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A SAFETY ANALYSIS OF FATIGUE AND DROWSY DRIVING IN THE STATE OF UTAH

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16. Abstract

Fatigue and drowsy driving in the state of Utah has been a causal factor in thousands of crashes over the years and poses a serious threat to public safety. The purpose of this research was to evaluate the impact of drowsy driving in the state, to identify locations where fatigue and drowsy driving may be contributing to current crashes, and to identify methods to help mitigate these crashes. A 3-year drowsy driving crash analysis spanning the years 2002-2004 was used to determine which segments of Utah highway are most prone to drowsy driving crashes. Drowsy driving corridors were identified on Interstates 15, 70, 80, and 84 as well as U.S. Routes 89 and 91 and on S.R. 36. To recommend appropriate drowsy driving countermeasures for these corridors, a review of existing countermeasures was conducted. A before-after study as well as a public survey of drowsy driving along Interstate 80 west of Salt Lake City was also completed. The before-after study indicated that drowsy driving freeway signage reduced crashes by as much as 63 percent, while a public opinion survey supplemented these findings. Recommendations were made for the drowsy driving corridors to aid in improved safety.

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EXECUTIVE SUMMARY

Fatigue and drowsy driving in the state of Utah as well as across the nation has been a causal factor in thousands of crashes over the years and poses a serious threat to public safety. According to research conducted by the United States National Highway Traffic Safety Administration (NHTSA), drowsiness or fatigue has been indicated as a primary factor in 3.6 percent of fatal crashes (Knipling and Wang 1994). Other research indicates that almost 20 percent of all serious car crash injuries are associated with driver sleepiness, independent of alcohol effects (Connor et al. 2002). Due to the seriousness of fatigue and drowsy driving in the state of Utah, it was imperative that a study be conducted to evaluate the impact of fatigue and drowsy driving in the state.

The purpose of this report is to present the results of research conducted to assess fatigue and drowsy driving on Interstate freeways and state highways in the state of Utah. The study was part of a research project funded by the Utah Department of Transportation (UDOT) and conducted by researchers at Brigham Young University (BYU) that began in September 2006

Background

In contrast to alcohol related crashes, no blood, breathalyzer, or other objective test can be performed at the scene of a crash to determine if the cause of a crash was fatigue or drowsy driving. With no specific test to determine the level of drowsiness at the scene of a crash, police officers have difficulty identifying driver fatigue as a contributing cause to a crash; hence fatigue-related crashes are likely under-reported and may be contributing to significantly more crashes than statistics indicate.

While most people are aware of the dangers of drinking and driving, many fail to recognize that driving while extremely fatigued can be just as dangerous and deadly. Research indicates that fatigue appears to be second only to alcohol as the most common cause of serious injury in vehicle crashes (Mitler 1989). Similar to drivers who are under the influence of alcohol, drowsy drivers have a slower reaction time, decreased awareness of their environment, and lack of judgment in their actions.

UDOT has recognized the seriousness of fatigue and drowsy driving and has implemented countermeasures to reduce fatigue-related crashes. One of the primary measures was the creation and installation of fatigue warning signs at several locations on Interstate 80 (I-80) between Wendover and Salt Lake City in mid 2004 as well as a more recent installation on eastbound Interstate 70 (I-70) approximately 50 miles west of Green River. The 2005 crash data on I-80 has tended toward a reduction in crash numbers related to drowsy driving, presumably as a result of the installation of the drowsy driving signs. In addition to the creation and installation of the fatigue warning signs, a task force comprised of the Utah Highway Patrol (UHP), UDOT, Utah Highway Safety Office, and a private consulting firm was formed in 2005 to promote awareness of drowsy driving through various media avenues. One of the primary accomplishments of the task was a media and education campaign that was carried out through radio public service announcements, television commercials, internet sources, and through displays at public events to help educate the public on the safety aspects of drowsy driving.

Objectives

Due to the seriousness of fatigue and drowsy driving in the state of Utah, the need existed to evaluate the impact of fatigue and drowsy driving in the state, to identify locations where fatigue and drowsy driving may be contributing factors to current crashes, to identify methods to help mitigate these crashes, and to determine the effectiveness of the drowsy driving freeway signage on I-80. The purpose of this research, therefore, was to develop a strategy to mitigate fatigue-related crashes statewide and determine the role that the drowsy driving freeway signage on I-80 plays in reducing drowsy driving crashes.

Analysis Procedure

It was determined through preliminary research that a relatively low number of crashes on a rural road may yield an extremely high crash rate depending upon the volume of traffic; therefore, it was recommended for practical purposes that the number of drowsy driving crashes within a predetermined segment be calculated as a starting point for this research followed by more detailed crash rate analyses. The count of drowsy driving crashes in 5-mile increments was then used to quickly determine which highways in Utah justified further investigation regarding high-crash drowsy driving corridors. Based upon the number of drowsy driving crashes on each facility statewide, a number of highways were eliminated from further study.

The key tool in retrieving the necessary data for all drowsy and fatigue-related analyses was UDOT's crash database (Anderson et al. 2005). Using this data, two unique methods were implemented to determine which corridors of Utah highway are most prone to have drowsy driving or fatigue-related crashes. The first method counted the number of crashes occurring in 5-mile increments while the second procedure incorporated annual average daily traffic (AADT) combined with the number of crashes to calculate a crash rate. In both cases, the data analyzed was limited to each crash having been caused by a driver who was asleep, fatigued, or ill as outlined in the police report. Additionally, the roadway surface conditions were restricted to dry or wet surface conditions.

Crash rates were calculated for each 5-mile segment of the highways analyzed followed by a critical crash rate exclusive to each facility. The purpose of a critical crash rate unique to each facility was to determine those segments of highway with crash rates exceeding the critical crash rate. Since three of the most heavily traveled facilities in Utah traverse both rural and urban areas, a critical crash rate was calculated for rural and urban areas on Interstate 15 (I-15) and I-80 as well as U.S. 89.

The basis for the results of the research was a 3-year crash analysis for the years 2002-2004 although similar analyses were conducted for five and 13 years of crash data to verify trends. The number of crashes and weighted AADT for the three years analyzed were modified to generate a multiple-year crash rate.

Results

The results of the 3-year crash rate analysis yielded 41 corridors across the state where a crash rate for a section of highway exceeded the critical crash rate. Critical corridors were located on Interstates 15, 70, 80, and 84. U.S. Routes 89 and 91 as well as S.R. 36 also contained segments in which the critical crash rate for each highway was exceeded. Figures ES-1 through ES-7 illustrate the critical corridors for I-15, I-70, I-80, I-84, U.S. 89, U.S. 91, and S.R. 36, respectively.

Existing Countermeasures

Four drowsy driving countermeasures used to combat drowsy driving were discussed. These countermeasures included: rumble strips, cable median barrier, rest areas, and drowsy driving freeway signage. Although drowsy driving signage has been installed on Interstates 15, 70, and 80, only the signage along I-80 was analyzed using a before-after study. Three methods were used in the before-after analysis to determine the effectiveness of the drowsy driving signs on I-80, namely the traditional, modified-traditional, and comparison group methods. The results of the three analyses are provided in Table ES-1.

Table ES-1. Summary of Drowsy Driving Signage Before-After Analyses

Method	Reduction in Number of Crashes (%)		Standard Deviation (%)		Number of Crashes Reduced	
	EB	WB	EB	WB	EB	WB
Traditional	45.0	12.5	52.6	25.0	9.0	0.0
Modified Traditional	46.4	5.3	24.8	57.5	4.2	0.0
Comparison Group	62.9	22.4	19.9	46.4	5.8	0.5

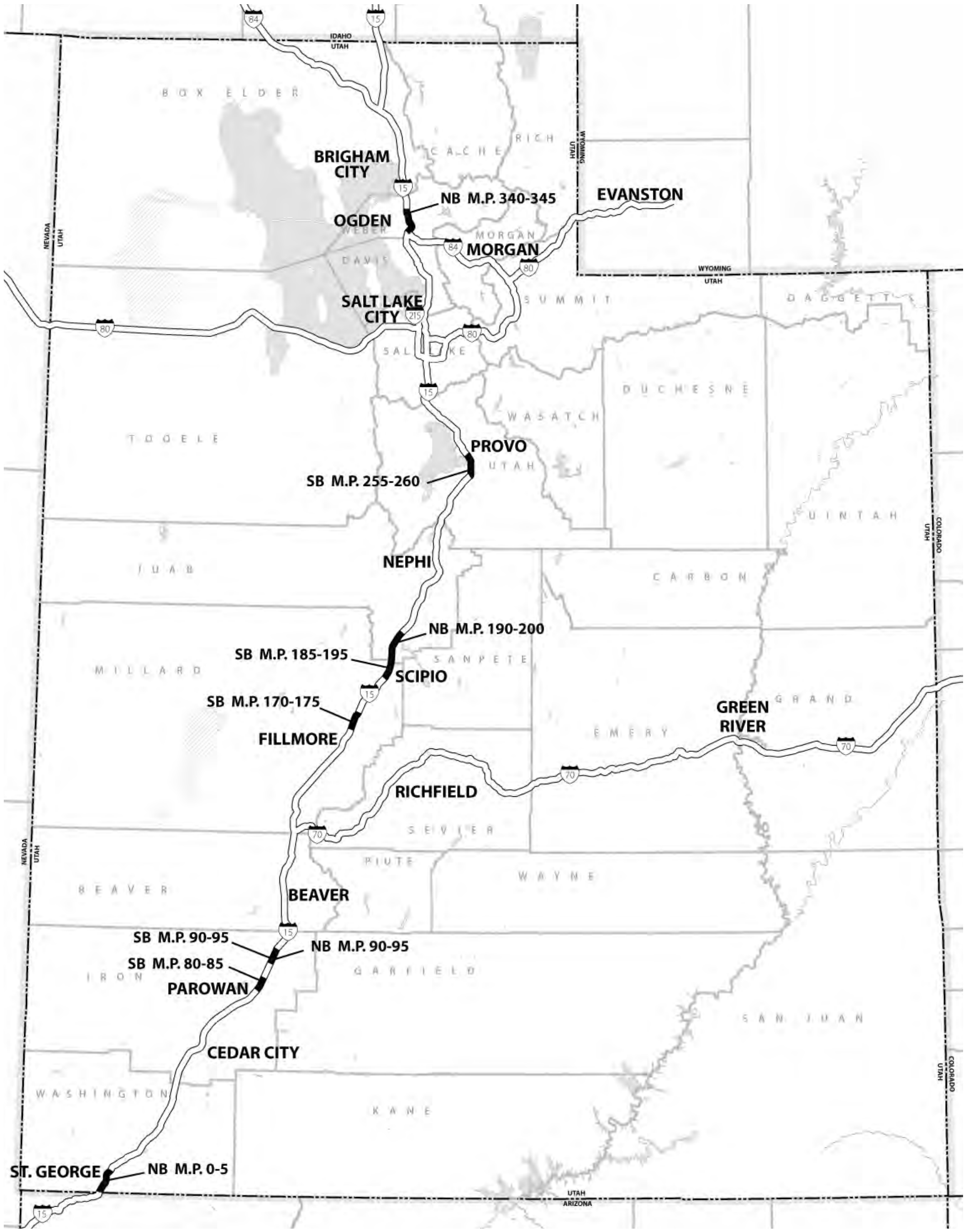

Figure ES-1. I-15 drowsy driving corridors.

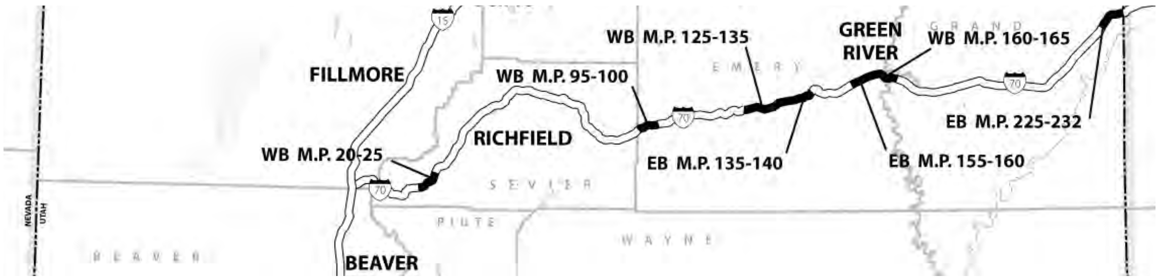

Figure ES-2. I-70 drowsy driving corridors.

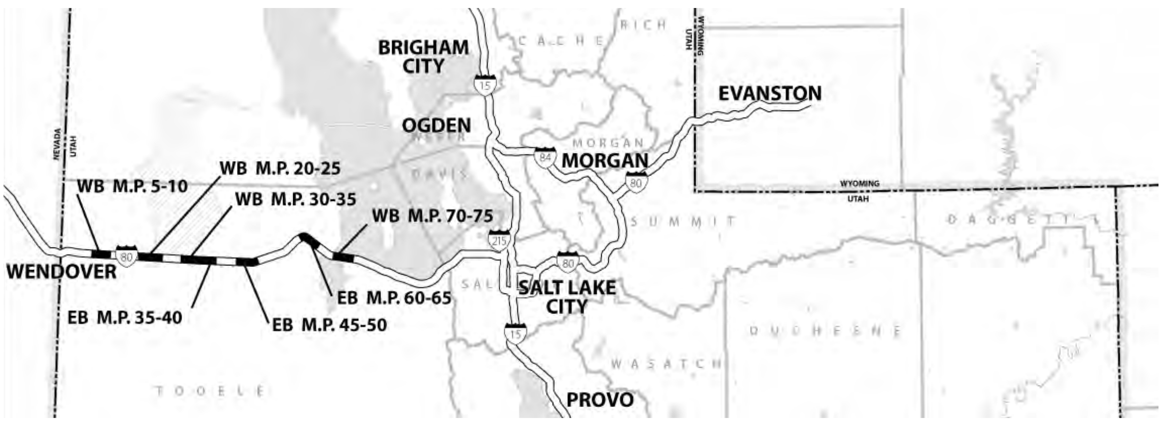

Figure ES-3. I-80 drowsy driving corridors.

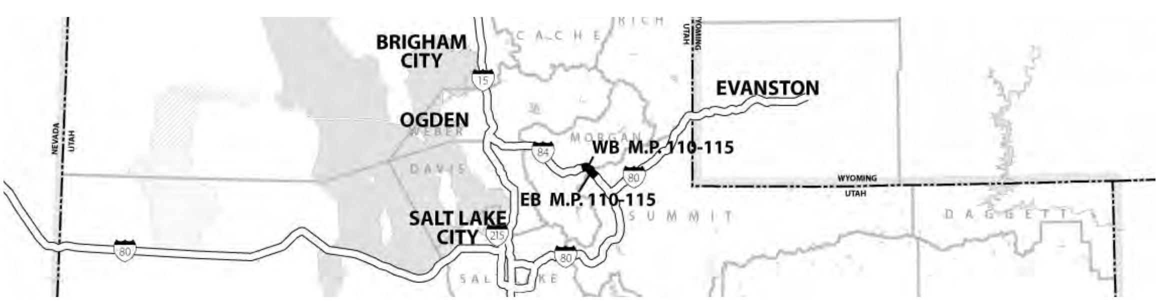

Figure ES-4. I-84 drowsy driving corridors.

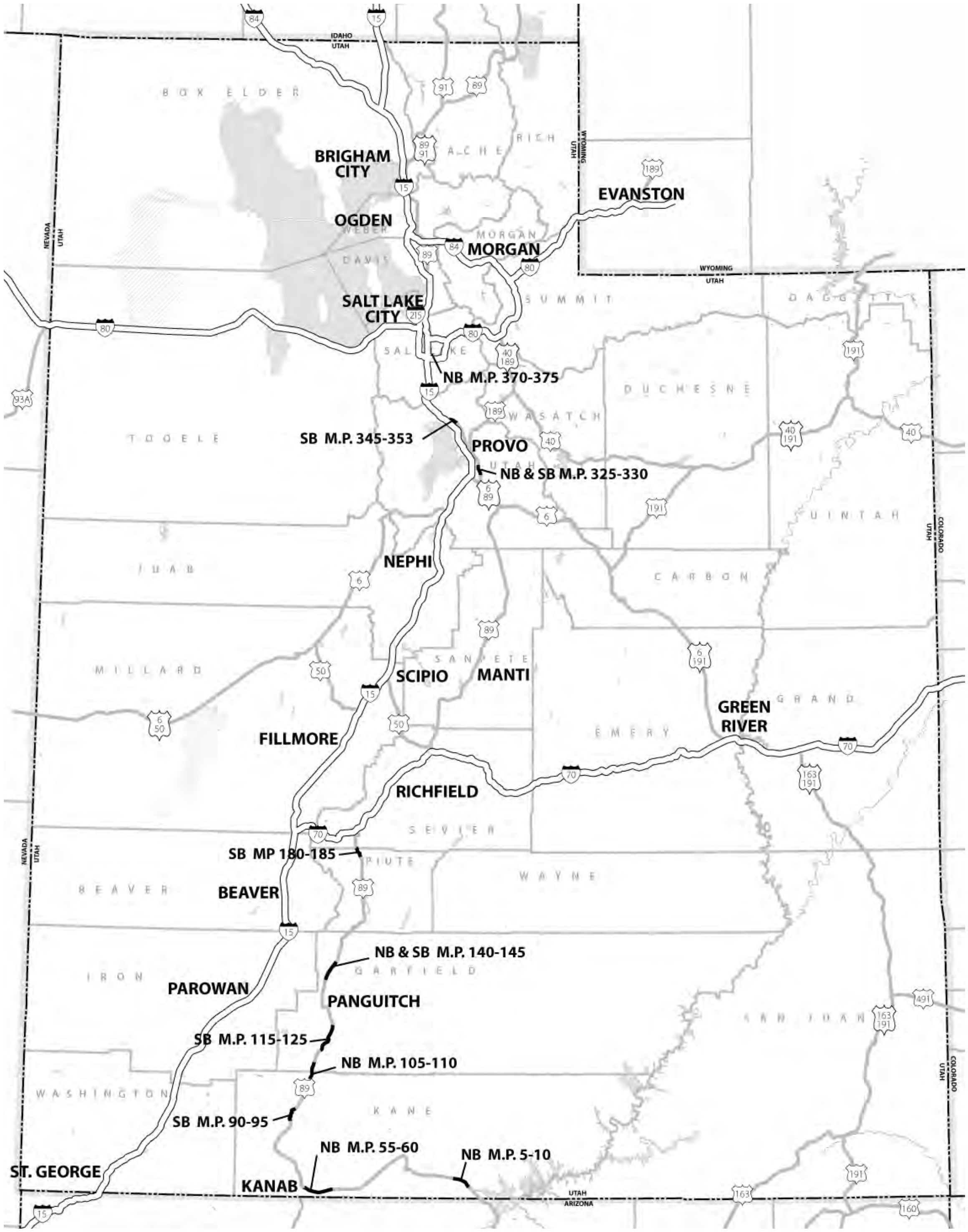

Figure ES-5. U.S. 89 drowsy driving corridors.

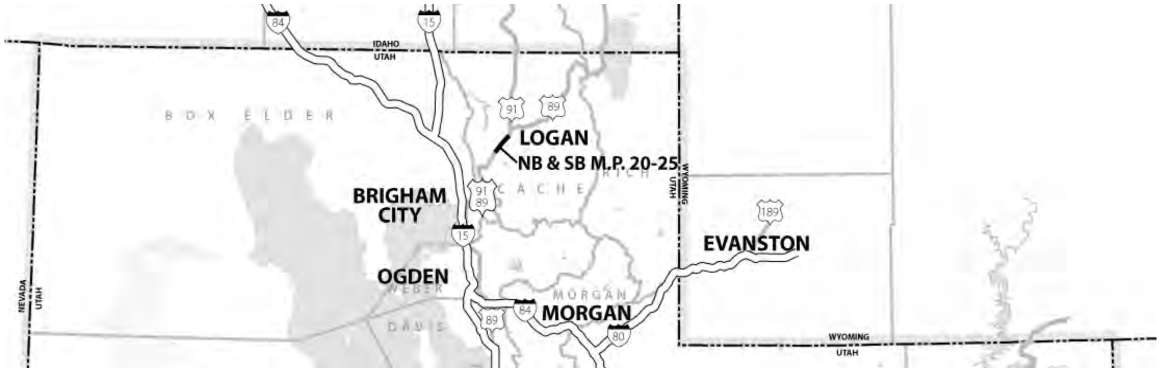

Figure ES-6. U.S. 91 drowsy driving corridors.

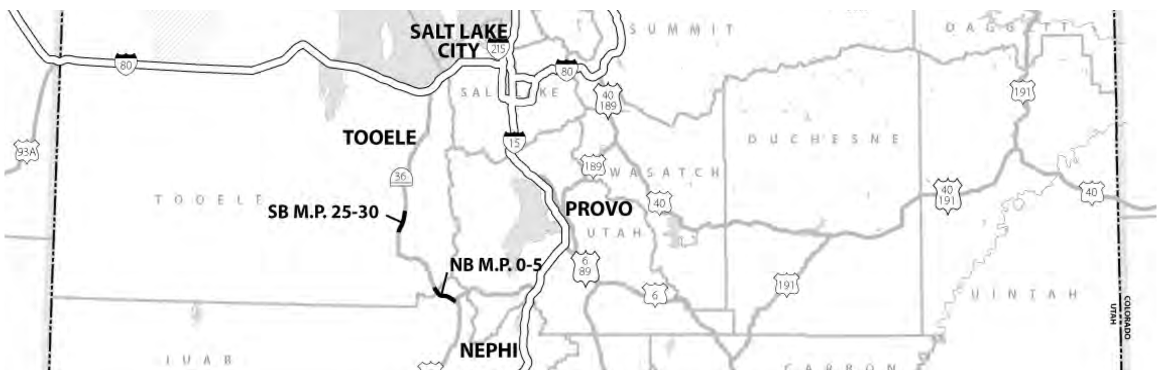

Figure ES-7. S.R. 36 drowsy driving corridors.

Public Survey: Drowsy Driving

A public survey was conducted to evaluate the opinions of drivers with respect to the drowsy driving freeway signage discussed. Surveys were conducted at the westbound Salt Flats rest area at M.P. 10 as well as at the eastbound Grassy Mountain rest area at M.P. 54. A total of 405 surveys were completed. It was determined that of the 387 surveyed drivers who saw the drowsy driving freeway signs, 33.6 percent indicated that the signs "definitely" or "somewhat" contributed to their decision to stop at one of the two rest areas. Also calculated from the survey was the effect that the signs had on drivers who admitted that one reason for stopping at one of the rest areas was drowsiness. Of the 45 people who cited feeling drowsy as a reason for stopping, 32 (71.1 percent) indicated that the drowsy driving signs "definitely" or "somewhat" contributed to their decision to stop.

Evaluation of Candidate Sites

Through a review of the literature and study of existing drowsy driving countermeasures in the state of Utah, various tools were discussed which may be useful in reducing the number of drowsy driving crashes statewide. It was determined that most of the critical corridors on Interstates have shoulder rumble strips while the critical corridors on U.S. and S.R. highways do not have rumble strips. Possible drowsy driving countermeasures identified include: shoulder and centerline rumble strips, additional drowsy driving highway signage, cable median barrier, clearing brush back to create wider shoulders, flattening slopes near shoulders, and using variable message boards in Salt Lake City to promote staying alert behind the wheel. Possible recommendations were made for each of the facilities evaluated. These recommendations are provided for UDOT to review and determine appropriate mitigation factors at these or other areas of concern throughout the state.

Summary

The results of the research indicate that drowsy driving occurs in both rural and urbanized areas alike. Although drowsy driving crashes represent only 3 percent of all crashes in Utah, they are responsible for approximately 14 percent of all fatal crashes on Interstates, U.S. Routes, and S.R. highways. Furthermore, the total number of drowsy driving crashes may be as high as 15 to 18 percent based on an analysis of potential underreporting of such crashes. The drowsy driving statistics calculated from Utah highways reaffirm many drowsy driving statistics outlined in the literature. For example, drowsy driving crashes typically had two peaks—one in the morning hours near 7 a.m. and one in the mid to late afternoon near 4 p.m. Along with time of day, it was determined that more drowsy driving crashes occurred on weekends than during the middle of the week. Other statistics from Utah highways identified drowsy driving crashes as more severe in nature. For example, on Interstate freeways approximately 6 percent of drowsy driving crashes ended in at least one fatality whereas in all crashes on these facilities combined less than 2 percent of crashes yielded a fatality.

The results of a crash rate analysis before and after installation of drowsy driving signs on I-80 west of Salt Lake City yielded promising results in helping to reduce drowsy driving crashes. Three before-after methods were outlined to calculate the effectiveness of the drowsy driving signs for the crash data available following sign installation. It was determined that the eastbound percent reduction in drowsy driving crashes ranged from 45 percent to a high of 63 percent while the westbound direction ranged from 5 percent to 22 percent. Again, the change in the number of crashes reflects not only the effect of the drowsy driving signage, but also the effect of factors such as traffic, weather, driver behavior, police report accuracy, and other unknown factors. It is not known what part of the change can be attributed to the drowsy driving signs and what part is due to the various other influences mentioned.

A public survey at two rest areas on I-80 was conducted to supplement the findings of the before-after drowsy driving freeway signage analyses discussed. It was determined that of the 387 surveyed drivers who saw the drowsy driving freeway signs, 33.6 percent indicated that the signs “definitely” contributed or “somewhat” contributed to their decision to stop at one of the two rest areas where surveys were conducted. Also calculated from the survey was the effect that the signs had on drivers who admitted that one reason for stopping at one of the rest areas was drowsiness. Of the 45 people who cited feeling drowsy as a reason for stopping, 32 (71.1 percent) indicated that the drowsy driving signs “definitely” or “somewhat” contributed to their decision to stop.

1 INTRODUCTION

The purpose of this report is to present the results of research conducted to assess fatigue and drowsy driving on Interstate freeways and state highways in the state of Utah. The study was part of a research project initiated in September 2006 by the Utah Department of Transportation (UDOT) and conducted by researchers at Brigham Young University (BYU). To understand the nature of drowsy driving in the state of Utah, this chapter is divided into four sections including a problem statement section, a background section, an objectives section, and a thesis organization section.

1.1 Problem Statement

A number of research projects have been performed to assess the fundamental causes of fatigue and drowsy driving. Typical results yield that approximately 1,500 fatalities each year can be attributed to falling asleep at the wheel or driving while severely fatigued in the United States (U.S.) (Knipling and Wang 1994). In Western Australia, driver fatigue is considered a factor in one in five fatal crashes (Main Roads 2007a). Other research indicates that almost 20 percent of all serious car crash injuries are associated with driver sleepiness, independent of alcohol effects (Connor et al. 2002). Due to the seriousness of fatigue and drowsy driving in the state of Utah, it was imperative that a study be conducted to evaluate the impact of fatigue and drowsy driving in the state.

To complete the assessment of fatigue and drowsy driving in the state of Utah, the UDOT crash database, a tool that has been proven extremely useful through previously conducted research studies, was utilized. The crash database permits researchers the ability to create filters, which can then be used to examine crash data. The filters allow users to retrieve crash data characteristics, identify high crash locations, and establish crash trends. This information can then be incorporated into a study to evaluate the character traits of the roadways in which these conditions occur, leading to the development of hypotheses on the possible reasons for such conditions. This information is very useful in establishing relationships between geometric and/or traffic conditions and overall safety levels.

1.2 Background

In recent years the United States Department of Transportation (USDOT) has placed a greater emphasis on reducing fatigue and drowsy driving. According to research conducted by the United States National Highway Traffic Safety Administration (NHTSA), drowsiness or fatigue has been indicated as a primary factor in 3.6 percent of fatal crashes (Knipling and Wang 1994). In the state of Utah, preliminary research shows that at least 10 percent of all fatal crashes are caused by either fatigue or drowsy driving according to current crash report statistics. Furthermore, research indicates that 2.9 percent of all crashes in Utah are directly related to drowsy drivers.

In contrast to alcohol related crashes, no blood, breathalyzer, or other objective test can be performed at the scene of a crash to determine if the cause of a crash was fatigue or drowsy driving. With no specific test to determine the level of drowsiness at the scene of a crash, police officers have difficulty identifying driver fatigue as a contributing cause to a crash; hence fatigue-related crashes are likely under-reported and may be contributing to significantly more crashes than statistics indicate.

While most people are aware of the dangers of drinking and driving, many fail to recognize that driving while extremely fatigued can be just as dangerous and deadly. Research indicates that fatigue appears to be second only to alcohol as the most common cause of serious injury in vehicle crashes (Mitler 1989). Similar to drivers who are under the influence of alcohol, drowsy drivers have a slower reaction time, decreased awareness of their environment, and lack of judgment in their actions. In 2004, the American Automobile Association (AAA) Foundation surveyed U.S. and Canadian police officers.

Of those surveyed, 88 percent had stopped a driver who they believed was under the influence of alcohol, but turned out to be drowsy (AAA 2004).

UDOT has recognized the seriousness of fatigue and drowsy driving and has taken a number of countermeasures to reduce fatigue-related crashes. One of the primary measures was the creation and installation of fatigue warning signs at several locations on Interstate 80 (I-80) between Wendover and Salt Lake City in mid 2004 as well as a more recent installation on eastbound Interstate 70 (I-70) approximately 50 miles west of Green River. The 2005 crash data on I-80 has tended toward a reduction in crash numbers related to drowsy driving, presumably as a result of the installation of the fatigue warning signs. In addition to the creation and installation of the fatigue warning signs, a task force comprised of the Utah Highway Patrol (UHP), UDOT, Utah Highway Safety Office, and a private consulting firm was formed in 2005 to promote awareness of drowsy driving through various media avenues. One of the primary accomplishments of the task was a media and education campaign that was carried out through radio public service announcements, television commercials, internet sources, and through displays at public events to help educate the public on the safety aspects of drowsy driving.

1.3 Objective

Due to the seriousness of fatigue and drowsy driving in the state of Utah, the need exists to evaluate the impact of fatigue and drowsy driving in the state, to identify locations where fatigue and drowsy driving may be contributing factors to current crashes, to identify methods to help mitigate these crashes, and to determine the effectiveness of the drowsy driving freeway signage on I-80. The purpose of this research, therefore, is to develop a strategy to mitigate fatigue-related crashes statewide and determine the role that the drowsy driving freeway signage plays in reducing drowsy driving crashes. The first step in this process is to identify high crash locations where fatigue and drowsy driving may be the significant causal factors. The next step in the process is to evaluate the effectiveness of current mitigation measures utilized by UDOT specifically the Interstate drowsy driving warning signs. The third step is to propose and evaluate possible engineering solutions to mitigate the concerns at the identified locations. These solutions may include additional highway signage, rumble strips, rest stops, and others. Finally recommendations will be provided for mitigation measures at the identified locations.

The results of this project will provide direction and guidance to UDOT on the identification and prioritization of corridors in which driver fatigue is a potential causal factor for crashes. Fatigue and drowsy driving is one of the primary focus areas of the "ZERO Fatalities" initiative currently underway in the state. UDOT will benefit from this research by implementing engineering mitigation measures at high crash locations identified to reduce crashes caused by fatigue and drowsy driving. The documented results will also be useful in aiding UDOT in understanding how to best apply the signage and education efforts for fatigue and drowsy driving in the future.

1.4 Report Organization

This report is organized into the following eight chapters: 1) Introduction; 2) Literature Review; 3) Analysis Procedure; 4) Results; 5) Existing Countermeasures; 6) Public Survey: Drowsy Driving; 7) Evaluation of Candidate Sites; and 8) Conclusions. A reference section and an Appendix follow the indicated chapters.

Chapter 2 is a literature review that outlines and defines the root causes of fatigue and drowsy driving and quantifies how rampant this problem is among drivers across the country. The countermeasures currently in use to combat drowsy driving are discussed followed by the background of the UDOT crash database.

Chapter 3 documents the steps followed during the analyses using the UDOT crash database. The procedure followed in using the crash database is outlined in sufficient detail so that correct data may be extracted for similar future analyses. Background on two before-after crash rate analyses on I-80 is also provided.

Chapter 4 presents the results of the analyses including tables and figures to aid in the presentation of the results. The chapter contains crash data for the highway corridors prone to have drowsy driving crashes based upon corridors found to have crash rates in excess of a critical crash rate. Drowsy driving statistics pertinent to each highway are identified. Examples of these statistics include the time of day and day of the week of drowsy driving crashes. Also identified are the vehicle type, severity, and result of drowsy driving crashes.

Chapter 5 summarizes the current countermeasures implemented by UDOT to reduce the number of drowsy driving crashes. These countermeasures include drowsy driving freeway signage, rumble strips, and cable median barrier. Also, the results of two before-after crash rate analyses are presented.

Chapter 6 outlines the results of a drowsy driving public survey conducted at two rest areas on I-80 west of Salt Lake City. The results of 14 Chi-Square analyses are provided in which correlations among gender and age were determined.

Chapter 7 identifies the recommended drowsy driving countermeasures for the critical corridors determined in Chapter 4.

Chapter 8 provides conclusions of the research. The chapter also recommends future research possibilities related to the effectiveness of yet to be installed countermeasures.

The Appendix includes the results of two corridor analyses spanning three, five, and 13 years as well as statistical analysis data from before-after studies discussed in Chapter 5. Also included in the Appendix are the results of the Chi-square tests performed using the public survey results.

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2 LITERATURE REVIEW

A comprehensive literature review has been performed on aspects related to the causes and mitigation techniques of fatigue and drowsy driving. This process consisted of assembling applicable information that could contribute to this study. The literature review covers several different topics. First, the common causes of drowsy driving are outlined including high-risk drowsy driving groups. High-risk groups identified include drivers with sleep disorders, young adults, and shift workers. Second, general characteristics of drowsy driving crashes are summarized using case studies. Characteristics discussed include time of day, age of driver, severity, speed, location, number of vehicles, and result of drowsy driving crashes. Third, a review of countermeasures and their effectiveness as implemented in other states and countries is performed. Countermeasures discussed to reduce drowsy driving crashes include rumble strips, cable median barrier, rest areas, physical stimuli, educational programs, and in-car countermeasures. Fourth, the background on crash database tools as useful resources for fatigue and drowsy driving analysis is given.

2.1 Common Causes of Drowsy Driving

Drowsy or fatigue driving is a concept generally understood by the public and yet difficult to narrowly define. Fatigue is defined as a "disinclination to continue performing the task at hand" (Brown 1994, pp. 298). Furthermore, fatigue refers to the reluctance to continue a task as a result of physical or mental exertion or a prolonged period of performing the same task. Sleepiness, also referred to as drowsiness, is defined as the urge to fall asleep (Beirness et al. 2005). Although the two terms have distinct meanings, they are used interchangeably throughout the literature since the difference is somewhat negligible.

Drivers may succumb to sleep for many reasons, but as noted in *Principles and Practice of Sleep Medicine*, "Heavy meals, warm rooms, boring lectures, and the monotony of long-distance automobile driving unmask the presence of physiological sleepiness, but do not cause it" (Roehrs et al. 2000, pp. 44). Drivers with sleep disorders, who use alcohol or medication, who are young, and who work odd shift hours fall into the high-risk category for sleep-related crashes. Related to young people, law enforcement officers and young military personnel are also part of the high-risk population (Stutts et al. 2005).

The following subsections discuss drivers who are at a high-risk for drowsy driving crashes due human factors or lifestyle. Other factors which contribute to sleep-related crashes are also outlined including the time on task at hand and circadian rhythm.

2.1.1 Sleep and Sleep Disorders

The National Sleep Foundation (NSF) indicates that adults should sleep seven to nine hours every night (NSF 2007). In a poll conducted by the NSF it was reported that 16 percent of American adults sleep six or fewer hours per night on weekdays, while 71 percent sleep less than the recommended eight hours (NSF 2005). For many people, sleeping seven to nine hours does not occur due to the need to allow more time for work, family obligations, or social events. One of the most common reasons behind drowsy driving crashes is sleeping less than five hours (Connor et al. 2002). Stutts et al. (2003) indicates that those who sleep between six and seven hours are 2.6 times more likely to be involved in a drowsy driving crash than someone who sleeps eight hours while those who sleep less than four hours are almost 20 times more likely to be in a fatigue-related crash. With such a small percentage of the population able to sleep as much as recommended, it is evident why thousands are involved each year in automobile crashes stemming from fatigue or drowsy driving.

Besides the 71 percent who sleep less than eight hours each night, millions of Americans suffer from sleep disorders. The National Heart, Lung, and Blood Institute

(NHLBI) estimated in 2003 that 50 to 70 million Americans suffer from a chronic disorder of sleep and wakefulness (NHLBI 2003). This may be in the form of chronic insomnia, restless legs syndrome, and sleep apnea (Colten and Altevogt 2006). Two of the most prominent sleep disorders are sleep apnea and narcolepsy. Sleep apnea is a condition in which a person stops breathing during sleep as the throat muscles relax and collapse thus blocking the intake of air. Persons with this disorder must constantly arouse to resume breathing (Stutts et al. 1999). The marker of sleep apnea is snoring, which occurs when the airway is narrow. This is one side of the spectrum while not breathing at all is the other end (Sagberg et al. 2004). Although sleep apnea appears in all age groups of both men and women, men are 2.0 to 3.7 times as likely as women to have a sleep disorder such as sleep apnea. Sleep apnea occurs in about 4 percent of middle-aged males and 2 percent of middle-aged females (Young et al. 1993). Untreated sleep apnea patients are three to four times more likely to have automobile crashes (NSF 2006; Teran-Santos et al. 1999). In one survey, driving was reported as a sleep-inducing situation by 50 percent of sleep apnea patients (Roehrs et al. 2000).

Although less common than sleep apnea, narcolepsy is equally serious and just as potentially dangerous for automobile drivers. Narcolepsy is a neurological disorder in which the brain fails to regulate sleep-wake cycles correctly thus causing a person to fall asleep without warning. Narcolepsy affects both sexes equally at any age, but symptoms typically surface first in young adulthood (Mignot 2005). The prevalence of narcolepsy has been documented in multiple population-based studies and occurs in 0.02 to 0.05 percent of the population of Western Europe and North America (Mignot 1998).

2.1.2 Alcohol and Medication

In the United States, alcohol-induced impairment is the single greatest contributing factor in fatal car crashes (CSA 1986). Although this may be true regarding all types of crashes, one study indicated that only 2 percent of drivers who nod off at the wheel reported having had consumed alcohol while 12 percent reported taking medications prior to their trip (Royal 2003). This same report indicated that drivers in the age bracket of 30 to 45 are least likely to report alcohol or medication as a factor in their drowsy driving episodes.

In a New York survey, 35 percent of those involved in a drowsy driving crash reported having consumed alcohol while another 10 percent admitting to taking medication (McCartt et al. 1996). Studies indicate that using certain medications increases the risk of drowsy driving crashes, particularly using prescribed benzodiazepine anxiolytics and sedating antihistamines (Ray et al. 1992; Gengo and Manning 1990). Other drugs that cause sedation include opioid analgesics, tricyclic antidepressants, antipsychotics, certain antihypertensives, and muscle relaxants (Lyznicki et al. 1998).

Alcohol can independently induce sleepiness, but research has shown that sleepiness and alcohol interact, with sleep restriction exacerbating the sedating effects of alcohol. Thus, one's psychomotor skills are adversely affected to a greater extent than that of sleepiness or alcohol alone (Roehrs et al. 1994).

2.1.3 Young Drivers

Many reasons exist as to why young adults tend to have poor sleeping habits. Carskadon (1990) in her research discussed multiple reasons why younger people, and specifically adolescents, do not sleep enough. Younger people are at risk for excessive sleepiness due to maturational changes which increase the need for sleep, changes in sleep patterns thus reducing nighttime sleep, and lifestyle factors. Lifestyle factors encompass demands from school and work, extracurricular activities, or socializing late into the night. Over a quarter of high school and college students were found to be sleep deprived according to Wolfson and Carskadon (1998). Carskadon (1990) also identified that young males working more than 20 hours per week while being involved in extracurricular activities were most likely to report falling asleep at the wheel.

Multiple studies in which drowsy driving crash data by gender and age group were analyzed determined that young people, and specifically males, were most likely to be involved in a drowsy driving crash (McConnell et al. 2003; Pack et al. 1995; Horne and Reyner 1995; Knipling and Wang 1994). In these four specific research studies, the label of "young" was defined differently, but the range spans from 16 to 29 years of age.

Pack et al. (1995) indicated that the peak age was 20 years old while the median age of the driver in all of the drowsy driving crashes studied was 23.5 years old. For the years 1989-1993, Knipling and Wang (1994) determined that 59 percent of drivers involved in drowsy driving crashes were under 30 years of age while Horne and Reyners' (1995) study revealed that 45 percent of the 606 drivers they studied were under 30 years of age.

2.1.4 Shift Workers

Shift work is on the rise and more prevalent in the rapid growing service sector of the economy according to Presser (1989). Research by Presser (1995) also indicated that one in five to one in six employed Americans do not work regular daytime schedules. Shift workers, and especially rotating shift workers, often have problems receiving sufficient sleep to perform necessary duties. They also tend to suffer from poor quality of sleep (Stutts et al. 1999).

One specific group of people working irregular hours is truck drivers. The schedules of long-distance truck drivers may place them at higher risk for drowsy driving (Williamson et al. 1996). This higher risk is attributed not only to high levels of driving exposure due to long, irregular work hours, but also due to truck drivers who frequently traverse long, monotonous, high-speed corridors. Furthermore, these drivers have limited opportunities to obtain restorative sleep, thus minimizing their sleep debt (McCartt et al. 2000). Truck drivers typically obtain less sleep than is required for alertness on the job (Mitler et al. 1997). The irregular work hours of truck drivers includes rotating shifts and night shifts, which has been linked to sleepiness-related driving (McCartt et al. 1996).

2.1.5 Time on Task at Hand

Drowsy driving is typically associated with drivers who have been behind the wheel for an extremely long period of time. The general public may experience long driving hours during vacations as drivers attempt to cover long distances over short periods of time—24 to 48 hours (Smiley 2002). Although drowsy driving does occur when driving for many hours, one study indicated that 47 percent of drivers who recently experienced a drowsy driving episode had only been on the road for an hour or less. In the same study, of those who had been on the road for five or more hours only 22 percent indicated having a drowsy driving issue (Royal 2003). A study of six years of drowsy driving crashes in Tennessee found that in almost 61 percent of the fatal/serious sleep-related crashes, the drivers were less than 25 miles from home, although the research could not verify how long the drivers had been driving (McConnell et al. 2003).

A meta-analysis conducted by Folkard (1997) showed that during the first two hours of driving there seems to be an early increase of risk of being in a drowsy driving crash. This was followed by a decrease for the next two hours before increasing again. Maycock (1996) noticed a greater risk of being involved in a fatigue-related crash when driving a longer time without taking a break, specifically when driving three hours or longer.

2.1.6 Circadian Rhythm

The sleep-wake cycle is governed by two factors, namely the homeostatic and circadian factors. Homeostasis relates to the neurobiological need to sleep, therefore, the longer one remains awake the greater the desire to sleep and more difficult it is to resist (Dinges 1995). The circadian pacemaker is an internal clock located in the hypothalamus which regulates physiological and behavioral functions on a 24-hour basis. Most people who have a regular routine of nightly sleep experience two periods of maximum sleepiness, at night during the hours of 1 a.m. to 6 a.m. and again in the mid-afternoon generally between the hours of 2 p.m. and 4 p.m. (Lyznicki et al. 1998). The circadian rhythm is synchronized by various time-keepers such as the rising and setting of the sun, knowledge of clock time, and work time (Kroemer and Grandjean 1997).

As indicated previously, shift workers work irregular hours and thus are more likely to be involved in a drowsy driving crash. This higher risk is likely associated with the circadian rhythm. Shift workers can readjust their circadian rhythm so that physiological activity is higher during the work period and lower during sleep, but the reversal is not usually complete even after several weeks (Kroemer and Grandjean 1997).

One study of commercial motor vehicle drivers concluded that the strongest and most consistent factor influencing driver fatigue and alertness is time of day due to the circadian rhythm (Wylie 1996).

2.1.7 High-Risk Drowsy Driving Summary

The previous sections identified groups of people at high-risk of being involved in drowsy driving crashes. The sleepiness which precedes drowsy driving leads to crashes because it impairs the human body's ability to perform safe driving (Dinges and Kribbs 1991). Impairments which have been identified by Dinges (1995) through laboratory and in-vehicle studies include slower reaction time and slower processing of information. Increasing reaction time intuitively decreases a driver's ability to avoid a collision. Also, pointed out by Dinges (1995) is that performance declines due to the diminished ability to process information and retain information in one's short-term memory.

2.2 Drowsy Driving Characteristics

One impediment to better understanding drowsy driving is the number of crashes caused by drowsiness which never are reported under this category. It is believed that drowsiness as a primary factor in crashes where the driver fell asleep is under-reported because in many cases no evidence suggests the driver fell asleep behind the wheel (McCartt et al. 2000). In contrast to alcohol-related crashes, no blood, breath, or other objective test for sleepiness currently exists that is administered to a driver at the scene of a crash. As indicated previously, drowsiness is defined differently for every person, and as such, no criteria are available for establishing how sleepy a driver is or at what point a driver is unable to safely maneuver a vehicle (NHTSA 1998). Despite the under-reporting of drowsy driving crashes, a relatively clear understanding of the statistics, characteristics, and trends of drowsy driving crashes can be identified as outlined in the following sections.

2.2.1 Time of Day and Age of Drivers in Drowsy Driving Crashes

Pack et al. (1995) identified trends in drowsy driving crashes by time of day. The crash data studied indicated that drowsy driving crashes predominately occurred after midnight with a secondary peak in the late afternoon. The timing of these crashes is consistent with the circadian rhythm as mentioned previously (NHTSA 1998). Knipling and Wang (1994) also cited that drowsy driving crashes peak in the early morning hours. Of the drowsy driving crashes studied from 1989 to 1993, 55 percent occurred between midnight and 8:00 a.m. with another 18 percent taking place between 1:00 p.m. and 5:00 p.m. (Knipling and Wang 1994). Other studies also identify the role that time of day plays in drowsy driving crashes (Horne and Reyner 1995; McCartt et al. 1996).

The temporal variation in drowsy driving crashes has been shown to be a function of age. From 16 to 45 years of age, drowsy driving crashes occur most commonly during the night; for drivers between 45 to 65 years of age, the peak hour is at 7 a.m.; lastly, for drivers over 65, the afternoon from 1 p.m. to 3 p.m. is the mostly likely time to have a drowsy driving crash (Pack et al. 1995; Åkerstedt and Kecklund 2001).

Multiple studies in which drowsy driving crash data by gender and age group were analyzed determined that young people, and specifically males, were most likely to be involved in a drowsy driving crash (Pack et al. 1995; Horne and Reyner 1995; Knipling and Wang 1994). McConnell et al. (2003) specifically indicated that the greatest number of sleep-related crashes in his study occurred during the late-night weekend hours, with the greatest number of 15 to 24 year old drivers falling asleep and crashing on Saturday followed closely by Sunday.

2.2.2 Severity of Drowsy Driving Crashes

The mortality rates associated with drowsy driving crashes are high, which may be in part due to the higher speeds involved in such crashes (Horne and Reyner 1995). Furthermore, drowsy drivers typically have a slower reaction time and reduced ability to process information, which when coupled with high speeds may result in more severe crashes (Dinges 1995). In a Tennessee study spanning the years 1994 to 1999, 38,797 fatal and/or injury crashes took place, 1,269 (3.3 percent) of which were attributed to drowsy drivers. Specifically, 1.9 percent of drowsy driving crashes were fatal while another 9.4 percent were incapacitating injuries. For comparison purposes, only 0.6 percent of all other crashes in the study resulted in fatalities, and 3.1 percent in incapacitating injuries (McConnell et al. 2003). Similar studies have concluded that a higher proportion of the most serious crashes are sleepiness related (Maycock 1996; Pack et al. 1995).

2.2.3 Speed, Location, Number of Vehicles, and Result of Drowsy Driving Crashes

Speed seems to play a role in the seriousness of drowsy driving crashes. Although speed does not cause drowsy driving, research indicates that a large percentage of sleep-related crashes occur where speeds are in excess of 50 mph (Pack et al. 1995; Stutts et al. 2005). Other research indicates that such crashes occur on roadways with 55 to 65 mph speed limits, and in non-urban areas (Knipling and Wang 1994). This is also confirmed by the NHTSA whose research shows that most drowsy driving crashes take place on higher speed roads in non-urban areas (NHTSA 1998).

Referring to a Tennessee study, 75 percent of sleep-related fatal and/or injury crashes occurred on rural roads. The same research indicated that of all rural road drowsy driving crashes studied, 55 percent took place on two-lane roads while another 22 percent happened on four-lane divided highways (McConnell et al. 2003). Another study of four years of crash data concluded that 75 percent of drowsy driving crashes occurred on two-lane roadways (Stutts et al. 2005). Maycock (1996) found that a larger absolute number of drowsy driving crashes occur in built-up areas, which is possibly due to the greater exposure of drivers in cities.

An analysis of North Carolina police crash reports showed that most non-alcohol, drowsy driving crashes were single-vehicle roadway departures (Pack et al. 1995). Validating the findings of Pack et al., McConnell et al. (2003) found that 77 percent of the fatal and/or injury sleep-related crashes studied involved single-vehicles.

Among a New York State telephone survey, almost 48 percent of drivers involved in a drowsy driving crash cited having driven off the roadway. Furthermore, almost 25 percent reported going off the road even though they did not crash (McCartt et al. 1996). Besides leaving the roadway altogether, research in Norway concluded that drifting out of one's lane occurs frequently (Sagberg 1999). In addition to run-off-road crashes, sleepy drivers also are likely to be overrepresented in rear-end and head-on collisions (Knipling and Wang 1994).

2.3 Drowsy Driving Countermeasures

As has been identified in this chapter, drowsy driving is a widespread concern which results in many fatalities each year. To combat the effects of drowsy driving and prevent tragic crashes, many types of countermeasures have been implemented by various agencies across the U.S. and other countries to reduce the number of drowsy driving crashes. This section discusses several drowsy driving countermeasures and their effectiveness. Countermeasures discussed in the following subsections include rumble strips, cable median barrier, wide longitudinal edge lines, rest areas, physical stimuli, educational programs, and in-vehicle countermeasures.

2.3.1 Rumble Strips

One of the most important objectives of good roadway design is to maintain vehicles in their designated lanes. If a vehicle accidentally drifts out of a lane and crosses the edge line, effective highway design should facilitate the recovery of the vehicle and aid the driver in safely reentering the roadway. Sorrowfully, in many cases, vehicles leave their lane of travel, cross over onto the shoulder, and end up as a run-off-road crash as has been identified previously (Neuman et al. 2003). To prevent run-off-road crashes, many states have installed rumble strips. Rumble strips function by providing audible and physical vibrations inside a vehicle when it runs over them. The physical jarring of a car passing over rumble strips is a technique used to alert and warn drivers of changes in roadway alignment when they have partially or completely left the travel lane (Harwood 1993). Wood (1994) indicated that run-off-road crashes can be reduced by as much as 70 percent using rumble strips. To have such success many types of rumble strips have been designed. These include shoulder rumble strips, centerline rumble strips, transverse rumble strips, and mid-lane rumble strips.

2.3.1.1 Shoulder Rumble Strips

Shoulder rumble strips are used to alert drivers that they have left the traveled way and that a steering correction is necessary to return to the middle of the travel lane (Harwood 1993). Two types of shoulder rumble strips which are used are continuous and discontinuous rumble strips. Figure 2-1 illustrates continuous shoulder rumble strips while Figure 2-2 shows discontinuous rumble strips.

Shoulder rumble strips have gained increased popularity over the past 15 years. In 1993, it was estimated that 18 to 21 states had shoulder rumble strips on rural highways (Harwood 1993). A more recent evaluation of shoulder rumble strips by the Federal Highway Administration (FHWA) indicated that approximately 85 percent of states now use this type of countermeasure to reduce run-off-road crashes (FHWA 1997).

(Photo by Hunter Young 2007)

Figure 2-1. Continuous shoulder rumble strips.


(Photo by Brian Christensen 2006)

Figure 2-2. Discontinuous rumble strips.

In recent years, multiple studies of rumble strips have been conducted to determine their effectiveness in preventing crashes. Research has shown that shoulder rumble strips reduce single-vehicle run-off-road crashes from 20 percent to as much as 70 percent (Griffith 1999; FHWA 1997). A Montana study not only attributed a 14 percent reduction in Interstate run-off-road crash rates to shoulder rumble strips, but also a 24 percent reduction in severity rates (Marvin and Clark 2003). Table 2-1 provides a summary of the effectiveness of shoulder rumble strips in reducing single-vehicle run-off-road crashes.

Table 2-1. Summary of Effectiveness of Shoulder Rumble Strips (FHWA 1997)

State	Year	Highway Type	Percent Crash Reduction
Pennsylvania	1994	Thruway – Rural	70
New Jersey	1995	Turnpike – Rural	34
New York	1994	Thruway – Rural	72
Massachusetts	1997	Turnpike – Rural	42
Washington	1991	Six Locations	18
California	1985	Interstate – Rural	49
Kansas	1991	Turnpike – Rural	34
FHWA	1985	Interstate – Rural (Five States)	20

2.3.1.2 Centerline Rumble Strips

The primary purpose of centerline rumble strips is to warn drivers whose vehicles are crossing the centerline of two-lane, two-way roadways to prevent crashes with opposing traffic (Russell and Rys 2005; Saito and Richards 2005). An illustration of centerline rumble strips provided by the Minnesota Department of Transportation (Mn/DOT) is shown in Figure 2-3. In 2004 it was reported that 20 U.S. states and several Canadian provinces were using centerline rumble strips (Noyce and Elango 2004).

(Source: Mn/DOT 2006)

Figure 2-3. Centerline rumble strips.

Various studies of the effectiveness of centerline rumble strips have been conducted across the U.S. One of the most compelling case studies took place on U.S. Route 301 in Delaware. U.S. Route 301 had a high fatality rate from head-on collisions, but after installing centerline rumble strips the fatality rate dropped to zero. Furthermore, a 90 percent decrease in head-on collisions resulted (FHWA 2002). Another centerline rumble strip study of three highways in Massachusetts found that the installation of centerline rumble strips showed no significant change in crash frequencies; however, no fatal crashes were observed at two of the three test sites after installation of the rumble strips (Noyce and Elango 2004). A before-after crash analysis of 17 miles of centerline rumble strips conducted by the Colorado Department of Transportation determined that head-on collisions were reduced by 34 percent with a 37 percent reduction in cross-over sideswipe crashes (Outcalt 2001).

2.3.1.3 Transverse Rumble Strips

Transverse rumble strips consist of a pattern of raised or grooved bars spaced relatively close to one another and are oriented perpendicular to the flow of traffic (Harwood 1993). In Harwood's (1993) report, 23 states are mentioned as having transverse rumble strips and using them for a range of applications. The most frequently identified reasons for this type of rumble strip pattern were to alert drivers of an unanticipated intersection and warn drivers in work zones (Harwood 1993). Another reason to use transverse rumble strips may be to enhance delineation of sharp curves in roadway alignment (Neuman et al. 2003). A before-and-after study conducted in Texas determined that the speeds of vehicles after passing over transverse rumble strips prior to a horizontal curve decreased between 1 mph to slightly more than 5 mph (Miles et al. 2005). Figure 2-4 shows an example of the transverse rumble strips used in the Texas study identified.

(Source: Miles et al. 2005)

Figure 2-4. Transverse rumble strips.

2.3.1.4 Mid-lane Rumble Strips

Mid-lane rumble strips are rumble strips located in the center of the travel lane verses the edge of the shoulder and are installed parallel with the flow of traffic. This type of rumble strip is an experimental treatment which could be used on roadways with no shoulders or narrow paved shoulders where insufficient shoulder width does not accommodate shoulder rumble strips (Neuman et al. 2003). As with all types of rumble strips, pros and cons do exists with mid-lane rumble strips. Some safety engineers believe that adding rumble strips to the middle of a lane will be another distraction for drivers. This type of rumble strip should be pilot tested before widespread use (Neuman et al. 2003).

2.3.1.5 Rumble Strips Summary

In conclusion, rumble strips do yield positive results as indicated by the various studies examined, but they also do have some adverse effects. In various surveys, states identified noise problems as well as pavement deterioration as main problems with rumble strips. Bicycle riders, motorcycle riders, and emergency vehicle operators have also been noted as parties with concerns about the use of rumble strips (Noyce and Elango 2004; Harwood 1993). One specific concern of centerline rumble strips is the effect they have on passing operations on two-lane, two-way highways. A study conducted in College Station, Texas concluded that centerline line rumble strips have little effect on passing operations when they are installed in passing zones on rural two-lane, two-way traffic (Pratt et al. 2006).

2.3.2 Cable Median Barrier

Cable median barrier has been found on the nation’s highways since about the 1930s. Today cable barriers use three or four cables supported by weak steel posts and have been used significantly by multiple states (McClanahan et al. 2004). Cable barriers are placed in the median between opposing directions of travel to reduce the probability of a crossover crash. When the cable is struck, the posts yield and the cable deflects up to

12 feet, effectively catching and decelerating the vehicle and keeping it in the median (Chandler 2007).

The South Carolina Department of Transportation completed the installation of 315 miles of cable median barrier on Interstates with medians less than 60 feet wide to address the growing concern of crossover median crashes. From 1999 to 2000, more than 70 people lost their lives in 57 separate Interstate median crashes in the state. During the three years following installation, the cable median barrier system was hit 3,000 times. Only 15 vehicles, which represented less than 1 percent of those that hit the median barrier, penetrated the cable system resulting in eight fatalities or 2.7 fatalities per year (Zeitz 2003). Figure 2-5 illustrates the cable median barrier implemented in South Carolina in 2003.

(Source: TFHRC 2007)

Figure 2-5. Cable median barrier in South Carolina.

In the 1990s, the Washington State Department of Transportation (WSDOT) was interested in installing cable median barrier in medians wider than 30 feet. WSDOT chose the cable barrier in part because it could be installed for about one-third the cost of concrete barrier and two-thirds the cost of W-beam guardrail. Following installation of the barrier, WSDOT conducted a before-after crash analysis of the cable median barrier installed along 24 miles of Interstate 5 in three locations. The number of annual fatal crossover crashes was 1.6 crashes before installation of the cable and dropped to 0 fatal crashes after having the cable installed. WSDOT reported that the number of annual crossover crashes was 16 crashes before installation of the cable, which decreased to 3.8 crossover crash following cable median installation, a 76 percent reduction (McClanahan et al. 2004).

The state of Missouri has recently undertaken an initiative to have 500 total miles of cable median barrier installed statewide by the end of 2008. The Missouri Department of Transportation (Missouri DOT) decided to install cable barrier on all Interstates with medians less than 60 feet wide. The installation of cable median barrier according to Missouri DOT costs $60,000 to $100,000 per mile depending on the amount of grading work to be done. One specific case study was conducted on I-70, the most heavily traveled highway in the state. In 2002, 24 motorists were killed in cross-median crashes on I-70 leading the state to install 179 miles of cable median barrier. In 2006, only two cross-median fatalities were reported on I-70, a 92 percent decrease (Chandler 2007).

2.3.3 Wide Longitudinal Edge Line Pavement Markings

Over the past two decades a greater understanding of drivers' visibility needs have become more prevalent. As such, some state transportation agencies have implemented the use of longitudinal pavement markings that are wider than the standard 4-inch minimum line width for centerline, edge line, or lane line applications. As of summer 2001, 29 of the 50 state DOTs were using some type of wider pavement marking to improve marking visibility (Gates and Hawkins 2002). Edge lines of 6-inch width are common on freeways and some lower class roads. Using a wide edge line of 8 in. to 12 in. on curvilinear sections, while not common, has been used to emphasize curves and provide a stronger visual guide for motorists (McGee and Hanscom 2006). McGee and Hanscom (2006) specify that a wide edge line on roadways with a pavement width less than 20 feet not be used as motorists could move too far left into opposing traffic. Figure

2-6 illustrates a wide 8-in. longitudinal pavement marking used to delineate a curvilinear roadway alignment.

(Source: McGee and Hanscom 2006)

Figure 2-6. Rural highway with 8-inch edge line.

Wide edge lines do have benefits and drawbacks. Gates and Hawkins (2002) identified the benefits of wider pavement markings to include: improved long-range detection under nighttime driving conditions, improved stimulation of peripheral vision, improved lane positioning, and improved driver comfort. The only drawback determined was the increased cost due to increased amounts of material. The benefits though appear to outweigh the drawbacks as indicated in a case study from New York. A study by the New York DOT in 1988 found that sections of curving two-lane rural roads with new 8-in. edge lines resulted in higher crash rate reductions than similar sections which had new 4-in. wide edge lines. The study cited that a 10 percent decrease in total crashes occurred where wider edge lines were used versus a 5 percent increase in total crashes where 4-in. wide edge lines were used (Neuman et al. 2003).

2.3.4 Rest Areas on Interstates

According to the California Department of Transportation (Caltrans) Web site, "Rest areas provide opportunities for motorists to safely stop, stretch, take a nap, use the restroom, get water, check maps, place telephone calls, switch drivers, check vehicles and loads, and exercise pets. Rest areas reduce drowsy and distracted driving and provide a safe and convenient alternative to unsafe parking along the roadside" (Caltrans 2007). Stutts et al. (2005) indicated that since most drowsy driving crashes occur on two-lane rural roadways "states should provide a continuum of options for safe stopping, ranging from smaller rest areas with most of the usual amenities to simple roadside parks with minimal or no amenities" (pp. V-11).

2.3.5 Physical Stimuli

Many types of countermeasures used to fight sleepiness are aimed at physical stimuli in the body. Techniques used to combat fatigue while behind the wheel include listening to music, drinking caffeinated beverages, rolling down the window, turning on the air conditioning, smoking, slapping oneself, and pulling off the highway to nap, eat, or stretch (Nguyen et al. 1998). Several of these countermeasures are discussed in the following paragraphs.

In a study by Stutts et al. (1999), 467 drivers that had been involved in sleep/fatigue-related crashes were asked what types of countermeasure strategies drowsy drivers use to maintain alertness while driving. In reporting the results, drivers deemed to have fallen asleep at the wheel were separated from those crashes reported due to fatigue. The most frequently cited strategy for these two groups was opening the window or adjusting the air conditioner to let in fresh air and reduce the temperature inside the vehicle cabin (Stutts et al. 1999). The overwhelming majority of sleep crash drivers (69 percent) and many of the fatigue crash drivers (57 percent) cited with the above strategy to maintain alertness. The second most cited countermeasure was listening to the radio, a tape, or a CD, which was cited by nearly 45 percent of drivers in both the sleep and fatigue crashes (Stutts et al. 1999). Interestingly, only 12 percent of sleep/fatigue crash drivers identified stopping to take a nap as a way they reduce drowsiness behind the wheel.

Although nearly half of drivers from the Stutts et al. (1999) study indicated listening to music as a method to reduce drowsiness, Reyner and Horne (1998) concluded that cold air and listening to the radio/tape player are of marginal and transient benefit. They even report that such countermeasures are effective for only about 15 minutes, long enough to allow a driver to stop at a suitable place and rest (Horne and Reyner 1999).

Sleeping seems to be the obvious remedy to drowsy driving. Naitoh (1992) indicated that the duration of each sleep episode must be longer than 4-10 minutes to be recuperative while at the same time unaccustomed naps beyond 20 minutes lead to unwanted sleep inertia or grogginess. Fifteen minutes seems to be the optimum length of time for a nap (Gillberg et al. 1994; Naitoh 1992). Horne and Reyner (1996) studied the consequences of giving test subjects a shorter than 15 minute nap, 150 mg of caffeine, and a coffee placebo. Their results concluded that naps and caffeine, which is a pharmacological stimulant, significantly reduced driving impairment. Other research also supports the claim that caffeine helps maintain alertness (Cummings et al. 2001). To this end, drivers in Western Australia can receive a cup of coffee free of charge at any one of over 100 “roadhouses.” An example of the roadway signs implemented to remind drivers of free coffee is shown in Figure 2-7.

(Source: MainRoads 2007b)

Figure 2-7. Highway signage in Western Australia indicating free coffee for drivers.

2.3.6 Educational Programs

Public education of drowsy and fatigue driving has been implemented by various agencies in recent years. The NHTSA (1998) in their report outlined three priorities for their educational campaign. First, educate young males ages 16 to 24 about drowsy driving and how to reduce lifestyle-related risks. Second, promote shoulder rumble strips as an effective countermeasure for drowsy driving. Third, educate shift workers about the risks of drowsy driving.

One method in which young drivers both male and female are educated about drowsy driving is through driver training courses and more specifically through graduated driver's license programs. Research indicates that some graduated drivers license programs have reduced total fatalities among young drivers by as much as 19 percent (Morrisey et al. 2006). Other courses of action to educate the general public about drowsy driving include television commercials and Web sites. This approach has been implemented in Utah as part of the *Zero Fatalities: A Goal We Can All Live With* campaign (UDOT 2006a). McConnell et al. (2003) believe that educational interventions have the most promise for mitigating drowsy driving since there are no legal sanctions against drowsy driving.

2.3.7 In-car Countermeasures

In recent years various in-vehicle systems have been created to measure sleepiness or some behavior associated with sleepiness in commercial and noncommercial driving. The technological tools include brain wave monitors, eye-closure monitors, devices that detect steering variance, and tracking devices that detect lane drift (Dinges 1995). Eye-closure monitors have received attention in research studies for many years. Stern et al. (1994) and Sagberg et al. (2004) identified eye-closure rates to be a good index of sleepiness, but Horne and Reyner (1999) disagree finding that eye-closure rates are unreliable since blinking in the driver is affected by a host of variables including the outside road lighting, oncoming headlights, and the air temperature and state of the ventilation system in the vehicle.

Brown (1997) remarked in research on technological countermeasures that even if wide-spread implementation of such countermeasures were to succeed, educational and exhortational countermeasures will continue to be needed. One reason Brown identified the continual need for educating the public is that drivers are typically aware that they are becoming drowsy, but that this awareness is not a reliable guide to their true alertness. A problem then exists since fatigue countermeasures rely solely on drivers self-monitoring their status. Although in-car countermeasures may ultimately yield some benefit, Sagberg et al. (2004) reported that “a possible negative effect of in-car warning systems may be that driver’s use them to stay awake and drive for longer periods rather than stopping and have a nap” (pp. 38).

2.4 Background of the UDOT Crash Database Tool

The research conducted in this report is the first such investigation of drowsy driving in the state of Utah. To determine from recent history where drowsy driving crashes have occurred, crash data was evaluated. Crash records were extracted from UDOT’s crash database that can be used to analyze crash statistics for all Interstate freeways, U.S. Routes, and Utah State Routes (S.R.).

One objective of the crash database is to allow for rapid retrieval and analysis of crash data. The system is designed to improve the investigation of the data in six ways (Anderson et al. 2005):

1. Custom tables and reports are created with only selected parameters, leaving off unneeded data. This simplifies the analysis by focusing on what is important to each individual user.
2. Placing the data on a “smart map” allows the decision-maker to visually identify hot spots or deficient areas. The analysis can be further refined by extracting selected information from the map as needed.
3. Simple statistical processes can be applied to the data by location using “Fixed Segment,” “Floating Segment,” or “Cluster” analysis.
4. Providing information from multiple databases in one Web site allows users to conduct “loose” integration of the data. Information extracted through a series

of queries from different data sources can be saved into a single spreadsheet for analysis. For example wet weather crashes, skid index, and AADT could be acquired for a site from three different databases.

5. Decision-makers will have more time to analyze the data since it takes less time to gather and compile the information. This will enhance the identification of problem areas, program delivery, and improved designs.
6. The system is designed to quickly download data for performance measurement. The effectiveness of improvements can be monitored over time in an efficient manner.

Crash analysis is a useful tool in the evaluation of the safety conditions of a highway. Crash reports include large quantities of information which supplement the type of crash recorded. This supplemental data encompasses the severity, cause, and location of where crashes occur. An in depth study of this information can lead to the implementation of effective engineering solutions and thus improve roadway safety. Crash analysis can also evaluate the impacts of safety improvements already in place by conducting before and after crash statistics. Various research projects have been conducted with the aid of the UDOT crash database, which include assessing the safety impacts of access management techniques (Schultz and Lewis 2006) and creating a prioritization process for access management implementation in Utah (Schultz and Braley 2007).

2.5 Literature Review Summary

In this chapter, a literature review was organized consisting of pertinent information regarding fatigue and drowsy driving. Common causes of drowsy driving were outlined as well as general statistics related to drowsy driving using case studies. A review of countermeasures and their effectiveness as implemented in other states and countries was discussed. Lastly, the background on crash database tools as useful resources for fatigue and drowsy driving analysis was given. In the following chapter, the analysis procedure used to determine drowsy driving corridors is outlined along with statistics of drowsy driving on Utah highways.

3 ANALYSIS PROCEDURE

To establish which corridors of Utah highway are most prone to drowsy driving crashes, a set procedure was created to utilize two corridor analyses. The manner in which data was retrieved from the UDOT crash database is set forth followed by the two corridor analyses. The first analysis is based upon crash rates while the second is based upon the number of crashes within a predetermined segment. The analyses were divided into rural and urban portions since the characteristics between these types of areas is drastic. How the rural-urban boundaries were determined is also outlined followed by the time periods in which the analyses were conducted. Background for two before-after crash rate analyses conducted on I-80 is also provided. The first before-after analysis discussed relates to the effectiveness of drowsy driving freeway signs while the second analysis discussed relates to the effectiveness of a rest area on drowsy driving crashes. In the following section, the process for extracting drowsy driving crash data is set forth.

3.1 Data Retrieval from UDOT Crash Database

The key tool in retrieving the necessary data for all drowsy and fatigue-related analyses was UDOT's crash database. The crash database consists of records and statistics from police reports for crashes occurring on Interstate freeways, U.S. Routes, and Utah S.R. highways. The database also has geographic information system (GIS) capabilities that allow users to generate a map identifying the location of crashes according to specified parameters. The crash database includes crash data and statistics dating back to 1992. Although the most recent crash data available from the UDOT crash database is for the year 2005, the drowsy driving critical corridors were determined using crash data through the end of 2004 as this was the most recent data available at the time the analyses were conducted. Crash data for the year 2005 was included in the before-after crash rate analyses, which were conducted after the 2005 data was added to the UDOT crash database.

Upon arriving at UDOT's crash database Web site, the "Accidents" option is chosen from the "Select Application" drop-down menu located at the top right corner of the screen as illustrated in Figure 3-1 (Anderson et al. 2005). At the top of the screen are located five tabs, which are used to navigate through various sections of the crash database. The first step to extracting the necessary data for analysis is to create a filter, where a filter is a set group of analysis parameters established by the user. The database then compares all of the data in its inventory according to the chosen filter and retrieves only the data with matching results.

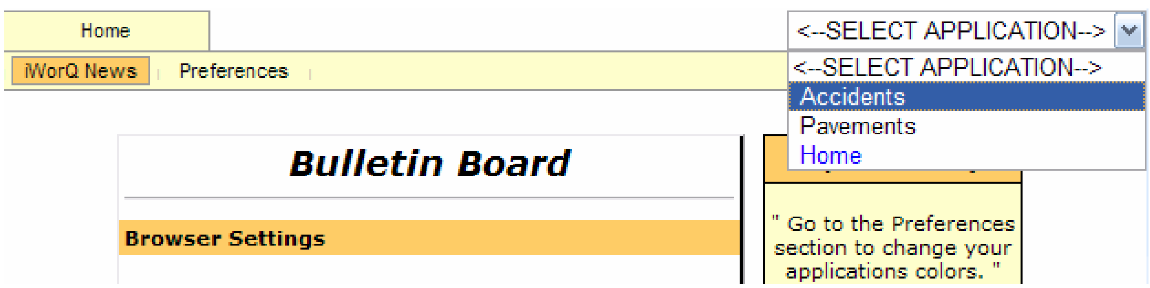


Figure 3-1. UDOT crash database homepage.

After selecting the "Filters" tab, two options located below the "Search" tab are available, namely "Filter Management" and "Create a Filter." The "Create a Filter" option is selected as illustrated in Figure 3-2.

Under the "Fields" section are 66 available parameters which may be used to construct a filter. Filters use Boolean operators to sift through the crash database inventory extracting applicable results. To create the "OR" Boolean operator, the user must choose the same parameter from the "Fields" menu multiple times until the desired variable appears under the "Search Fields" section the appropriate number of selected times as demonstrated in Figure 3-3. If the "AND" Boolean operator is desired as part of the filter, the user must select each desired parameter only once.

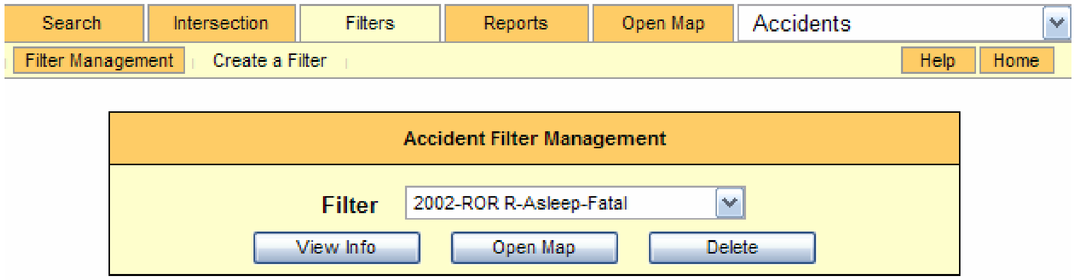


Figure 3-2. Example of "filters" tab in UDOT crash database.

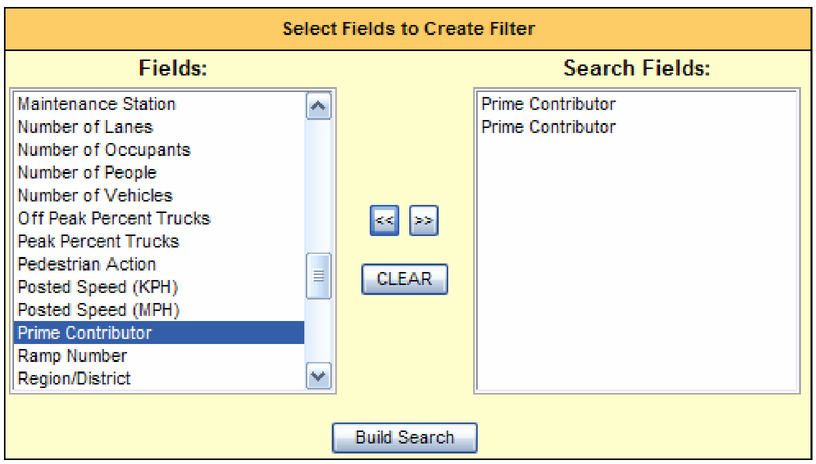


Figure 3-3. Example of a filter with "OR" Boolean operator capabilities.

Once the desired parameters have been added to the "Search Fields" section, the user selects the "Build Search" button where a filter name may be entered. Other specific information under the "Enter Filter Criteria" must be supplied such as the required years of analysis as well as which specific fields to be used as already chosen from Figure 3-3. Continuing the previous example of the "OR" Boolean function with two "Prime Contributor" selections, one variable from each range of choices is selected as illustrated in Figure 3-4 followed by the "Save" button.

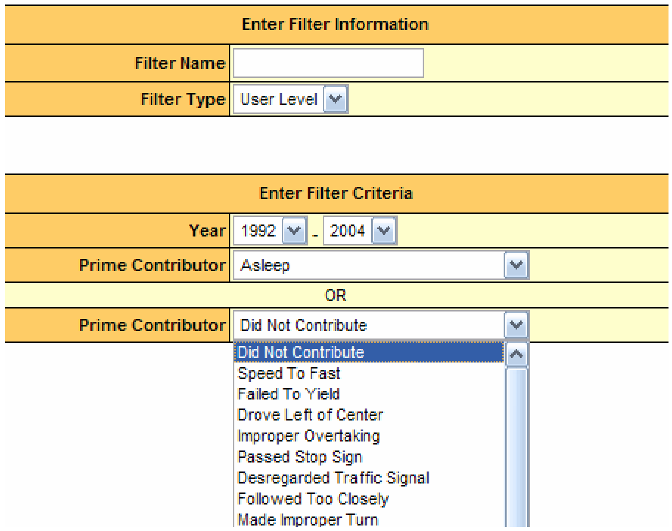


Figure 3-4. Example of entering filter criteria.

After a filter is created, the data sought may be retrieved in a report format. Two types of reports may be produced using the crash database, namely an "accident" report and a "vehicle" report. When creating an "accident" report, the UDOT crash database generates one line of results for every crash meeting the filter criteria. Contrastingly, when producing a "vehicle" report, one line of results for each person involved in a crash is generated in the database.

Referring to Figure 3-2, the "Reports" tab is selected after which the four steps under the "Report Steps" section are followed to create the report as demonstrated in Figure 3-5. From the drop-down menu in step one, "Accident Custom" is selected, from which the results are chosen. Likewise, from the drop-down menu in step three, the desired filter followed by the "Display Report" button is selected. With the desired results selected, a report can be generated very quickly. An "accident" report for the parameters outlined in Figure 3-5 is illustrated in Figure 3-6. The results of any report may be easily transferred from the crash database to a spreadsheet program. The data to be transferred to a spreadsheet is simply copied and pasted where desired. With the results in a spreadsheet, the data may be analyzed to determine trends, create graphs, or calculate other pertinent statistics.

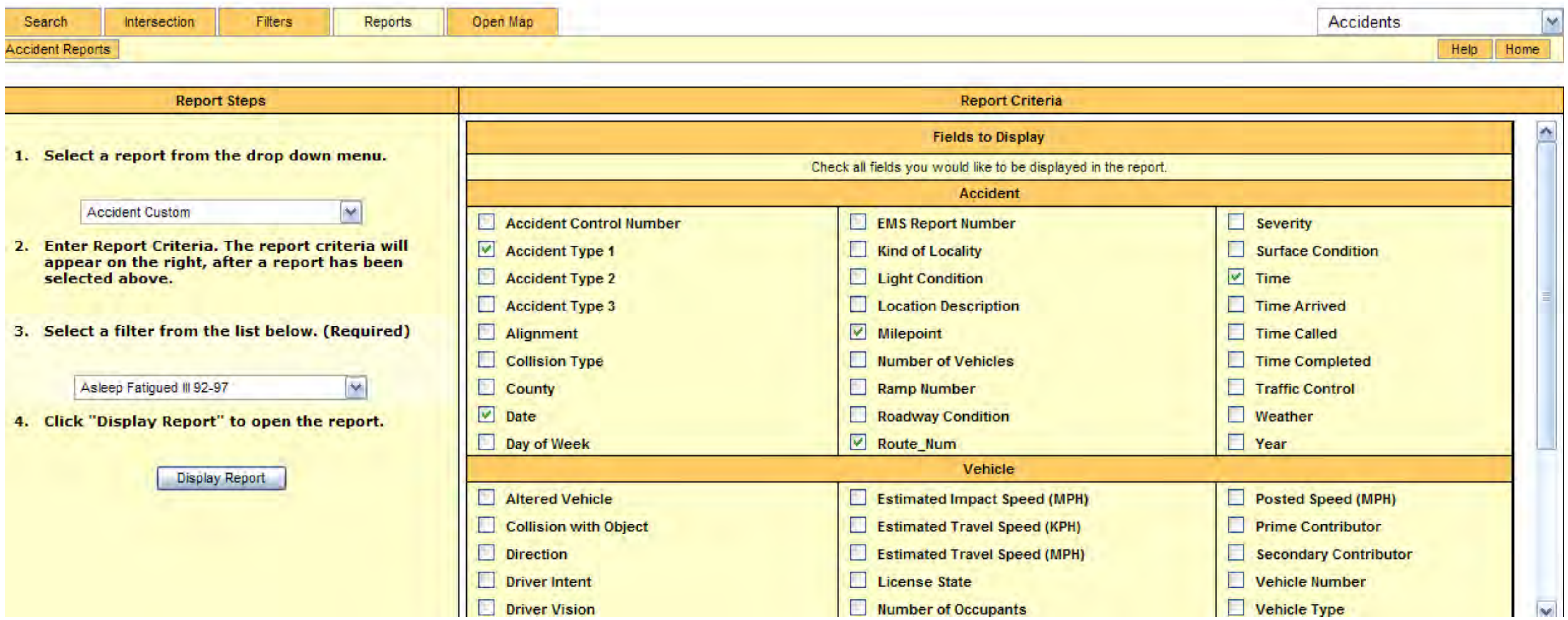


Figure 3-5. Example of preparing an "accident" report with a filter using the crash database tool.

Accident Report PRINT

Filter Used: Asleep Fatigued Ill 92-97

Milepoint	Date	Time	Route_Num	Accident Type 1
12.32	8/19/1992	07:08	0006	Ran Off Roadway-Right
50.36	4/25/1992	03:04	0006	Ran Off Roadway-Left
53.6	8/16/1992	05:08	0006	Ran Off Roadway-Left
97.86	5/19/1992	16:05	0006	Ran Off Roadway-Right
138.7	9/7/1992	13:09	0006	Ran Off Roadway-Right
176.14	5/22/1992	23:05	0006	Ran Off Roadway-Left
180.14	6/10/1992	08:06	0006	Ran Off Roadway-Right
182	4/24/1992	15:04	0006	Ran Off Roadway-Right
190.01	7/8/1992	14:07	0006	MV-MV
192	7/11/1992	01:07	0006	Ran Off Roadway-Left
192.18	9/22/1992	14:09	0006	MV-Fixed Object
195.38	7/7/1992	00:07	0006	Ran Off Roadway-Left
220.12	7/8/1992	17:07	0006	Ran Off Roadway-Right
236.29	2/1/1992	02:02	0006	Ran Off Roadway-Right
237.43	4/19/1992	13:04	0006	Ran Off Roadway-Right
246.4	4/10/1992	11:04	0006	Ran Off Roadway-Right
252.88	8/28/1992	06:08	0006	Ran Off Roadway-Right
263.13	5/8/1992	23:05	0006	Ran Off Roadway-Right

Figure 3-6. Example of an "accident" report using the crash database tool.

3.2 Corridor Analyses

It has been determined through preliminary research that a relatively low number of crashes on a rural road may yield an extremely high crash rate depending upon the volume of traffic; therefore, it was recommended for practical purposes that the number of drowsy driving crashes within a predetermined segment be calculated as a starting point for this research followed by more detailed crash rate analyses. The count of drowsy driving crashes in 5-mile increments was then used to quickly determine which highways in Utah justified further investigation regarding high-crash drowsy driving corridors. Based upon the number of drowsy driving crashes on each facility statewide, the vast majority of highways were eliminated from further study and not included in the two corridor analyses discussed in the following sections.

Two unique methods were implemented to determine which corridors of Utah highway are most prone to have drowsy driving or fatigue-related crashes. The first method counted the number of crashes occurring in 5-mile increments while the second procedure incorporated annual average daily traffic (AADT) combined with the number of crashes to calculate a crash rate. In both cases, the data analyzed was limited to each crash having been caused by a driver who was asleep, fatigued, or ill as outlined in the police report. Additionally, the roadway surface conditions were restricted to dry or wet surface conditions. Muddy, snowy, icy, and oily surface conditions were excluded from the data based upon the recommendation of the UDOT technical advisory committee (TAC). The two corridor analyses mentioned were then conducted on the state system.

3.2.1 Corridor Analysis by Number of Crashes

In preparation for analyzing crash data, two filters were created to span the 13-year study period. As mentioned previously, data was limited to crashes having been caused by a driver who was asleep, fatigued, or ill on dry or wet pavement as outlined in police reports. The crash database reports were entered into a spreadsheet to facilitate the examination of the data. The parameters included in the two reports were route number, milepost (M.P.), time of day, direction of travel, and date.

The critical corridors were determined using a macro in a spreadsheet. The macro incorporated two independent parameters: 1) the interval length measured in miles and 2) the minimum number of crashes to be counted before displaying any results. All Interstate freeways, U.S. Routes, and S.R. highways were examined using an interval length of 5 miles. The minimum-number-of-crashes parameter was set to zero crashes to identify all crashes within each predetermined segment of roadway.

The macro developed only simulates what is known as a "floating segment analysis," but is not actually executed in the same manner as "floating segment analysis." A true "floating segment analysis" permits a user to inspect an entire corridor of highway using a moving interval of specified length. After the first interval of the facility is examined, the moving or "floating" segment advances according to a "floating incremental length" as defined by the user. However, for the purposes of this research the macro did not use a "floating incremental length," but rather it counted the number of drowsy driving crashes in the first 5-mile segment before advancing to the next M.P. representing a different crash wherein a new 5-mile segment was inspected. This process was continued until the end of the highway under consideration was reached.

Once the number of crashes for all segments of highways included in the study was calculated, a mean and standard deviation of the number of crashes were calculated for all of the segments included in the analysis. A unique critical number-of-crashes value was then calculated from which corridors most prone to drowsy driving crashes were easily discernable. The number of crashes for all segments was calculated by direction of travel as this can be an important part in understanding where crashes take place. Again, a mean, standard deviation, and critical number-of-crashes value were calculated. This methodology, in which critical corridors were determined by direction of travel, was incorporated when determining the final critical corridors

3.2.2 Corridor Analysis by Crash Rate

Population-base rates or exposure-based rates can be calculated for various highway crash statistics. Examples include fatalities, crashes, or involvements per 1,000 miles of highway. Rates are standardized to aid in comparing crash rates from different facilities. The standard used in this research was the number of drowsy driving crashes per 1 million vehicle-miles traveled (VMT). Drowsy driving crash rates were calculated for 5-mile segments according to Equation 3-1 (Hummer 2000). The segment length of 5 miles was used in the analyses for two reasons. First, smaller stretches of highway such as 1 or 2 miles were deemed too narrow considering that one of the research objectives was to determine broad areas where drowsy driving was a causal factor in many crashes. Second, 5-mile corridors were used to ensure that high-crash areas were captured in the analyses due to inaccurate reporting of the locations of drowsy driving crashes by law enforcement personnel.

$$RSEG = \frac{1{,}000{,}000 \times A}{365 \times T \times V \times L} \tag{3-1}$$

where: *RSEG* = crash rate for the segment (crashes per million VMT),

A = number of reported crashes for the time period,

T = number of years being analyzed,

V = weighted AADT for analysis segment, and

L = length of the segment in miles.

For the Interstate freeways, U.S. Routes, and S.R. highways analyzed, AADT volumes were available at regular intervals along the corridors, and as such were used when calculating the crash rates for these facilities. Due to the dynamic nature of AADT, the volumes for the specified years under analysis were used when calculating multiple-year crash rates. Furthermore, since AADT changes according to geographic location and may change within a segment under consideration, a weighted AADT volume must be calculated before computing a crash rate. Equation 3-2 (Schultz and Lewis 2006) demonstrates how weighted AADT volumes were calculated for segments which contain varying AADT volumes. More specific information on the AADT volumes utilized in this analysis is provided in the section that follows.

$$AADT_{wt} = \frac{(AADT_1 \times L_1) + (AADT_2 \times L_2) + \ldots + (AADT_n \times L_n)}{L_1 + L_2 + \ldots + L_n} \tag{3-2}$$

where: $AADT_{wt}$ = weighted AADT for analysis segment,

$AADT_n$ = AADT of each individual section within the analysis segment,

L_n = length of individual section within the analysis segment, and

n = total number of AADT sections in analysis segment.

3.2.2.1 Annual Average Daily Traffic Data

AADT data are available on UDOT's Web site for the years 1986-2005. From UDOT's home page, the "Inside UDOT" tab is selected followed by the "Systems Planning and Programming" link. From there, the "Traffic Statistics" link is selected from the list of "Subtopics." Lastly, the "Automatic Traffic Monitoring Station History" link is selected followed by the "AADT History – 2005-1986" link. Once the document is downloaded, a specific highway may be located by scrolling down through the file. Furthermore, the AADT values may be copied and inserted into a spreadsheet for easy analysis. A modified excerpt from "AADT History – 2005-1986" from UDOT's Web site is provided in Table 3-1.

Table 3-1. Example AADT Volumes for 2003-2005 of I-80 (Adapted from UDOT 2005)

Starting M.P.	Ending M.P.	Description	2005	2004	2003
0	1.48	Nevada State Line	6,230	6,110	5,995
1.48	2.55	Wendover Interchange	7,520	7,835	7,690
2.55	3.99	East Incl. Wendover	7,520	7,835	7,690
3.99	41.28	Bonneville Speedway Interchange	7,775	7,626	7,460
41.28	48.94	Knolls Interchange	7,900	7,600	7,458
48.94	56.2	Clive Interchange	8,005	7,850	7,705
56.2	61.84	Aragonite Interchange	8,485	8,323	8,200
61.84	69.53	Lakeside Interchange	8,415	8,255	8,100
69.53	76.42	Delle Interchange	8,450	8,285	8,130
76.42	83.38	Rowley Interchange	9,360	9,090	9,145
83.38	88.42	Stansbury Interchange/Grantsville	10,940	10,624	10,695

With drowsy driving crash rates calculated for 5-mile segments according to Equation 3-1, a method was sought to determine which corridors of highway are most prone to drowsy driving crashes. Critical crash rates for each facility under inspection were calculated to aid in this determination. In addition to examining each highway without regards to direction of travel, critical crash rates were calculated for each direction of travel. This was done to determine if one direction of travel had more crashes within a given area than the opposing direction of travel. It was assumed that the directional distribution of each weighted AADT was 50 percent in each direction. In determining the final critical corridors, the analyses in which the direction of travel was separated were used as these analyses were more accurate and representative of fatigue and drowsy driving situations.

3.2.2.2 Critical Crash Rates

The purpose of a critical crash rate unique to each facility was to determine those segments of highway with crash rates exceeding the critical crash rate. With crash rates computed for all 5-mile segments as outlined in Equation 3-1, a mean and standard deviation of the rates were calculated for all of the segments included in the analysis period. Distinctive critical crash rates were then calculated using a confidence level of 95 percent in one tail (Z = 1.645) in accordance with Equation 3-3 (Hummer 2000). The overlying assumption for determining critical corridors is that approximately 5 percent of each corridor has critical segments on the upper end of the distribution (greater than the mean). The location of corridors with a crash rate in excess of the calculated critical crash rate was quickly identified once the critical crash rate was determined.

$$C = \bar{x} + (Z \times \sigma_s) \tag{3-3}$$

where: C = critical crash rate for portion of facility under consideration,

$\bar{x}$ = mean crash rate for portion of facility under consideration,

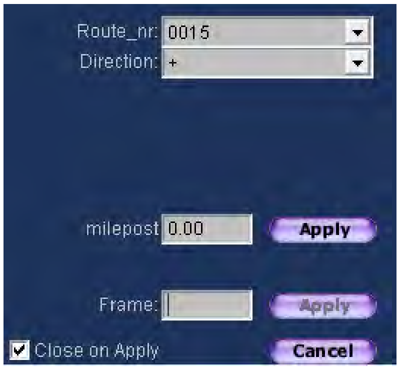
Z = constant corresponding to a level of confidence (Z = 1.645 for this analysis), and

σ_s = sample standard deviation for portion of facility under consideration.

3.3 Rural-Urban Corridors

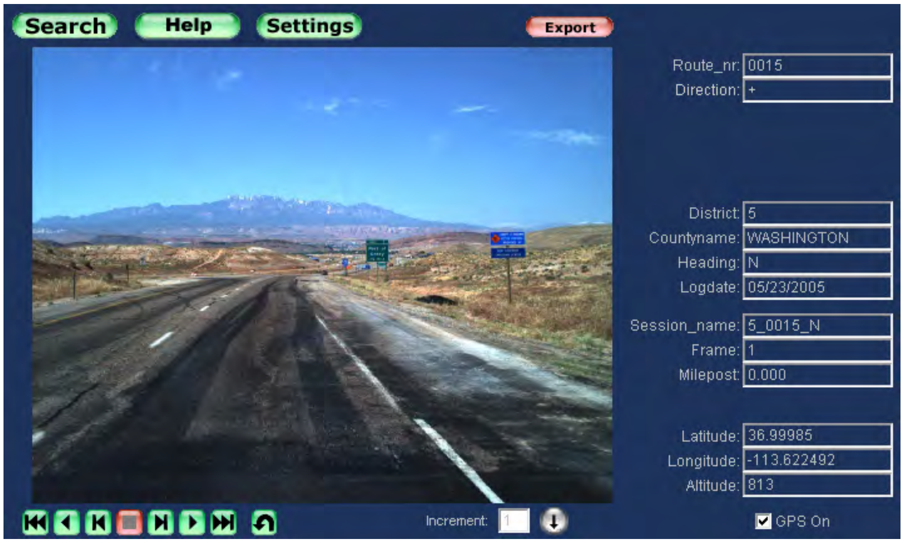
Three of the most heavily traveled facilities in Utah traverse both rural and urban areas. Due to the stark contrast in driving conditions and traffic volumes between these two types of areas, Interstate 15 (I-15) and I-80 as well as U.S. 89 were divided into sections where rural areas were analyzed separately from those deemed to be urbanized areas. Two methods were used to identify the rural-urban boundaries, namely UDOT's Roadview program (UDOT 2007a) and "AADT History – 2005-1986" (UDOT 2005).

First, Roadview Explorer 2.0 was utilized (UDOT 2007a). This program consists of video footage of every Interstate, U.S. Route, and S.R. highway in Utah. The user can view a highway by selecting a route number, direction of travel, and M.P. as illustrated in Figure 3-7. Figure 3-8 illustrates northbound I-15 at M.P. 0.



(Source: UDOT 2007a)

Figure 3-7. Roadview Explorer search dialog box.



(Source: UDOT 2007a)

Figure 3-8. Example of Roadview Explorer on I-15 at M.P. 0.

The rural-urban boundaries were located in Roadview Explorer by visually identifying the location where the speed limit changed from a rural speed limit of 75 mph to an urban speed limit of 65 mph. Second, the "AADT History – 2005-1986" (UDOT 2005) as mentioned in Section 3.2.2.1 was used. This history file not only contains AADT volumes, but also a description of each segment as illustrated previously in Table 3-1. These descriptions specify the location of the rural-urban boundaries used in the analyses. Based on the two methodologies outlined, the beginning and ending urban mileposts for I-15, I-80, and U.S. 89 are shown in Table 3-2. All other sections of highway not located within the boundaries identified in Table 3-2 are rural, including the whole of I-70.

Table 3-2. Rural-Urban Boundaries

Highway	Beginning Urban M.P.	Ending Urban M.P.
I-15	255	345
I-80	110	130
U.S. 89	325	470

3.4 Multiple-Year Analyses

The two analyses described in Sections 3.2.1 and 3.2.2, namely the *Corridor Analysis by Number of Crashes* and *Corridor Analysis by Crash Rate*, were used to determine critical drowsy driving corridors for time periods spanning three, five, and 13 years in length. This methodology was completed to determine if critical drowsy driving corridors located in the 13-year analysis also resulted from the 3- and 5-year analyses, or if critical drowsy driving corridors from the 13-year study were possibly eliminated in the shorter timeframe studies due to influential factors such as maintenance activities, land use changes, traffic volumes, roadway improvements, etc.

Cheng and Washington (2005) indicate that longer crash history periods are usually associated with increasingly less stable safety performance functions over time. Furthermore, three years of crash history is optimal as this timeframe is sufficient to minimize random fluctuation in the number of crashes and yet short enough to exclude the effects of population growth or other demographic changes. In addition to the 3-year crash analysis, which is the basis for the results of this research, the following subsections include a brief summary of the 5- and 13-year analyses for comparison purposes.

3.4.1 3-Year Analysis

A 3-year crash analysis for the years 2002-2004 was conducted. The crash rate for all sections of highway was calculated using Equation 3-1. The number of crashes and weighted AADT were modified to generate a multiple-year crash rate. Table 3-3 illustrates the 3-year crash rate for each 5-mile segment of eastbound I-80 as an example. Similar tables for the 3-year analysis of other facilities are included in Appendix A. From the calculated crash rates in Table 3-3, the mean, standard deviation, and critical crash rates were calculated using Equation 3-3. The crash rates identified in bold print in Table 3-3 are the crash rates in excess of the critical crash rate; no urban segments were deemed critical in this example.

3.4.2 5-Year Analysis

A 5-year analysis consisting of the years 2000-2004 inclusive was conducted to compare with the initial results of the 3- and 13-year analyses. The crash rate for each section of highway was calculated using Equation 3-1 with one modification—the number of drowsy driving crashes and weighted AADT were adapted to reflect a multiple-year crash rate. Table 3-4 displays the results of eastbound I-80 for the 5-year analysis as an example. Similar tables for the 5-year analysis of other facilities are included in Appendix A. From the crash rates in Table 3-4, the mean, standard deviation, and critical crash rates were calculated using Equation 3-3. Again, the crash rates identified in bold print in Table 3-4 are the crash rates in excess of the critical crash rate. No critical segments were identified in the urbanized area of Salt Lake City.

Table 3-3. Eastbound I-80 3-Year Crash Rate Analysis

	Crash Rate per Million Vehicle-Miles Traveled	
	Milepost	**2002 - 2004**
Rural Area	0-5	0.000
	5.01-10	0.000
	10.01-15	0.143
	15.01-20	0.096
	20.01-25	0.048
	25.01-30	0.000
	30.01-35	0.239
	35.01-40	**0.383**
	40.01-45	0.288
	45.01-50	**0.335**
	50.01-55	0.233
	55.01-60	0.270
	60.01-65	**0.356**
	65.01-70	0.089
	70.01-75	0.266
	75.01-80	0.122
	80.01-85	0.037
	85.01-90	0.128
	90.01-95	0.028
	95.01-100	0.097
	100.01-105	0.102
	105.01-110	0.084
Urban Area	110.01-115	0.070
	115.01-120	0.000
	120.01-125	0.007
	125.01-130	0.021
Rural Area	130.01-135	0.042
	135.01-140	0.034
	140.01-145	0.045
	145.01-150	0.087
	150.01-155	0.125
	155.01-160	0.055
	160.01-165	0.057
	165.01-170	0.055
	170.01-175	0.027
	175.01-180	0.053
	180.01-185	0.134
	185.01-190	0.057
	190.01-197	0.283

Table 3-4. Eastbound I-80 5-Year Crash Rate Analysis

	Crash Rate per Million Vehicle-Miles Traveled	
	Milepost	**2000 - 2004**
Rural Area	0-5	0.000
	5.01-10	0.000
	10.01-15	0.086
	15.01-20	0.086
	20.01-25	0.029
	25.01-30	0.000
	30.01-35	0.172
	35.01-40	0.258
	40.01-45	0.228
	45.01-50	**0.339**
	50.01-55	**0.278**
	55.01-60	0.243
	60.01-65	0.239
	65.01-70	0.079
	70.01-75	**0.290**
	75.01-80	0.197
	80.01-85	0.115
	85.01-90	0.119
	90.01-95	0.035
	95.01-100	0.119
	100.01-105	0.097
	105.01-110	0.081
Urban Area	110.01-115	0.058
	115.01-120	0.000
	120.01-125	0.008
	125.01-130	0.026
Rural Area	130.01-135	0.031
	135.01-140	0.032
	140.01-145	0.051
	145.01-150	0.054
	150.01-155	0.077
	155.01-160	0.069
	160.01-165	0.053
	165.01-170	0.034
	170.01-175	0.016
	175.01-180	0.033
	180.01-185	0.097
	185.01-190	0.102
	190.01-197	0.250

3.4.3 13-Year Analysis

The 13-year analysis was conducted differently from the 3- and 5-year analyses. A multiple-year crash rate spanning the 13-year dataset was not calculated for each 5-mile segment whereas with the 3- and 5-year data a multiple-year crash rate was determined according to the corresponding number of years. A mean, standard deviation, and critical crash rate were calculated for rural areas as well as urban areas where applicable. With a crash rate calculated for each 5-mile segment, the number of years a segment was critical was determined. If a segment had at least three of 13 years deemed critical then it was included in the results for this analysis.

The overlying assumption for determining critical corridors is that approximately 5 percent of each highway has critical segments, or 0.05. Therefore, the three year minimum was determined by testing each segment to ascertain if the proportion of critical years over the 13-year time period was greater than 0.05. To determine whether or not a segment should be included in the results of this analysis, a *p*-value for each segment was calculated based upon three values. First, an "*x*" value representing the proportion of critical years out of the 13-year study period was calculated. Second, the standard deviation of "*x*" was computed using Equation 3-4 (Ramsey and Schafer 2002). Lastly, a Z-statistic was calculated using Equation 3-5 (Ramsey and Schafer 2002) and used in conjunction with a cumulative standard normal distribution table to determine *p*-values (Ramsey and Schafer 2002). Table 3-5 outlines how the *p*-value for each of critical year was calculated.

$$S_i = \sqrt{\frac{x_i(1 - x_i)}{n}} \tag{3-4}$$

where: S_i = standard deviation where i is the number of critical years,

x_i = proportion of years out of n-year study period, and

n = total number of years in sample size.

$$Z_i = \frac{x_i - 0.05}{S_i} \quad (3\text{-}5)$$

where: Z_i = standard normal score

x_i = proportion of years out of n-year study period, and

S_i = standard deviation where i is the number of critical years.

Table 3-5. *P*-value Calculations for the 13-Year Analysis

Number of Years	x_i	S_i	Z_i	*p*-value
1	0.077	0.074	0.364	0.358
2	0.154	0.100	1.038	0.150
3	0.231	0.117	1.547	0.061
4	0.308	0.128	2.013	0.022
5	0.385	0.135	2.480	0.007
6	0.462	0.138	2.976	0.001
7	0.538	0.138	3.533	0.000
8	0.615	0.135	4.190	0.000
9	0.692	0.128	5.018	0.000
10	0.769	0.117	6.155	0.000
11	0.846	0.100	7.956	0.000
12	0.923	0.074	11.813	0.000

As indicated in Table 3-5, the *p*-value for four or more critical years is less than 0.05, which is the usual standard for representing significance at the 95th percentile. Initially, four years was the minimum threshold, but after considering the number of variables which affect drowsy driving crashes and their reporting, variables such as changes in roadway alignment and inaccurate reporting of the exact M.P. of crash locations, it was determined through initial discussion and consultation with the TAC that the difference in using three years versus four years as a minimum threshold was not practically important. Thus, all 5-mile segments which had three or more years deemed critical were included in the initial results. Table 3-6 indicates the crash rates for eastbound I-80 for this analysis while other facilities are located in Appendix A. The crash rates identified in bold print are the crash rates in excess of the critical crash rate.

Table 3-6. Eastbound I-80 13-Year Crash Rate Analysis

		Crash Rate per Million Vehicle-Miles Traveled												
	Milepost	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Rural Area	0-5	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5.01-10	0.00	0.00	0.00	0.00	0.00	0.15	0.14	0.00	0.00	0.00	0.00	0.00	0.00
	10.01-15	0.17	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.28	0.00	0.14
	15.01-20	0.17	0.34	0.16	0.15	0.00	0.00	0.00	0.14	0.00	0.14	0.28	0.00	0.00
	20.01-25	0.17	0.00	0.00	0.15	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.14
	25.01-30	0.34	**0.50**	0.16	0.00	0.32	0.00	0.29	**0.42**	0.00	0.00	0.00	0.00	0.00
	30.01-35	0.34	0.00	**0.64**	0.15	0.00	0.29	**0.43**	0.14	0.00	0.14	0.28	0.29	0.14
	35.01-40	**0.85**	**0.67**	0.00	0.00	0.32	0.00	0.14	0.00	0.00	0.14	**0.84**	0.15	0.14
	40.01-45	0.17	0.33	0.16	0.30	0.31	**0.87**	0.00	0.14	0.28	0.00	**0.56**	0.15	0.14
	45.01-50	0.33	**0.66**	0.00	**0.45**	0.16	**0.58**	0.00	**0.41**	0.27	**0.42**	**0.42**	0.29	0.29
	50.01-55	0.17	0.00	0.31	**0.45**	0.31	0.14	0.28	0.27	0.14	**0.55**	0.00	**0.71**	0.00
	55.01-60	0.00	**0.49**	0.30	**0.72**	**0.45**	0.14	**0.69**	0.27	0.27	0.14	0.14	**0.68**	0.00
	60.01-65	0.00	0.00	0.30	0.28	0.15	0.14	0.14	0.13	0.13	0.00	**0.53**	**0.40**	0.13
	65.01-70	0.16	0.00	0.15	0.00	0.30	**0.41**	0.13	0.13	0.00	0.13	0.13	0.00	0.13
	70.01-75	0.16	0.31	0.00	0.00	0.15	**0.55**	0.13	0.39	0.26	**0.39**	0.13	0.27	**0.40**
	75.01-80	**0.44**	**0.44**	0.14	0.13	**0.55**	0.26	0.39	**0.62**	0.25	0.38	0.00	0.00	0.37
	80.01-85	0.14	0.00	0.27	0.00	0.26	0.25	0.37	0.24	**0.48**	0.00	0.11	0.00	0.00
	85.01-90	0.13	**0.40**	**0.40**	0.12	0.13	0.12	0.00	0.00	0.11	0.10	0.09	0.19	0.10
	90.01-95	0.12	0.12	0.13	0.00	0.25	0.00	0.00	0.00	0.00	0.09	0.00	0.09	0.00
	95.01-100	0.34	0.17	0.26	0.25	0.00	0.22	0.21	0.21	0.26	0.06	0.11	0.17	0.00
	100.01-105	0.27	0.13	0.00	0.12	0.06	0.00	0.05	0.05	0.09	0.09	0.08	0.13	0.09
	105.01-110	0.15	0.07	0.00	0.07	0.06	0.06	0.11	0.06	0.16	0.00	0.05	0.10	0.11
Urban Area	110.01-115	**0.12**	**0.16**	0.00	0.05	**0.14**	0.05	**0.13**	0.08	0.04	0.04	0.10	0.03	0.07
	115.01-120	0.03	0.00	0.00	0.02	0.02	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	120.01-125	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.00	0.01	0.02	0.00	0.00
	125.01-130	0.00	**0.13**	0.09	0.00	0.00	0.00	0.03	0.06	0.00	0.07	0.04	0.00	0.02
Rural Area	130.01-135	0.07	0.03	0.00	0.03	0.00	0.00	0.00	0.06	0.00	0.03	0.05	0.03	0.05
	135.01-140	0.00	0.07	0.06	0.03	0.00	0.08	0.03	0.03	0.06	0.00	0.08	0.03	0.00
	140.01-145	0.04	0.04	0.04	0.07	0.00	0.00	0.06	0.00	0.06	0.06	0.05	0.03	0.05
	145.01-150	0.08	0.16	0.14	0.00	0.00	0.06	0.06	0.06	0.00	0.00	0.05	0.11	0.10
	150.01-155	0.11	0.00	0.29	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.08	0.15
	155.01-160	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.10	0.09	0.08	0.08	0.00
	160.01-165	0.00	0.00	0.23	0.00	0.00	0.10	0.00	0.00	0.00	0.09	0.00	0.09	0.09
	165.01-170	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.00
	170.01-175	0.00	0.00	0.00	0.10	0.10	0.00	0.09	0.09	0.00	0.00	0.00	0.00	0.08
	175.01-180	0.00	0.00	0.00	0.00	0.10	0.00	0.09	0.00	0.00	0.00	0.16	0.00	0.00
	180.01-185	0.12	0.22	0.00	0.10	0.00	0.00	0.00	0.08	0.08	0.00	0.23	0.08	0.08
	185.01-190	0.12	0.33	0.11	0.10	0.20	0.19	0.28	0.09	0.17	0.17	0.00	0.09	0.09
	190.01-197	0.00	0.16	0.08	0.38	0.38	0.21	0.21	0.26	0.19	0.12	0.23	0.20	0.20

3.5 Interstate 80 Drowsy Driving Signage—A Before-After Study

On July 21, 2004, UDOT completed the installation of drowsy driving freeway signage in the west desert of I-80 in both the westbound and eastbound directions. The purpose of these signs is to warn drivers of the adverse affects of driving while extremely fatigued. To determine the effectiveness in reducing the drowsy driving crash rate west of Salt Lake City, a before-after analysis of crash data was conducted.

The "after" time period used in the before-after analysis began August 21, 2004 and terminated December 31, 2005. The one month grace period directly following the completion of installation of the signs was necessary to ensure that long term results of the statistical analysis would not be distorted by short term reaction to the new signs. The ending date of the analysis was the final day of 2005 since no crash data for 2006 was available via the UDOT crash database at the time of the analysis. With the "after" time period confirmed, the "before" timeframe of the analysis was established encompassing the same duration of time beginning August 21, 2002 and ending December 31, 2003.

Following the procedures outlined in Section 3.1, two filters were created to extract the necessary data from the UDOT crash database. The filters were generated based upon four parameters, namely the prime contributor, date, surface conditions, and route number. As in Section 3.2, the prime contributors implemented in this filter were asleep, fatigued, and ill while the date parameter comprised of time intervals from August 21st to December 31st according to the years retrieved. The surface conditions were set to wet or dry with the route number set to I-80.

Once the filters were created, two reports were produced. The selected parameters included in each report were milepoint, date, time, and direction. The report data were then transferred into a spreadsheet, sorted by direction of traveled, and analyzed. Since the drowsy driving signs were installed at different locations according to the direction of travel, the report data were sorted in this manner to facilitate the comparing of drowsy driver sign location with crash locations. The crash data were grouped into bins 5 miles in length and then plotted to visualize the trends produced.

Once the plots were created, the locations of the drowsy driving signs were added to the two figures for comparison purposes.

3.6 Interstate 80 Milepost 54 Rest Area—A Before-After Study

Rest areas typically provide amenities such as restrooms, picnic tables, water fountains, telephone services, and parking for both trucks and recreational vehicles. They offer travelers a place to relax, take photos of scenery, and if necessary, sleep. The Grassy Mountain rest area was constructed at M.P. 54. in 2000. To determine whether this specific rest area has played a role in reducing the drowsy driving crash rate west of Salt Lake City, the researchers conducted a before-after analysis of drowsy driving crash data.

Following the procedures outlined in Section 3.1, the researchers created two filters used to extract the necessary data encompassing the time periods studied. The filters were generated based upon four parameters, namely the prime contributor, date, surface conditions, and route number. The prime contributors used were asleep, fatigued, and ill. The "before" time period incorporated the years 1997-1999 while the "after" timeframe included the years 2001-2003.

3.7 Analysis Procedure Summary

In order to determine which corridors of highway are most prone to drowsy driving crashes, a set procedure for two analyses was outlined in this chapter. The analyses are the *Corridor Analysis by Crash Rate* and the *Corridor Analysis by Number of Crashes*. Each analysis was performed twice—once without regards to direction of travel and once with direction of travel included. Using UDOT's crash database, many types of data were retrieved for use in two before-after crash rate analyses. The results of the corridor analyses are discussed in Chapter 4 while the results of the before-and-after crash rate analyses are presented in Chapter 5. To supplement the before-after studies, Chapter 6 summarizes the findings from Chi-Square analyses.

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4 RESULTS

The stretches of roadway most prone to drowsy or fatigue-related crashes are naturally those along the Interstate freeways due to the excessive volume, high speed, and high exposure rate of vehicles using these facilities. The results of the 3-year crash rate analysis yielded various corridors across the state where a crash rate for a section of highway exceeded the critical crash rate. Critical corridors were located on Interstates 15, 70, 80, and 84. In similar fashion to Interstate freeways, many U.S. and S.R. highways have excessive volume, high speed, and high exposure rate of vehicles. U.S. Routes 89 and 91 as well as S.R. 36 contained segments in which the critical crash rate for each highway was exceeded.

The set procedure for analyzing corridors described in Chapter 3 is followed in this chapter for the analysis of drowsy driving crashes. In this chapter results for each critical corridor prone to have drowsy driving crashes are outlined by direction of travel. These results identify the M.P. location of critical corridors in accordance with the method outlined in Section 3.2.2. In addition to discussing the critical corridor results, drowsy driving trends and statistics are provided for each Interstate freeway, U.S. Route, and S.R. highway containing critical corridors. Statistics include: drowsy driving crash consequences, roadway alignment impact, time of day and day of week of drowsy driving crashes, vehicle type and object struck in drowsy driving crashes, and a comparison of the severity of drowsy driving crashes versus all crashes. Lastly, an estimate of how under-reported drowsy driving crashes are in the state of Utah is provided.

4.1 Interstate 15

I-15 is the major north-south facility providing accessibility to many of the most densely populated areas in the state of Utah. Beginning at the Arizona-Utah border to the south and terminating at the Idaho-Utah border to the north, I-15 consists of 400 miles of roadway and is one of the most heavily traveled routes in the state. The 3-year crash rate analysis for the years 2002-2004 indicated that I-15 has nine critical corridors ranging in length from 5 miles to 10 miles. The M.P. and direction of travel for these corridors are summarized in Table 4-1. To better understand the spatial relationship among the segments in Table 4-1, the critical sections have been highlighted in black on a Utah state map as illustrated in Figure 4-1. The sections are labeled according to direction and M.P.

Seven of the nine critical corridors are located in rural areas of which two corridors have both northbound and southbound directions that coincide. The first of these areas is located north of Parowan beginning at M.P. 90 and extending to M.P. 95 near the junction of S.R. 20. The second coinciding critical corridor begins at M.P. 190 north of Scipio and terminates at M.P. 195.

Table 4-1. I-15 Drowsy Driving Corridors

Area and Direction of Travel	Rural Area		Urban Area	
	Northbound (NB)	**Southbound (SB)**	**Northbound (NB)**	**Southbound (SB)**
Critical Crash Rate per Million VMT	0.286	0.202	0.069	0.055
M.P.	0 - 5	--	--	--
	--	80 - 85	--	--
	90 - 95	90 - 95	--	--
	--	170 - 175	--	--
	190 - 200	185 - 195	--	--
	--	--	--	255 - 260
	--	--	340 - 345	--

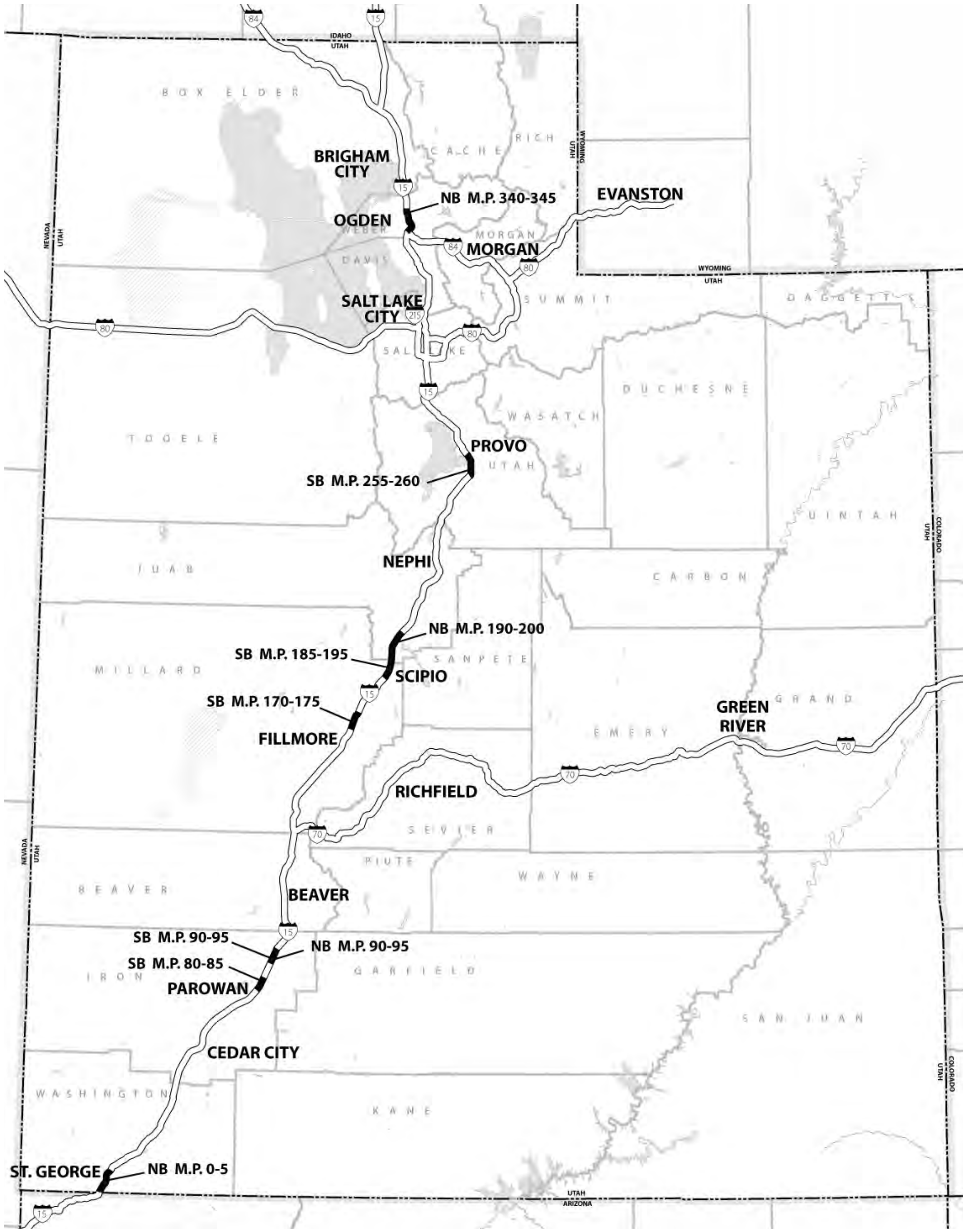

Figure 4-1. I-15 drowsy driving corridors.

The roadway alignment in each critical corridor was analyzed to determine if specific curves in the alignment contributed to the fatigue and drowsy driving crashes. One mile intervals were scanned using a “floating segment” one-half mile in length to determine the number of crashes which were reported to have occurred on any given curve. An interval length of one mile may seem large when seeking out specific roadway curves but was necessary due to possible inaccurate reporting of M.P. The corridor from M.P. 0-5 has a curve in the alignment between M.P. 4 and M.P. 5 at which 10 drowsy driving crashes occurred during the years 1992-2004. This particular curve had the greatest number of reported crashes due to a curve in roadway alignment within the drowsy driving corridors. Other curves in the critical corridors which yielded similar results are located near M.P. 94 and 257 (seven crashes in each corridor), M.P. 185 and 197 (eight crashes in each corridor), and M.P. 174 and 342 (nine crashes in each corridor). For comparison purposes, the maximum number drowsy driving crashes at one curve was 17 and occurred twice, once at M.P. 270 and again at M.P. 282.

The two urban area critical corridors are the most northern and southern 5-mile segments of the 90-mile urban corridor traversing Utah, Salt Lake, and Davis counties. It is theorized that these two segments may be critical for the following reason. A relatively large AADT is found in the Springville/Provo area (M.P. 255-260) and the Ogden area (M.P. 340-345) when compared to the rural area AADT’s of I-15, but when compared to the AADT volumes near Salt Lake City, which exceed 100,000 vehicles per day, the two critical corridors do not handle nearly as much daily traffic. This leads to higher crash rates due to lower AADT volumes when other variables are held constant in Equation 3-1.

As mentioned previously, seven of the nine critical corridors are located in rural areas. These corridors are isolated areas between urban cities. The only exception is the northbound corridor consisting of M.P. 0-5, a portion of which passes through the Bloomington area of St. George.

Various statistics pertinent to drowsy driving crashes on I-15 were calculated to serve two purposes. First, to provide the necessary background and understanding of drowsy driving crashes in Utah such that appropriate mitigation techniques may be implemented to reduce drowsy driving crashes and second, to verify, and add to, the drowsy driving statistics reported in the literature. All statistics reported are for the years 1992-2004.

Of the 3,883 drowsy driving crashes on I-15 for the years previously identified, 3,194 (82.3 percent) were reported as single-vehicle crashes while only 689 crashes (17.7 percent) involved two or more vehicles. This coincides well with the literature in which one study indicated that 80 percent of drowsy driving crashes were single-vehicle crashes (Knipling et al. 1994). Of the 3,883 drowsy driving crashes on I-15, 147 were fatal crashes (3.8 percent). During the specified years, 611 fatal crashes occurred, which interprets to 24.1 percent of all fatal crashes on this facility being related to drowsy driving.

4.1.1 Run-Off-Roadway Crashes and Roadway Alignment

The majority of fatigued drivers ran off the roadway. This is outlined in Table 4-2 by the 75.3 percent of drivers who "Ran Off Roadway-Thru Median," "Ran Off Roadway-Right," and "Ran Off Roadway-Left." During the course of the research, it was determined there may be no apparent difference between "Ran Off Roadway-Thru Median" and "Ran Off Roadway-Left." This difference is based upon how the reporting officer identifies the crash in his or her crash report. Also identified in Table 4-2 is the number of motor-vehicle/motor-vehicle (MV-MV) crashes, which represent almost 14 percent of the drowsy driving crashes.

The roadway alignment can play an important factor in the location of where drowsy driving crashes occur. Table 4-3 breaks down how drowsy driving crashes relate to roadway alignment. As identified in Table 4-3, 2,240 of the 3,883 drowsy driving crashes (57.7 percent) occurred on stretches which were "Straight and Level" while 23.1 percent of the crashes occurred in locations where a curve was present.

Table 4-2. I-15 Drowsy Driving Crash Consequences

Crash Consequence	Number of Crashes	Percent of Total Crashes
Ran Off Roadway-Right	1,270	32.8
Ran Off Roadway-Left	1,004	25.9
Ran Off Roadway-Thru Median	650	16.7
MV-MV	541	13.9
MV-Fixed Object	322	8.3
Other Non-Collision	48	1.2
Overturned	30	0.8
MV-Other Object	12	0.3
MV-Animal (Wild)	5	0.1
MV-Bicycle	1	0.0
Total	3,883	100.0

Table 4-3. Drowsy Driving Correlation to Roadway Alignment on I-15.

Alignment Type	Number of Crashes	Percent of Total Crashes
Straight and Level	2,240	57.7
Grade Straight	692	17.8
Curve Level	512	13.2
Curve Grade	359	9.2
Hillcrest Straight	45	1.2
Curve Hillcrest	22	0.6
Dip Straight	8	0.2
Dip Curve	5	0.1
Total	3,883	100.0

4.1.2 Time of Day and Day of Week

Drowsy driving crashes occur at all hours of the day, but generally have two peaks—one in the morning and one in the afternoon, both of which are shown in Figure 4-2. The morning peak reached a climax of 319 crashes (8.2 percent of drowsy driving crashes) during the 7 a.m. hour while the afternoon peak was calculated as 69 percent of the morning peak, or 219 crashes (5.6 percent of drowsy driving crashes). The latter peak occurred during the 4 p.m. hour. The hour in which the least number of drowsy driving crashes occurred was the 9 p.m. hour in which only 43 crashes (1.1 percent) occurred. The variation in time of day of the drowsy driving crashes on I-15 coincides extremely well with the data presented in the literature. The timing of these crashes is consistent with the circadian rhythm where typically the morning peak represents the period in which the most drowsy driving crashes occur (NHTSA 1998). Also included in Figure 4-2 is the percentage of total background traffic in Salt Lake City by hour as recorded by UDOT. Although the total percentage of traffic is relatively low in the early morning hours, the percentage of drowsy driving crashes is relatively high by comparison. The trend in total background traffic is relatively consistent with the overall trend in drowsy driving crashes following the 8 a.m. hour. After 5 p.m. in the afternoon, both the drowsy driving crash trend as well as the total background traffic trend decrease until approximately the 9 p.m. hour.

The results indicate that drowsy driving crashes occurred more on weekends than during the week. Figure 4-3 identifies this trend in the data by separating the number of crashes according to the day of the week. Of all drowsy driving crashes, 712 (18.3 percent) occurred on Saturday followed by Sunday with 650 crashes (16.7 percent). On I-15 the day in which the least number of drowsy driving crashes occurred was Wednesday with 480 crashes (12.4 percent). Also identified in Figure 4-3 are the number of fatigue-related crashes by day which occurred between the hours of 12 a.m. and 7 a.m. and the percentage of total background traffic by day as recorded by UDOT. These are included to visualize the number of crashes occurring during normal sleep-time hours versus those crashes occurring during the day and evening hours as well as comparing drowsy driving crashes to overall daily traffic. Specifically, 35.1 percent of drowsy driving crashes on this facility occurred between 12 a.m. and 7 a.m. For drowsy driving crashes that occurred between the hours of 12 a.m. and 7 a.m., 276 (7.1 percent) took place during the middle of the night or early morning hours on Saturday.

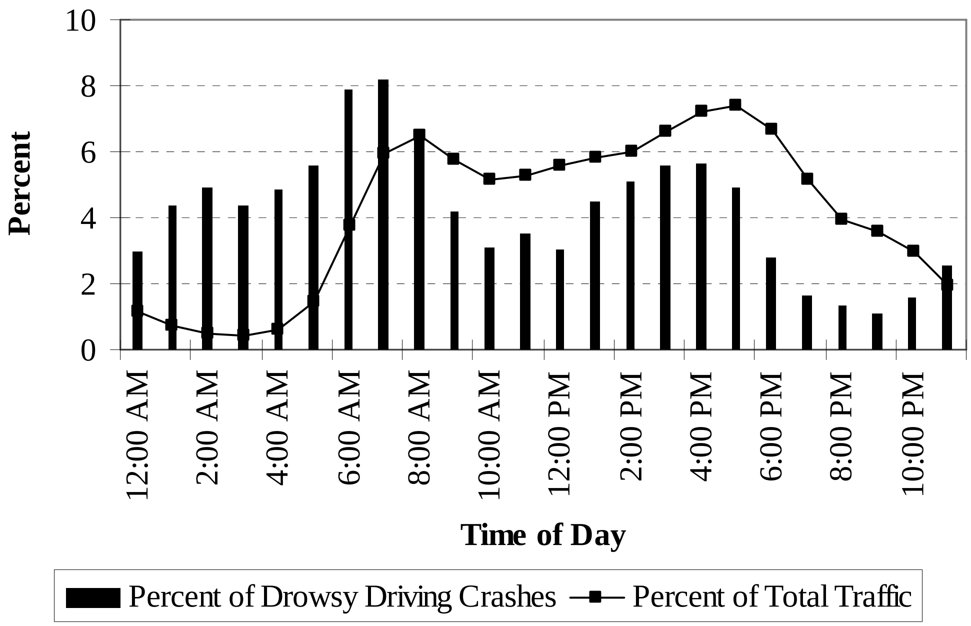

Figure 4-2. Histogram of drowsy driving crashes on I-15.

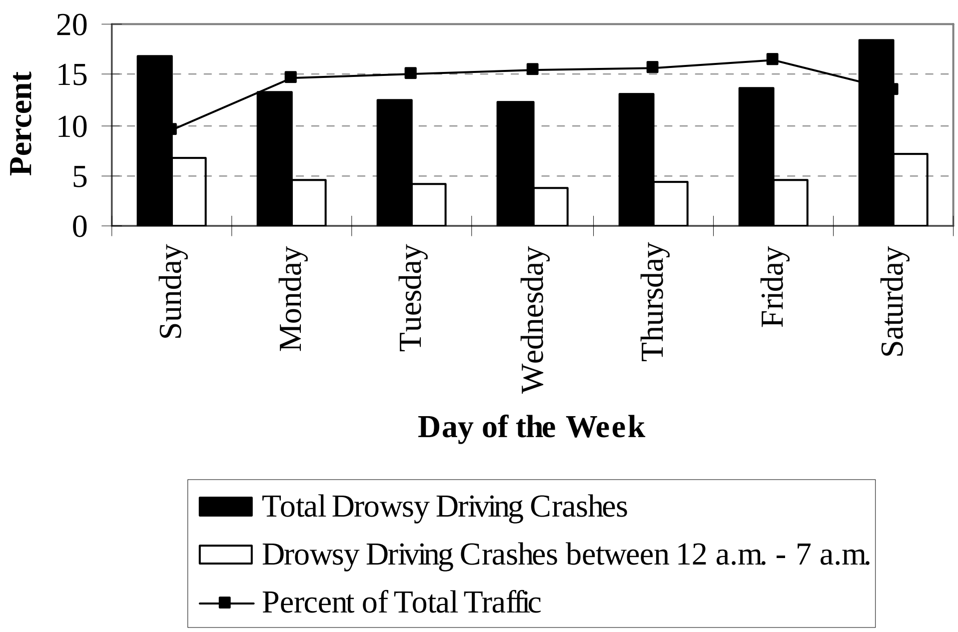

Figure 4-3. Drowsy driving crashes by day of the week on I-15.

4.1.3 Vehicle Type, Object Struck, and Severity

Although truck drivers do travel long distances frequently, they only accounted for slightly more than 4 percent of all vehicles involved in drowsy driving crashes. The most common vehicle type involved in this style of crash on I-15 was the passenger car as denoted in Table 4-4. The total number of vehicles in which a driver was responsible for a crash or partially responsible for a drowsy driving crash summed to 4,001 crashes, 118 more than the total number of crashes. In some cases, the police report indicated that two drivers were responsible for the crash.

A number of objects along a highway which drivers hit, and which are recorded in the UDOT crash database, are listed in Table 4-5. The most frequently hit object on I-15 was a delineator post, which was struck by 19.2 percent of drowsy drivers. In 1 percent of the crashes, the reporting officer cited "Other" for the object struck. The specific objects struck that were recorded as "Other" were not included in the UDOT crash database. No object was struck in 36.3 percent of the crashes.

Table 4-4. Vehicle Types of Drowsy Drivers on I-15

Vehicle Type of Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Passenger Car/Pickup	3,403	85.1
Truck/Tractor and Trailer	179	4.5
Passenger Car/Pickup with Trailer	65	1.6
Single Unit Enclosed Box (Min. 2 Axles and 6 Tires)	20	0.5
Motorcycle	6	0.1
Dump Truck	4	0.1
Buses—Commercial and School	3	0.1
No Vehicle Type Recorded	321	8.0
Total	4,001	100.0

Table 4-5. Objects Struck by Drowsy Drivers on I-15

Object Struck by Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Delineator Post	767	19.2
Fence	374	9.3
Dirt Embankment/Ditch/Berm (Mountainside)	350	8.7
Rigid Barrier (Concrete)	299	7.5
Guardrail	229	5.7
Sign Post	154	3.8
Tree/Shrubbery	100	2.5
Bridge Culvert or Other Highway Structure	66	1.6
Guardrail End Section	53	1.3
Crash Attenuator	51	1.3
Other	39	1.1
Utility Pole	27	0.7
Traffic Channelization Device	19	0.5
Building/Other Structure (Wall)	6	0.1
Wild Animal	5	0.1
Snow Embankment	4	0.1
Curb or Safety Island	3	0.1
Mailbox or Fire Hydrant	3	0.1
No Object Struck	1,452	36.3
Total	4,001	100.0

The UDOT crash database includes license plate data, specifically the state in which a vehicle is registered, dating back to the year 1996. To determine if the distribution of drowsy driving crashes on I-15 was skewed towards Utah residents more than out-of-state visitors, license plate data from police reports were analyzed for the timeframe 1996-2004. This analysis encompassed 2,850 crashes. Utah residents represented 66.6 percent of drivers responsible for the fatigue-related crashes in this study while 33.3 percent were recorded as out-of-state drivers. Vehicle license plates were not recorded in 0.1 percent of the crashes.

One interesting question to be answered through the research was whether drowsy driving crashes are more severe in nature when compared to all types crashes combined. Table 4-6 is divided into two parts in order to answer this question. The first part indicates a percentage for each severity type among solely drowsy driving crashes while the second part gives a percentage for each severity level generated from all crashes on I-15 from 1992-2004. As noted, drowsy driving crashes yielded a greater percentage of fatal crashes when compared to all fatal crashes on this highway. Furthermore, severity levels in drowsy driving crashes were worse overall with fewer crashes yielding "No Injury."

Table 4-6. Severity of Drowsy Driving Crashes Versus All Crashes on I-15

Severity	Drowsy Driving Crashes	All Crashes
Fatal	3.8	1.0
Broken Bones or Bleeding Wound	22.3	7.3
Bruises and Abrasions	17.0	8.5
Possible Injury	14.2	17.7
No Injury	42.7	65.5
Total	100.0	100.0

4.1.4 Directional Distribution

I-15 traverses an array of topography from a hot desert in the south to rugged mountainous regions in the north parts of Utah. For this reason the trends in directional distribution of drowsy driving crashes were determined. Of the 3,883 drowsy driving crashes, 54.4 percent occurred in the northbound direction while the remaining 45.6 percent were in the southbound direction. Figure 4-4 illustrates the directional distribution from M.P. 0 to M.P. 200 while Figure 4-5 shows the same trends from M.P. 200 to M.P. 401. From M.P. 90 to M.P. 110, 152 northbound crashes took place while 71 occurred in the southbound direction; therefore, twice as many northbound crashes occurred as southbound crashes. From Figure 4-5, it can be seen that the 5-mile section of highway with the most drowsy driving crashes from 1992-2004 was between M.P. 280 to M.P. 285 near the city of Lehi.

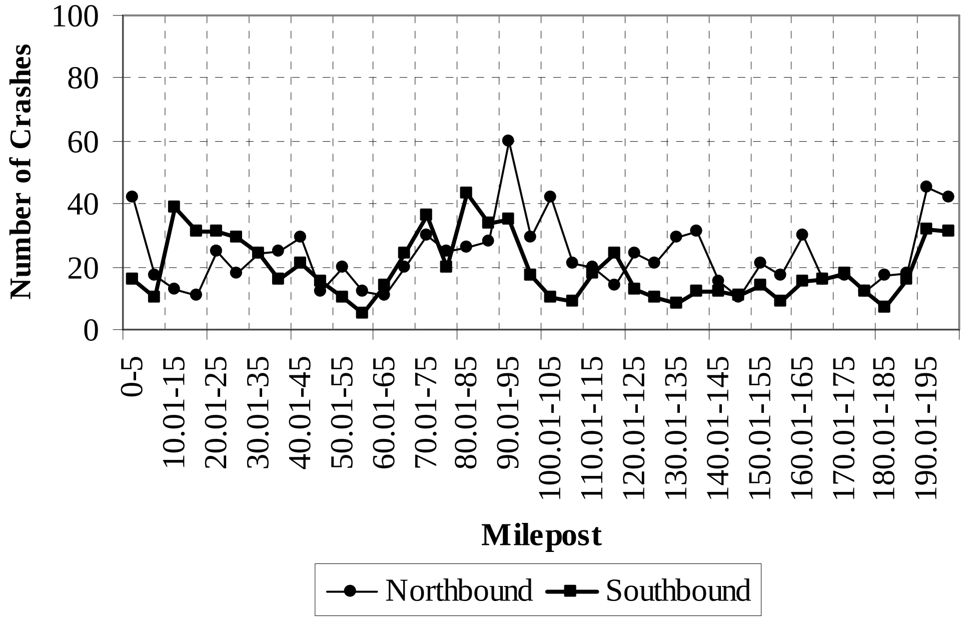

Figure 4-4. Directional distribution of drowsy driving crashes on I-15 from M.P. 0 to M.P. 200.

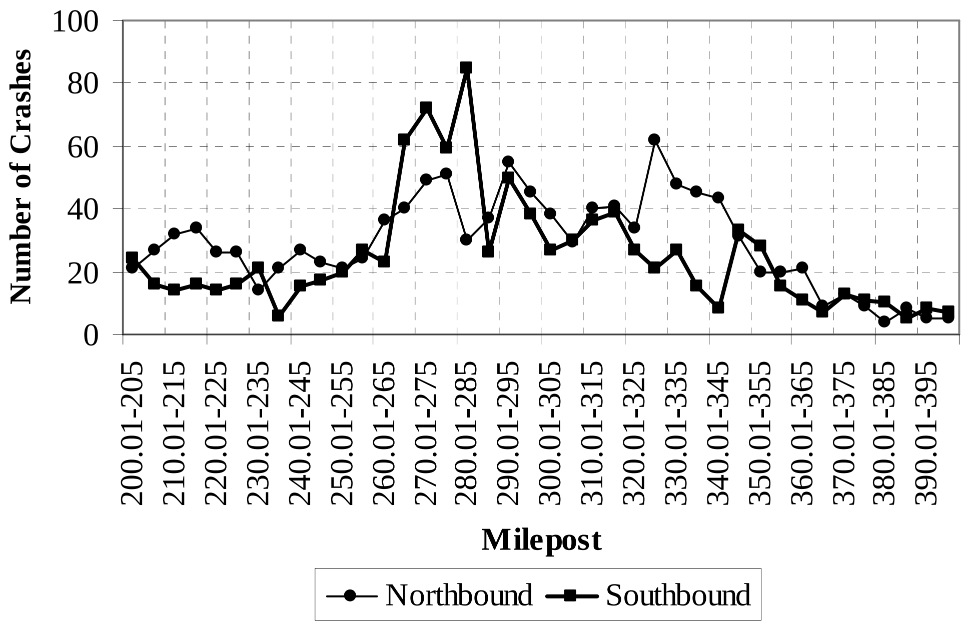

Figure 4-5. Directional distribution of drowsy driving crashes on I-15 from M.P. 200 to M.P. 401.

4.2 Interstate 70

I-70 is one of two east-west facilities providing accessibility to many of the rural areas of Utah. Beginning 20 miles north of Beaver, Utah and terminating at the Colorado-Utah border approximately 25 miles west of Grand Junction, Colorado, I-70 consists of 232 miles of highway. The 3-year crash rate analysis for the years 2002-2004 indicated that I-70 has seven critical corridors ranging in length from 5 miles to 10 miles. Table 4-7 identifies the M.P. and direction of travel for these corridors while Figure 4-6 graphically illustrates the corridors by their direction and M.P. on a Utah state map. As indicated previously, I-70 does not traverse an urbanized area. None of the three eastbound critical corridors coincide with westbound corridors although a change in direction does occur at M.P. 135 as well as at M.P. 160 near the city of Green River.

Table 4-7. I-70 Drowsy Driving Corridors

Area and Direction of Travel	Rural Area Eastbound (EB)	Rural Area Westbound (WB)
Critical Crash Rate per Million VMT	0.482	0.360
M.P.	--	20 - 25
	--	95 - 100
	--	125 - 135
	135 - 140	--
	155 - 160	--
	--	160 - 165
	225 - 232	--

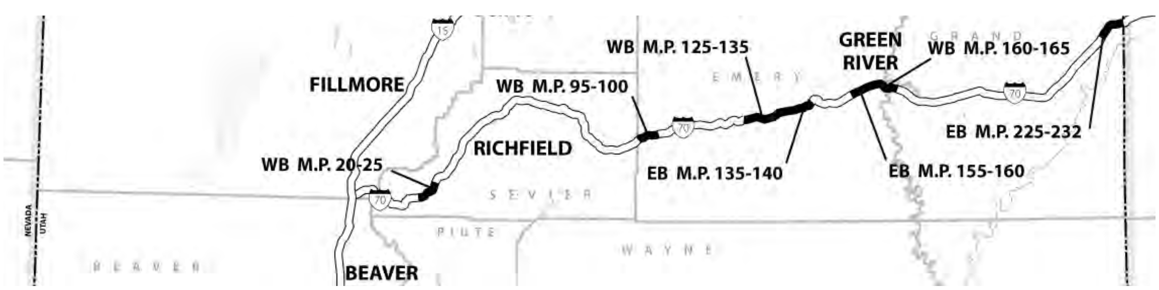

Figure 4-6. I-70 drowsy driving corridors.

The roadway alignment in each critical corridor was analyzed to determine if specific curves in the alignment contributed to fatigue and drowsy driving crashes. One mile intervals were scanned using a "floating segment" one-half mile in length to determine the number of crashes which were reported to have occurred on any given curve. Only two curves out of the seven corridors had at least seven drowsy driving crashes. The corridor from M.P. 20-25 has one curve in the alignment near M.P. 20 at which seven drowsy driving crashes occurred during the years 1992-2004. This value was only superseded between M.P. 228 and M.P. 229 where 10 crashes occurred. This particular curve had the greatest number of reported crashes due to a curve in roadway alignment within the drowsy driving corridors on I-70. For comparison purposes, the maximum number drowsy driving crashes at one curve was 10, which occurred at the location previously described as well as between M.P. 32 and M.P. 33.

Various drowsy driving statistics were calculated for I-70 spanning the years 1992-2004. During this time period, 864 drowsy driving crashes (96.1 percent) were reported as single-vehicle crashes while only 35 crashes (3.9 percent) involved two or more vehicles. Of the 899 drowsy driving crashes, 75 crashes (8.3 percent) were identified as fatal crashes. Considering only 160 fatal crashes occurred on I-70 for the years studied, fatal drowsy driving crashes represented 46.9 percent of all fatal crashes on this facility.

4.2.1 Run-Off-Roadway Crashes and Roadway Alignment

The majority of fatigued drivers on I-70 were involved in run-off-road crashes. This is outlined in Table 4-8 by the 86.9 percent of drivers who "Ran Off Roadway-Thru Median", "Ran Off Roadway-Right", and "Ran Off Roadway-Left." Independent of run-off-road crashes, 65 (7.5 percent) and 29 (3.2 percent) hit a fixed object and another vehicle, respectively. Roadway alignment plays an important role in the location of drowsy driving crashes. Table 4-9 breaks down how drowsy driving crashes related to roadway alignment for the years 1992-2004. Of the 899 drowsy driving crashes, 418 (46.5 percent) occurred on stretches which were "Straight and Level" while 34.7 percent of the crashes occurred in locations where a curve was present. Overall, 65.0 percent of the crashes were on a straight portion of highway alignment.

Table 4-8. I-70 Drowsy Driving Crash Consequences

Crash Consequence	Number of Crashes	Percent of Total Crashes
Ran Off Roadway-Left	350	38.9
Ran Off Roadway-Right	331	36.9
Ran Off Roadway-Thru Median	100	11.1
MV-Fixed Object	65	7.2
MV-MV	29	3.2
Overturned	16	1.8
Other Non-Collision	5	0.6
MV-Animal (Wild)	2	0.2
MV-Other Object	1	0.1
Total	899	100.0

Table 4-9. Drowsy Driving Correlation to Roadway Alignment on I-70.

Alignment Type	Number of Crashes	Percent of Total Crashes
Straight and Level	418	46.5
Curve Grade	196	21.8
Grade Straight	156	17.4
Curve Level	103	11.5
Curve Hillcrest	12	1.3
Hillcrest Straight	10	1.1
Dip Straight	3	0.3
Dip Curve	1	0.1
Total	899	100.0

4.2.2 Time of Day and Day of Week

Two peaks are generally characteristic of drowsy driving crashes—one in the morning and one in the afternoon. The morning peak, which climaxed at 109 crashes, is easily discernable in Figure 4-7 whereas the afternoon peak is practically nonexistent.

The afternoon peak occurred during both the 12 p.m. hour and 3 p.m. hour. Five percent of all drowsy driving crashes occurred in each of these two hours. The hour in which the least overall percentage of drowsy driving crashes occurred was the 10 p.m. hour, which had only 0.9 percent of all drowsy driving crashes on I-70. Also included in Figure 4-7 is the percentage of total background traffic by hour, which can be used to compare with the percentage of drowsy driving crashes. Although the total percentage of traffic is relatively low in the early morning hours, the percentage of drowsy driving crashes is relatively high by comparison. In the afternoon hours, a large difference between the total percentage of drowsy driving crashes and the total background traffic can be seen. Overall, the drowsy driving crash and traffic trends identified in Figure 4-7 are typical of major facilities such as I-70. The traffic data in Figure 4-7 was not collected on I-70, but rather adapted from the *Traffic Monitoring Guide* (FHWA 2001) as typical hourly data on a rural highway.

Although drowsy driving crashes typically occur more on weekends than during the week, the drowsy driving crashes on I-70 remained relatively constant throughout the week as indicated in Figure 4-8. Of all drowsy driving crashes, 149 (16.6 percent) occurred on Saturday followed by Monday with 133 crashes (14.8 percent). On I-70 the days in which the least number of drowsy driving crashes occurred were Tuesday and Thursday with 121 crashes (13.5 percent). Also identified in Figure 4-8 are the number of fatigue-related crashes by day which occurred between the hours of 12 a.m. and 7 a.m. This is included in the figure to visualize the number of crashes occurring during normal sleep-time hours versus those crashes occurring during the day and evening hours. Specifically, 29.8 percent of drowsy driving crashes on this facility occurred between 12 a.m. and 7 a.m. For drowsy driving crashes that occurred between the hours of 12 a.m. and 7 a.m., 48 (5.3 percent) took place during the middle of the night or early morning hours on Saturday. Similar to Figure 4-7, Figure 4-8 also contains the percentage of total background traffic by day for comparison purposes with the percentage of drowsy driving crashes.

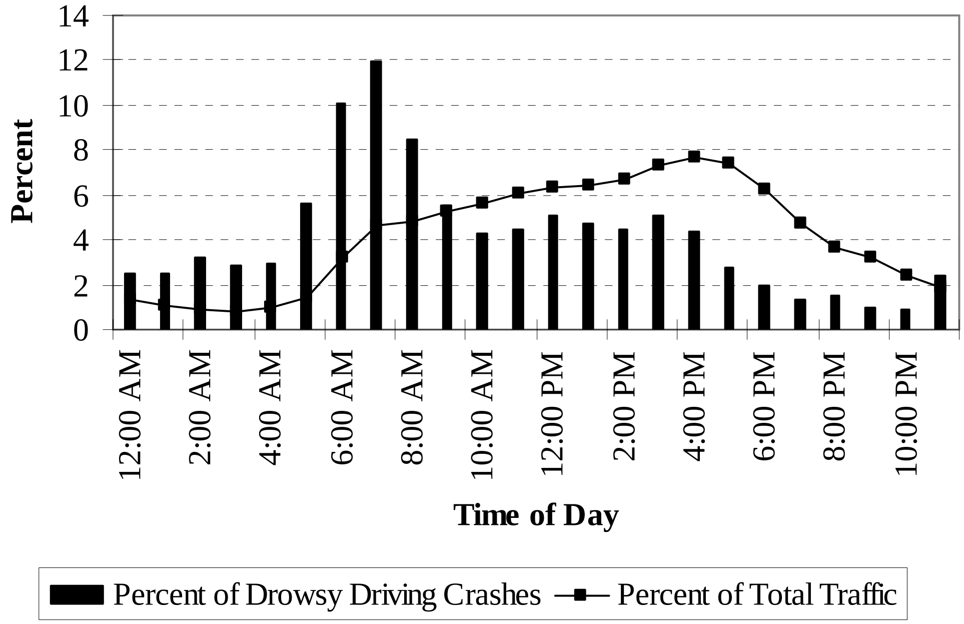

Figure 4-7. Histogram of drowsy driving crashes on I-70.

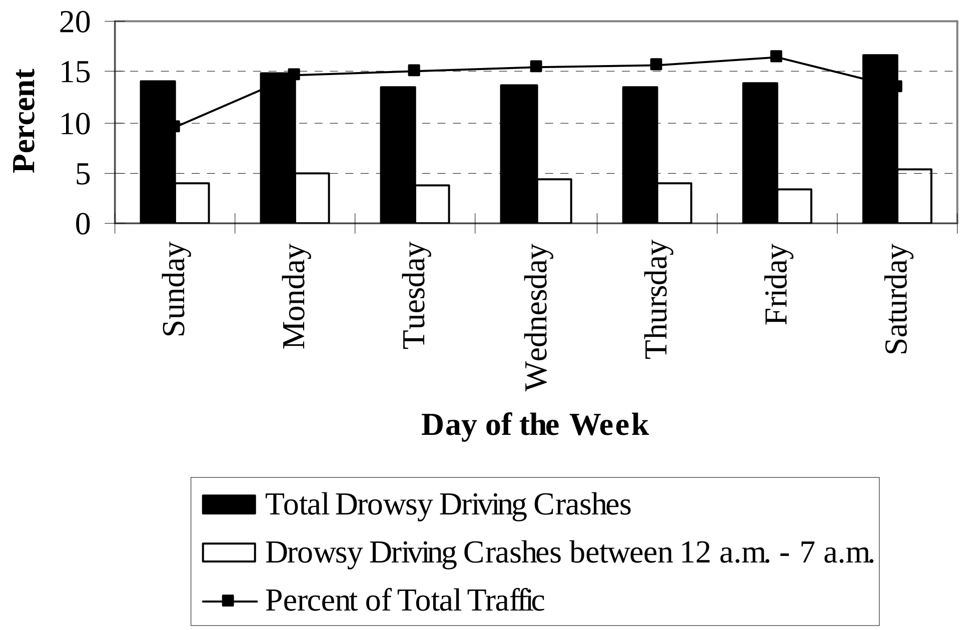

Figure 4-8. Drowsy driving crashes by day of the week on I-70.

4.2.3 Vehicle Type, Object Struck, and Severity

Semi-trucks represented approximately 6 percent of all vehicles involved in drowsy driving crashes on I-70. The most common vehicle type involved in this style of crash was the passenger car as outlined in Table 4-10, which was involved in nearly 82 percent of all drowsy driving crashes on I-70. No vehicle type was reported in 10 percent of the drowsy driving crashes on this facility. The total number of vehicles in which a driver was responsible for a crash or partially responsible for a drowsy driving crash summed to 918 crashes, 19 more than the total number of crashes. In some cases, the police report indicated that two drivers were responsible for the crash.

A number of objects along a highway which drivers hit, and which are recorded in the UDOT crash database, are listed in Table 4-11. The first and second most frequently hit objects were delineator post and dirt embankment, which were struck by 28.2 and 17.2 percent of drowsy drivers, respectively. Guardrails and fences were each hit in more than 6 percent of the crashes while the remaining 10 percent of vehicles struck other objects.

Table 4-10. Vehicle Types of Drowsy Drivers on I-70

Vehicle Type of Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Passenger Car/Pickup	751	81.8
Truck/Tractor and Trailer	53	5.8
Passenger Car/Pickup with Trailer	11	1.2
Single Unit Enclosed Box (Min. 2 Axles and 6 Tires)	7	0.8
Motorcycle	4	0.4
No Vehicle Type Recorded	92	10.0
Total	918	100.0

Table 4-11. Objects Struck by Drowsy Drivers on I-70

Object Struck by Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Delineator Post	259	28.2
Dirt Embankment/Ditch/Berm (Mountainside)	158	17.2
Guardrail	62	6.8
Fence	58	6.3
Bridge Culvert or Other Highway Structure	20	2.2
Sign Post	19	2.1
Rigid Barrier (Concrete)	18	2.0
Guardrail End Section	13	1.4
Crash Attenuator	5	0.5
Other	3	0.3
Tree/Shrubbery	3	0.3
Utility Pole	3	0.3
Building/Other Structure (Wall)	2	0.2
Wild Animal	2	0.2
Curb or Safety Island	1	0.1
Traffic Channelization Device	1	0.1
No Object Struck	291	31.8
Total	918	100.0

To determine if the distribution of drowsy driving crashes on I-70 was skewed towards Utah residents more than out-of-state visitors, license plate data from police reports were analyzed for the timeframe 1996-2004. This analysis incorporated 687 crashes. Utah residents represented only 16.4 percent of drivers responsible for the fatigue-related crashes in this study while 83.4 percent were recorded as out-of-state drivers. Vehicle license plates were not recorded in 0.1 percent of the crashes.

The data in Table 4-12 are provided to determine whether drowsy driving crashes are more severe in nature when compared to all types crashes combined. The first part of the table indicates a percentage for each severity type among solely drowsy driving crashes, while the second part gives a percentage for each severity level generated from all crashes on I-70 from 1992-2004. As noted, drowsy driving crashes yielded a greater percentage of fatal crashes when compared to all fatal crashes on this highway. Furthermore, severity levels in drowsy driving crashes were worse overall with fewer crashes yielding “No Injury.” The top two severity levels, “Fatal” and “Broken Bones or Bleeding Wounds,” accounted for 35.3 percent of drowsy driving crashes, nearly twice that recorded for the same severity levels for all crashes on I-70.

Table 4-12. Severity of Drowsy Driving Crashes Versus All Crashes on I-70

Severity	Drowsy Driving Crashes	All Crashes
Fatal	8.3	3.0
Broken Bones or Bleeding Wound	27.0	15.1
Bruises and Abrasions	16.5	11.3
Possible Injury	12.5	9.7
No Injury	35.7	60.9
Total	100.0	100.0

4.2.4 Directional Distribution

The trends in directional distribution of drowsy driving crashes were determined for I-70. Of the 899 drowsy driving crashes, 60.4 percent occurred heading eastbound while the remaining 39.6 percent were in the westbound direction. Figure 4-9 illustrates the directional distribution from M.P. 0 to M.P. 232. For various sections of this facility the drowsy driving trends are consistent, but in two locations the trends vary greatly. In the 40-mile corridor from M.P. 125 to M.P. 165 west of Green River, 130 eastbound crashes took place over the 13 years from 1992-2004 while 61 crashes occurred in the westbound direction, thus more than twice as many drowsy driving crashes occurred heading eastbound. Similar results between M.P. 200 and M.P. 232 are shown in Figure 4-9 as 2.5 times as many crashes occurred in the eastbound direction as the westbound direction of travel.

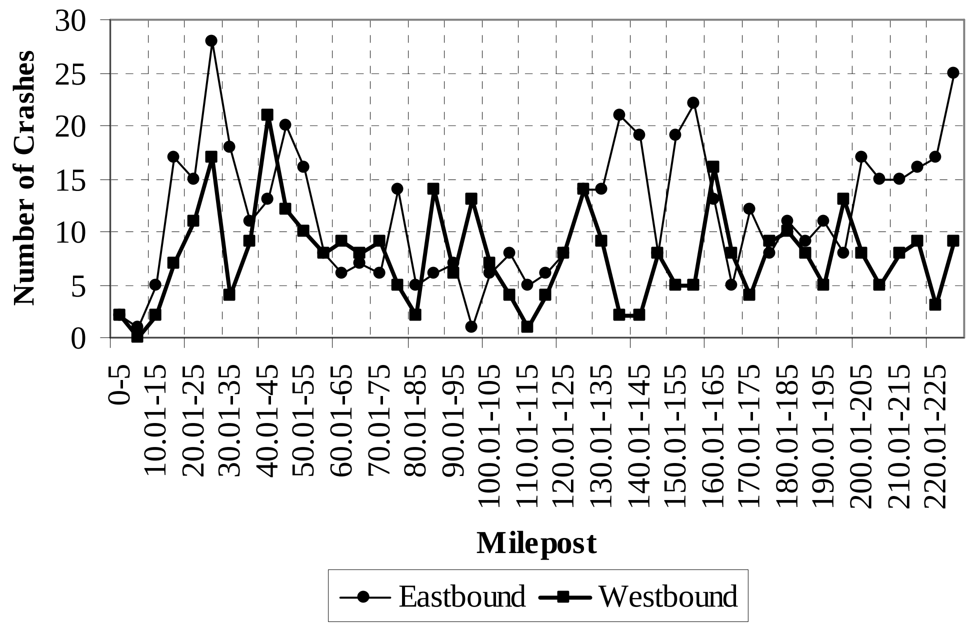

Figure 4-9. Directional distribution of drowsy driving crashes on I-70.

4.3 Interstate 80

I-80 traverses the state of Utah beginning at the Nevada-Utah border with the city of Wendover and terminating 196 miles to the east at the Wyoming-Utah border just a few miles west of Evanston, Wyoming. A short section of I-80, approximately 3 miles in length, coincides with I-15 near downtown Salt Lake City. All drowsy driving crashes which occurred on this short segment of highway were recorded with the I-15 data. The 3-year crash rate analysis for the years 2002-2004 indicated that I-80 has seven critical corridors all of which are 5 miles in length. Table 4-13 identifies the M.P. and direction of travel for these corridors while Figure 4-10 graphically illustrates the corridors on a Utah state map. All seven critical corridors are located in the desert west of Salt Lake City. None of the three eastbound critical corridors coincide with westbound corridors although at M.P. 35 a change in direction of critical corridors does occur.

Table 4-13. I-80 Drowsy Driving Corridors

Area and Direction of Travel	Rural Area		Urban Area	
	Eastbound (EB)	Westbound (WB)	Eastbound (EB)	Westbound (WB)
Critical Crash Rate per Million VMT	0.307	0.175	0.077	0.047
M.P.	--	5 - 10	--	--
	--	20 - 25	--	--
	--	30 - 35	--	--
	35 - 40	--	--	--
	45 - 50	--	--	--
	60 - 65	--	--	--
	--	70 - 75	--	--

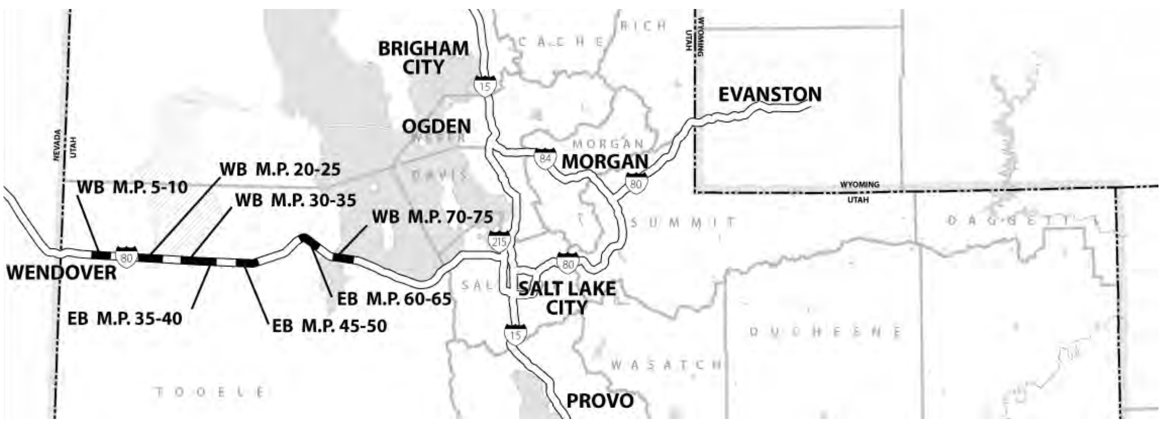

Figure 4-10. I-80 drowsy driving corridors.

The roadway alignment in each critical corridor was analyzed to determine if specific curves in the alignment contributed to fatigue and drowsy driving crashes. One mile intervals were scanned using a "floating segment" one-half mile in length to determine the number of crashes which were reported to have occurred on any given curve. Only one curve out of the seven corridors had at least eight drowsy driving crashes. The curve is near M.P. 60 and had eight crashes during the years 1992-2004. For comparison purposes, the maximum number drowsy driving crashes at one curve was 10, which occurred just east of M.P. 132.

The first four critical corridors beginning at M.P. 5 and terminating at M.P. 40 encompass the Bonneville Salt Flats. This section of I-80 is extremely flat, straight, and somewhat monotonous. Very few services where drivers can rest, such as gas stations and restaurants, are located in the first 95 miles between Wendover on the Nevada-Utah border and the junction of S.R. 36 with I-80 north of Tooele. Although the monotony of driving through the Bonneville Salt Flats is only one of a few possible reasons as to why many drivers fall asleep behind the wheel, it does seem to be the most reasonable explanation for drowsy driving in the area.

Various drowsy driving statistics were calculated for I-80 spanning the years 1992-2004. During this time period, 818 drowsy driving crashes (88.7 percent) were reported as single-vehicle crashes while only 104 crashes (11.3 percent) involved two or more vehicles. Of the 922 drowsy driving crashes, 57 crashes (6.2 percent) were identified as fatal crashes. I-80 had 243 fatal crashes; therefore, fatal drowsy driving crashes represented 23.5 percent of all fatal crashes on this facility.

4.3.1 Run-Off-Roadway Crashes and Roadway Alignment

The majority of fatigued drivers on I-80 were involved in run-off-roadway crashes. This is evident in Table 4-14 by the 79.7 percent of drivers who "Ran Off Roadway-Thru Median", "Ran Off Roadway-Right", and "Ran Off Roadway-Left." In 17.2 percent of the drowsy driving crashes, the driver either struck a fixed object or collided with another vehicle. In approximately 2 percent of the crashes, the vehicle overturned. Roadway alignment plays an important role in the location of drowsy driving crashes. Table 4-15 identifies how drowsy driving crashes related to roadway alignment for the years 1992-2004. Of the 922 drowsy driving crashes, 582 (63.1 percent) occurred on stretches which were "Straight and Level" while 24.9 percent of the crashes occurred in locations where a curve was present.

Table 4-14. I-80 Drowsy Driving Crash Consequences

Crash Consequence	Number of Crashes	Percent of Total Crashes
Ran Off Roadway-Left	309	33.5
Ran Off Roadway-Right	309	33.5
Ran Off Roadway-Thru Median	117	12.7
MV-Fixed Object	79	8.6
MV-MV	79	8.6
Overturned	18	1.9
Other Non-Collision	8	0.9
MV-Other Object	2	0.2
MV-Bicycle	1	0.1
Total	922	100.0

Table 4-15. Drowsy Driving Correlation to Roadway Alignment on I-80.

Alignment Type	Number of Crashes	Percent of Total Crashes
Straight and Level	582	63.2
Curve Level	118	12.8
Curve Grade	105	11.4
Grade Straight	99	10.7
Hillcrest Straight	10	1.1
Curve Hillcrest	5	0.5
Dip Curve	2	0.2
Dip Straight	1	0.1
Total	922	100.0

4.3.2 Time of Day and Day of Week

Two peaks are generally characteristic of drowsy driving crashes—one in the morning and one in the afternoon. The morning peak, which climaxed at 88 crashes and occurred during the 6 a.m. hour, is easily discernable in Figure 4-11. The afternoon peak, although not as easy to discern as the morning peak, was 46 crashes during the 2 p.m. hour. The timing of the peaks is once again consistent with the circadian rhythm (Horne and Reyner 1995). The hour in which the least overall percentage of drowsy driving crashes occurred was the 8 p.m. hour, which had only 1.0 percent of all drowsy driving crashes on I-80. Also included in Figure 4-11 is the percentage of total background traffic by hour as recorded by UDOT, which can be used to compare with the percentage of drowsy driving crashes. The traffic data was collected on I-80 west of downtown Salt Lake City and illustrates well the difference between the percentage of traffic during both the early morning hours and the late afternoon hours with the percentage of drowsy driving in those time periods. Although the total percentage of traffic is relatively low in the early morning hours, the percentage of drowsy driving crashes is relatively high by comparison. In the afternoon and evening hours, a large difference between the total percentage of drowsy driving crashes and the total background traffic can be identified during the 4 p.m. and 8 p.m. hours, respectively. Overall, the drowsy driving crash and traffic trends identified in Figure 4-11 are typical of major facilities such as I-80.

Drowsy driving crashes typically occur more on weekends than during the week. Figure 4-12 indicates that for the years studied more drowsy driving crashes took place on I-80 on Saturdays and Sundays than occurred during the week. Of all drowsy driving crashes, 182 (19.7 percent) occurred on Saturday followed by Sunday with 169 crashes (18.3 percent). On I-80 the day in which the least number of drowsy driving crashes occurred was Wednesday with 101 crashes (11.0 percent). Also identified in Figure 4-12 are the number of fatigue-related crashes by day which occurred between the hours of 12 a.m. and 7 a.m. This is included in the figure to visualize the number of crashes occurring during normal sleep-time hours versus those crashes occurring during the day and evening hours. Specifically, 38.1 percent of drowsy driving crashes on this facility occurred between 12 a.m. and 7 a.m. Of all drowsy driving crashes, 74 (8.0 percent) took place during the middle of the night or early morning hours on Saturday. Similar to Figure 4-11, Figure 4-12 also contains the percentage of total background traffic as recorded by UDOT by day for comparison purposes with the percentage of drowsy driving crashes.

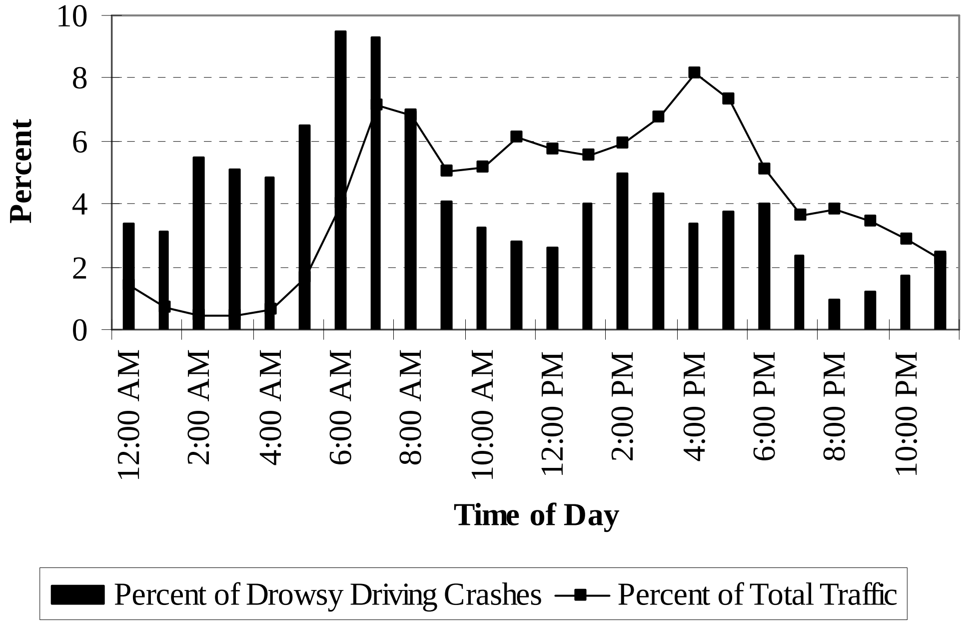

Figure 4-11. Histogram of drowsy driving crashes on I-80.

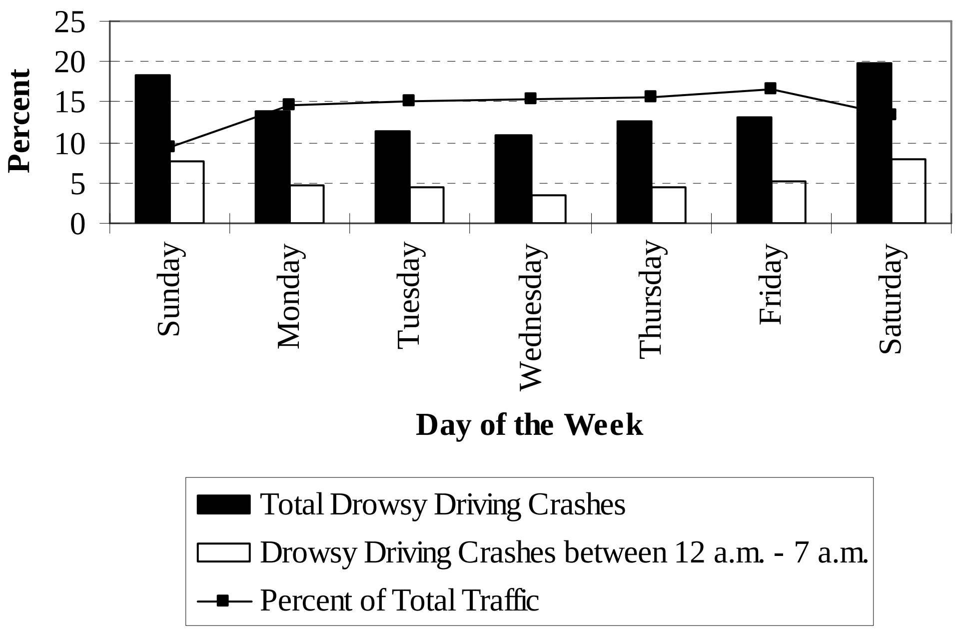

Figure 4-12. Drowsy driving crashes by day of the week on I-80.

4.3.3 Vehicle Type, Object Struck, and Severity

Semi-trucks represented approximately 6 percent of all vehicles involved in drowsy driving crashes on I-80. The most common vehicle type involved in this style of crash was the passenger car, which was involved in more than 84 percent of the drowsy driving crashes as outlined in Table 4-16. In 69 drowsy driving crashes (7.3 percent), no vehicle type was recorded The total number of vehicles in which a driver was responsible for a crash or partially responsible for a drowsy driving crash summed to 943 crashes, 21 more than the total number of crashes. In some cases, the police report indicated that two drivers were responsible for the crash.

A number of objects along a highway which drivers hit, and which are recorded in the UDOT crash database, are listed in Table 4-17. The first and second most frequently hit objects were delineator post and dirt embankment, which were struck by 24.8 and 9.5 percent of drowsy drivers, respectively. Other frequently hit objects included concrete barriers, fences, and guardrails. No object was struck in more than 40 percent of the crashes.

Table 4-16. Vehicle Types of Drowsy Drivers on I-80

Vehicle Type of Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Passenger Car/Pickup	795	84.3
Truck/Tractor and Trailer	60	6.4
Passenger Car/Pickup with Trailer	10	1.1
Single Unit Enclosed Box (Min. 2 Axles and 6 Tires)	6	0.6
Buses—Commercial and School	1	0.1
Concrete Mixer	1	0.1
Motorcycle	1	0.1
No Vehicle Type Recorded	69	7.3
Total	943	100.0

Table 4-17. Objects Struck by Drowsy Drivers on I-80

Object Struck by Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Delineator Post	234	24.8
Dirt Embankment/Ditch/Berm (Mountainside)	90	9.5
Rigid Barrier (Concrete)	58	6.2
Fence	51	5.4
Guardrail	37	3.9
Sign Post	33	3.5
Other	14	1.7
Bridge Culvert or Other Highway Structure	7	0.7
Tree/Shrubbery	7	0.7
Crash Attenuator	6	0.6
Guardrail End Section	6	0.6
Utility Pole	5	0.5
Traffic Channelization Device	3	0.3
Building/Other Structure (Wall)	2	0.2
Curb or Safety Island	1	0.1
No Object Struck	389	41.3
Total	943	100.0

To determine if the distribution of drowsy driving crashes on I-80 was skewed towards Utah residents more than out-of-state visitors, license plate data from police reports were analyzed for the timeframe 1996-2004. This analysis incorporated 668 crashes. Utah residents represented only 64.8 percent of drivers responsible for the fatigue-related crashes in this study while 35.2 percent were recorded as out-of-state drivers.

The data in Table 4-18 can be used to determine whether drowsy driving crashes are more severe in nature when compared to all types of crashes combined. As noted, drowsy driving crashes yielded a greater percentage of fatal crashes when compared to all fatal crashes on this highway. Furthermore, severity levels of drowsy driving crashes were worse overall. The top two severity levels, “Fatal” and “Broken Bones or Bleeding Wounds,” accounted for 27.9 percent of all drowsy driving crashes, nearly three times that recorded for the same severity levels for all crashes on I-80.

Table 4-18. Severity of Drowsy Driving Crashes Versus All Crashes on I-80

Severity	Drowsy Driving Crashes	All Crashes
Fatal	6.2	1.8
Broken Bones or Bleeding Wound	21.7	9.4
Bruises and Abrasions	19.8	9.6
Possible Injury	12.9	13.8
No Injury	39.4	65.4
Total	100.0	100.0

4.3.4 Directional Distribution

I-80 is unique among the Interstate freeways in Utah due to the geographical areas which it traverses. To determine the trends in directional distribution for drowsy driving crashes, Figure 4-13 is provided. Drowsy driving crashes have been an increasing concern in the desert west of Salt Lake City over the past few years. Figure 4-13 illustrates that more drowsy driving crashes occurred in the westbound direction of travel from M.P. 0 to M.P. 30 than eastbound. From M.P. 30 to the urban boundary of Salt Lake City at M.P. 110, a large increase in drowsy driving crashes occurred. Of the 922 drowsy driving crashes, 63.6 percent were heading eastbound while the remaining 36.4 percent were driving westbound. The possible reasons for these trends are discussed in Chapter 5. The directional distribution of drowsy driving crashes was approximately the same in the area of Salt Lake City, but quickly separated near M.P. 130. Near the Utah-Wyoming border, a large increase in drowsy driving crashes occurred in the last seven miles of highway for eastbound drivers between M.P. 190 and M.P. 197. In this section, 38 drowsy driving crashes occurred heading eastbound while only eight crashes occurred in the westbound direction over the 13 years of data analyzed.

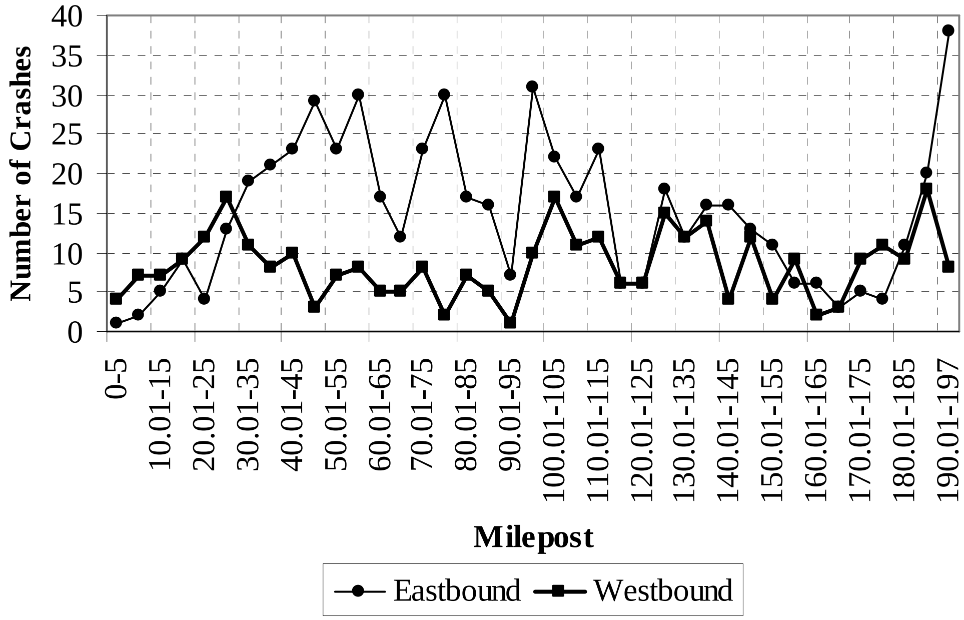

Figure 4-13. Directional distribution of drowsy driving crashes on I-80.

4.4 Interstate 84

Interstate 84 (I-84) begins at the Idaho-Utah border 40 miles north of the City of Tremonton and terminates 120 miles to the east at the junction of I-80 approximately 30 miles from the Wyoming-Utah border. Although I-84 is 120 miles in length, a 40 mile stretch from Tremonton to Ogden coincides with I-15. Therefore, all drowsy driving crashes which occurred on the I-15/I-84 corridor were recorded as part of the I-15 data. The 3-year crash rate analysis for the years 2002-2004 indicated that I-84 has two critical corridors. Table 4-19 identifies the M.P. and direction of travel for these corridors while Figure 4-14 graphically illustrates the corridors on a Utah state map. The two critical corridors coincide with each other from M.P. 110 to M.P. 115. No curves in the roadway alignment were identified in this critical corridor.

M.P. 110-115 is located near the small city of Henefer east of Morgan. I-84 in this particular area is rural and winds through some small canyons before entering a flatland just before M.P. 115. The speed limit in this area is 70 mph.

Table 4-19. I-84 Drowsy Driving Corridors

Area and Direction of Travel	Rural Area	
	Eastbound (EB)	Westbound (WB)
Critical Crash Rate per Million VMT	0.231	0.135
M.P.	110 - 115	110 - 115

Figure 4-14. I-84 drowsy driving corridors.

Various drowsy driving statistics were calculated for I-84 across the years 1992-2004. During this time period, 143 drowsy driving crashes (89.4 percent) were reported as single-vehicle crashes, while 17 crashes (10.6 percent) involved two or more vehicles. Of the 160 drowsy driving crashes, 6 crashes (3.8 percent) were identified as fatal crashes. Considering 39 fatal crashes occurred on I-84 from 1992-2004, fatal drowsy driving crashes represented 15.4 percent of all fatal crashes on this facility.

4.4.1 Run-Off-Roadway Crashes and Roadway Alignment

The majority of fatigued drivers on I-84 were involved in run-off-road crashes. This is evident in Table 4-20 by the 77.5 percent of drivers who “Ran Off Roadway-Thru Median”, “Ran Off Roadway-Right”, and “Ran Off Roadway-Left.” Besides run-off-road crashes, 7.5 percent of crashes resulted in one motor-vehicle colliding with another motor-vehicle.

Roadway alignment as indicated previously plays an important role in the location of drowsy driving crashes. Table 4-21 identifies how drowsy driving crashes related to roadway alignment for the years 1992-2004 on I-84. Of the 160 drowsy driving crashes, 70 (43.8 percent) occurred on stretches which were “Straight and Level” while 40.6 percent of the crashes occurred in locations where a curve was present.

Table 4-20. I-84 Drowsy Driving Crash Consequences

Crash Consequence	Number of Crashes	Percent of Total Crashes
Ran Off Roadway-Right	55	34.3
Ran Off Roadway-Left	43	26.9
Ran Off Roadway-Thru Median	26	16.3
MV-Fixed Object	15	9.4
MV-MV	12	7.5
Overturned	5	3.1
MV-Other Object	3	1.9
MV-Pedestrian	1	0.6
Total	160	100.0

Table 4-21. Drowsy Driving Correlation to Roadway Alignment on I-84.

Alignment Type	Number of Crashes	Percent of Total Crashes
Straight and Level	70	43.7
Curve Level	37	23.1
Curve Grade	24	15.0
Grade Straight	22	13.8
Curve Hillcrest	3	1.9
Hillcrest Straight	3	1.9
Dip Curve	1	0.6
Total	160	100.0

4.4.2 Time of Day and Day of Week

Generally, two peaks are characteristic of drowsy driving crashes—one in the morning and one in the afternoon. The drowsy driving crashes on I-84 did not follow the typical trend. The afternoon peak, which climaxed at 15 crashes and occurred during the 3 p.m. hour, is easily discernable in Figure 4-15. The morning time period did not have a specific peak hour as drowsy driving crashes were spread out. Also included in Figure 4-15 is the percentage of total background traffic by hour, which can be used to compare with the percentage of drowsy driving crashes. Although the total percentage of traffic is relatively low in the early morning hours, the percentage of drowsy driving crashes is relatively high by comparison. The traffic data in Figure 4-15 was not collected on I-84, but rather adapted from the *Traffic Monitoring Guide* (FHWA 2001) as typical hourly data on a rural highway.

Drowsy driving crashes typically occur more on weekends than during the week. Figure 4-16 indicates that for the years studied the most drowsy driving crashes took place on I-84 on Saturdays. Of all drowsy driving crashes, 34 (21.3 percent) occurred on Saturday followed by Sunday with 21 crashes (14.4 percent). On I-84 the day in which the least number of drowsy driving crashes occurred was Monday with 16 crashes (10.0 percent). Also identified in Figure 4-16 are the number of fatigue-related crashes by day which occurred between the hours of 12 a.m. and 7 a.m. This is included in the figure to visualize the number of crashes occurring during normal sleep-time hours versus those crashes occurring during the day and evening hours. Specifically, 34.4 percent of drowsy driving crashes on this facility occurred between 12 a.m. and 7 a.m. Of all drowsy driving crashes, 11 (6.9 percent) took place during the middle of the night or early morning hours on Saturday. Similar to Figure 4-15, Figure 4-16 also contains the percentage of total background traffic by day for comparison purposes with the percentage of drowsy driving crashes.

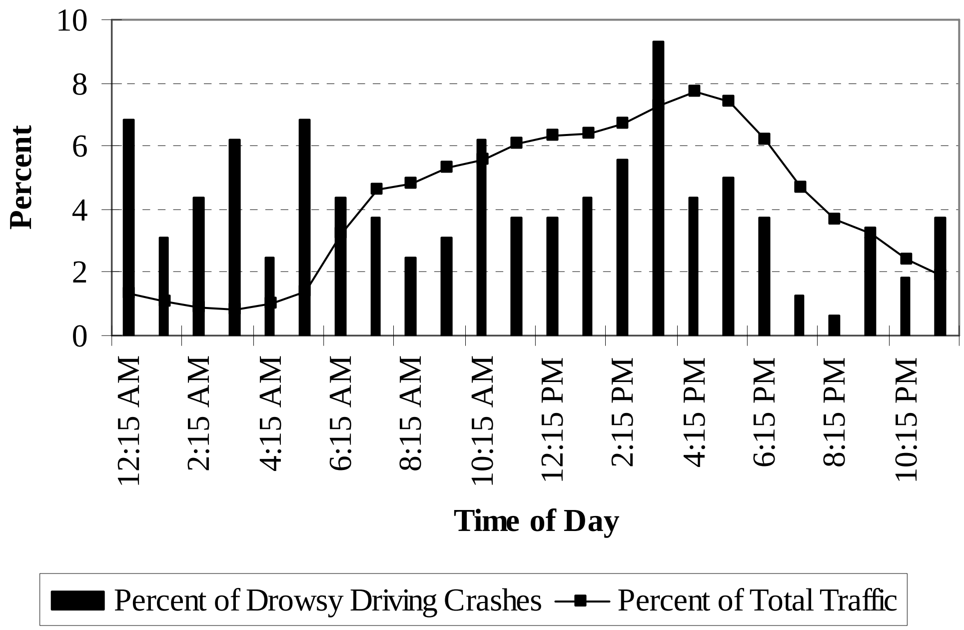

Figure 4-15. Histogram of drowsy driving crashes on I-84.

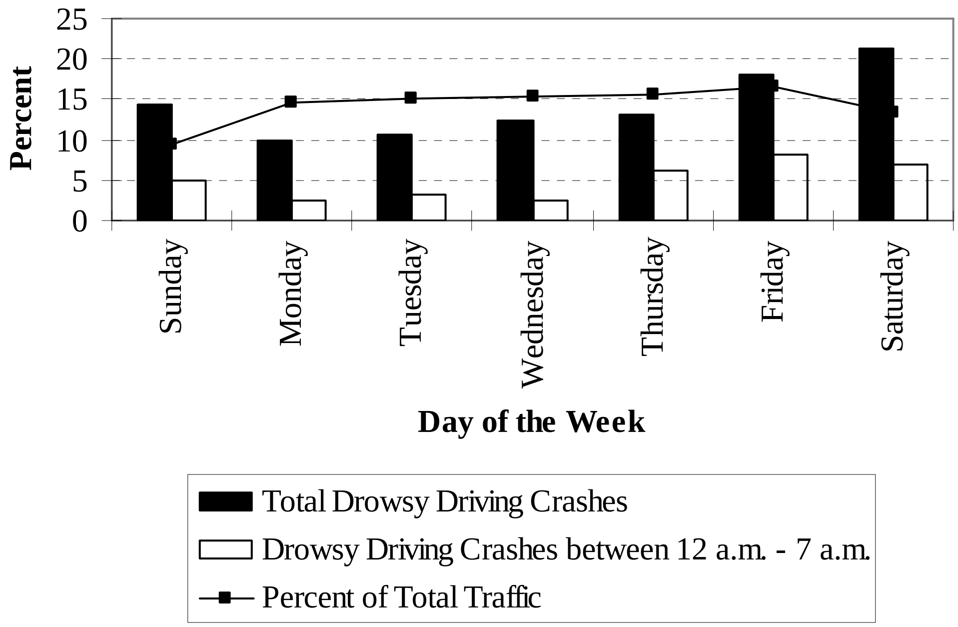

Figure 4-16. Drowsy driving crashes by day of the week on I-84.

4.4.3 Vehicle Type, Object Struck, and Severity

Semi-trailer trucks on I-84 accounted for 12.3 percent of all vehicles involved in drowsy driving crashes, which is twice as much as calculated on I-15 (4.5 percent), I-70 (5.8 percent), or I-80 (6.4 percent). The most common vehicle type involved in this style of crash was the passenger car as denoted in Table 4-22, which was involved in slightly more than 77 percent of the reported crashes. The total number of vehicles in which a driver was responsible for a crash or partially responsible for a drowsy driving crash summed to 163 crashes, 3 more than the total number of crashes as in some instances the police report indicated that two drivers were responsible for the crash.

A number of objects along a highway which drivers hit, and which are recorded in the UDOT crash database, are listed in Table 4-23. The most frequently hit objects were a delineator post, which was struck by 27.6 percent of drowsy drivers, and a mountainside. The mountainside or dirt embankment was struck in 9.2 percent of the crashes while in 1.8 percent of the crashes, the reporting officer cited “Other” for the object struck. The specific objects struck that were recorded as “Other” were not included in the UDOT crash database. No object was struck in 22.7 percent of the crashes.

Table 4-22. Vehicle Types of Drowsy Drivers on I-84

Vehicle Type of Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Passenger Car/Pickup	126	77.3
Truck/Tractor and Trailer	20	12.3
Passenger Car/Pickup with Trailer	3	1.8
No Vehicle Type Recorded	14	8.6
Total	163	100.0

Table 4-23. Objects Struck by Drowsy Drivers on I-84

Object Struck by Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Delineator Post	45	27.6
Dirt Embankment/Ditch/Berm (Mountainside)	15	9.2
Fence	14	8.7
Rigid Barrier (Concrete)	12	7.4
Guardrail	10	6.1
Sign Post	9	5.5
Tree/Shrubbery	7	4.3
Bridge Culvert or Other Highway Structure	3	1.8
Crash Attenuator	3	1.8
Other	3	1.8
Traffic Channelization Device	2	1.2
Guardrail End Section	1	0.6
Snow Embankment	1	0.6
Utility Pole	1	0.6
No Object Struck	37	22.8
Total	163	100.0

To determine if the distribution of drowsy driving crashes on I-84 was skewed towards Utah residents more than out-of-state visitors, license plate data from police reports were analyzed for the timeframe 1996-2004. This analysis encompassed 131 crashes. Utah residents represented 60.3 percent of drivers responsible for the fatigue-related crashes in this study while 39.7 percent were recorded as out-of-state drivers.

The data in Table 4-24 are provided to determine whether drowsy driving crashes are more severe in nature when compared to all types crashes combined. The first part of this table indicates a percentage for each severity type among drowsy driving crashes while the second part gives a percentage for each severity level from all crashes on I-84. As noted, drowsy driving crashes yielded a greater percentage of fatal crashes and fewer crashes with “No Injury.”

Table 4-24. Severity of Drowsy Driving Crashes Versus All Crashes on I-84

Severity	Drowsy Driving Crashes	All Crashes
Fatal	3.8	1.3
Broken Bones or Bleeding Wound	25.6	9.0
Bruises and Abrasions	16.3	8.9
Possible Injury	13.8	12.3
No Injury	40.5	68.5
Total	100.0	100.0

4.4.4 Directional Distribution

The trends in directional distribution of crashes were determined for I-84 and are illustrated in Figure 4-17. Of the 160 drowsy driving crashes, 51.3 percent and 48.7 percent occurred in the eastbound and westbound directions, respectively. The number of crashes climaxed near Tremonton, but decreased after I-84 merged with I-15.

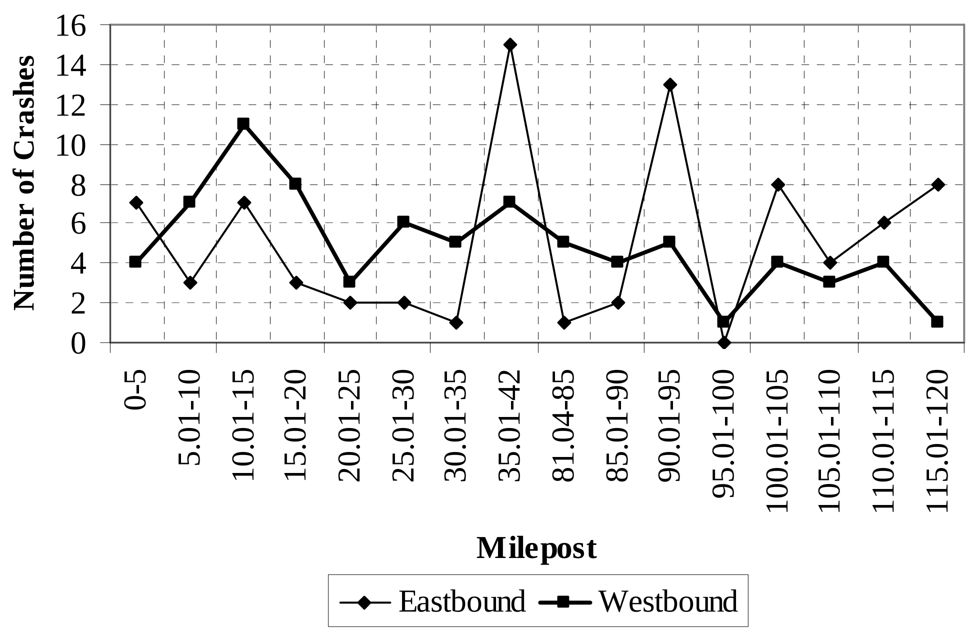

Figure 4-17. Directional distribution of drowsy driving crashes on I-84.

4.5 United States Route 89

U.S. 89 begins at the Arizona-Utah border a few miles north of Page, Arizona and terminates at M.P. 503 north of Garden City, Utah at the Idaho-Utah border. Although U.S. 89 is 503 miles in length it does shares multiple segments of roadway with other facilities in the state. The first portion of U.S. 89 to coincide with another highway occurs near Sevier (M.P. 191) at the junction of I-70. The two routes share 33 miles of I-70. U.S. 89 also shares a 10 mile stretch of highway with U.S. 6 between Thistle (M.P. 312) and the mouth of Spanish Fork Canyon (M.P. 322). In both the first and second scenarios where the roadway was shared, all drowsy driving crashes were reported with the I-70 and U.S. 6 data, respectively. Other locations where U.S. 89 coincides with other highways include U.S. 89 and I-15 at two locations (M.P. 353-362 and M.P. 389-396) and U.S. 89 and U.S. 91 southwest of Logan from M.P. 433 to M.P. 459. The 3-year crash rate analysis indicated that U.S. 89 has 12 critical corridors. Table 4-25 identifies these corridors while Figure 4-18 illustrates the corridors on a map. The coinciding corridors are between M.P. 140 and M.P. 145 and M.P. 325 and M.P. 330.

Table 4-25. U.S. 89 Drowsy Driving Corridors

Area and Direction of Travel	Rural Area		Urban Area	
	Northbound (NB)	Southbound (SB)	Northbound (NB)	Southbound (SB)
Critical Crash Rate per Million VMT	0.328	0.436	0.079	0.083
M.P.	5 - 10	--	--	--
	55 - 60	--	--	--
	--	90 - 95	--	--
	105 - 110	--	--	--
	--	115 - 125	--	--
	140 - 145	140 - 145	--	--
	--	180 - 185	--	--
	--	--	325 - 330	325 - 330
	--	--	--	345 - 353
	--	--	370 - 375	--

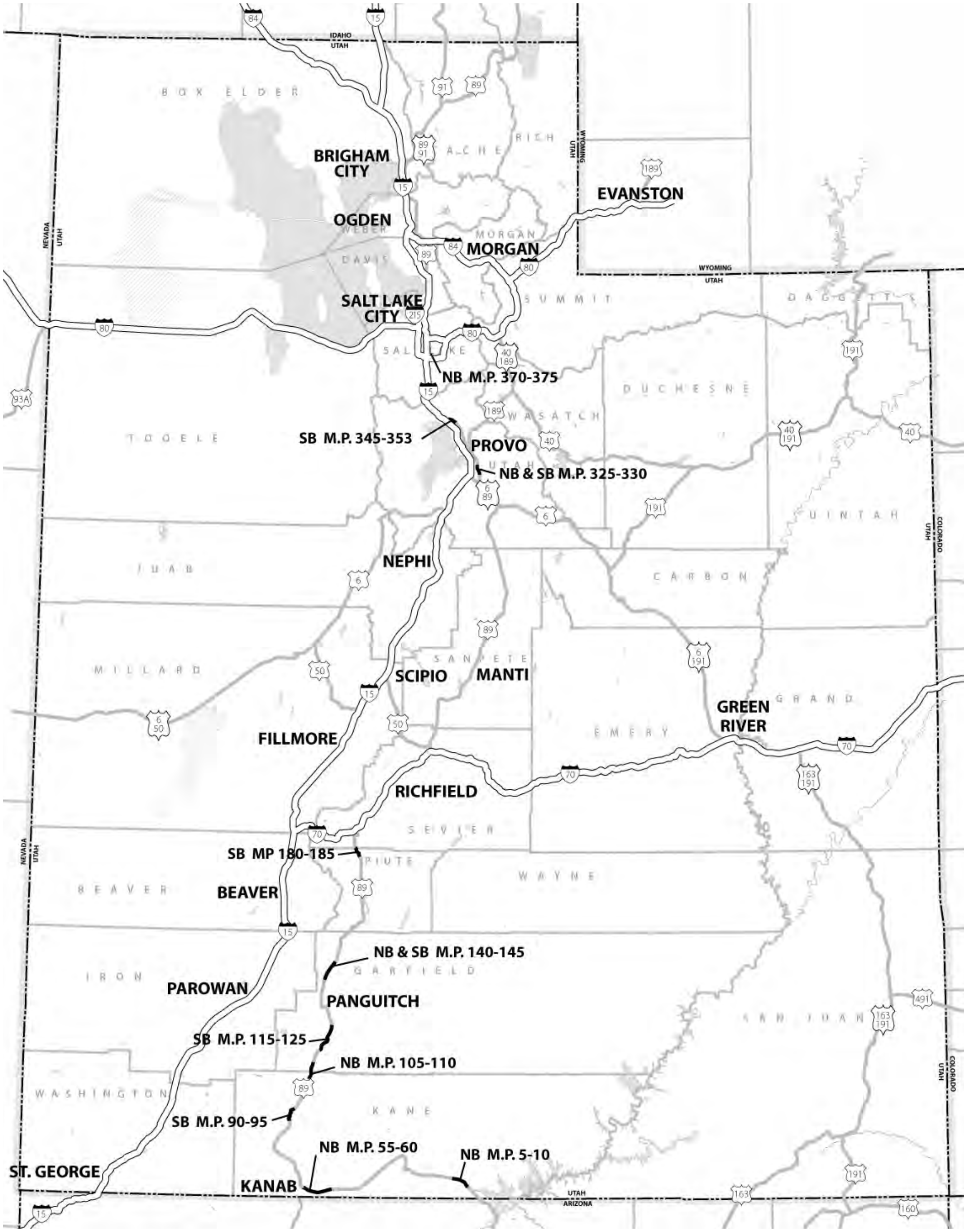

Figure 4-18. U.S. 89 drowsy driving corridors.

The roadway alignment in each critical corridor was analyzed to determine if specific curves in the alignment contributed to fatigue and drowsy driving crashes. One mile intervals were scanned using a “floating segment” one-half mile in length to determine the number of crashes which were reported to have occurred on any given curve. None of the critical corridors yielded a relatively large number of crashes on any given curve. The maximum number of crashes on a curve for all of U.S. 89 was only four crashes.

Various drowsy driving statistics were calculated for U.S. 89 for the years 1992-2004. During this time period, 628 drowsy driving crashes (71.6 percent) were reported as single-vehicle crashes while 249 crashes (28.4 percent) involved two or more vehicles. Of the 877 drowsy driving crashes, 18 crashes (2.1 percent) were identified as fatal crashes. U.S. 89 had 245 fatal crashes from 1992-2004; therefore, fatal drowsy driving crashes represented 7.3 percent of all fatal crashes on this facility. By comparison this is approximately one-third of the drowsy driving mortality rates on Interstates 15, 80, and 84.

4.5.1 Run-Off-Roadway Crashes and Roadway Alignment

It is evident in Table 4-26 that the majority of fatigued drivers were involved in run-off-road crashes since 64.7 percent of drivers ran off the road on U.S. 89. Outside of run-off-road crashes, 23.7 percent of crashes involved two motor-vehicles, which is likely due to a lack of a barrier separating the direction of traffic. This is also reflected in the extremely low “Ran Off Roadway-Thru Median” percentage. In 9 percent of the crashes, the driver struck a fixed object along side of the highway.

Roadway alignment as indicated previously plays an important role in the location of drowsy driving crashes. Table 4-27 identifies how drowsy driving crashes related to roadway alignment for the years 1992-2004. Of the 877 drowsy driving crashes, 567 (64.7 percent) occurred on stretches which were “Straight and Level” while 17.9 percent of the crashes occurred in locations where a curve was present. Another 133 crashes (15.2) percent took place on a straight grade.

Table 4-26. U.S. 89 Drowsy Driving Crash Consequences

Crash Consequence	Number of Crashes	Percent of Total Crashes
Ran Off Roadway-Right	351	40.1
MV-MV	208	23.8
Ran Off Roadway-Left	207	23.6
MV-Fixed Object	79	9.0
Overturned	10	1.1
Ran Off Roadway-Thru Median	9	1.0
Other Non-Collision	8	0.9
MV-Other Object	3	0.3
MV-Animal (Domestic)	2	0.2
Total	877	100.0

Table 4-27. Drowsy Driving Correlation to Roadway Alignment on U.S. 89

Alignment Type	Number of Crashes	Percent of Total Crashes
Straight and Level	567	64.7
Grade Straight	133	15.2
Curve Grade	84	9.6
Curve Level	68	7.8
Hillcrest Straight	17	1.9
Curve Hillcrest	5	0.5
Dip Straight	3	0.3
Total	877	100.0

4.5.2 Time of Day and Day of Week

The two peaks that are generally characteristic of drowsy driving crashes occur in the morning and in the afternoon. The morning peak, which climaxed at 54 crashes and occurred during both the 6 a.m. and 7 a.m. hours, is easily discernable in Figure 4-19. The afternoon peak was 64 crashes and occurred twice, once during the 3 p.m. hour and again during the 5 p.m. hour. The hour in which the least overall percentage of drowsy driving crashes occurred was the 9 p.m. hour. Only 1 percent of all drowsy driving crashes on U.S. 89 took place during this one hour time period.

Drowsy driving crashes typically occur more on weekends than during the week. Figure 4-20 indicates that for the years studied the most drowsy driving crashes took place on Saturdays. Of all drowsy driving crashes, 167 (19.0 percent) occurred on Saturday followed by Friday with 140 crashes (16.0 percent). On U.S. 89 the day in which the least number of drowsy driving crashes occurred was Monday with 98 crashes (11.2 percent). Also identified in Figure 4-20 are the number of fatigue-related crashes by day which occurred between the hours of 12 a.m. and 7 a.m. This is included in the figure to visualize the number of crashes occurring during normal sleep-time hours versus those crashes occurring during the day and evening hours. Specifically, 29.3 percent of drowsy driving crashes on this facility occurred between 12 a.m. and 7 a.m. Of all drowsy driving crashes, 54 (6.2 percent) took place during the middle of the night or early morning hours on Saturday while 52 (5.9 percent) occurred on Monday.

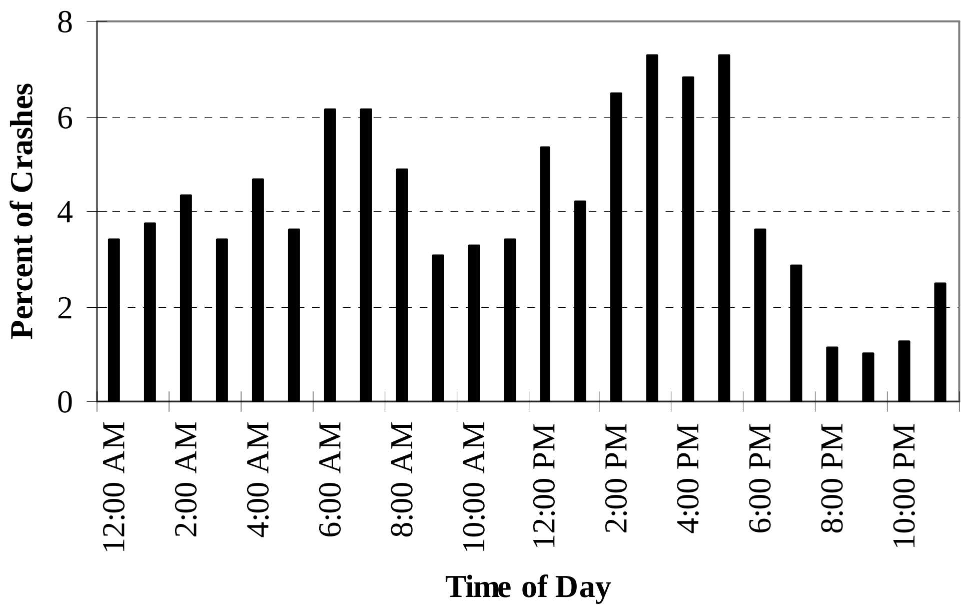

Figure 4-19. Histogram of drowsy driving crashes on U.S. 89.

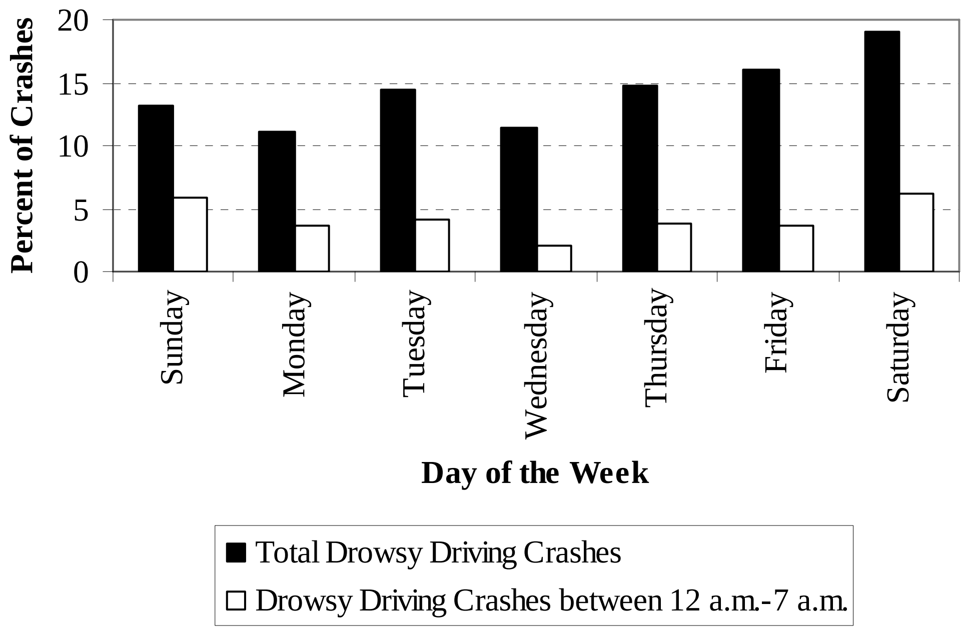

Figure 4-20. Drowsy driving crashes by day of the week on U.S. 89.

4.5.3 Vehicle Type, Object Struck, and Severity

Semi-trucks represented approximately 2 percent of all vehicles involved in drowsy driving crashes on U.S. 89. The most common vehicle type involved in this style of crash on U.S. 89 was the passenger car as outlined in Table 4-28. The total number of vehicles in which a driver was responsible for a crash or partially responsible for a drowsy driving crash summed to 941 crashes, 64 more than the total number of crashes. In some cases, the police report indicated that two drivers were responsible for the crash.

A number of objects along a highway which drivers hit, and which are recorded in the UDOT crash database, are listed in Table 4-29. The first and second most frequently hit objects were dirt embankment and fence, which were struck by 14.8 and 8.4 percent of drowsy drivers, respectively. The objects struck by drowsy drivers were more widespread along U.S. 89 than the Interstate freeways. This is likely due to the type of facility which is U.S. 89. No object was struck in 35.1 percent of the crashes.

Table 4-28. Vehicle Types of Drowsy Drivers on U.S. 89

Vehicle Type of Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Passenger Car/Pickup	832	88.4
Truck/Tractor and Trailer	22	2.3
Passenger Car/Pickup with Trailer	14	1.5
Single Unit Enclosed Box (Min. 2 Axles and 6 Tires)	5	0.5
Motorcycle	2	0.2
Dump Truck	1	0.1
No Vehicle Type Recorded	65	7.0
Total	941	100.0

Table 4-29. Objects Struck by Drowsy Drivers on U.S. 89

Object Struck by Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Dirt Embankment/Ditch/Berm (Mountainside)	139	14.8
Fence	79	8.4
Delineator Post	68	7.2
Utility Pole	68	7.2
Sign Post	48	5.1
Tree/Shrubbery	46	4.9
Guardrail	36	3.8
Curb or Safety Island	29	3.1
Other	23	2.5
Bridge Culvert or Other Highway Structure	19	2.0
Building/Other Structure (Wall)	13	1.4
Rigid Barrier (Concrete)	13	1.4
Mailbox or Fire Hydrant	11	1.2
Guardrail End Section	7	0.7
Snow Embankment	4	0.4
Traffic Channelization Device	4	0.4
Domestic Animal	2	0.2
Crash Attenuator	1	0.1
Wild Animal	1	0.1
No Object Struck	330	35.1
Total	941	100.0

To determine if the distribution of drowsy driving crashes on U.S. 89 was skewed towards Utah residents more than out-of-state visitors, license plate data from police reports were analyzed for the timeframe 1996-2004. This analysis incorporated 681 crashes. Utah residents represented 78.7 percent of drivers responsible for the fatigue-related crashes in this study while 21.3 percent were recorded as out-of-state drivers.

The data in Table 4-30 are provided to determine whether drowsy driving crashes are more severe in nature when compared to all types crashes combined. The first part of the table indicates a percentage for each severity type among solely drowsy driving crashes while the second part gives a percentage for each severity level generated from all crashes on U.S. 89 from 1992-2004. As noted, drowsy driving crashes yielded a greater percentage of fatal crashes when compared to all fatal crashes on this highway. Furthermore, severity levels of persons involved in drowsy driving crashes were worse overall with fewer persons able to escape such crashes with “No Injury.” The top two severity levels, “Fatal” and “Broken Bones or Bleeding Wounds,” accounted for 23.5 percent of all drowsy driving crashes, more than three times that recorded for the same severity levels for all crashes on U.S. 89. The difference in severity between drowsy driving crashes and all crashes is smaller on this highway than the difference in severity on the Interstate freeways.

Table 4-30. Severity of Drowsy Driving Crashes Versus All Crashes on U.S. 89

Severity	Drowsy Driving Crashes	All Crashes
Fatal	2.1	0.5
Broken Bones or Bleeding Wound	21.4	6.6
Bruises and Abrasions	19.7	10.2
Possible Injury	17.7	21.5
No Injury	39.1	61.2
Total	100.0	100.0

4.5.4 Directional Distribution

In similar fashion to I-15, U.S. 89 also traverses an array of topography from a hot desert in the south to rugged mountainous regions in the north parts of Utah. For this reason the trends in directional distribution of drowsy driving crashes were calculated to determine if specific areas of the highway had more drowsy driving crashes in one direction than the other. Of the 877 drowsy driving crashes, 52.0 percent occurred in the northbound direction while the remaining 48.0 percent were in the southbound direction. Figure 4-21 illustrates the directional distribution from M.P. 0 to M.P. 250 while Figure 4-22 shows the same trends from M.P. 250 to M.P. 503.

In Figure 4-21, the overall directional split of drowsy driving crashes is relatively even between northbound and southbound directions with the exception of the area between M.P. 40 and M.P. 55. In Figure 4-22, a large decrease in crashes occurs near M.P. 355. This is one location in which U.S. 89 merges with I-15; therefore, no drowsy driving crashes were reported in this 5-mile segment.

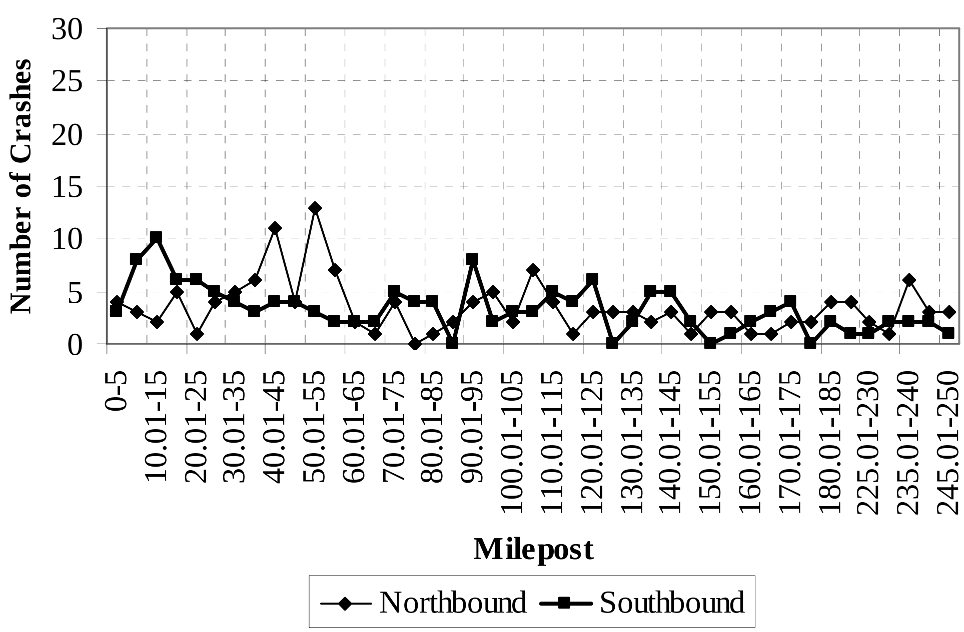

Figure 4-21. Directional distribution of drowsy driving crashes on U.S. 89 from M.P. 0 to M.P. 250.

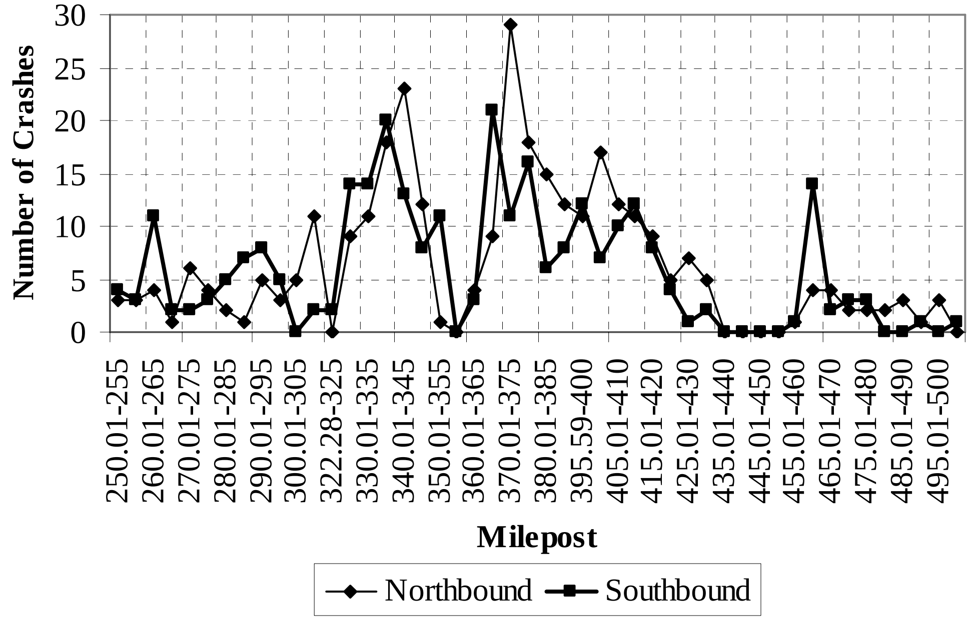

Figure 4-22. Directional distribution of drowsy driving crashes on U.S. 89 from M.P. 250 to M.P. 503.

4.6 United States Route 91

U.S. 91 begins just south of Brigham City, Utah and terminates 15 miles due north of Logan, Utah at the Idaho-Utah border. In total, U.S. 91 only covers 45 miles of highway in Utah. The 3-year crash rate analysis indicated that U.S. 91 has two critical corridors as identified in Table 4-31 and illustrated in Figure 4-23. Both the northbound and southbound corridors coincide with each other between M.P. 20 and M.P. 25.

Table 4-31. U.S. 91 Drowsy Driving Corridors

Area and Direction of Travel	Rural Area	
	Northbound (NB)	**Southbound (SB)**
Critical Crash Rate per Million VMT	0.222	0.100
M.P.	20 - 25	20 - 25

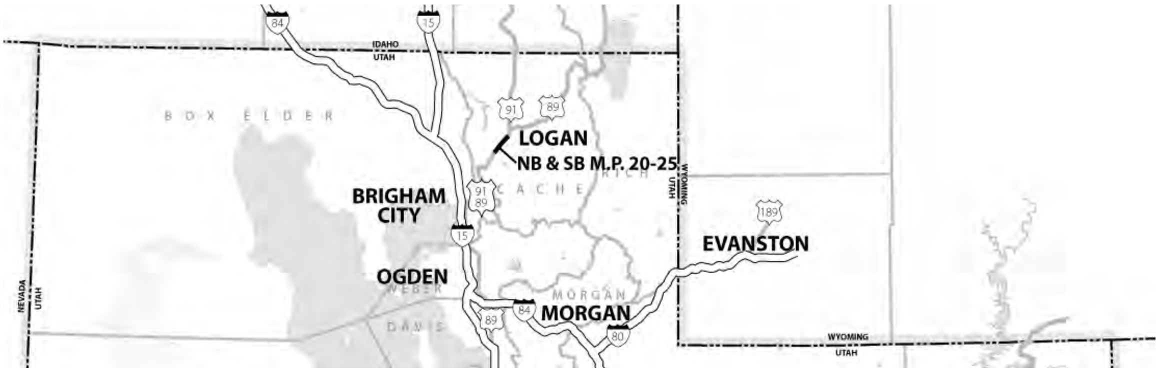

Figure 4-23. U.S. 91 drowsy driving corridors.

The roadway alignment in each critical corridor was analyzed to determine if specific curves in the alignment contributed to fatigue and drowsy driving crashes. One mile intervals were scanned using a "floating segment" one-half mile in length to determine the number of crashes which were reported to have occurred on any given curve. The one critical corridor had two crashes attributed to a curve while the maximum number of crashes on a curve for all of U.S. 91 was six crashes near M.P. 26.

The critical corridor from M.P. 20-25 borders the city of Logan in the Cache Valley. As with all of U.S. 91 south of Logan, this section of roadway is a five-lane highway with a two-way left-turn lane separating the flow of traffic. The critical corridor passes through agricultural fields and appears to have no shifts in alignment which may increase the number of run-off-road crashes. One possible reason why this stretch of highway may be critical is the type of driver. The city of Logan is home to Utah State University (USU), which provides education to more than 23,000 students (USU 2007). As mentioned in the literature, young adults are most likely to be involved in a drowsy driving crash on a high-speed corridor (Stutts et al. 2005; Knipling and Wang 1994). Although the increased number of young adults living in Logan may explain in part why more drowsy driving crashes have occurred from M.P. 20-25, this assumption cannot be validated since age is not one of the driver characteristics included in the UDOT crash database.

Various drowsy driving statistics were calculated for U.S. 91 for the years 1992-2004. During this time period, 179 (66.1 percent) drowsy driving crashes were reported as single-vehicle crashes while 92 crashes (33.9 percent) involved two or more vehicles.

Of the 271 drowsy driving crashes, 5 crashes (1.8 percent) were identified as fatal. U.S. 91 had 59 fatal crashes from 1992-2004; therefore, fatal drowsy driving crashes represented 8.5 percent of all fatal crashes on this facility.

4.6.1 Run-Off-Roadway Crashes and Roadway Alignment

It is evident in Table 4-32 that the majority of fatigued drivers were involved in run-off-road crashes since 64.9 percent of drivers ran off the roadway. Outside of run-off-road crashes, 28.0 percent of crashes involved two vehicles, which may be attributed to the type of facility. As indicated, U.S. 91 mainly consists of a five-lane cross-section with a two-way left-turn lane in the middle. Not having a barrier separating the flow of traffic may explain the higher MV-MV crash results.

Roadway alignment as indicated previously plays an important role in the location of drowsy driving crashes. Table 4-33 identifies how drowsy driving crashes related to roadway alignment for the years 1992-2004. Of the 271 drowsy driving crashes, 206 (76.0 percent) occurred on stretches which were “Straight and Level” while 9.2 percent of the crashes occurred in locations where a curve was present.

Table 4-32. U.S. 91 Drowsy Driving Crash Consequences

Crash Consequence	Number of Crashes	Percent of Total Crashes
Ran Off Roadway-Right	118	43.6
MV-MV	76	28.0
Ran Off Roadway-Left	54	19.9
MV-Fixed Object	15	5.5
Other Non-Collision	4	1.5
Ran Off Roadway-Thru Median	4	1.5
Total	271	100.0

Table 4-33. Drowsy Driving Correlation to Roadway Alignment on U.S. 91

Alignment Type	Number of Crashes	Percent of Total Crashes
Straight and Level	206	76.0
Grade Straight	37	13.7
Curve Grade	12	4.4
Curve Level	12	4.4
Hillcrest Straight	2	0.7
Curve Hillcrest	1	0.4
Dip Straight	1	0.4
Total	271	100.0

4.6.2 Time of Day and Day of Week

The two peaks that are generally characteristic of drowsy driving crashes occur in the morning and in the afternoon. The drowsy driving crashes which occurred on U.S. 91 did not follow the normal morning and evening peak, but rather the crashes were widespread throughout the day. No well defined morning peak is illustrated in Figure 4-24 since a steady number of crashes took place between the hours of 5 a.m. and 11 a.m. The afternoon peak was 20 crashes and occurred twice, during both the 3 p.m. and 4 p.m. hours.

Generally, drowsy driving crashes occur more on weekends than during the week. Figure 4-25 indicates that for the years studied the most drowsy driving crashes on U.S. 91 occurred on Tuesdays in contrast to the other facilities studied where the most crashes occurred on Saturday. Also identified in Figure 4-25 are the number of fatigue-related crashes by day which occurred between the hours of 12 a.m. and 7 a.m. This is included in the figure to visualize the number of crashes occurring during normal sleep-time hours versus those crashes occurring during the day and evening hours. Specifically, 29.9 percent of drowsy driving crashes on this facility occurred between 12 a.m. and 7 a.m. Of all drowsy driving crashes, 16 (5.9 percent) took place during the middle of the night or early morning hours on Monday while 15 (5.5 percent) occurred on Saturday.

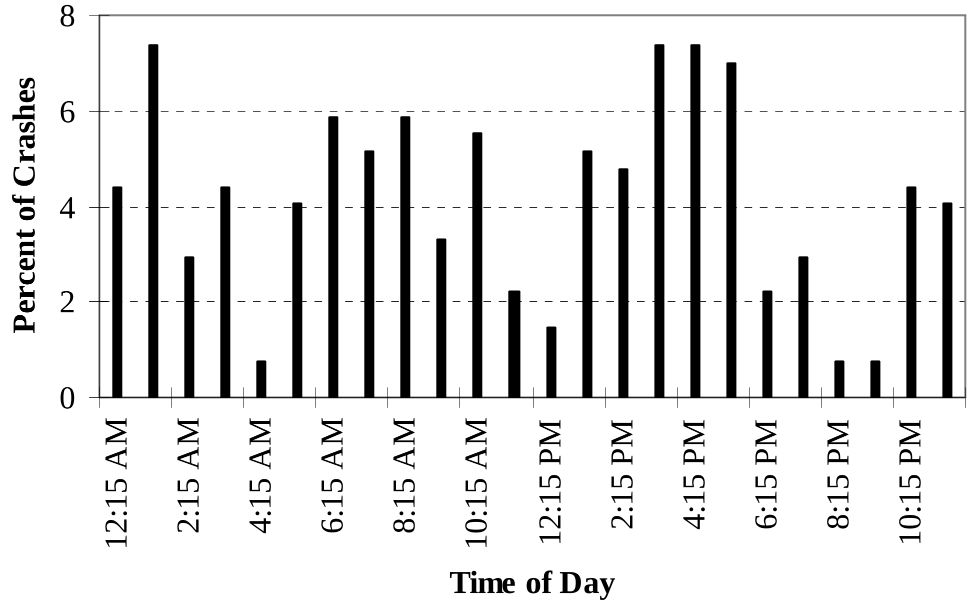

Figure 4-24. Histogram of drowsy driving crashes on U.S. 91.

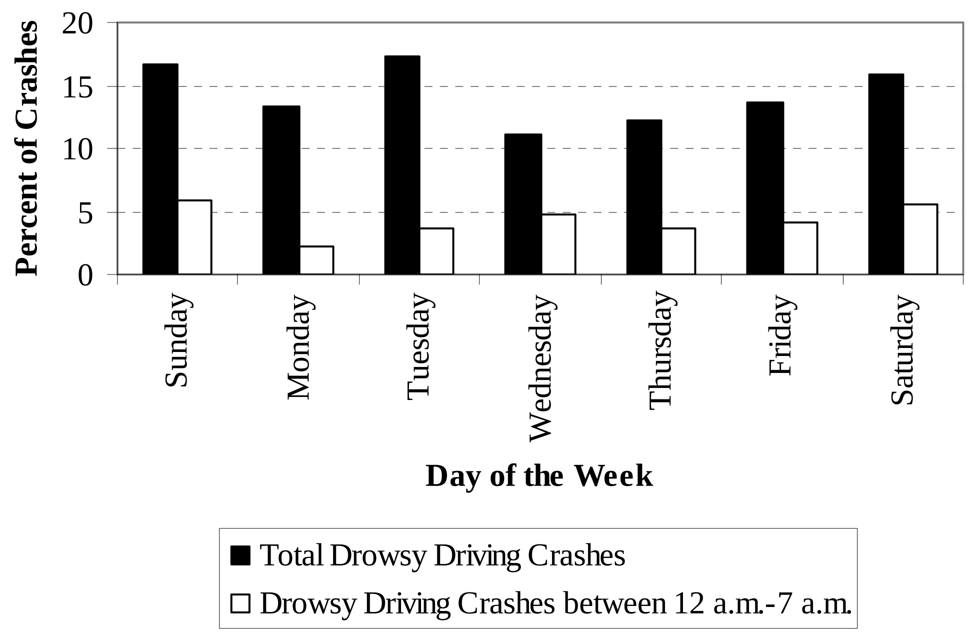

Figure 4-25. Drowsy driving crashes by day of the week on U.S. 91.

4.6.3 Vehicle Type, Object Struck, and Severity

Semi-trucks only represented approximately 0.7 percent of all vehicles involved in drowsy driving crashes on U.S. 91. The most common vehicle type involved in this style of crash was the passenger car as outlined in Table 4-34. The total number of vehicles in which a driver was responsible for a crash or partially responsible for a drowsy driving crash summed to 288 crashes, 16 more than the total number of crashes as some cases the police report indicated that two drivers were responsible for the crash.

Table 4-34. Vehicle Types of Drowsy Drivers on U.S. 91

Vehicle Type of Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Passenger Car/Pickup	253	87.8
Passenger Car/Pickup with Trailer	4	1.4
Single Unit Enclosed Box (Min. 2 Axles and 6 Tires)	3	1.0
Truck/Tractor and Trailer	2	0.7
No Vehicle Type Recorded	26	9.1
Total	288	100.0

A number of objects along a highway which drivers hit, and which are recorded in the UDOT crash database, are listed in Table 4-35. The first and second most frequently hit objects were dirt embankment and fence, which were struck by 14.2 and 11.5 percent of drowsy drivers on U.S. 91, respectively. The objects struck by drowsy drivers were more widespread along U.S. 91 than the Interstate freeways. This is likely linked to the functional classification of U.S. 91. Since this highway traverses through urban areas, it seems reasonable that more utility poles, sign posts, and curbs would be stuck as a result of drowsy driving. In 35.8 percent of the crashes, no object was struck by a vehicle.

Table 4-35. Objects Struck by Drowsy Drivers on U.S. 91

Object Struck by Person(s) Responsible for Crash	Number of Vehicles	Percent of Vehicles
Dirt Embankment/Ditch/Berm (Mountainside)	41	14.2
Fence	33	11.5
Utility Pole	30	10.4
Delineator Post	19	6.6
Sign Post	19	6.6
Other	9	3.1
Tree/Shrubbery	9	3.1
Mailbox or Fire Hydrant	8	2.8
Curb or Safety Island	7	2.4
Snow Embankment	4	1.4
Bridge Culvert or Other Highway Structure	2	0.7
Crash Attenuator	2	0.7
Building/Other Structure (Wall)	1	0.3
Rigid Barrier (Concrete)	1	0.3
No Object Struck	103	35.9
Total	288	100.0

To determine if the distribution of drowsy driving crashes on U.S. 91 was skewed towards Utah residents more than out-of-state visitors, license plate data from police reports were analyzed for the timeframe 1996-2004. This analysis incorporated 206 crashes. Utah residents represented 87.9 percent of drivers responsible for the fatigue-related crashes in this study while 12.1 percent were recorded as out-of-state drivers.

The data in Table 4-36 are provided to determine whether drowsy driving crashes are more severe in nature when compared to all types crashes combined. The first part of the table indicates a percentage for each severity type among drowsy driving crashes while the second part gives a percentage for each severity level generated from all crashes. As noted, drowsy driving crashes yielded a greater percentage of fatal crashes when compared to all fatal crashes on this highway. Furthermore, severity levels of drowsy driving crashes were worse overall. The difference in severity between drowsy driving crashes and all crashes is smaller on this highway than the difference in severity on the Interstate freeways.

Table 4-36. Severity of Drowsy Driving Crashes Versus All Crashes on U.S. 91

Severity	Drowsy Driving Crashes	All Crashes
Fatal	1.8	0.6
Broken Bones or Bleeding Wound	17.0	6.1
Bruises and Abrasions	14.0	8.8
Possible Injury	13.3	16.9
No Injury	53.9	67.6
Total	100.0	100.0

4.6.4 Directional Distribution

The directional distribution of crashes was evaluated and is shown in Figure 4-26. Of the 271 drowsy driving crashes, 71.6 percent occurred heading northbound while the remaining 28.4 percent were in the southbound direction. M.P. 20 to M.P. 25 had the largest difference in the directional distribution of drowsy driving crashes, which was 46.

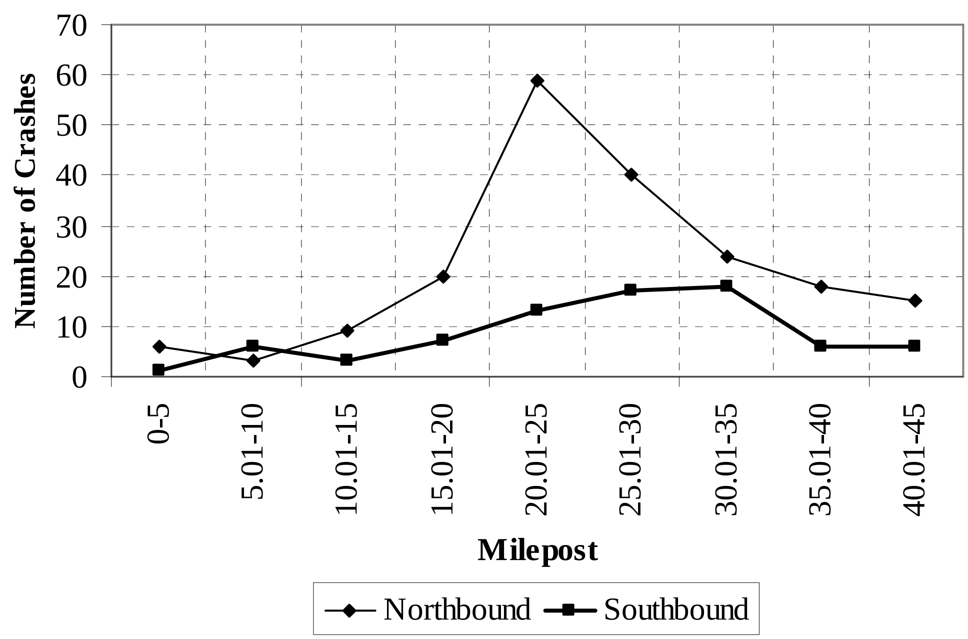

Figure 4-26. Directional distribution of drowsy driving crashes on U.S. 91.

4.7 State Route 36

S.R. 36, which is mostly a rural highway, begins 25 miles northwest of Nephi, Utah and terminates at its junction with I-80 approximately 10 miles north of Tooele, Utah. In total, S.R. 36 only traverses slightly more than 65 miles of Utah. Only two critical corridors were located on S.R. 36. Table 4-37 identifies the M.P. and direction of travel for these corridors while Figure 4-27 illustrates the corridors on a Utah state map.

Table 4-37. S.R. 36 Drowsy Driving Corridors

Area and Direction of Travel	Rural Area	
	Northbound (NB)	**Southbound (SB)**
Critical Crash Rate per Million VMT	1.318	0.225
M.P.	0 - 5	--
	--	25 – 30

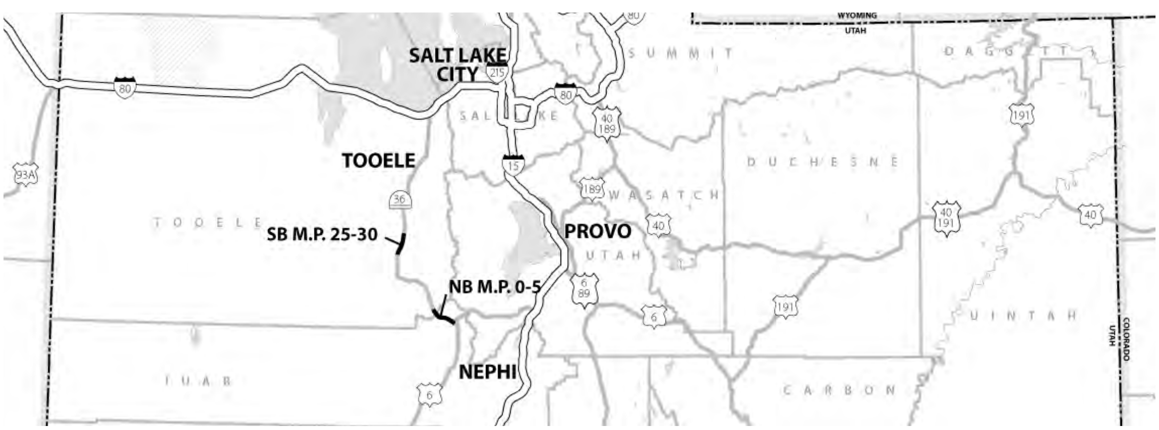

Figure 4-27. S.R. 36 drowsy driving corridors.

The roadway alignment in each critical corridor was analyzed to determine if specific curves in the alignment contributed to fatigue and drowsy driving crashes. One mile intervals were scanned using a “floating segment” one-half mile in length to determine the number of crashes which were reported to have occurred on any given curve. Only one drowsy driving crash occurred between M.P. 0 and M.P. 5 on a curve while none took place on a curve from M.P. 25-30. For comparison purposes, only five crashes on a curve for all of S.R. 36 occurred from 1992-2004.

The critical crash rates for both northbound and southbound directions are drastically different as indicated in Table 4-37. The crash rate calculated for northbound M.P. 0-5 was 2.10. This high crash rate can likely be attributed to the extremely low AADT since only two drowsy driving crashes occurred in this 5-mile segment regardless of roadway alignment over the three years of data studied. The AADT in the area is approximately 350 vehicles per day throughout the year. The southbound corridor consisting of M.P. 25-30 was determined critical, but only included one drowsy driving crash in three years. Again this is partly due to a low AADT, but also due to very few drowsy driving crashes in the other rural sectors of the highway thus affecting the critical crash rate as calculated in Equation 3-3 in Section 3.2.2.2.

Many drowsy driving crashes occurred on S.R. 36 over the years, but these crashes were concentrated on the highway between Tooele (M.P. 51) and the junction of S.R. 36 with I-80 (M.P. 66). It is believed that many of the crashes on this 15-mile stretch were caused by commuters who live in the area near Tooele and commute to Salt Lake City everyday. This is based on the fact that of the 66 drowsy driving crashes between M.P. 51 and M.P. 66, 51 crashes (77 percent) were in the southbound direction, the direction that commuters would have been traveling at the end of the workday. The peak hour of drowsy driving crashes in this 15-mile corridor was between 4 p.m. and 5 p.m. with approximately 14 percent of the drowsy driving crashes in the southbound direction occurring in this one hour. Although this section of highway did have a large number of drowsy driving crashes, it was not deemed critical. This is likely attributed to the high AADT in this 15-mile stretch of S.R. 36.

Various drowsy driving statistics were calculated for S.R. 36 for the years 1992-2004. During this time period, 73 (80.2 percent) drowsy driving crashes were reported as single-vehicle crashes while 18 crashes (19.8 percent) involved two or more vehicles. Of the 91 drowsy driving crashes, 2 crashes (2.2 percent) were identified as fatal. S.R. 36 had 29 fatal crashes from 1992-2004; therefore, fatal drowsy driving crashes represented 6.9 percent of all fatal crashes on this facility.

4.7.1 Run-Off-Roadway Crashes and Roadway Alignment

Table 4-38 indicates that the majority of fatigued drivers were involved in run-off-road crashes. Besides the run-off-road crashes, 16.5 percent of crashes involved two vehicles. This may be attributed to the fact that S.R. 36 is proportionately a two-lane two-way rural road with a low AADT volume, which may explain the why no “Ran Off Road-Thru Median” crashes were reported.

Table 4-38. S.R. 36 Drowsy Driving Crash Consequences

Crash Consequence	Number of Crashes	Percent of Total Crashes
Ran Off Roadway-Right	48	52.7
Ran Off Roadway-Left	23	25.3
MV-MV	15	16.5
MV-Fixed Object	3	3.3
MV-Animal (Wild)	1	1.1
Other Non-Collision	1	1.1
Total	91	100.0

Table 4-39. Drowsy Driving Correlation to Roadway Alignment on S.R. 36

Alignment Type	Number of Crashes	Percent of Total Crashes
Straight and Level	67	73.6
Grade Straight	10	11.0
Curve Level	9	9.9
Curve Grade	4	4.4
Hillcrest Straight	1	1.1
Total	91	100.0

Roadway alignment as indicated previously has a critical role in the location of drowsy driving crashes. Table 4-39 identifies how drowsy driving crashes related to roadway alignment for the years 1992-2004. S.R. 36 begins with a curvilinear alignment for 19 miles before becoming relatively straight for the remaining 47 miles of highway. This may be the reason why only 13 crashes (14.3 percent) occurred where a curve was present. Of the 91 crashes identified in Table 4-39, 67 (73.6 percent) crashes occurred on stretches which were “Straight and Level.”

4.7.2 Time of Day and Day of Week

Generally drowsy driving crashes exhibit two peak hours in a 24 hour period—one in the morning and one in the afternoon. As with U.S. 91, the drowsy driving crashes which occurred on S.R. 36 did not follow this trend, but rather the crashes were widespread throughout the day. No morning peak is illustrated in Figure 4-28 as a relatively constant number of crashes took place throughout the morning hours. The afternoon peak is easily discernable in Figure 4-28 as it occurred during the 4 p.m. hour reaching a maximum of 14 crashes.

Drowsy driving crashes more frequently occur on weekends than during the week, but the crash data for S.R. 36 indicates that this typical trend was not followed. Figure 4-29 indicates that for the years studied the largest number of drowsy driving crashes occurred on Saturday. Of all drowsy driving crashes, 17 (18.7 percent) occurred on Saturday followed by Tuesday with 16 crashes (17.6 percent). On S.R. 36 the day in which the least number of drowsy driving crashes occurred was Thursday with 7 crashes (7.7 percent). Also identified in Figure 4-29 are the number of fatigue-related crashes by day which occurred between the hours of 12 a.m. and 7 a.m. Of drowsy driving crashes on this facility, 25.3 percent occurred between the hours of 12 a.m. and 7 a.m. For drowsy driving crashes that occurred between the hours of 12 a.m. and 7 a.m., 6 (6.6 percent) took place during the middle of the night or early morning hours on Saturday while 5 crashes (5.5 percent) occurred on Sunday morning. No drowsy driving crashes were reported to have occurred on any Wednesday morning during the years studied.