total passenger motor vehicle fatality to form the county sampling frame. The counties included in the sampling frame are Clark, Washoe, Nye, Elko and Lyon counties.

In Table 2.2, the most recent Annual Vehicle Miles Traveled (AVMT) data for the year 2009 obtained from Nevada DOT has been given. Table 2.2 shows that Clark, Washoe, Nye, Elko and Lyon accounts for about 88 percent of annual vehicle miles
of travel in Nevada. Since the selected five counties, Clark, Washoe, Nye, Elko and Lyon also satisfy the 85 percent of total fatality criterion, no further stage 1 sampling is required.

Table 2.2: List of Counties in Nevada with AVMT in 2009 [13]

<table>
<thead>
<tr>
<th>County</th>
<th>AVMT (millions)</th>
<th>Change from 2008-09</th>
<th>AVMT %</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark</td>
<td>13,678</td>
<td>-0.9%</td>
<td>65.40%</td>
<td>65.40%</td>
</tr>
<tr>
<td>Washoe</td>
<td>3,220</td>
<td>-0.98%</td>
<td>15.40%</td>
<td>80.80%</td>
</tr>
<tr>
<td>Nye</td>
<td>378</td>
<td>0.8%</td>
<td>1.81%</td>
<td>82.61%</td>
</tr>
<tr>
<td>Elko</td>
<td>656</td>
<td>-0.61%</td>
<td>3.14%</td>
<td>85.75%</td>
</tr>
<tr>
<td>Lyon</td>
<td>485</td>
<td>1.25%</td>
<td>2.32%</td>
<td>88.07%</td>
</tr>
<tr>
<td>Douglas</td>
<td>513</td>
<td>-1.1%</td>
<td>2.45%</td>
<td>90.52%</td>
</tr>
<tr>
<td>Carson City</td>
<td>358</td>
<td>-.72%</td>
<td>1.71%</td>
<td>92.23%</td>
</tr>
<tr>
<td>Churchill</td>
<td>295</td>
<td>1.71%</td>
<td>1.41%</td>
<td>93.64%</td>
</tr>
<tr>
<td>Humboldt</td>
<td>313</td>
<td>2.62%</td>
<td>1.5%</td>
<td>95.14%</td>
</tr>
<tr>
<td>White Pine</td>
<td>158</td>
<td>3.27%</td>
<td>0.76%</td>
<td>95.90%</td>
</tr>
<tr>
<td>Pershing</td>
<td>252</td>
<td>6.8%</td>
<td>1.2%</td>
<td>97.10%</td>
</tr>
<tr>
<td>Lander</td>
<td>123</td>
<td>3.36%</td>
<td>0.59%</td>
<td>97.69%</td>
</tr>
<tr>
<td>Mineral</td>
<td>111</td>
<td>0.1%</td>
<td>0.53%</td>
<td>98.22%</td>
</tr>
<tr>
<td>Storey</td>
<td>28</td>
<td>1.51%</td>
<td>0.14%</td>
<td>98.35%</td>
</tr>
</tbody>
</table>

continued on next page
<table>
<thead>
<tr>
<th>County</th>
<th>AVMT (millions)</th>
<th>Change from 2008-09</th>
<th>AVMT %</th>
<th>Cumulative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln</td>
<td>124</td>
<td>4.2%</td>
<td>0.59%</td>
<td>98.95%</td>
</tr>
<tr>
<td>Eureka</td>
<td>126</td>
<td>3.3%</td>
<td>0.6%</td>
<td>99.55</td>
</tr>
<tr>
<td>Esmeralda</td>
<td>89</td>
<td>2.3%</td>
<td>0.43%</td>
<td>99.98</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20,914</strong></td>
<td><strong>-0.51%</strong></td>
<td><strong>100%</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>

### 2.1.2 PSU Sample Selection

In the previous subsection a sampling frame of counties has been prepared accounting for 85 percent of the total passenger motor vehicle fatalities. Now after the exclusion based on historical fatality counts only five counties are retained in the sampling frame. In such a scenario NHTSA has provided with an alternative design where all the sampled counties are selected with certainty. The procedure to calculate the sample size for the number of roadway segments in each selected county is shown in the next subsection.

### 2.1.3 Sample Size Determination

The sample size at all the stages of the sampling is dependent on the seat belt use rate estimator and the variance constraint from criterion 1340.5.d. To optimally allocate sample sizes at all stages and all strata we will need the total variance formula of the seat-belt use rate estimator. The current sample design has six stages of sample selection: county, road segment, time segment, direction, lane and vehicle.
The sample size at time segment, road direction and lane stages are determined by operation constraints. So we will only consider sample allocation at county, road segment and vehicle stages. Firstly, we will use a simplified variance model to allocate an average sample size to each stage and then allocate sample sizes to strata at each stage.

We first assume the population has \( N \) PSUs (counties), each PSU has \( M \) secondary sampling units (SSUs, road segments), and each SSU has \( K \) third-stage units (TSUs, vehicles). A sample is selected in three stages: selecting \( n \) counties out of total \( N \) counties at first stage, selecting \( m \) road segments out of total \( M \) road segments at second stage, and selecting \( k \) vehicles out of total \( K \) vehicles at third stage.

The only difference to the above described strategy is that we have already selected all the PSUs at the first stage in the frame, i.e.,

\[
n = N
\]

Now under this model, if \( y_{ijk} \) is the driver’s seat belt status, the belt use rate can be estimated by the sample mean \( \bar{y} = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{u=1}^{k} y_{iju} / nmk \) and the variance model is:

\[
V(\bar{y}) = \frac{1 - f_1}{n} S_1^2 + \frac{1 - f_2}{nm} S_2^2 + \frac{1 - f_3}{nmk} S_3^2 
\]

(2.1)

Here \( f_1 = n/N, f_2 = m/M, f_3 = k/K \) are sampling fractions at each stage. And because \( n = N \), therefore \( 1 - f_1 = 0 \). So the total variance reduces to

\[
V(\bar{y}) = \frac{1 - f_2}{nm} S_2^2 + \frac{1 - f_3}{nmk} S_3^2 
\]

(2.2)
Notice the actual second-stage sample is stratified by road type - both considered to be correlated with belt use rate. Therefore we believe at the second stage, the actual design is more efficient than this simplified model. But at the third stage this model may underestimate the actual variance because of the dropped stages. To make this model more conservative, we notice $1 - f_i < 1 (i = 2, 3)$, therefore

$$V(\bar{y}) < \frac{1 - f_2}{nm} S^2_2 + \frac{1 - f_3}{nmk} S^2_3$$

(2.3)

With this simplified variance model, the sample allocation becomes the following optimization problem:

$$\text{Min}: c_1 n + c_2 nm + c_3 nmk$$

$$\text{st }: \frac{1}{nm} S^2_2 + \frac{1}{nmk} S^2_3 = (2.5\%)^2$$

(2.4)

Here $c_1$ is the cost for adding one PSU to the sample such as travel to the selected county; $c_2$ is the cost for adding one road segment to the sample such as travel among the selected road segments and set up time at each site; $c_3$ is the cost for adding one vehicle to the sample, i.e. the time to wait, observe and record a vehicle. All costs are measured by or converted to the same unit such as time so they are comparable.

Now as we have $n = N$, so minimizing $c_1 n + c_2 nm + c_3 nmk$ is the same as minimizing $c_2 m + c_3 mk$. Therefore the above optimization problem reduces to:

$$\text{Min}: c_2 m + c_3 mk$$
\[ st : \frac{1}{m} S_2^2 + \frac{1}{mk} S_3^2 = n \times (2.5\%)^2 \] (2.5)

In the variance model, \( S_3^2 \) is the population variance of the driver’s belt use status \( y_{iju} \) around the road segment and is estimated by historical data:

\[
S_3^2 = \frac{1}{n'm'(k' - 1)} \sum_{i=1}^{n'} \sum_{j=1}^{m'} \sum_{u=1}^{k'} (y_{iju} - \hat{p}_{ij})^2
\] (2.6)

Here \( n', m', k' \) are historical data sample sizes. \( \hat{p}_{ij} \) are road segment driver’s belt use rates estimated from historical data. \( S_2^2 \) is the population variance of the road segment belt use rates around county belt use rate. Ignoring the finite population correction \( f_i \), \( S_2^2 \) can be estimated by:

\[
\hat{S}_2^2 = s_2^2 - \frac{s_3^2}{k'}
\] (2.7)

here

\[
s_2^2 = \frac{1}{n'(m'-1)} \sum_{i=1}^{n'} \sum_{j=1}^{m'} (\hat{p}_{ij} - \hat{p}_i)^2
\]

\( \hat{p}_i \) is county \( i \) driver’s belt use rate estimated from historical data.

Using this notation, the solution to the optimization problem is:

\[
k = \sqrt{\frac{c_2}{c_3}} \frac{S_2^2}{S_3^2}
\]

\[
m = \frac{s_2^2 + \frac{1}{m} S_2^2}{n \times (2.5\%)^2}
\]

Here \( n = N \) is the known number of all counties remain in the county frame after the county exclusion based on fatality counts.
According to the historical data, the estimated variance $S^2_2 = 0.0447$ and $S^2_3 = 2.0995$. Using the above formulas the value for m, i.e. the number of road segments in each county was found out to be 22. The calculated value for k was found out to be 88, i.e. the total number of vehicles to be observed at a site is 88. However, the observation time at each site has been decided as 45 minutes at each site.

The number of vehicles expected to be observed per site (k) is 88 and the total expected sample size (n*m*k) is 9680.

2.1.4 Roadway Sampling Frame

For each selected county, we shall form a sampling frame of roadways by applying the restriction allowed in Criterion 1340.5.a to the roads in Nevada. A comprehensive and up-to-date database of the roadways in the above mentioned sampled counties was obtained from U.S. Census Bureau [9]. The roadway database strictly comprises only of the road segments as allowed in Criterion 1340.5.a. The rural local roads in counties that are not included in U.S. Census Metropolitan Statistical Area (MSA) are excluded from the design. A roadway segment database was requested from NHTSA with size of roadway segments less than 5 miles. The Nevada’s roadway database is primarily divided in 15 divisions of roadway segments out of which only three are included in the criterion namely S1100, S1200 and S1400. These three road types are described below:

**S1100 - Primary Road**
Primary roads are generally divided, limited-access highways within the interstate highway system or under state management, and are distinguished by the presence of interchanges. These highways are accessible by ramps and may include some toll highways.

**S1200 - Secondary Road**

Secondary roads are main arteries, usually in the U.S. Highway, State Highway or County Highway system. These roads have one or more lanes of traffic in each direction, may or may not be divided, and usually have at-grade intersections with many other roads and driveways. They often have both a local name and a route number.

**S1400 - Local Neighborhood Road, Rural Road, City Street**

These are generally paved non-arterial streets, roads, or byways that usually have a single lane of traffic in each direction. Roads in this feature class may be privately or publicly maintained. Scenic park roads would be included in this feature class, as would (depending on the region of the country) some unpaved roads.

The sampled counties are further subdivided in the above discussed categories of road types, where the length of the road types is the measure of size (MOS).

Also, functional classification maps [12] are provided by Nevada DOT for roadway segments falling in rural and urban areas for Clark, Washoe, Nye, Elko and Lyon counties. This can be seen in Figures 2.1, 2.2, 2.3, 2.4, 2.5.
Figure 2.1: Roadway Functional Classification - Clark County
Figure 2.2: Roadway Functional Classification - Washoe County
Figure 2.3: Roadway Functional Classification - Nye County
Figure 2.4: Roadway Functional Classification - Elko County
Figure 2.5: Roadway Functional Classification - Lyon County
2.1.5 Selection of Road Segments

Now the number of roadway segments to be selected from each stratum in a county is known, the roadway segment can be selected from the roadway segment database provided by NHTSA. The sampling method being used to select the roadway segment is based on selecting segments with probability proportional to size (PPS) where the length of roadway segment (in miles) is the measure of size (MOS).

Suppose if \( r \) represents total number of roadway segments to be selected in a county \( c \), \( r_{ch} \) represents total roadway segments to be selected from a stratum \( h \) in a given county \( c \), \( M_{ch} \) is the total length of roadway segments in a stratum \( h \) of a county \( c \). Then:

\[
r_{ch} = r \frac{M_{ch}}{\sum M_{ch}} \tag{2.8}
\]

Table 2.3 shows the number of roadway segments after applying the above division criteria from Stage 2. As shown in the table that the calculated values are fractions, rounding off the fraction to the next integer gives the number of roadway segments in each stratum.

Within each road-type stratum \( h \), each selected road segment receives a selection probability given by \( \pi_{hi|c} \) as:

\[
\pi_{hi|c} = r_{ch} \frac{M_{chi}}{\sum M_{chi}} \tag{2.9}
\]

Here \( M_{chi} \) is the measure of size (length) for roadway segment \( i \).
Table 2.3: Number of roadway segments after Stage 2

<table>
<thead>
<tr>
<th>County</th>
<th>Road-type</th>
<th>$M_{ch}$</th>
<th>$r_{ch}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clark</td>
<td>S1100</td>
<td>461.07</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>S1200</td>
<td>511.65</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>S1400</td>
<td>7258.81</td>
<td>19.40</td>
</tr>
<tr>
<td>Washoe</td>
<td>S1100</td>
<td>85.21</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>S1200</td>
<td>324.91</td>
<td>2.09</td>
</tr>
<tr>
<td></td>
<td>S1400</td>
<td>3014.71</td>
<td>19.37</td>
</tr>
<tr>
<td>Nye</td>
<td>S1100</td>
<td>0.67</td>
<td>0.0195</td>
</tr>
<tr>
<td></td>
<td>S1200</td>
<td>752.98</td>
<td>21.9805</td>
</tr>
<tr>
<td></td>
<td>S1400</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Elko</td>
<td>S1100</td>
<td>254.07</td>
<td>6.95</td>
</tr>
<tr>
<td></td>
<td>S1200</td>
<td>550.41</td>
<td>15.05</td>
</tr>
<tr>
<td></td>
<td>S1400</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lyon</td>
<td>S1100</td>
<td>29.79</td>
<td>2.37</td>
</tr>
<tr>
<td></td>
<td>S1200</td>
<td>246.34</td>
<td>19.63</td>
</tr>
<tr>
<td></td>
<td>S1400</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2.4: Distribution of sites

<table>
<thead>
<tr>
<th>Strata</th>
<th>Clark</th>
<th>Washoe</th>
<th>Nye</th>
<th>Elko</th>
<th>Lyon</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1100</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>

*continued on next page*
The locations of 117 selected road segments for the survey is being shown in the Appendix along with their latitudes and longitudes. The table also displays the length of the road segment and the probability for its selection. These roadway segments are selected from the database obtained by NHTSA. Length of the roadway segments (in miles) was used a measure of size, due to the unavailability of VMT data of the roadway segments in Nevada.

The roadway segments were sorted by segment length in ascending order and cumulative of the length was also generated for each county. After all certainty road segments were identified, a sampling interval (I) was calculated as the total length across all remaining road segments within the county divided by the number of road segments to select within each county. A random start (RS) was selected (using Microsoft Excel function RANDBETWEEN) between 0 and the calculated I, which determined the first road segment selected. Subsequent road segments selected were determined by adding multiples of I to the RS until the desired number of road segments was selected and/or the end of the sorted list was reached.
2.1.6 Selection of Time Segments

To minimize the travel time and the distance required to conduct the surveys, observation sites have been grouped into geographic clusters. After road segments are selected, all selected road segments are mapped and grouped in close geographic proximity. Within each group, road segments are connected by the shortest route of roadways for data collection. Each group of road segments should be equivalent to one day of data collection work. A day of the week to begin data collection is assigned to a cluster (using the Random Function in the software program Microsoft Excel). All days of the week (including Saturday and Sunday) are eligible for selection. For the same, a function in Microsoft Excel would be used (RANDBETWEEN) which would generate random number between 0 and 6. Here 0 corresponds to Sunday and in the same order 6 corresponds to Saturday and so on.

Moreover, within a cluster, first site is randomly selected from the cluster and the remaining follow an operational efficient route, such that the overall travel time within the sites is minimized.

Seven 90-minute blocks of daylight time are identified for observations as follows:

- 7:00 AM - 8:30 AM
- 8:30 AM - 10:00 AM
- 10:00 AM - 11:30 AM
- 12:30 PM - 2:00 PM
- 2:00 PM - 3:30 PM
• 3:30 PM - 5:00 PM

• 5:00 PM - 6:30 PM

One observation time period is 45 minutes within any of the aforementioned time blocks.

The observing time segment at road segment $i$ denoted as $t_{chij}$ was fixed to 45 minutes ($\frac{3}{4}$ hour). The total number of eligible hours in an year is 4,015 hours (365 days multiplied by 11 hours per day). Then the selection probability of time segment $j$ for a roadway segment $i$ in a stratum $h$ of a county $c$ is given by $\pi_{j|chi}$ as:

$$\pi_{h|chi} = \frac{t_{chij}}{4,015}$$  \hspace{1cm} (2.10)

### 2.1.7 Determination of Site Location on Road Segments

According to Criterion 1340.5.b.1, the specific observation site locations on the sampled road segments may be deterministically selected. The site for road segment $i$ shall be the first intersection or ramp encountered on the selected road segment $i$ when traveling along the shortest route connecting all the selected road segment for the collection day. If there is no intersection or ramp on the road segment, then any point on the road can be selected for observation.
2.1.8 Selection of Vehicle to be Observed

After the road segment sample is selected and the observation site is determined, the subsequent sample selection may be performed by the data collector on site. At the observation site of the selected roadway segment, the data collector will first record how many roadway directions and lanes are on the selected road segment. If there are more than one roadway directions or lanes are present and data collector can observe only one, then the data collector will randomly select one direction or lane. Therefore the direction selection probability is:

\[
\pi_{k|chij} = \frac{d_{chij}}{D_{chij}}
\]

(2.11)

Here \(D_{chij}\) is the total number of directions, \(d_{chij}\) is the number of directions to be observed at county \(c\), road type stratum \(h\), road segment \(i\) and time segment \(j\).

Then data collector will record total number lanes \((L_{chijk})\) in the selected directions and decide how many lanes can be observed conveniently \((l_{chijk})\). Then the lane selection probability is given by:

\[
\pi_{l|chijk} = \frac{l_{chijk}}{L_{chijk}}
\]

(2.12)

As the total number of vehicles passing the observation site is unknown before the observation, it is impossible to randomize the selection of vehicles in advance. Therefore, the data collector will observe as many vehicles as possible during the time segment and at the same time to keep a record of total number of vehicles passing.
the selected lanes during the observation time. Then the vehicle selection probability is:

\[ \pi_{m|\text{chijl}} = \frac{e_{\text{chijkl}}}{E_{\text{chijkl}}} \]  \hspace{1cm} (2.13)

Here \( e_{\text{chijkl}} \) is the number of observed vehicles in the selected lanes and \( E_{\text{chijkl}} \) is the total number of vehicles passing the selected lanes during the observation time.

### 2.1.9 Selection of Alternate Sites

Criterion 1340.5.b requires that states propose a protocol for selecting alternate sites. These sites should have a similar characteristics as the site for which they are serving as alternate. The alternate observation sites must be in the same county and the same road classification as the observation site the state is replacing. If an observation site is temporarily available, observers can either return to the observation site on the same day of the week and at the same time of the day. If a site is permanently unavailable then the observers can select an alternate site, by traveling on the road segment until they reach an (different) intersection on the same road, and that intersection shall serve as the alternate site. The data collectors will be trained in this protocol and to exercise it in the data collector training.

For future studies, to replace permanently unworkable sites, alternate sites would be selected probabilistically. To ensure that the alternate is has the same characteristics as the original, it will be selected from the road segments immediately preceding and immediately following the original road segment actually selected, and thus are
implicitly stratified by functional classification group and segment length to correspond to the original road segment actually selected. Thus, these are considered selected with PPS using road segment length as MOS by the same approach as the original site. Thus, for the purposes of data weighting, the reserve road segment inherits all probabilities of selection and weighting components up to and including the road segment stage of selection from the original road segment actually selected. Probabilities and weights for any subsequent stages of selection will be determined by the reserve road segment itself.
2.2 Assignment of Observation Times

Criterion 1340.6 requires that all hours between sunrise and sunset be eligible for assignment in data collection. The data collection time has been fixed for 45 minutes at all sites. Table 2.5 presents a tentative schedule of data collection for two different teams.

<table>
<thead>
<tr>
<th>Task</th>
<th>Schedule A</th>
<th>Schedule B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect data at the first site</td>
<td>7:00-7:45 a.m.</td>
<td>7:45-8:30 a.m.</td>
</tr>
<tr>
<td>Travel to second site</td>
<td>7:45-8:30 a.m.</td>
<td>8:30-9:15 a.m.</td>
</tr>
<tr>
<td>Collect data at the second site</td>
<td>8:30-9:15 a.m.</td>
<td>9:15-10:00 a.m.</td>
</tr>
<tr>
<td>Travel to third site</td>
<td>9:15-10:00 a.m.</td>
<td>10:00-10:45 a.m.</td>
</tr>
<tr>
<td>Collect data at the third site</td>
<td>10:00-10:45 a.m.</td>
<td>10:45-11:30 a.m.</td>
</tr>
<tr>
<td>Travel to fourth site</td>
<td>10:45-11:30 a.m.</td>
<td>11:30 a.m.-12:15 p.m.</td>
</tr>
<tr>
<td>Collect data at the fourth site</td>
<td>11:30 a.m.-12:15 p.m.</td>
<td>12:15-1:00 p.m.</td>
</tr>
<tr>
<td>Travel to fifth site</td>
<td>12:15-1:00 p.m.</td>
<td>1:00-1:45 p.m.</td>
</tr>
<tr>
<td>Collect data at the fifth site</td>
<td>1:00-1:45 p.m.</td>
<td>1:45-2:30 p.m.</td>
</tr>
<tr>
<td>Travel to sixth site</td>
<td>1:45-2:30 p.m.</td>
<td>2:30-3:15 p.m.</td>
</tr>
<tr>
<td>Collect data at the sixth site</td>
<td>2:30-3:15 p.m.</td>
<td>3:15-4:00 p.m.</td>
</tr>
<tr>
<td>Travel to seventh site</td>
<td>3:15-4:00 p.m.</td>
<td>4:00-4:45 p.m.</td>
</tr>
</tbody>
</table>

continued on next page
<table>
<thead>
<tr>
<th>Strata</th>
<th>Schedule A</th>
<th>Schedule B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect data at the seventh site</td>
<td>4:00-4:45p.m.</td>
<td>4:45-5:30p.m.</td>
</tr>
<tr>
<td>Travel to eighth site</td>
<td>4:45-5:30p.m.</td>
<td>5:30-6:15p.m.</td>
</tr>
<tr>
<td>Collect data at the eighth site</td>
<td>5:30-6:15p.m.</td>
<td>6:15-7:00p.m.</td>
</tr>
</tbody>
</table>
CHAPTER 3

DATA COLLECTION

3.1 Observation Protocols

Data collection is another important aspect of a survey. This chapter explains in brief about the data collection procedures followed to collect the Seat-belt usage data in Nevada. Two teams comprising of two data collectors each were formed by Transportation Research Center (TRC) to record the seat-belt data. The same set of data collectors were used in each county in order to have a uniform data with minimum human error. These data collectors were extensively trained before the survey for data collection in similar locations across all road types.

3.2 Survey Variables

The surveyor recorded a motorist as "belted" if the data collector can see or reasonably infer that the shoulder belt is in front of the motorist’s shoulder. The surveyor recorded a motorist as "non belted" if the data collector can see or reasonably infer that the shoulder belt is not in front of the motorist’s shoulder. Other cases were recorded as belt use "unknown". In case there is no right-front passenger in the vehicle, it was recorded as "no passenger (NP)" by the data collectors.
3.3 Vehicle and Occupant Coverage

The data collectors observed the driver and right-front passenger of all passenger vehicles up to 10,000 pounds. The data collector recorded the seat-belt status (Belted/Non belted/Unknown), gender (Male/Female), age group (< 15/15-19/20-60/> 60), ethnicity (Caucasian/African-American/Hispanic/Other), State of registration of vehicle (NV/CA/Other), Vehicle Type (Sedan, SUV/Van, Truck) for both the driver and the right-front passenger. The survey also included right-front passengers who appear to be in booster seats. Although children in safety seats were excluded. Apart from the observed vehicles, the data collectors also recorded the total number of vehicles crossed during the observation period, from the observed lane in the corresponding direction being observed.

3.4 Data Collection Environment

Data collectors wore casual clothing with an orange/green safety vest. To make the data collection environment less biased neither police vehicles nor people in law enforcement uniforms were visible to the motorists at the observation sites. No signage or other communication were perceivable to motorists approaching the observation sites that would indicate that a seat belt survey is being conducted. This is to avoid any bias in the data collected. Although to ensure safety of the data collectors a traffic safety cone was encouraged to be kept at the front and back of the vehicle.
3.5 Data Collection Software

An iPhone application was developed at Transportation Research Center (TRC), UNLV to be used by the observers during data collection process. The software is shown in Figure 3.1(a) and 3.1(b). The seat-belt status of the driver and right front passenger was recorded during the survey. Moreover, driver’s age, right front passenger’s age, driver’s gender, right front passenger’s gender, vehicle type, license of registration were also recorded. The data collection software also provides the option to record the name of the observation site, total and observed directions, total and observed lanes in the observed direction, road and weather conditions, date and time of the observation as shown in Figure 3.1(a). The abbreviations used in the data collection software, Figure: 3.1(b) are as follows:

1. **Seat-belt Status:** As mentioned in the PART 1340 Uniform Criteria for State Observational Surveys of Seat-belt Use, that observer should record driver’s and right front passenger’s seat-belt status as:

   - Belted (B), if the observer can clearly observe a seat-belt over the shoulder
   - Unbelted (NB), if the observer can clearly observe no seat-belt over the shoulder
   - Unknown (U), if the observer cannot clearly observe a seat-belt

2. **License of Registration:** The license of registration of the vehicles was mainly divided into three categories. The data collectors were trained to look at the license plate of the vehicle and identify the state of registration of the vehicle.
As obtained from the historic data, that majority of the vehicles were registered in Nevada, this was set as a default in the entry form. In addition to, any license plate not belonging to either Nevada or California was identified as Other.

- N - Nevada Registered
- C - California Registered
- O - Other State Registered (vehicles not registered in Nevada and California)

3. **Type of Vehicle:** To ease the data collection process, vehicles were primarily divided into three major categories. The data collectors were thoroughly trained to identify the type of vehicle by observing the size of the vehicle. Sedan/Station Wagons were set as default in the data entry form to speed up the data collection process. This was done based on the historical data for Nevada.

- S - Sedan/Station Wagon
- SV - SUV/Mini Van
- T - Pickup Truck

4. **Ethnicity:** This category was broadly divided into four sub categories. During the training period the data collectors were trained to identify the ethnicity of people by looking at them.

- C - Caucasian
- AA - African American
• H - Hispanic

• O - Other (people not belonging to the above ethnic groups)

5. **Age - Gender:** The age and gender were combined and recorded as one observation. The age was sub divided into following four categories, <15, 15-19, 20-60 and >60 years. The observers were trained to predict the best possible estimate for a person’s age group depending on the above mentioned categories.

• M (Men) - Male with 20-60 years of age

• W (Women) - Female with 20-60 years of age

• TM (Boys) - Male with 15-19 years of age

• TF (Girls) - Female with 15-19 years of age

• EM (Elderly Men) - Male with >60 years of age

• EF (Elderly Women) - Female with >60 years of age

• CM (Younger Boys) - Male with <15 years of age

• CF (Younger Girls) - Female with <15 years of age

The green half of data collection template, as shown in Figure 3.1(b), is for collecting data related to the driver. The pink half of the template is used for collecting data according to the observed passenger. The observers were well trained before the actual data collection on this software. Survey forms in paper were also printed as a backup.
Figure 3.1: Data Collection Software
3.6 Quality Control Procedures

According to the new criteria 1340.8.a, to monitor the surveys a Quality Control (QC) Monitor was employed. The QC Monitor made unannounced random visits to 5 percent of the observation sites. During these visits, the QC Monitor evaluated the Data Collector’s performance from a distance (if possible), and then worked alongside the Data Collector. The schedule for the data collection was given before hand to the QC monitor with the observation time at each observation site.

The QC Monitor ensured that the data collector is following all survey protocols including: being on time at assigned sites, completing the cover sheet and observation forms, and making accurate observations of seat belt use. The QC monitor also served as a point of contact for the data collectors during the data collection process.

The QC Monitor reviewed the data after the completion of the survey. If the rate of unknowns exceeds 10% for any site (potentially leading to an overall nonresponse rate of 10% or more), then the data collectors were sent back to that site for an additional observation period.
4.1 Sampling Weights

The following is a summary of the subscripts used in the design.

- \( c \) - Subscript for county
- \( h \) - Subscript for road segment strata
- \( i \) - Subscript for road segment
- \( j \) - Subscript for time segment
- \( k \) - Subscript for road direction
- \( l \) - Subscript for lane
- \( m \) - Subscript for vehicle

Under this stratified multistage design, the inclusion probability for each observed vehicle is the product of selection probabilities at all stages: \( \pi_c \) for county, \( \pi_{hi|c} \) for road segment, \( \pi_{j|hi} \) for time segment, \( \pi_{k|hi} \) for direction, \( \pi_{l|hi} \) for lane and \( \pi_{m|hi} \) for vehicle. So the overall vehicle inclusion probability is:

\[
\pi_{ijklm} = \pi_c \pi_{hi|c} \pi_{j|hi} \pi_{k|hi} \pi_{l|hi} \pi_{m|hi} \tag{4.1}
\]
The sampling weight for vehicle m is:

\[ w_{chijklm} = \frac{1}{\pi_{chijklm}} \quad (4.2) \]

4.2 Nonresponse Adjustment

If eligible vehicles passed an eligible site or an alternate eligible site during the observation time but no usable data was collected for some reason, then this site is considered as a "non-responding site". The weight for a non-responding site should be distributed over other sites in the same road type in the same PSU. However, for PSU’s having only one site in the sample, data would be collected again on the same day and same time of the week. Also, if this doesn’t work out then an alternate site would be selected and data would be collected on the same day and same time of the week at that site. Let

\[ \pi_{chi} = \pi_c \pi_{hi|c} \quad (4.3) \]

be the road segment selection probability,

\[ w_{chi} = \frac{1}{\pi_{chi}} \quad (4.4) \]

be the road segment weight. Factor

\[ f_{ch} = \frac{\sum_{alli} w_{chi}}{\sum_{responding} w_{chi}} \quad (4.5) \]
is multiplied to all weights of non-missing road segments in the same road type of
the same county and the missing road segments are dropped from the analysis file.
However, if there were no vehicle passing the site during the selected observation time
(say 45 minutes) then this is simply an empty block at this site and this should not
be considered as non-responding site. This site may be dropped for estimation but
no adjustment is needed.

4.3 Belt Use Rate Estimator

Let the driver/passenger belt use status be:

\[
  y_{ijklmn} = \begin{cases} 
  1 & \text{if belted} \\
  0 & \text{otherwise} 
  \end{cases} 
\]  

(4.6)

The first belt rate estimator to be considered is a ratio estimator given by:

\[
  p = \frac{\sum_{allijklmn} w_{ijklmn} y_{ijklmn}}{\sum_{allijklmn} w_{ijklmn}} 
\]  

(4.7)

This estimator does not require the knowledge of VMT data for a state.

4.4 Variance Estimation

As the sampling process is divided in multiple stages, direct variance estimation for
belt use rate estimator can be complicated, tedious and costly. Hence, a specialized
software designed to handle this kind of design and estimator would be used. The
ratio procedure in RTI International SUDAAN software [10] along with the joint PSU selection probability to calculate the seat belt use rate and its variance could be used.
CHAPTER 5

RESULTS

5.1 Introduction

Two seat belt usage surveys for 117 sites across the State of Nevada were conducted in the month of May and June 2012. The collected data was analyzed statewide, based on gender, ethnicity, type of vehicles, and vehicle registration. The overall weighted seat-belt usage rate of the state of Nevada is 87.42% during the Pre-Mobilization and 90.39% during the Post-Mobilization survey. The data showed that the unweighted estimate of statewide seat belt usage rate for 2012 is 87.99% during the Pre-Mobilization and 93.38% during the Post-Mobilization. Combining the data for both the surveys, the unweighted estimate of the statewide seat-belt usage for the year 2012 is 90.69% for all the occupants. Male occupants were found to be less belted than the female occupants in both the surveys. The seat-belt usage was the lowest among African-Americans and Hispanics, while Caucasians and 'Other' category occupants showed the highest seat-belt usage. From the age-gender analysis, the boys within 15-19 age group were found to be least belted and Elderly women over 60 years of age showed highest seat-belt usage during both the surveys. It was also observed that the least belted occupants were between 15-19 years of age. Furthermore, the seat-belt usage was observed to be lowest in Pickup trucks and the highest in Vans/SUVs.
The data was analyzed based on functional classification of streets, and based on the growth in the region. For all the front seat occupants combined, data showed that the S1400 had the least seat belt usage, whereas S1100 showed the highest seat belt usage. The rural regions of Nevada (i.e. Nye, Elko and Lyon) showed the highest seat-belt usage during both the surveys. Finally, statistical analysis done to find the change after the 2012 Mobilization showed a significant increase in seat-belt usage from Pre-Mobilization to Post-Mobilization.

5.2 Statewide Seat-belt Usage Summary

5.2.1 Genderwise Seat-belt Usage

Figures 5.1 and 5.2 shows the seat-belt usage for occupants in the driver seat and passengers in the right front passenger seat for 2012 Daytime Seat-belt Pre-mobilization survey respectively. It was observed during the survey that both male and female passengers had a higher seat-belt usage rate than male and female drivers respectively. Also, it was observed that females had a higher seat-belt usage than males. A similar result was observed during the Post-mobilization survey as shown in figure 5.2.
Figure 5.1: Statewide Seat-belt Usage for Drivers

Figure 5.2: Statewide Seat-belt Usage for Passengers

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5.2.2 Age-wise Seat-belt Usage

Figures 5.3 and 5.4 show a age wise distribution of total occupants for 2012 Daytime Seat-belt Usage Survey. During the pre-mobilization survey Men (20-60 years) had shown the least seat-belt usage (84.32%) in Nevada whereas Elderly Men (>60 years) had shown the highest seat-belt usage (92.07%). However during the post-mobilization survey Boys (15-19 years) have shown the least seat-belt usage (88.40%) whereas Young Boy Passengers (<15 years) have shown the highest seat-belt usage (97.07%) in Nevada.

![Age-wise Seat-belt Usage - Male](image)

Figure 5.3: Age-wise Seat-belt Usage - Male
Similarly amongst females, Women (20-60 years) were observed to have the least seat-belt (89.32%) and Girls (15-19 years) were observed to have the highest seat-belt usage (94.51%) during pre-mobilization survey. However during post-mobilization survey the seat-belt usage rate improved significantly across all categories with least observed seat-belt usage (94.75%) amongst women (20-60 years) and the highest seat-belt usage (100%) to be reported for Young Girl Passenger (<15 years).

Figure 5.4: Statewide Seat-belt Usage - Female
5.2.3 Seat-belt Use for Nevada Registered Vehicles

In addition to the use of seat belt, the state registration and type of vehicle were recorded. 10,037 vehicles were observed during Pre-Mobilization and 10,343 vehicles during the Post-Mobilization survey. During Pre-Mobilization, 77.75% (7,804) of the vehicles were registered in Nevada, 11.65% (1,169) in California, and 10.60% (1,064) registered in states other than Nevada and California. Similarly, during Post-Mobilization survey, 80.69% (8,346) of the vehicles were registered in Nevada, 7.31% (756) in California, and 12% (1,241) registered in states other than Nevada and California. Thus, over 77% of the vehicles during both the surveys were registered in Nevada. This distribution has been shown in Figure 5.5. Since vehicles registered

![Figure 5.5: States of Registration](image)

(a) Pre-Mobilization survey  (b) Post-Mobilization survey

in Nevada cover the majority of the observed vehicles, seat belt usage for these vehicles is analyzed in detail. For Nevada registered vehicles, 85.94% of male drivers and 91.06% of female drivers were belted during Pre-Mobilization survey. Similarly,
84.64% male passengers and 89.31% female passengers were belted. However, during the Post-Mobilization, these percentages increased up to 91.73% belted male drivers and 94.73% belted female drivers. Furthermore, 91.59% male passengers and 95.19% female passengers were belted during Post-Mobilization survey. Figure 5.6 shows the seat-belt usage for vehicles registered in Nevada during 2012 Daytime Seat-belt Usage Survey.

Figure 5.6: Seat-belt Usage - NV Registered Vehicles
5.2.4 Seat-belt Usage Rates Based on Vehicle Type

Three major categories of vehicles were observed for this study. They were: Sedans/Station Wagons, Pickups, and Vans/Sport Utility Vehicles (SUVs). Figure 5.7 shows the distribution of these vehicles types observed during this data collection effort. Figures 5.8 and 5.9 shows the seat-belt usage distribution across different vehicle types. During pre-mobilization survey, drivers and passengers driving in Van/SUVs observed to be the most belted where as drivers and passengers in PickUps were least belted.

The overall seat-belt usage for both drivers and passengers in pickups was found to be the lowest (83.45% during Pre-Mobilization and 91.59% during Post-Mobilization), with sedans/station wagons (88.31% during Pre-Mobilization and 93.65% during Post-Mobilization) and SUVS (91.28% during Pre-Mobilization and 94.89% during Post-Mobilization) organized in the ascending order of the seat-belt usage. A similar
Figure 5.8: Seat-belt Usage by Vehicle Type - Pre-mobilization trend was observed during the post-mobilization survey.
Figure 5.9: Seat-belt Usage by Vehicle Type - Post-mobilization
5.2.5 Seat-belt Usage Based on Ethnicity

The ethnicity of the occupants was also recorded during the field observations. The observers had past experience/training in performing similar observations based on ethnicity. The ethnicity was recorded as African-American, Hispanic, Caucasian, and Other. The Other category is comprised of drivers and passengers who were not African-American, Hispanic, or Caucasian. Figure 5.10 shows the breakdown of drivers based on ethnicity. As can be seen from this figure, Caucasians account for over 78% of drivers in both the surveys.

![Ethnicity Breakdown](image)

(a) Pre-Mobilization survey  
(b) Post-Mobilization survey

Figure 5.10: Breakdown by Ethnicity of Drivers

From figure 5.11, the seat belt usage rate was lowest among the Hispanic drivers (83.53%) but the seat-belt usage rate for African-American drivers was also close (84.25%) to the former. The highest seat-belt usage was observed among the Caucasian drivers (89.40%). Last but not the least, the seat-belt usage rate for the Other category drivers was found out to be 87.47%. As far as the passengers were concerned,
the highest seat-belt usage was observed for the Caucasians (89.35%) while the least seat-belt usage was witnessed for the African-American passengers (68.23%). The Hispanic category passengers showed the seat usage rates of 78.75% while the usage rates for Other category passengers was found to be 85.37%.

Figure 5.11: Seat-belt Usage by Ethnicity - Pre-mobilization

Similarly, according to figure 5.12 based on Post-Mobilization survey, the lowest seat belt usage was observed among the Hispanic drivers (91.62%). However, the seat-belt usage rate for African-American drivers was also close (91.79%) to the Hispanic drivers. The highest seat-belt usage during Post-Mobilization survey was
observed among the 'Other' category drivers (96.08%). Additionally, the seat-belt usage rate for the 'Caucasian' category drivers was found out to be 93.71%. Considering the passengers, the highest seat-belt usage was observed for the 'Other' category (98.04%) while the least seat-belt usage was witnessed for the African-American passengers (86.67%). The Hispanic category passengers showed the seat-belt usage rates of 91.83% while the usage rates for Caucasian passengers was found to be 95.25%.

Thus, based upon the findings from Pre-Mobilization and Post-Mobilization survey, Hispanic and African-American drivers remained least belted. However, Caucasian and 'Other' category drivers showed the highest seat-belt usage rates.
Seat-belt Usage for Caucasian Drivers

Since people belonging to Caucasian ethnicity cover a significant portion of all the drivers observed, they are analyzed separately for Pre-Mobilization and Post-Mobilization surveys.

From figure 5.13, it can be seen that the seat-belt usage for female Caucasian drivers was higher (91.19% during Pre-Mobilization and 95.40% during Post-Mobilization) than the male Caucasian drivers (88.41% during Pre-Mobilization and 93.51% during Post-Mobilization).
Seat-belt Usage for Non-Caucasian Drivers

Figure 5.14 show the seat-belt usage for non-Caucasian drivers during Pre-Mobilization and Post-Mobilization survey respectively. From figure 5.14, it can be seen that the seat-belt usage for female non-caucasian drivers is higher (90.29% during Pre-Mobilization and 94.17% during Post-Mobilization) than the male non-caucasian drivers (81.91% during Pre-Mobilization and 88.88% during Post-Mobilization).
5.2.6 Seat-belt Usage by Functional Classification of Streets

The seat belt observation sites are divided into three classes: S1100 (Primary roads), S1200 (Secondary roads), and S1400 (Local Neighborhood roads and rural streets). The detailed information about the seat-belt usage by drivers and passengers according to the functional classification of streets is given in figures 5.15 and 5.16.

![Figure 5.15: Seat-belt Usage by Functional Classification of Streets - Pre-mobilization](image)

From figure 5.15 and 5.16, it can be noted that S1100 have the highest seat-belt usage (91.88% in Pre-mobilization and 95.35% in Post-mobilization) for all front seat occupants. On the other hand, the lowest seat-belt usage was observed over the
Figure 5.16: Seat-belt Usage by Functional Classification of Streets - Post-mobilization

S1200 during Pre-Mobilization (86.97%) and S1400 during Post-Mobilization (91.58%).
5.2.7 Seat-belt Usage by County

This section summarizes the seat-belt usage across each county. Figures 5.17 and 5.18 show that least seat-belt usage was observed in Clark county (86.92% during the Pre-Mobilization survey and 90.99% during the Post-Mobilization survey). Additionally, the highest seat-belt usage was observed in Washoe (90.48%) during Pre-Mobilization and Lyon (94.52%) during Post-Mobilization). Figures 5.17 and 5.18 also shows that the seat belt usage by drivers remains above 85% during pre-mobilization and 90% during post-mobilization survey.
Figure 5.18: Seat-belt Usage by County - Post-mobilization
SECTION II: DRIVER’S BEHAVIOR
6.1 Introduction

The reason behind the majority of the roadway crashes in the United States has been attributed to so many different factors such as driving under influence, speeding, distracted driving, fatigue etc. But all these various factors converge to a single behavioral attribute, i.e. inattention as shown in figure 6.1. All the above mentioned factors affect drivers reaction time which in turn increases chances for accidents and roadway fatalities.

Figure 6.1: Accident contributing factors leading to inattention
Several studies have been conducted in the past to model driver’s road behavior based on the road performance and the parameters obtained from the vehicle. This chapter explains in brief about the studies that have been conducted so far.

The influence of driver’s impairment in motor vehicle crashes is already well established. To analyze driving profile and to be able to predict potential dangers based on the driving pattern, vehicle based sensing techniques have attracted significant attention. Culp et al. [14] discusses various techniques to monitor driver condition. The underlying idea is to capture data through various sensors embedded in the vehicle and then to use data processing techniques to characterize the data and identify different levels of impairment and then to find a relationship between the levels of impairment and driver’s data characteristics [15]. Depending upon the type of sensor used to capture data, driver impairment detection and monitoring technique can be classified as follows:-

- By capturing driver’s physiological signals such as Electroencephalogram (EEG), Electrocardiogram (ECG), eye tracking, postural stability etc. one can get significant and highly reliable information about the driver’s current state of mind. Various studied have been conducted to monitor driver’s performance by capturing these signals and thereby studying distraction [16, 17, 18, 19]. As these signals are directly obtained from driver, the information about driver’s physiological condition is very rich. However these sensors are highly sophisticated and are not so commonly found in existing commercial vehicles, it becomes difficult to employ the setup without posing additional discomfort to the driver.
• Signals obtained from vehicle motion such as vehicle speed, lateral position and
time headway are widely used in various collision avoidance systems [20, 21].
In addition, these signals have also been used to model and monitor driver’s
behavior behind the wheel. Sezikawa et al. [22] have used distance between
cars on the road to model human driving behavior. Similarly Toledo et al. [23]
used lane changing information and acceleration rate to model human driving
behavior behind the wheel.

• The most readily available signals are the driver’s input such as steering wheel
angle, gas/brake pedal activity etc. These signals are most easily available in
most of the modern vehicles. As these signals are direct output from the driver
and are not affected by the vehicle dynamics, thereby act as better indicators of
driver conditions compared to the earlier mentioned signals. These signals have
been used in various studies as measures of driver performance measurement.
Desai et al. [24] proposed a measure of sharp changes in the driving signal to
estimate drowsiness of the driver. Similarly entropy of the steering wheel has
been employed as a measure of driver workload [25] and driver performance [26].

The connection between the motor vehicle crashes and alcohol has been very
well established [27, 28]. According to studies it has been noted that when BAC
goes beyond 0.08, the probability of a serious crash increases dramatically. Several
studies have been conducted in the past to analyze the effects of alcohol on a driver’s
performance. Perrine et. al. [29] and Coldwell et. al. [30] have performed these
studies in actual field test settings where as Moskowitz et. al. [31] and Sugarman et. al. [32] performed the study in a controlled lab environment on a driving simulator.

The main hindrance for conducting the study in actual field setting, has been attributed to the safety hazards and also due to the procedural problems. As the alcohol intake of an individual is very specific and varies from person to person, the results obtained are relatively generalizable. From these studies it has been concluded that the performance of a driver on a divided attention task is sensitive to alcohol [33, 34, 35]. Moreover, alcohol seems to cause a tunneling effect such that the information is either missed, ignored or the reaction time of the driver had increased [36].
7.1 Driving Simulator and Scenario Design

Driving Simulator are the most popular and safe way to carry out an experimental research as it gives a close enough real world feel with in the safe environment. In addition, it also offers low cost, high control and safety on the experiments.

A "driving simulator" is a virtual reality tool which gives a driver on board impression that he/she drives a real time actual vehicle by predicting vehicle motion caused by driver input and feeding back corresponding visual, motion, audio, proprioceptive cues to the driver [37]. It includes a real time system to simulate vehicle dynamics, visual/audio systems to recreate an actual driving setting, an interface between the driver and the simulator, an operator monitoring system, data collectors and synchronization system. Driving simulators have been widely used for safety studies, understanding vehicle dynamics, human factor study etc.

In this study a STISIM® Drive Simulator Version 10 was used to acquire data. STISIM® Drive is a personal computer based interactive driving simulator developed by Systems Technology, Inc. [38]. It includes a vehicle dynamics model, visual and auditory feedback, steering wheel feedback and a driver performance measurement system. To create driving scenarios a unique Scenario Definition Language (SDL)
can be used. SDL provides user with the freedom to design an arbitrary sequence of tasks, events and performance measurement intervals. The STISIM® has been used in various research projects.

Figure 7.1: Simcraft Driving Simulator

The scenario simulates a 3 mile drive on an outskirts of a city with the speed limit of 45 miles/hr. By varying the overall light level of the simulation, color and brightness of the surrounding the time and day of the simulation can be adjusted. The normal drive time is around 4-5 minutes. Figure 7.1 shows the basic setting of
the experiment with a driving simulator. The data was collected for three different settings which were:-

- Normal Driving
- Alcohol-impaired Driving
  - Driving with Moderate BAC (0.01-0.07)
  - Driving with High BAC (0.17-0.20)
- Driving with Distraction
  - Talking on Cellphone
  - Texting on Cellphone

To make a person comfortable with the simulator 2-3 practice sessions were provided to each participant before starting the data collection. After each driving session participants were provided with a break to relax and to avoid the study being monotonous. To remove biases, each participant was asked to perform a driving task for three times, hence making the overall driving for 15 minutes for each setting. Various parameters were recorded during each session which includes lateral distance from the centerline, steering wheel angle input, brake/gas pedal input, speed of the vehicle and speed limit of the roadway. The sampling rate for the recording was about 4 samples per second.
7.2 Subject Selection

The subjects of the study were recruited from the staff and students in Transportation Research Center (TRC). The only requirement for participating in this study was to have a valid US driving license and belonging to the age group 20-30. The main objective of selective subjects from TRC was to minimize unfamiliarity bias from the study as the subjects were already well aware about the working of the simulator.

7.3 Procedure

The entire study for one participant was conducted in one day. To avoid monotony in the study, participants were given breaks in between and the study. In addition, different settings were shuffled instead of recording three driving for one setting. To measure alcohol-induced behavior, driver’s were provided with Fatal Vision® goggles with equivalent BAC in moderate (0.01-0.07) and high (0.17-0.20) ranges. Figure 7.2 shows a fatal vision goggles which were used in the study.

To study driver’s performance with distraction, cellphone was used as a medium of

Figure 7.2: Fatal Vision® Goggles
distraction. Both talking and texting were used to distract the driver separately as driver’s performance was recorded.
CHAPTER 8

BASIC ANALYSIS

8.1 Data Recording

Five subjects were recruited from Transportation Research Center at University of Nevada, Las Vegas. Each subject completed six sessions on a driving simulator (i.e. one familiarization trial, one normal driving without any hindrance, two alcohol-impaired driving trials and two distraction-impaired driving trials). Duration for each trial was approximately 5 minutes. Four different kinds of data was recorded in each trial. Moreover, each trial was conducted for three times to remove any bias whatsoever. The STISIM® driving simulator recorded all information as specified in the scenario file.

8.2 Data Pre-processing

There are two main reasons for doing data pre-processing. Firstly, it enables to demonstrate that there is a relationship between the driver’s performance and the driver’s physiological condition caused by various measures employed during the study. The measures which are being tested here are alcohol-impaired driving and driving with distraction. Secondly, the data obtained from the study need to be
reduced so that significant conclusions can be reached. Data in its current form contains a lot of information which needs to be extracted to be able to use it further. Among the various channels of data recorded, steering wheel angle (SWA), lateral lane position (LLP), speed of vehicle (SOV), brake/ gas pedal input are the most important in the analysis of the data. The lateral lane position and speed of vehicle directly relates to the risks of being in an accident on the road while steering wheel angle and brake/ gas pedal input reflects the driving behavior. Thus the first task is to find any relationship between these two sets of data.

8.3 Time Domain Analysis

8.3.1 Standard Deviation analysis of LLP and SWA

A time window approach is applied to the analysis as single data points do not convey much information about the data set. The raw data from the LLP and SWA channel were grouped into 4-seconds window. Each window thus includes 16 sampling points. For each window, various analysis tools can be used to identify a basic pattern among the data set. The tools can be basic statistical measures such as mean, standard deviation and histogram etc. The standard deviation was selected as a tool for this study because it tells how tightly all the various sampling points are clustered around the mean in the window. It also explains the variation of the data in a selected window, which related to the objective of the study. Hence, the mean and standard deviation of all windows are calculated and compared.

Equations 8.1 - 8.4 shows the calculation of mean and standard deviation of LLP
and SWA over a window. Here $N$ is the length of the window.

$$\mu_{LLP} = \frac{1}{N} \sum_{i=1}^{N} LLP_i$$ \hfill (8.1)  

$$\sigma_{LLP} = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (LLP_i - \mu_{LLP})^2}$$ \hfill (8.2)  

$$\mu_{SWA} = \frac{1}{N} \sum_{i=1}^{N} SWA_i$$ \hfill (8.3)  

$$\sigma_{SWA} = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (SWA_i - \mu_{SWA})^2}$$ \hfill (8.4)  

The standard deviation of all the lateral lane positions ($\sigma_{LLP}$) of all windows were calculated and the windows were sorted in an ascending order based on the value of $\sigma_{LLP}$. The steering wheel angle behavior of the corresponding window (the standard deviation of steering wheel angle, $\sigma_{SWA}$) were also compared.

The mean $\sigma_{SWA}$ of normal driving sessions and driving with fatal vision goggles with moderate and high equivalent BAC are shown in figure 8.1. Similarly, the mean $\sigma_{LLP}$ for the respective sessions are shown in figure 8.2.

The results indicate that $\mu_{SWA}$ increases when the thresholds increases. Thereby indicating at a close relationship between $\sigma_{LLP}$ and $\sigma_{SWA}$. As mentioned earlier, that lateral lane position is directly associated with the risks where as steering wheel angle is directly associated with the driver’s physiological status.

From figure 8.1 it can be seen that the $\mu_{SWA}$ in moderate and high BAC conditions is significantly higher than that in normal driving conditions with different thresholds.
When the thresholds are smaller, i.e. the deviation in the lateral lane position is small, the driver maintains lower steering wheel movements to control the vehicle whereas in the other settings when a fatal vision goggles are provided to induce the effect of alcohol to maintain the lane position, driver has to provide higher steering wheel movements. This can be explained as follows: in normal situations, subjects recognized lane deviations more quickly and made small and precise steering wheel movements to correct it. However, due to the induced alcoholic effect from fatal vision goggles, subjects had delayed responses to the lane deviations and hence required larger wheel movement to correct the lane drift. A similar analogy also exists for the driver’s behavior between moderate BAC and high BAC. For high BAC, subjects had...
to make even larger wheel adjustments to keep the vehicle in its lane. This shows that an alcohol influenced driver can maintain the lane of the vehicle (\(\sigma_{LLP}\) is small) and can control the vehicle successfully, but he/she has to move the steering wheel more often (\(\mu_{\sigma_{SWA}}\) is large).

However, for scenarios involving distraction using cellphone (i.e. texting and talking), it can be observed from figure 8.1 that texting while driving has a very high \(\mu_{\sigma_{SWA}}\) compared to the other scenarios indicating a larger steering wheel input by the driver to keep the vehicle lateral lane deviation as low as possible. Similarly while talking on the cellphone the \(\mu_{\sigma_{SWA}}\) of the subject is more than it is in the normal driving situation.

![Figure 8.2: \(\mu_{\sigma_{LLP}}\) with varying \(\sigma_{SWA}\) Ranges](image-url)

Figure 8.2: \(\mu_{\sigma_{LLP}}\) with varying \(\sigma_{SWA}\) Ranges
Similarly from figure 8.2 it can be seen that the $\mu_{\sigma_{LLP}}$ values in alcohol influenced sessions are higher than those in normal sessions with different thresholds. It also indicates that under similar steering wheel control behavior, the lane deviation are larger in alcohol influenced session than in normal session. This means that alcohol influenced drivers have poor lane keeping ability than regular drivers. Moreover for texting while driving scenario even with a little deviation in the steering wheel input causes a significant deviation in the lateral lane position.

![Figure 8.3: $\mu_{\sigma_{LLP}}$ with varying $\sigma_{SOV}$ Ranges](image)

A similar analysis has been performed for lateral lane position (LLP) and steering
wheel angle (SWA) with respect to speed of vehicle (SOV). Figure 8.3 and 8.4 shows the $\mu_{\sigma_{LLP}}$ with varying $\sigma_{SOV}$ ranges and $\mu_{\sigma_{SWA}}$ with varying $\sigma_{SOV}$ respectively. For lower deviation in the speed of the vehicle, deviation in the lateral lane position and steering wheel angle is higher for when the driver is influenced with moderate BAC fatal vision goggles and when the driver is texting while driving. For texting session the deviation in the lateral lane position increases drastically as compared to the rest of the scenarios to maintain respective deviation in the speed of the vehicle.

Figure 8.4: $\mu_{\sigma_{SWA}}$ with varying $\sigma_{SOV}$ Ranges
8.4 Frequency Domain Analysis

A signal can be represented in an infinite number of different ways depending on the application. The most popular, important and fundamental representation is time and frequency domain representation of signals. The time domain indicates how a signal changes with time and the frequency domain indicates how often these changes take place. The time domain signal was converted to frequency domain using Fourier transform as shown in equation 8.5. The Fourier Transform involves decomposition of a signal as the sum of weighted sinusoidal functions of varying frequencies. Hence, the projection of the values of these signals forms the Fourier Transform of the original signal. As the lateral lane position is a discrete signal, discrete Fourier transform (DFT) was applied to the signal to obtain a frequency domain signal.

\[
X(w) = \sum_{n=-\infty}^{\infty} x[n] e^{-iwn} \tag{8.5}
\]

Figure 8.5 shows the lateral lane position of Subject 1 in time domain. It is evident from figure 8.5 that, scenario where subject was texting while driving shows a lot of oscillation from the driving lane than in the normal driving scenario. In moderate BAC, the performance of the subject was better than the texting scenario but that can be attributed to the fact that even while driving with fatal vision goggles, driver is conscious and can focus on the road, but while texting, attention and eyes of the driver were mostly off the road. It was also interesting to note that the oscillation in the lane position when the driver was talking on the cellphone was more than the
normal driving scenario but significantly less as compared to other distraction based scenarios. Figure 8.6 shows the single sided frequency spectrum of the standard deviation of lateral lane position (LLP) of subject 1.

![Figure 8.5: Time variation of Lateral Lane Position (LLP) of Subject 1 (in feet)](image)

Similarly, figure 8.7 shows the variation of steering wheel angle with time. When the subject was texting while driving, the oscillations in the steering wheel angle was exceptionally large. However, during the other distraction based scenarios the oscillation is slightly lower than texting but was in the relative decreasing order of HIGH BAC, MOD BAC, Talking and Normal Driving Scenarios. Figure 8.8 shows the single side spectrum of the standard deviation of steering wheel angle (SWA) of subject 1.
Figure 8.6: Single Sided Spectrum of Lateral Lane Position (LLP) of Subject 1

Figure 8.7: Time variation of Steering Wheel Angle (SWA) of Subject 1 (in radian)
Figure 8.8: Single Sided Spectrum of Steering Wheel Angle (SWA) of Subject 1

Figure 8.9: Time variation of Speed of Vehicle (SOV) of Subject 1
Figure 8.10: Single Sided Spectrum of Speed of Vehicle (SOV) of Subject 1
8.5 Entropy Based Analysis

In electrical engineering, entropy is defined as a function which conveys information about the behavior or attributes of a physical system. In thermodynamics, entropy is associated with the chaos or randomness in a given system. A system with higher entropy is considered more random or chaotic than the system with lower entropy. It has been used as a performance measure to assess driving performance of the subjects in various research environments. The main objective of this study was to monitor the effects of various scenarios involving distraction and driving under influence on the driver. Entropy as a performance measure was found appropriate to calculate the randomness introduced in the system due to different scenarios. Moreover, it also measures driver’s efforts to bring the system back to its normal state as quickly and closely as possible. Hence it reduces the randomness and the overall entropy of the system.

For a discrete random variable $X$, the measure of uncertainty associated with the value of $X$ is defined as entropy $H$. For a discrete signal $X$, entropy is defined as

$$H = \sum_{x \in X} -p(x)\log(p(x))$$  \hspace{1cm} (8.6)$$

where $p(x)$ gives the probability for any $x \in X$.

Lateral lane position (LLP), steering wheel angle (SWA) and speed of vehicles (SOV) all are directly related to the driver’s driving pattern. As this study was conducted on a driving simulator with the scenario involving driving on a straight
Figure 8.11: Entropy variation of LLP for Subject 1

road under various distractions and influence, the main objective was to study the randomness in the driving pattern. The degree of randomness is shown in this section in figures 8.11, 8.12 and 8.13.

From figure 8.12, it can be seen that when the driver was texting while driving, lateral lane position has high degree of randomness as compared to the normal driving scenario. Similarly, for the scenario involving HIGH BAC the randomness is higher than normal but slightly lower than the texting while driving scenario. This explains the amount of distraction a driver may face on the road if engaged in these activities. It should also be noted that as these experiments were performed in a laboratory controlled environment, the actual behavior on the road could be different for different
drivers.

Figure 8.12: Entropy variation of SWA for Subject 1
Figure 8.13: Entropy variation of SOV for Subject 1
CHAPTER 9

RESULTS & CONCLUSION

9.1 Results

9.1.1 2012 Daytime Seat-belt Usage Survey

Two seat belt usage surveys for 117 sites across the State of Nevada were conducted in the month of May and June 2012. The collected data was analyzed statewide, based on gender, ethnicity, type of vehicles, and vehicle registration. The overall weighted seat-belt usage rate of the state of Nevada is 87.42% during the Pre-Mobilization and 90.39% during the Post-Mobilization survey. The data showed that the unweighted estimate of statewide seat belt usage rate for 2012 is 87.99% during the Pre-Mobilization and 93.38% during the Post-Mobilization. Combining the data for both the surveys, the unweighted estimate of the statewide seat-belt usage for the year 2012 is 90.69% for all the occupants. Male occupants were found to be less belted than the female occupants in both the surveys. The seat-belt usage was the lowest among African-Americans and Hispanics, while Caucasians and 'Other' category occupants showed the highest seat-belt usage. From the age-gender analysis, the boys within 15-19 age group were found to be least belted and Elderly women over 60 years of age showed highest seat-belt usage during both the surveys. It was also observed that the
least belted occupants were between 15-19 years of age. Furthermore, the seat-belt usage was observed to be lowest in Pickup trucks and the highest in Vans/SUVs. The data was analyzed based on functional classification of streets, and based on the growth in the region. For all the front seat occupants combined, data showed that the S1400 had the least seat belt usage, whereas S1100 showed the highest seat belt usage. The rural regions of Nevada (i.e. Nye, Elko and Lyon) showed the highest seat-belt usage during both the surveys. Finally, statistical analysis done to find the change after the 2012 Mobilization showed a significant increase in seat-belt usage from Pre-Mobilization to Post-Mobilization.

9.1.2 Driver’s Performance

Driving as a task requires a lot of focus and attention from the driver. The main objective of the thesis to study the driver’s performance behind the wheel with different distractions and influences. The data sets recorded gave a slight glimpse of different levels of distraction for different driving scenarios. Evidently, as shown from the results, texting while driving or driving under the influence of alcohol inhibits a driver’s ability to control the vehicle tremendously. As observed from the deviation in the lateral lane position (LLP) of the driver or the deviation in steering wheel angle (SWA) which was made to retract the vehicle back to its earlier position, if happens in a real life environment might cause severe road accidents. These accidents not only endanger the life of the driver who is driving the vehicle but also puts at risk the life of all the other people on the road.
To study the effects of alcohol on a driver’s performance, fatal vision goggles have been used. Although, the fatal vision goggles simulate an effect similar to what might a person be feel under the influence of alcohol, it is necessary to point out that with fatal vision goggles the driver is still conscious. Under the influence of alcohol, the performance will be far more affected than with fatal vision goggles.

9.2 Future Work

The study of driver’s performance is a very interesting and rapidly growing field. Several technological advancements including the study of human mind, heart or skin is being conducted throughout the world to correlate and derive a better relationship between driver’s performance on the road and state of mind. This can be extended to develop a system to capture driver’s Electroencephalogram (EEG), Electrocardiograph (ECG) and Galvanic Skin Response (GSR) to effectively study and analyze the driver’s reaction to different settings behind the wheel.
### Table 9.1: Selected Road Segments: Clark County

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|--------|---------------------------|------------|------------|----------|----------------|
| S1100  | Summerlin Pkwy           | -115.275875| 36.177731  | 0.250014 | 0.001084495    |
|        | I- 15                     | -114.254226| 36.777953  | 1.214737 | 0.005269209    |
| S1200  | W Charleston Blvd         | -115.289165| 36.159027  | 0.236655 | 0.000925066    |
|        | Northshore Rd             | -114.513784| 36.244201  | 1.352207 | 0.005285672    |
|        | W Eldorado Ln             | -115.212255| 36.053229  | 0.012612 | 3.47495E-05    |
|        | W Sycamore Grove Ct       | -115.230465| 36.049584  | 0.030567 | 8.42452E-05    |
|        | Powder Brook Dr           | -114.948202| 36.007741  | 0.040135 | 0.000110583    |
|        | S Walnut Rd               | -115.087658| 36.148747  | 0.046446 | 0.000127971    |
|        | Parkhurst St              | -115.094212| 36.178273  | 0.050263 | 0.000138488    |
|        | E Lariat Dr               | -115.08137 | 36.117488  | 0.057629 | 0.000158784    |
|        | Warbonnet Way             | -115.265906| 36.149015  | 0.066125 | 0.000182192    |
|        | N Golden Harmony St       | -115.190195| 36.270594  | 0.076543 | 0.000210897    |
| S1400  | Prosser Creek Pl          | -114.946672| 36.005334  | 0.08725  | 0.000240398    |
|        | Mount Vernon Ave          | -115.09515 | 36.121974  | 0.098101 | 0.000270295    |
|        | S Redwood St              | -115.238439| 36.056743  | 0.111403 | 0.000306946    |
|        | Winchester Dr             | -114.970828| 36.011925  | 0.119536 | 0.000329354    |
|        | Eula St                   | -115.312862| 36.126162  | 0.126336 | 0.00034809     |
|        | W Alomar Ave              | -115.23212 | 36.099335  | 0.13911  | 0.000383286    |
|        | Mantis Way                | -115.095919| 36.179164  | 0.16142  | 0.000444756    |
|        | W Winley Chase Ave        | -115.141214| 36.236277  | 0.189507 | 0.000522143    |
|        | Longridge Ave             | -115.214587| 36.156308  | 0.231223 | 0.000637082    |
|        | Redwood St                | -115.238925| 36.153535  | 0.258574 | 0.000712442    |
|        | E Magnasite Rd            | -114.442044| 36.517746  | 0.421842 | 0.00116229     |
|        | Gas Pipeline Rd           | -114.909987| 35.510734  | 1.079108 | 0.002973237    |</p>
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BIBLIOGRAPHY


[38] STISIM Drive, http://stisimdrive.com/
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Thesis Title: Study of Seat-belt Usage & Driver’s Performance

Thesis Examination Committee:
   Chairperson, Dr. Pushkin Kachroo, Ph.D.
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   Committee Member, Dr. Ebrahim Saberinia, Ph.D.
   Graduate Faculty Representative, Dr. Amei Amei, Ph.D.