AN EVALUATION OF THE EFFECTIVENESS OF WILDLIFE CROSSINGS ON MULE DEER AND OTHER WILDLIFE

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil and Environmental Engineering

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ABSTRACT

Highways retrofitted with overpasses and underpasses for wildlife use have been implemented in the United States and the world. The observed level of mortalities of mule deer and other wildlife species on U.S. highways appears to have negative consequences on wildlife population. Studies in other states indicate that more than 50% of the deer-vehicle collisions nationwide are not reported and there are no records for deer-vehicle collisions that occurred in remote areas although records for collisions within or near urban areas may be reported. The primary objective of this study is to evaluate the effectiveness of wildlife overpasses, using a case in the State of Nevada. The 4.1-mile study section is along the U.S. 93 Highway in Elko, NV, with 3 miles of fencing on both sides of the highway. This thesis focuses on evaluating the level of effectiveness of the overpass in reducing deer-vehicle collisions. An Empirical Bayes approach was applied to compare the ‘before’ and ‘after’ crash changes. A benefit-cost analysis of the wildlife overpass is also included to identify its effectiveness considering factors like number of mortalities, deer-vehicle collisions threats to human injuries or fatalities, and the construction costs.

DEDICATION

This study is dedicated to my family especially my loving mum, Florence Attah, who provided me unconditional love and support throughout my pursuit of this dream.
ACKNOWLEDGEMENTS

This thesis would not have been completed without the support of many people.

I would like to thank first and foremost Dr. Zong Tian, not only for steering me into this program and fascinating topic but for his continuous effort and guidance throughout the research. Special thanks go to NDOT for funding this research and providing data requirements for analysis of the research. I would like to thank my mum, and my friends whose constant encouragement, support, and love have played an important role throughout this academic period.
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CHAPTER 1

INTRODUCTION

The observed high mortalities of mule deer along a stretch of U.S. 93 Highway in Elko County shown in Figure 1 have led to the construction of several overpasses and underpasses to mitigate the animal deaths. The wildlife overpass under study was built and opened for use in August 2010 with a 3.1 mile by 96-inch chain-link fencing. The U.S. 93 Highway is a north to south route extending from the Canadian Border in Montana to Wickenburg, Arizona, a total distance of 1457 miles (1). In Nevada, it passes through the wide and open valleys of the Great Basin region and in northern Nevada, runs from Jackpot to Wells, near the Idaho border to I-15. This roadway facility has a posted speed limit between 55 mph and 65 mph with an average AADT of about 5500 within the city limit of Wells, NV. Data for animal-vehicle collisions has been collected by Nevada Department of Transportation (NDOT) and Nevada Department of Wildlife (NDOW) along a 20-mile stretch of U.S. 93 Highway between Wells and Contact, has documented 75 - 150 known deer killed annually with an estimated total of 300 deer killed per year (2). These data indicate that this portion of U.S. 93 Highway is a ‘hotspot’ for deer-vehicle collisions particularly during spring and autumn migration seasons, when deer are forced to cross U.S. 93 Highway to reach seasonal feeding ranges. A study conducted by NDOW indicated only 29% (8 of 28) of the deer kills were reported. Although the sample was not large, this reporting rate is similar to a source from Utah, an adjacent state, indicating that only 15% to 20% of deer-vehicle collisions were reported (4). In a recent five-year span, there were over 2,000 reported animal-vehicle collisions in Nevada,
including nearly 1,500 collisions involving deer. Research estimates that more than 50 percent of such collisions go unreported to authorities, pointing to a potential higher number of animal related incidents (5).

This study corridor begins at mile post EL (Elko) 81.6 and ends at EL 85.7 (4.1 miles) and is approximately 10 miles north of Wells. The study corridor which houses the wildlife overpass with fencing would be considered for analysis.

Figure 1-1 Deer Migration Routes across U.S. 93 Highway (3)
(The black dots represent the mile posts along U.S. 93 Highway and the colors represent animal movements of GPS collars showing deer locations to track deer movements)
1.1 Background

Every year in the United States approximately 1.5 million deer-vehicle collisions occur resulting in more than 29,000 human injuries, 200 human fatalities, 1.3 million deer fatalities, and over 1 billion dollars’ worth of property damage. Deer–vehicle collisions are increasing in the United States and worldwide as traffic volume increases, more roads are constructed, and deer habitat becomes more fragmented (4). Across the nation, traffic crashes involving wildlife cause an estimated $5 to $8 billion in damage each year. In 1980, Williamson reported that about 200,000 deer was killed on U.S. roadways in deer vehicle collisions. In 1991, more than 538,000 deer were estimated to have been killed by vehicles in the U.S. (5). This estimate was considered conservative since numerous hits were not recorded and the estimate only included 36 states (6). Despite the magnitude of this problem, there are relatively few studies that assess the effectiveness of measures to reduce deer vehicle collisions. In 2002; the Nevada Department of Transportation (NDOT) reported 698 collisions between large ungulates (antelopes, bear, burros, cows, elk, deer and horses) and motor vehicles throughout the state (Error! Bookmark not defined.). Collisions related to mule deer alone were about 25% whereas the percentage regarding cows was 60%. Horses were involved in 6% of the collisions and all other animals combined were involved in the remaining 9% (2). These percentages indicate that collisions with cows and horses cause more severe damage than with deer. Along a stretch of U.S. 93 Highway in Elko County, the observed mortalities of mule deer appear to have negative impact on their population. Deer-vehicle collisions have resulted in high number of human injuries, damage to property and increased mortality of mule deer. To
mitigate these impacts, several overpasses and underpasses have been constructed along this stretch of the road. The project was completed in September 2010 and involved about $155,000 funded by the NDOT. Furthermore, the Nevada Department of Wildlife (NDOW) data indicated that only 29% of deer-vehicle collisions were reported to authorities on a rural section of the I-80.

1.2 Objectives and Scope

The main goal of this thesis is to evaluate the effectiveness of wildlife crossings in reducing animal-vehicle collisions. The specific objectives and scope of this research are the following:

1. Perform a thorough review of the literature related to the evaluation and effectiveness of wildlife crossing in reducing animal-vehicle collisions and mitigation measures applied.

2. Evaluate the level of effectiveness of the U.S. 93 Highway overpass in reducing deer-vehicle collisions by conducting:
   a) A Before-After study on traffic crash reductions
   b) A Benefit-Cost analysis considering factors such as construction costs, savings from reduced crashes and animal mortalities.
1.3 Thesis Organization

This thesis comprises of six chapters. The organization of the chapters is as shown below:

Chapter 1 consists of the introduction, scope and statement of objectives of this study.

Chapter 2 leads the reader through a literature review related to the evaluation of the effectiveness of wildlife crossings and several mitigation measures that can be applied.

Chapter 3 introduces a general overview of the methodologies that will be applied in this study, which involves an evaluation of the effectiveness of wildlife overpasses in reducing deer-vehicle collisions (DVCs) using the U.S. 93 Highway Wildlife overpass as a case study. Chapter 4 deals a benefit-cost study to determine the economic justifiability of implementing a wildlife crossing whiles Chapter 5 includes an analysis of DVCs and carcass removal data to identify the discrepancies that exists between the two datasets.

Chapter 6 presents the summary, conclusions and recommendations for further studies.
CHAPTER 2

LITERATURE REVIEW

This chapter focuses on the literature related to evaluation of wildlife crossings, its effectiveness in reducing animal-vehicle collisions and several mitigation methods applied. Overpasses and underpasses have been used in different parts of the United States as well as countries all over the world. There are several studies that focus not only on deer behavioral use of these crossings, but the ideal dimensions to be used employed when being implemented.

2.1 Overpasses and Underpasses

Overpasses and underpasses are common methods that allow deer to safely cross over a highway’s right of way while reducing deer vehicle collisions. Deer migrating in Florida and Colorado were found to be using underpasses during their travel and also during early mornings but about 75% of the mule deer appeared reluctant and frightened to use the underpasses (7). Deer behavior towards underpasses was studied for a period of 10 years and no significant change was seen which indicated that mule deer did not habituate to the small, fully enclosed underpass that was evaluated (7). In a similar manner, Gibby reported that migrating mule-deer eventually used underpasses during migrations to Colorado (Error! Bookmark not defined.). Ward however concluded that deer could learn to use underpasses over a period of time (11).
2.1.1 Deer Behavioral Use of Underpasses and Overpasses

The willingness of deer to use an overpass depends on the structure’s height, length and width. \((8)\). Nonetheless, Clevenger \((9)\) states categorically that the above mentioned parameters are just a few of the several parameters which includes: location in the landscape, distance between the structures, habitat surrounding the structures, dimensions, human use in the area, species-specific preferences and time from installation since animals have a learning curve for using the structure. Location is one of the most critical factors that impact the use of a wildlife crossing and may be chosen based on expert judgment, deer mortality locations, deer migratory patterns and habitat \((10)\). Other location related data includes species densities, number of vehicles travelling on the roadway and vegetation \((10)\). Naturally, deer avoid confining spaces where a means of escape does not appear to be clear \((10)\). However, underpasses have been found to be effective tools in reducing highway mortality in a number of studies \((11)\).

2.1.2 Ideal Underpass/ Overpass Sizes

The openness of underpasses has been found to be important in determining whether wildlife, particularly deer, will be willing to use them \((12)\). Gibby \((Error! Bookmark not defined.)\) found that mule deer \((Odocoileus hemionus)\) exhibited more behavioral indicators of hesitancy in response to smaller underpasses than larger, bridge type underpasses. Gibby \((Error! Bookmark not defined.)\) however recommends that in planning the construction of underpasses for mule deer, openness factor of at least 2.0 be used \((7)\) when using the following equation:

\[
OF = \frac{(H)(W)}{L}
\]
H- height of opening, W-width of opening, L-length of opening OF- Openness Factor.

Conversely, Foster and Humphrey (19) suggested that in considering underpass openness, width may be more important than height, and recommend that underpasses be designed with a view of the habitat and horizon on the opposite side. Clevenger and Waltho (12) likewise found that width and openness were correlated with deer underpass use and that height was not. It was also found that the use of a crossing often increases with the age of the structure. For instance, Reed et al (Error! Bookmark not defined.) concluded on a data describing the use of an underpass in Colorado that mule deer adapted to the underpass sometime between the second and the third year of migration. In addition to this, several studies showed that deer prefer wildlife crossings with a floor (underpass and overpass) covered with soil and natural vegetation. This vegetation may attract and help calm an approaching deer, and may also help direct deer to a crossing along with fencing.

### 2.2 History and Some Examples of Wildlife Crossings

Various crossing structures have been used by European countries such as Netherlands, Switzerland, Germany and France to reduce wildlife-vehicle collisions for several decades (13). Those crossings are in the form of overpasses and underpasses. Wildlife crossings later became very increasingly common in Canada and the United States: with the most recognizable wildlife overpass found in Banff National Park in Alberta, Canada. This overpass has vegetation cover which provides safe passage over the Trans-Canada Highway for deer, bears, moose, wolves, elk and many other species (14). Areas with some examples of wildlife crossings include: overpass/underpass in Banff National Park, Canada, underpass in Black Forest, Australia, underpass in Southern California, USA,
underpass in Collier and Lee Counties in Florida, USA and underpass in Northern Nevada near Hallelujah Junction.

2.2.1 Overpass/Underpass in Banff National Park, Canada

Banff National Park is one of the first locations in Canada to take the lead in an attempt to reduce deer vehicle collisions along the Trans-Canada Highway. The construction began in the mid-1980s with the twinning of the highway from the east park entrance to the junction with Bow Valley Parkway. A series of 11 wildlife underpasses were constructed in conjunction with a 2.4m fence along each side of the highway. This was later accompanied by 11 additional wildlife underpasses and two wildlife overpasses in 1997 beginning from where the original stretch ended. Each overpass cost about 1.851 million dollars and consisted of 9 culverts and 2 creek bridges (15). In 1996, researchers began to determine its effectiveness and the results showed that the overpasses were very effective for elk, deer and coyotes (15). Wildlife overpass and underpass in Canada has a natural vegetation cover that helps direct deer to a crossing along with fencing (Figure 2-1). However, large carnivores were reluctant to use them and that led to the building of 2 additional overpasses.

Figure 2-1: Overpass/Underpass- Banff National Park (14)
2.2.2 Underpass in Black Forest, Australia

A similar underpass was constructed by the Victorian Government in Australia at a cost of $3 million and its effectiveness in reducing wildlife mortality was monitored for a period of 12 months in order to determine the abundance and diversity of species using the underpass (16). During the 12 month period, 79 species of wildlife were detected in the underpass, compared with 116 species detected in the surrounding forest. This result demonstrated that underpasses could be useful not only to deer alone but to a wide array of species.

2.2.3 Underpass in Southern California, USA

Wildlife underpasses have also been of much importance for protecting wildlife in several areas in Southern California. Biologists have erected fences along Route 58 in the San Bernardino County to compliment underpasses. Studies by Haas (17) reported that underpasses in Orange, Riverside and Los Angeles counties have drawn significant use from various kinds of species including mule deer, coyotes and gray fox.

2.2.4 Collier and Lee Counties, Florida, USA

Twenty-four wildlife crossings (highway underpass) and 12 bridges that have been modified for wildlife have been constructed along a 40-mile stretch of I-75 in Collier and Lee Counties in Florida (18). The underpasses on I-75 appeared to benefit bobcats, deer, and raccoons and significantly reduced wildlife-vehicle collisions along the interstate (19). However, those crossings were designed to protect the endangered Florida panther which was found to be highly vulnerable to wildlife-vehicle collisions (18). The Florida Fish and Wildlife Commission used several mitigation measures to protect Florida
panther but the combination of wildlife crossings and fences proved to be the most effective (18).

2.3 Deer Vehicle Collisions in Nevada

In 2002, the State of Nevada reported crash records of 698 collisions between large ungulates (antelopes, bear, burros, cows, elk, deer and horses) and motor vehicles at the Nevada Department of Transportation (Error! Bookmark not defined.). Collisions related to mule deer alone were about 25% whereas the percentage regarding cows was 60%. Horses were involved in 6% of the collisions and all other animals combined were involved in the balance of 9 % (2). These percentages indicate that collisions with cows and horses cause more severe damage than with deer. Furthermore, Nevada Department of Wildlife (NDOW) data indicated that only 29% of deer-vehicle collisions were reported to authorities on a rural section of the I-80.

A literature review concerning deer vehicle collisions in Nevada focused on one effective countermeasure, being the wildlife grade separation (Error! Bookmark not defined.). Furthermore, the group also elaborated on other six countermeasures which includes; wildlife grade separation with exclusionary fencing and vegetation, deer crossing warning signs activated during migration, deer crossing warning signs activated by presence of deer, at-grade crossings with exclusionary fencing and warning signs, roadside reflectors and roadway lighting (Error! Bookmark not defined.). However, the following countermeasures were recommended for evaluation: an overpass structure with exclusionary fencing and vegetation at a high collision location on U.S. 93 Highway, installation of an at-grade deer crosswalk with exclusionary fencing and escape gateways,
deer-warning signs with flashers, sensors to detect animals and painted cattle guards at a high collision location on U.S. 93 Highway and installation and of high-level luminaries on I-80 in the U.S.

2.3.1 Collision Data

The collision data regarding deer vehicle collisions in Nevada was U.S. 93 Highway, between Wells and Jackpot included the reported deer kills and collisions whereas I-80 in the vicinity of Pequob Summit only included collisions (Error! Bookmark not defined.). The method of field data collection was such that the number of collisions is the only reported collisions. These underestimate the magnitude of the problem since many collisions remained unreported. The data was collected for a period of 4 years starting from 2000 to 2004 at milepost 76 (North of Wells) and ended at milepost 140 (near Nevada-Idaho border). Table 2-1 shows the reported number of deer killed (388) in 290 deer-vehicle collisions over a 65-mile section of U.S. 93 Highway (Error! Bookmark not defined.). This clearly shows that the greatest number of collisions occurs during October through April.

Table 2-1: Deer Collisions by Month on U.S. 93 Highway in Wells, NV from 2000-2004 (2)

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<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
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<th>Nov</th>
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<td>39</td>
<td>50</td>
<td>6</td>
<td>3</td>
<td>11</td>
<td>6</td>
<td>5</td>
<td>106</td>
<td>49</td>
<td>25</td>
<td>388</td>
</tr>
</tbody>
</table>
Figure 2-2 is a graphical representation of deer collisions by month on U.S. 93 Highway in Wells, NV from 2000-2004 with the highest number of collisions and mortalities occurring in October.

![Figure 2-2: Deer Collisions by Month on U.S. 93 Highway in Wells, NV from 2000-2004](image)

2.4 Review of Mitigation Measures

2.4.1 The Use of Fencing as a Mitigation Measure

Clevenger et al. (14) conducted a research on the effectiveness of highway mitigation fencing. Their purpose was to assess the effectiveness of highway mitigation fencing at reducing wildlife vehicle collisions. The group’s hypothesis was that wildlife vehicle collisions were distributed randomly along fenced sections of the highway. However, after conducting the research, their hypothesis was flawed when values of wildlife vehicle collisions recorded in their study area were not distributed randomly, but occurred in specific areas along the highway (this was associated with and close to fence ends). This group argued that the number of wildlife vehicle collisions declined after
mitigation fencing was implemented despite annual increases in traffic volumes. They however included that there were significantly more wildlife vehicle collisions in the two year pre-fencing compared to the two year post-fencing. On the other hand, Romin and Bissounette (5) argued that fencing alone isn’t enough to mitigate wildlife vehicle collisions, but would be much more effective if used in conjunction with wildlife overpasses and or underpasses. Figure 2-3 shows the use of fencing in combination with an underpass.

Figure 2-3: Use of Fencing in Combination with Underpass

2.4.2 Crosswalks in Combination with Fencing as a Mitigation Measure

In a similar manner, Lehnert and Bissounette (6) examined the effectiveness of deer crosswalks in conjunction with 2.3m high fencing to reduce deer vehicle collisions. In this design, crossing areas were delineated with white paint, and signs alerted motorist of crossing. In their study, although crosswalks in conjunction with fencing decreased deer vehicle collisions as much as 42%, further evaluation by Bissounette (5) showed that crosswalks do not work on high volume roads but may work on low-volume roads when
combined with animal-activated signs. Figure 2-4 shows a diagram depicting the use of a crosswalk in combination with fencing. Nevertheless, after conducting a research on a 7-mile long, 8 foot high deer-proof fence, which was used in conjunction with installed migratory deer signs, Reeve (Error! Bookmark not defined.) observed that deer mortality still remained high.

![Figure 2-4: Crosswalk in Combination with Fencing](image)

**2.4.3 Use of Reflectors**

Deer mirrors and reflectors are intended to visually repel wildlife from the roadway as shown in Figure 2-5. Unlike fencing, reflectors, in theory, provide a “barrier” only when vehicles are present, (20). These reflectors direct vehicle headlights off the roadway into the surrounding right-of-way. Colored reflectors beam light from headlights into roadside habitat or onto the roadway itself. However, most studies that tested reflectors found no effect on wildlife-vehicle collisions. Swareflex® reflectors are the commonly used reflectors and are based on the assumption that deer can distinguish red as a color, but there is very little evidence supporting this claim. An underlying assumption of Swareflex reflectors is that deer are attentive to the reflected red light as vehicles approach and remain motionless (21). However, Zacks (22) found no evidence that red-
light deterred deer from moving toward the light. He also concluded that there was no evidence of deer being frightened by red light reflected from Swareflex reflectors.

Figure 2-5 Reflectors for Wildlife Warning

2.4.4 Road Signs
These are signs that warn motorists of high deer-crossing probabilities in order to reduce deer vehicle collisions. Romin and Bissounette (5) suggested that deer crossing signs may be effective if drivers would reduce their vehicle speed. There are basically four categories of signs that alert motorists of the presence of deer. These include: caution signs, temporary signs, dynamic-message signs and animal-activated warning systems.

2.4.4.1 Caution Signs
These include simple caution signs (most frequently used) and the enhanced caution signs. Many studies have noted, however, that the latter are so prevalent along road that motorists ignore them (4). No studies to date however, have examined the direct effect of caution signs on the number of deer vehicle collisions. The main reason for using these ineffective warning signs is likely to avoid potential legal problems. Some variations were made to these countermeasures which include the addition of flashing lights and/or
flags and animated deer figures. These modifications only reduced vehicle speeds but were not effective in reducing deer-vehicle collisions.

2.4.4.2 Temporary Signs

These are signs erected during a short period in the fall and the spring when mule deer migration begins. They usually include signs with flashers that were activated during migration. These were found to decrease the percentage of speeding vehicles from 19% to 8% and decreased deer vehicle collisions by an estimated 50% (23). In general, this countermeasure was found to be effective in reducing deer-vehicle collisions.

2.4.4.3 Dynamic Message Signs

These are either positioned on portable trailers beside the roadway or mounted permanently above the roadway. One study evaluated the use of lighted, animated deer crossing signs and found out that it reduced vehicle speed by 3mph (24). Pojar et al. (Error! Bookmark not defined.) concluded that motorist observed the animated signs, but the reduction in speed was insignificant enough to affect the reduction in deer vehicle collisions.

2.4.4.4 Animal Activated Warning Systems

These are systems that use sensors to detect animals near the roadway at designated deer crossing sites. These sensors activate deer crossing signs to warn motorists of probable wildlife on or near the highway. Europe and North America were a few of the places to take the lead in animal detection system installation. In addition to this, two of these systems have been installed in Wyoming and Pennsylvania and are being thoroughly evaluated.
2.4.5 Repellants

In Europe, chemical repellants and noise deterrents have been used to reduce deer-vehicle crash rates. Another strategy used in Germany was the chemical fences to reduce deer-vehicle collisions. Chemicals in the form of chemical repellant compounds are sprayed on fences along roadways to deter deer and other wildlife species. These chemicals break down during daylight to release the compound. However, these have not been adequately tested (20). Noise deterrents are deer whistles attached to a vehicle that make noise when vehicle speeds reach 45km/hr or more to frighten deer away from the roadway. Studies have found that deer hearing is most sensitive in the range of 2-6 kHz (25) or 4-8 kHz (26). Whistles tested however, emitted both inside (3 kHz) and outside (12 kHz) these hearing ranges. D’Angelo et al calculated that a whistle would need to emit 100dB sound pressure level at 1m to be heard 100m from a vehicle under normal conditions. However, whether this distance would prevent a deer from being hit is unknown. This conclusion was corroborated by Romin and Dalton who found that the reactions of deer to vehicles equipped with whistles and to those without them were similar. Despite this observation, deer whistles continued to be used nationwide (5).

2.4.6 Speed Limit Reduction

Romin and Bissounette (5) suggested that lowering the speed limits may reduce deer vehicle collisions if strongly enforced. Bashore et al. (27) after conducting a series of studies and tests found that there was a correlation between average vehicle speed and the number of deer vehicle collisions. Conversely, no studies have actually tested whether
decreasing the speed limit on a highway actually decreased the frequency of deer vehicle collisions.

2.4.7 In-Vehicle Detection System

These are new technologies that use infrared or night vision devices to enhance motorists’ abilities to detect wildlife on the road. This system uses thermal imaging to detect and then display images of the road ahead, thus enabling a driver to see 3 to 5 times farther than they could with typical low-beam headlamps (28). This system has its merits but needs additional innovative work to detect and identify deer and other large ungulates. However, if this technology can be developed to provide effective warning of ungulates, it may prove to be one of the less expensive countermeasures for the state’s Department of Transportation since the cost of the device would be taken care of by the driver. This technique is believed to reduce deer vehicle collisions by intuition; however, its ability to decrease deer vehicle collisions has not been tested.

2.5 Management Techniques

2.5.1 Salt Alternatives

During the winter seasons, salt is used to keep the road clear of snow in many states. However, this road salt attracts deer to a highway’s right of way to satisfy their need for salt. Fraser et al. speculated that increased traffic volumes may have been responsible for the increased deer vehicle collisions (29). In spite of this, Feldhamer et al. (30) suggested that deicers without salt could be used in areas of high deer vehicle collisions to reduce the attractiveness of the right of way. As a result of this, most biologists recommended the use of salts such as CaMg-acetate instead of NACl (31). Conversely, large animals
use the plowed roads in states where there is snow. This is because it is less energetic to move on plowed roads than deep snow. However, no studies have documented reductions in deer vehicle collisions in the use of road salt, the use of salt alternatives, or the placement of salt licks away from the road in their effectiveness in reducing the number of deer vehicle collisions.

2.5.2 Obstructive Vegetation

Vegetation that grows along the highway sometimes obstructs the right of way (ROW) and increases motorists’ inability to see deer standing along the road. However, clearing this vegetation also raises issues such as aesthetics, maintenance, costs and ecological impacts (32). Providing deer with areas other than the ROW to forage has also been shown to reduce deer-vehicle collisions. The attractiveness of ROW to deer can also be reduced by planting unpalatable plant species along the ROW. Wood and Wolf (33) concluded that intercept feeding (providing deer food sources between bedding areas and highway ROWs) may have reduced deer-vehicle collisions by 50% in Utah. However, intercept feeding is not recommended for long term deer-vehicle collisions reduction.

2.5.3 Hunting or Relocation

Several studies reported that the implementation of hunting or deer-relocation programs reduced the number of deer vehicle collisions (34). In a similar manner, hunting restrictions have been correlated with increased number of deer vehicle collisions (35). In spite of this, reducing the number of deer may be effective in reducing the number of deer vehicle collisions in a localized area. However, Waring et al. (36) found that deer
vehicle collisions did not decline on their study area even though the deer population decreased.

2.6 Non-Intervention Systems

2.6.1 Public Education

The main aim of this measure is to reduce death and serious injury as a result of deer vehicle collisions by increasing motorist awareness of the causes of wildlife vehicle collisions, high risk locations, and preventive measures. The media generally used to disseminate such information includes: radio, television, brochures, posters, bumper stickers and general messages on the website. The effectiveness of this is unknown. However, Knapp et al. (37) suggest that campaigns providing specific information (e.g. mule deer migration times and locations) are more likely to be effective than those that provide general education.

2.6.2 Lighting

It was studied that most (80% to 95%) deer vehicle collisions occur between sunset and sunrise (21) hence, street lights may enhance motorists’ ability to see a deer in sufficient time to avoid it. Conversely, Reed and Woodard (Error! Bookmark not defined.) found that lighting had no effect on deer vehicle collisions. However, highway lighting did not affect motorist behavior or deer crossings-per-crash ratios (38). Also, highway lighting did not affect the location of deer crossings or their behavior. After a series of research and findings, Reed concluded that increased highway lighting was not effective at reducing deer-vehicle collisions.
2.7 STUDY AREA

The 4.1 mile study segment which starts from MP EL 81.6 to EL 85.7 at the 10 mile Summit Site, is located in Wells, NV along the U.S. 93 Highway in Elko County. The U.S. 93 Highway runs north to south from Wickenburg, Arizona to the Canadian Border in Montana, a total distance of 1457 miles (39). In Nevada, its route passes through the wide, open valleys of the Great Basin region and runs from Lages Junction to Wells, Nevada. This roadway facility has a posted speed limit between 55 mph and 65 mph with an AADT of about 11,600 within Wickenburg City limit. Data on animal-vehicle collisions collected by Nevada Department of Transportation (NDOT) and Nevada Department of Wildlife (NDOW) along a 20-mile stretch of U.S. Hwy 93 between Wells and Contact, Nevada has documented 75 - 150 known deer killed annually with an estimated total of approximately 300 deer killed per year (40). Those data indicate that this portion of U.S. 93 Highway is a ‘hotspot’ for deer-vehicle collisions particularly during spring and autumn migration, when deer are forced to cross U.S. 93 Highway to reach seasonal ranges.
CHAPTER 3

BEFORE-AFTER STUDY METHODOLOGIES

3.1 INTRODUCTION

State Departments of Transportation and engineers engaged in research have been collecting and analyzing traffic incident information for decades. Of particular interest to practitioners and researchers alike are ranking of hazardous sites, evaluation of the effectiveness of site improvements and prediction of the effect of potential modifications to a set of sites. In all of these cases, it is important to obtain a reliable estimate of the expected number of crashes at a specific site or group of sites in order to compare with actual occurrences. Often times, those estimates and the policy decisions that rely on them are based on relatively scarce information about the site or group of sites, either because traffic volumes at those particular locations are comparatively low, or because only a few years (or perhaps even a single year) of crash data are available for the locations of interest. This chapter comprises of a general overview of the methods that would be applied in this study. These include an overview of the different types of before-after studies with emphasis on the comparison group before-after study and the Empirical Bayes (EB) before-after study. Also included is a brief overview of the benefit-cost analysis and the model applied to obtain the benefit-cost ratio. Previous studies used the before-after study and the EB method to determine Crash Reduction Factors (CRFs) which are used to estimate the potential number of traffic crashes expected to be
prevented from investment in safety improvement projects (41). This approach estimates the safety impacts of an improvement based on the difference in the number of crashes occurring before and after the project was implemented, as follows:

\[
CRF = \frac{N_b - N_a}{N_b}
\]  

(3.1)

where: \(N_b\) and \(N_a\) are respectively the number of crashes before and after a treatment on a facility.

With the EB method, a Safety Performance Function (SPFs) developed by the Federal Highway Administration (FHWA) for roadway segments prone to deer-related crashes will be used. SPFs are statistical models used to estimate the average crash frequencies for a specific site type (with specified base conditions), based on traffic volume and roadway segment length using regression models (52). This SPF was used because none has been developed for the State of Nevada due to data limitations. Although they require more data, SPFs developed using the Empirical Bayes approach are more accurate than crash frequency or crash rate as a predictor because they account for the regression to the mean bias and random fluctuations in crash data over a period of time.

3.2 METHODS OVERVIEW

3.2.1 Before-After (B-A) Study

The before-after method is the simplest way to estimate the effectiveness of a safety improvement. One of the typical methods of evaluating the safety improvement of a treatment is comparing the crash prevalence associated with the transportation facility before and after the treatment was implemented. The data used in this approach are the
before and after crash counts of a facility. In this case, crashes that occurred during the
construction period are not included in the analysis. Earlier studies (42) suggest that the
following factors be considered in the estimate of before-after studies:

1. The need for some measure of vehicle-miles for both the before and after periods
   in order to equate crash exposure.
2. Traffic volumes for each of the two periods should be approximately the same;
   else marked differences in volumes will affect the crash experience.
3. The traffic composition on the study segment should remain unchanged during
   each of the two periods as this may influence crash experience.
4. Since fatal crashes consistently tend to decrease over the years, the crash total in
   the after period should be corrected for any existing trends.
5. If crash data for several years before modification are available, and show a
   variation of no more than 20 percent from year to year, they may be averaged.

There are three main types of before-after study to evaluate the safety performance of a
facility after treatment has been applied (43). These include: 1) the naïve before-after
study; 2) comparison group before-after study; and 3) the before-after study using the
Empirical Bayes method. A B-A study involves four major steps as shown below:

1) Estimation of \( \bar{\lambda} \) and predict \( \pi \)

where \( \bar{\lambda} \) is the expected number of target crashes in the‘after’period with the treatment in
place.
π Expected number of target crashes in the ‘after’ period if the treatment had not been installed, calculated by:

2) Estimation of VAR \{\bar{\lambda}\} and VAR \{\pi\}

3) Estimation of \delta and \theta

where \delta is reduction in the expected number of crashes given by:

$$\delta = \pi - \bar{\lambda}: \text{Change in safety due to the treatment}$$ (3.2)

and \theta is the safety index of effectiveness calculated using the formula;

$$\theta = \frac{\bar{\lambda}}{\pi} / (1 + VAR[\pi]/\pi^2)$$ (3.3)

4) Estimation of VAR \{\delta\} and VAR \{\theta\} can be obtained using equations;

$$VAR\{\delta\} = VAR\{\pi\} + VAR\{\bar{\lambda}\}$$ (3.4)

$$VAR\{\theta\} = \theta^2(VAR\{\bar{\lambda}\}|\bar{\lambda}|^2 + VAR\{\pi\}/\pi^2)/[1 + VAR\{\pi\}/\pi^2]^2$$ (3.5)

The reduction in the expected number of crashes thus computed using the following notations:

3.2.1 Naïve Before-After Study Method

In the naïve before-after study, crash counts in the before period are used to predict the expected number of crashes in the after period had the treatment not been implemented. Prediction may be done by e.g., using one year before crash counts, a comparison group, and three-year before average or regression analysis. Thus, the effectiveness of the treatment is the change in safety performance measure purely due to the treatment. When
data at a particular location span only a few years, the naive before-after analysis that relies on information from that site alone fails to capture the true (yet unobservable) long-term behavior at that site. This technique however can lead to inaccurate conclusions since it does not account for the following external factors:

1. Regression-to-the mean
2. Crash Migration
3. Maturation
4. External causal factors.

### 3.2.1.1 Regression-to-the-Mean

Regression-to-the-mean is a statistical phenomenon that occurs whenever a non-random sample is selected from a population (50). In practice, a location is usually selected for treatment when it has an unusually high number of crashes. The locations with high crash frequencies for the before periods thus tend to have higher reductions in crash frequency after improvements, that even without any treatments, the crash frequencies would likely reduce simply because the sites tend to ‘regress’ or return to the long-term mean number of crashes. The effect of regression-to-the mean is shown in a hypothetical example as illustrated in Figure 3-1 using the study site crash data. In this figure, the number of crashes ranges from 0 to 8, with an average crash of 3. It can be seen that if an improvement were constructed in 2004 in response to the large number of crashes that occurred in 2005, the results would have shown a 20 percent crash reduction after treatment. While the treatment may have some effect, some portion of the crash reduction was due to the regression to the mean and not the improvement, thus overestimating the
effectiveness of the treatment. Failure to account for the regression-to-the-mean bias in an analysis could thus lead to statistically significant results for treatments that are actually ineffective (Error! Bookmark not defined.).

![Crash Frequency Chart](image)

**Figure 3-1 Illustration of Regression-to-the-Mean Bias**

### 3.2.1.2 Crash Migration

The issue of crash migration is usually geographic or non-geographic. Geographic migration, usually referred to as ‘geographic crash migration’ (47) occurs when crashes are transferred from a treatment site to surrounding locations as a result of a treatment. For instance, when a particular high crash location on a highway is improved, crashes at that location may decrease, but crashes at the next high crash location may increase. Non-geographic migration on the hand, involves a shift across severity levels and/or crash types due to a treatment. A typical example is installing road signs that warn motorists of high deer-crossing probabilities in order to reduce deer vehicle collisions, but may increase fixed-object crashes, which may also increase the overall crash severity.
Mountain et al. (44) suggested that the assessment of safety improvements be based on crash data collected over a wider area rather than simply at the treatment site itself. This allows changes in the number of crashes for the expanded site location to reflect both the treatment effect at the treatment at the treatment sited and the crash migration effect at the surrounding sites.

### 3.2.1.3 Maturation

This phenomenon is when crash rates on a roadway often show trends due to temporal changes in factors such as traffic flow, weather, economy, crash reporting practices etc; often referred to as maturation (45). It is recommended that analysis of treatment effectiveness at treatment sites consider crash trends to obtain accurate results. For example, if a treatment at selected sites shows a change in crash rates in before and after periods, it is possible that this change was due to the implemented improvement; however, it might also be an extension of a continuing decreasing trend that had been occurring for years.

### 3.2.1.4 External Causal Factors

Factors that influence the safety of highways can be classified into two categories;

a) Factors that can be recognized measured and understood, such as traffic volume growth. This type of factors can be explicitly quantified and accounted for.

b) Factors that cannot be easily recognized, measures or understood, such as weather conditions, economic conditions. A major problem with simple before-after study is that it cannot distinguish between the effect of the treatment and the effect of
such causal factors that may have also changed from the ‘before’ to the ‘after’ period. These factors include;

**The Treatment Effect**- This is the change in safety performance of a transportation facility observed by implementation of a specific treatment. The net improvement in terms of safety performance is determined by finding and comparing the answers to the following two questions:

- What would have been the safety performance of the facility in the after period had the treatment not been applied?
- What is the safety performance of the treated facility in the after period?

**The Exposure Effect**- This is change in traffic volume and patterns on the transportation facility. A direct relationship exists between traffic volume and crash frequencies thus, crash frequency of a facility increases with increasing traffic volume and vice versa. Its significance is observed if the treatment applied to the facility significantly mitigates the problem.

**The Trend Effect**- The trend effect is due to causal factors that are not recognized, measured and understood. These include, traffic composition (such as a higher/lower percentage of trucks or pedestrians), driver composition (in terms of behavior, age, etc.), enforcement level, weather conditions, etc. can be changed from the before period to the after period.

**The Random Effect**- The random effect occurs because of a phenomenon referred to as regression-to-the-mean bias in statistics. Based on the prior definitions of the above
effects, it can be concluded that even if no safety treatment had been applied to the facility, it would have been likely to observe a change in crash frequency from the before to the after periods.

3.2.2 Comparison Group Before-After Study

To solve the external causal factors and maturation problems, researchers developed the before-after study with the comparison group method. A comparison group is a group of control sites selected as being similar to the treatment site if no treatment had been implemented. In this technique, a facility or facilities are selected; with similar characteristics to the comparison site such as traffic volume and weather. The philosophy is that the larger the comparison group, the better the assessment. Moreover, it’s based on the assumption that the unknown causal factors affect the comparison group in a similar manner as they influence the treatment group. Therefore, the change in the number of crashes from the ‘before’ period to the ‘after’ period, had the treatment sites been left unimproved, would have been in the same proportion as the matching comparison site. Under this assumption, the crash frequency at each treatment site in the before period is multiplied by the ratio of after-to-before crashes at the comparison site, to predict the expected number of crashes in the after period at the treated site without the improvement. This method can potentially produce more accurate estimates than the simple before-after method. Its strength increases as the similarity between treatment and comparison sites increases. The expected number of crashes in the after period for treatment site without the improvement can be predicted as the observed number of crashes in the before period for treatment group, multiplied by the ratio of after-to-before
crashes at the comparison sites (46). Pendleton (47) proposed the following formula for the odds ratio:

\[
Odds \ Ratio = \frac{(M/N)}{K/L}
\]

where \( K \) = before crash counts for treatment group

\( L \) = after crash counts for treatment group

\( M \) = before crash counts for comparison group, and

\( N \) = after crash counts for comparison group

Thus \( M/N \) is the odds of the before-after crashes in the comparison group and \( K/L \) is the same odds for the treatment group. Griffith and Hauer (46) defined another odds ratio as follows:

\[
Odds \ Ratio = \frac{(KN)}{(LM)(1+1/L+1/M)}
\]

Where, the variables are as previously defined. This formula uses the sums of the before-after crashes to calculate the overall effectiveness of the improvement at the treatment sites. Hauer (46) suggested that a comparison should meet the following requirements:

1. The length of before and after periods for the treatment and the comparison group should be the same.
2. There should be some confidence that the change in the factors that affected safety is similar for both groups.
3. The number of crashes in the comparison group should be sufficiently large compared with the number in the treatment group.
3.2.3 Empirical Bayes (EB) Before-After Method

The Empirical Bayes (EB) study is a method known to correct for regression-to-the-mean bias. The EB method is recommended if a suitable and sufficiently large number of comparison locations are not available. In the EB study, the expected number of crashes in the after period without treatment is estimated using an SPF. The SPF is a mathematical model that predicts an estimate of crash occurrences for a given roadway segment (48). The SPF is used to estimate the expected number of crashes in each year of the before period at locations with traffic volumes and other characteristics similar to a treatment site being analyzed. The sum of these annual SPF estimates is then combined with the count of crashes in the before period at the treatment site to obtain an estimate of the expected number of crashes before the treatment.

3.2.3.1 Safety Performance Function, SPF

The SPF is determined from data collected in the period before any treatments were made to the roadway segment. Each type of roadway, Interstate and non-Interstate, have different SPFs to predict the expected number of crashes. Various statistical modeling software packages such as the LIMDEP Version 7.0 and multiple linear regression equations could be used to establish SPFs. The multiple linear regression equation is of the following form:

\[ SPF_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_{p-1} x_{i,p-1} + \varepsilon_i \]  

(3.8)

Where:
- SPF$_i$ denotes the dependent variable (crashes per three years for roadway segment $i$ before any treatment.

- $x_{i1}$ through $x_{i,p-1}$ denotes the independent, explanatory variables (average annual daily traffic (AADT), number of lanes, lane width, shoulder width, speed limit, etc.) for roadway segment $i$.

- $\beta_0$ through $\beta_{p-1}$ denote estimable parameters (determined by LIMDEP), $\beta_0$ represents the y-intercept value and

- $\epsilon_i$ denotes the unexplainable, random error not accounted for in the model.

### 3.2.3.2 Over-dispersion Parameter, $\varphi$

Researchers more commonly assume a negative binomial distribution to represent the distribution of crash frequencies. One of the parameters used to confirm whether the probability distribution of a crash dataset is correctly identified as negative binomial is the over-dispersion parameter, $\varphi$. Data is said to be over-dispersed if the variance exceeds its mean. In this study, the crash data was found to be over-dispersed (the variance exceeds the mean). This overall over-dispersion parameter represents all roadway segments in combination. This is then used to account for the varying degrees of over-dispersion between roadway segments attributable to differences in roadway traits and crash occurrences. If each roadway segment were of equal length and had consistent geometric characteristics, traffic characteristics, etc., the overall over-dispersion parameter would be directly applicable to each individual roadway segment. However, since roadway segments vary in length and characteristics, a unique over-dispersion parameter, $\varphi_i$, must be determined for each roadway segment. Segment length is assumed
to be a primary determinant affecting individual over-dispersion parameter values. Under this assumption, using the overall over-dispersion parameter as the over-dispersion for each individual segment would skew the outcome by placing more emphasis on the longer roadway segments (49). To better estimate the expected number of crashes for each individual roadway segment, the over-dispersion parameter can be adjusted based on length to represent the individual segment, \( i \) (49):

\[
\varphi_i = \varphi * L_i^\beta
\]  

(3.9)

where: \( \varphi_i \) denotes the adjusted over-dispersion parameter for roadway segment \( i \)

\( \varphi \) denotes the overall over-dispersion parameter for all combined roadway segments.

\( L_i \) denotes the length of roadway segment \( i \).

\( \beta \) is a constant between 0 and 1.

The \( \beta \)-value accounts for the differences in geometric characteristics, traffic characteristics, etc. between individual roadway segments. A \( \beta = 0 \) would be represented by the overall over-dispersion parameter whereas \( \beta = 1 \) represents the overall over-dispersion parameter adjusted only by the segment length. A \( \beta \) value somewhere between 0 and 1 is most representative for segments defined along a continuous roadway.

The EB approach consists of a series of steps which includes:
3.2.3.3 $E(k)$

This step involves the use of SPFs to predict an estimate of crash occurrence for a given roadway segment using mathematical models (48). This mathematical model links the expected crash frequency on the roadway to measurable roadway traits such as AADT, length of roadway segment, roadway width, shoulder width, number of lanes etc. The estimate of roadway’s SPF takes into account varying degrees of over dispersion between a roadway segment attributable to differences in roadway traits and crash occurrences. Hauer mentioned that crash occurrence is best modeled using a multivariate statistical model (50). The method is based on the following three assumptions:

1. The number of crashes at any site follows a Poisson distribution
2. The mean for a population of systems can be approximated by a Gamma distribution.
3. Changes from year to year from different factors are similar for all reference sites.

Estimating $E(k)$ consists of the following two general methods (46):

1. Establishing the foundation for the prediction by estimating what the expected frequency of target crashes in the ‘before’ period would have been.
2. Predicting how the expected number of crashes would have changed from the ‘before’ to the ‘after’ period as a result of changes in traffic, weather and other factors based on this foundation.
3.2.3.4 Relative Weight, $\alpha$

A relative weight, $\alpha$ is applied to the segment to adjust for varying degrees of over dispersion. The relative weight is thus obtained as follows;

\[
\alpha = \frac{1}{1 + \sum_{i=1}^{n} E(k)/\varphi}, \text{ where } 0 \leq \text{Weight} \leq 1
\]  (3.10)

If the estimated ‘weight’ is close to 1, the estimate of the expected crashes for the treatment sites is close to the mean of its reference sites; if the estimated ‘weight’ is near 0, the estimate of the expected crashes at the treatment sites will mainly reflect the recorded count of crashes.

3.2.3.5 Expected number of Crashes, $E\{k/K\}$

If $K$ is the actual crash count at the treatment sites and $E(k)$ as previously defined, then $E \{k/K\}$ is the expected number of crashes at the treatment sites given that the site recorded $K$ crashes. This is expressed as follows:

\[
E\{k|K\} = \alpha E(k) + (1-\alpha)K
\]  (3.11)

where all other variables as previously defined.

The variance of the estimate of the expected number of crashes given by the following equation:

\[
VAR\{k|K\} = (1-\alpha)E\{k|K\}
\]  (3.12)

Hauer (46) suggested the following two methods for calculating $VAR\{K\}$ and $E\{k\}$ based on populations that have a gamma distribution: 1) the method of sample moments,
2) the multivariate regression method. Common to both methods are the two equations below:

\[
E\{k\} = E\{K\} \quad (3.13)
\]

\[
VAR\{K\} = E\{k\} + VAR\{k\} \quad (3.14)
\]

The formulas for the method of sample moments are:

\[
E\{k\} = E\{K\} = \bar{K} \quad (3.15)
\]

\[
VAR\{k\} = s^2 - \bar{K} \quad (3.16)
\]

where \(\bar{K}\) is the sample mean and \(s^2\) is the sample variance of the crashes at the reference sites and can be calculated from the following equations:

\[
\bar{K} = \frac{\sum K N_K}{N} \quad (3.17)
\]

where \(N\) is the number of reference sites, \(N_K\) is the number of sites that have recorded \(K\) crashes during a specified period. As \(N\) increases, \(\bar{K}\) approaches \(E\{k\}\) and \(s^2\) approaches \(VAR\{K\}\). Thus, \(E\{K\}\) and \(VAR\{K\}\) can be replaced by \(\bar{K}\) and \(s^2\). Therefore, this method requires a larger number of samples. The larger the reference population, the more accurate these estimates are.
3.2.3.6 Index of Effectiveness, $\theta$

The index of effectiveness $\theta$, being the means of expressing the resulting effectiveness of any treatment as a relative difference in crash occurrence between actual and expected crashes is given by:

$$\theta = \frac{K/E\{k/K\}}{1+(\sigma^2/E\{k/K\})}$$  \(3.18\)

where, $\sigma = \sqrt{(1 - \alpha) * E\{k/K\}}$  \(3.19\)

The index of effectiveness takes into account the uncertainties resulting from:

- Sampling a small segment to represent the larger population,
- The resulting low explanatory power (i.e., goodness of fit) of the SPF,
- The assumptions supporting the determination of the over dispersion parameters and relative weights.

3.3 CASE STUDY

3.3.1 Comparison Group Method

A comparison site along U.S. 93 Highway, which is similar in characteristics, was selected. This site along the U.S. 93 Highway falls within mile post EL (Elko) 91 to EL 94.7. Crash data from 10/01/2000 through 10/01/2010 was requested from the Nevada Department of Transportation. Table 3-1 shows a summary of deer-related crashes for target accidents and comparison crashes of 10 years ‘before’ (2001-2010) and one year ‘after’ (2011) data along the U.S. 93 Highways in Wells, NV as well as their corresponding mean and variances. Although more years of ‘after’ period are desired, this was the only available data at the time of this study.
Table 3-1 Deer-Related Crash Summary

<table>
<thead>
<tr>
<th>Year</th>
<th>Before (2001-2011)</th>
<th>After (2001-2011)</th>
<th>Total (before)</th>
<th>Mean</th>
<th>VAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>4</td>
<td>30</td>
<td>3.00</td>
<td>6.667</td>
</tr>
<tr>
<td>Treatment</td>
<td>0</td>
<td>4</td>
<td>30</td>
<td>3.00</td>
<td>6.667</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>5</td>
<td>17</td>
<td>1.70</td>
<td>2.011</td>
</tr>
<tr>
<td>Comparison</td>
<td>1</td>
<td>5</td>
<td>17</td>
<td>1.70</td>
<td>2.011</td>
</tr>
</tbody>
</table>

Table 3-2 shows the before-after crash frequencies for the treatment and comparison group crash data along the U.S. 93 Highway in Wells NV.

Table 3-2 Crash Frequencies

<table>
<thead>
<tr>
<th></th>
<th>Treatment Group</th>
<th>Comparison Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>K=30</td>
<td>M =17</td>
</tr>
<tr>
<td>After</td>
<td>L= 1</td>
<td>N = 2</td>
</tr>
</tbody>
</table>

The reduction in the expected number of crashes is calculated as follows:

\[ \lambda = L \]

\[ r_c = \frac{N}{M} = \frac{2}{17} = 0.1176; \text{ where } N \text{ and } M \text{ are as previously defined.} \]

\[ \pi = r_c K = 0.1176 \times 30 = 3.528 \]

\[ \delta = \pi - \lambda = 2.528 \]; thus a reduction in the expected number of crashes by 2.53.

*Estimating VAR \{\pi, \lambda, \text{ and } \theta\}*

\[ \text{VAR} \{\pi\} = \pi^2 \left[ \frac{1}{K} + \frac{1}{M} + \frac{1}{N} + \text{VAR}\{\omega\} \right] \]

\[ \text{VAR} \{\pi\} = 3.528^2 \left[ \frac{1}{30} + \frac{1}{17} + \frac{1}{2} + 0 \right] = 7.37 \]
Because this study uses only one comparison site, it is conceivable to have different estimates when other comparison sites are used. Consequently, the findings based on the evaluation of the facility will vary with relatively wide confidence limits and also, it’s unable to address the issue of regression-to-the-mean bias. However, the estimate yielded a reduction of 8.2% (2.53) in the expected number of crashes.

### 3.3.2 Empirical Bayes Method

To obtain the modeled number of crashes, \( E(k) \) using the Empirical Bayes, similar roads within this jurisdiction for segment-based rural two-lane SPF = 0.02652×ADT\(^{0.53} \) and (Annual Modification Factor) AMF=0.95 were selected for use. This was obtained from SafetyAnalyst SPF models developed by the Federal Highway Administration (51), due to the fact that none has been modeled for the State of Nevada. Thus, e.g., for 2001 and under nominal conditions, roads with \( \text{ADT} = 5060 \) are estimated to have 0.02652×5060\(^{0.53} \) = 2.436 crashes/(mile-year) as can be seen in row 4, Table 3-3. To further convert from nominal to real conditions, results in row 4 were further multiplied by the AMF as shown in row 5, Table 3-3. Listed in row 6 are the expected crashes when
segment length has been accounted for. Obtaining a VAR \( k \) = 0.5066 and \( E(k) = 23.582 \), the relative weight, \( \alpha \) was computed as follows:

\[
\alpha = \frac{1}{1 + 10 \times \left( \frac{0.5066}{23.582} \right)} = 0.8232
\]

### Table 3-3 Empirical Bayes Estimate

<table>
<thead>
<tr>
<th></th>
<th>Year</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>ADT</td>
<td>5060</td>
<td>5270</td>
<td>5350</td>
<td>5200</td>
<td>5200</td>
<td>5050</td>
<td>5400</td>
<td>5200</td>
<td>5200</td>
<td>5200</td>
<td>5200</td>
</tr>
<tr>
<td>3</td>
<td>Crashes</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>8</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>4</td>
<td>( \frac{E(k)_{\text{year}}}{(\text{mile-year})} )</td>
<td>2.436</td>
<td>2.489</td>
<td>2.509</td>
<td>2.472</td>
<td>2.472</td>
<td>2.434</td>
<td>2.546</td>
<td>2.522</td>
<td>2.472</td>
<td>2.472</td>
<td>24.823</td>
</tr>
<tr>
<td>5</td>
<td>( E(k)_{\text{year}} \times \text{AMF} )</td>
<td>2.314</td>
<td>2.365</td>
<td>2.384</td>
<td>2.348</td>
<td>2.348</td>
<td>2.312</td>
<td>2.419</td>
<td>2.396</td>
<td>2.348</td>
<td>2.348</td>
<td>23.582</td>
</tr>
<tr>
<td>7</td>
<td>Expected Annual Acc for Segment ( \frac{E(k)<em>{\text{year}}}{\sum E(k)</em>{\text{year}}} )</td>
<td>2.426</td>
<td>2.479</td>
<td>2.498</td>
<td>2.461</td>
<td>2.461</td>
<td>2.423</td>
<td>2.535</td>
<td>2.511</td>
<td>2.461</td>
<td>2.461</td>
<td>24.717</td>
</tr>
</tbody>
</table>

The expected number of crashes for the 10-mile summit study site within the period 2001-2010 is:

\[
E(k/K) = 0.8232 \times (23.582) + (1 - 0.8232) \times 30
\]

\[
E(k/K) = 24.717
\]

\[
s.d. = \sqrt{(1 - 0.8232) \times 24.717} = 2.090
\]

Thus, the expected crashes = 24.72 ± 2.09 crashes in 10 years.

As can be seen in Table 3-3, this estimate is based on the full ten-year crash history and this explains the small weight \( \alpha \), attached to what is expected at similar sites. The
estimate for any specific year can now be computed by multiplying the estimate for the entire period by the ratio, \( E(k) \text{ year}/\sum E(k) \text{ year} \). Thus, for 2001 the estimate is:

\[
[24.717 \pm 2.09]*2.436/24.823 = 2.426\pm0.205 \text{ as can be seen in row 7, Table 3-3.}
\]

Applying SPF's developed for another state requires calibration of the model to reflect differences across time and space due to factors such as collision reporting practices, weather, driver demographics, and wildlife movements. In the calibration procedure, a multiplier is estimated to reflect these differences by first using the model to predict the number of collisions for this site for the time period. The sum of the collisions for the site is divided by the sum of the model predictions to derive the multiplier as follows:

\[
Cr = \sum \frac{\text{observed}}{(SPF)\text{predicted}} = \frac{30}{23.582} = 1.27
\]

Calibrated SPF is thus given by:

\[
\text{SPF}_{\text{NEVADA}} = Cr \times SPF
\]

\[
= 1.27*24.717 = 31.39
\]

The index of effectiveness is thus given by:

\[
\sigma = \sqrt{(1 - 0.8232) \times 31.39} = 2.36
\]

\[
\theta_i = \frac{30/31.39}{1 + \left( \frac{5.55}{31.39} \right)} = 0.81
\]

Finally, the relative difference in crash occurrence between actual and expected crashes is determined as:

Relative difference in Crash Occurrence = 100(1-0) = 100*(0.19) = 19
The Empirical Bayes methodology, if properly undertaken, does produce results that are substantially different, but more valid than those produced by more traditional methods like the B-A method; by combining crash counts with knowledge about the safety of similar entities. This is due to the fact that the E-B method increases the precision of the estimate and corrects the regression-to-the mean bias. Obtaining an estimate of 31.39 indicates an increase of about 4.4% (1 crash), had the treatment not been implemented.

CHAPTER 4

BENEFIT –COST ANALYSIS

4.1 INTRODUCTION

Benefit-Cost Analysis (BCA) is a systematic process for quantifying and comparing benefits and costs of a project to determine if it is a sound investment (52). It considers the changes in benefits and costs that would be caused by a potential improvement to the status quo facility. Wildlife crossings are generally installed at locations with significant wildlife populations, a history of animal–vehicle collisions, and other site characteristics which make crossings favorable, and which are not common on the entire road system. A benefit-cost estimate may be used to help determine:

1. Whether or not a project should be undertaken, i.e., whether the project’s life cycle benefits exceeds its costs.
2. When a project should be undertaken; by revealing whether a project may not pass economic muster presently, but would be worth pursuing several years later due to specific reasons.

3. Which alternative, among other competing alternatives and projects should be funded given a limited budget?

In a BCA, a discount rate is applied to the benefits and costs incurred in each year of the project’s life cycle which yields one or more alternative measures of a project’s economic merit. In as much as benefits and costs should be quantified and monetized, other benefits and costs may be unsuited for monetization, e.g., estimating the acres of wildlife habitat that will be impacted.

4.1.1 Objectives and Scope

The main objective of this BCA of the wildlife overpass is to identify its effect on mule deer population levels due to high levels of mortalities, deer-vehicle collisions and threats to human injuries or fatalities as well as to determine whether having wildlife crossings at high deer vehicle locations is economically justifiable. The analysis period selected was 10 years prior to the construction of the overpass and 2 years after the completion of the overpass. The wildlife overpass, located within the 4.1 mile segment which starts from MP EL 81.6 to EL 85.7 in Wells, NV along the U.S. 93 Highway in the Elko County was completed and operational in August, 2010. The entrances and exits of the Overpass are equipped with motion detectors and cameras to track exactly how many deer or other wild animals cross the bridge at certain times.
4.1.2 Benefits

Benefits (both monetary and safety aspect) of a transportation project are commonly defined as a combination of the effectiveness of the mitigation measure in reducing collisions and the costs associated with an average collision (52). Ideally, the level of effort allocated to quantifying benefits and costs in the BCA is proportional to the expense and complexity of the project. The benefits derived from constructing wildlife crossings to extend wildlife migration corridors over and under major roads appear to outweigh the costs of construction and maintenance.

4.1.3 Costs

Costs are defined as the resources such as land, labor and material expended on the project by the entity providing it (53). Also included are the design, implementation, maintenance and removal efforts. Deer-vehicle collisions can also impose a variety of costs which include property damages, traffic delay, emergency response services and medical care, rehabilitation expenses, lost productivity, suffering and grief. DVCs in which somebody is injured, disabled or killed, are less frequent but much more costly to society. These are generally easier to measure or quantify than benefits. In effect, costs are largely construction oriented in the present whereas benefits are distributed more uniformly over the life of the project. Typical cost of a transportation improvement project includes:

4.1.3.1 Initial Costs

Initial costs are those that are incurred during the design and construction process. These include the planning, preliminary engineering and project design; land acquisition and
construction costs. Table 4-1 shows the construction costs involved implementing the wildlife overpass and in Table 4-2, the highlighted bid shows the winning bid and its subsequent initial costs. The bid amount of 1,862,862.00 was adjusted to 2011 dollars amounting to 2,329,598.00 based on Consumer Price Index.

Table 4-1 Construction Costs (54)

<table>
<thead>
<tr>
<th>CONSTRUCTION COST (CC)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate cost of overpass</td>
<td>$2,018,000.00</td>
</tr>
<tr>
<td>Backfill and Top Soil</td>
<td>$112,085.00</td>
</tr>
<tr>
<td>Fencing and Vegetation</td>
<td>$196,150.00</td>
</tr>
<tr>
<td>Maintenance Cost (annual)</td>
<td>$134,520.00(3,363*40)</td>
</tr>
<tr>
<td><strong>Total Construction Cost</strong></td>
<td><strong>$2,460,755.00</strong></td>
</tr>
</tbody>
</table>

4.1.3.2 Maintenance Costs

These are the costs incurred after completion of the facility and while it is in use. It involves routine maintenance of the facility (sometimes referred to as preventive maintenance) as well as repair and cleanup required by crashes. The maintenance cost adjusted to 2011 dollars amounted to 134,520.00 based on Consumer Price Index.

4.1.3.3 Costs Associated with Deer-Vehicle Collisions

Costs for an average deer-vehicle collision could be estimated based on property damage, human injuries and human fatalities. Other parameters include: vehicle repair costs, costs associated with human injuries and fatalities, towing, incident attendance and investigation, the monetary value of deer per collision (substantially higher, thus driving
up the cost of the average deer-vehicle collision) (55). Although different studies have different cost estimates, cost estimates for this study will be based on the Utah data because the 2002 statewide Nevada cost of $3500 was the average for all property damage. In this analysis, 2006 USDOT estimates for motor vehicle crash costs would be used and adjusted to 2011 dollars based on Consumer Price Index (52). Table 4-3 shows a summary of the estimated costs of wildlife vehicle collisions for deer.

Table 4-2 Summary of Estimated Average Costsof a DVC adjusted to 2011 (52)

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage Cost (DC) (2011)</td>
<td>$7,625.20</td>
</tr>
<tr>
<td>2003 Utah data adjusted to 2011</td>
<td>$1,941.30</td>
</tr>
<tr>
<td>Value of deer in Nevada (2011)</td>
<td>$4,990.00</td>
</tr>
<tr>
<td>2011 value of hunters’ travel, food, lodging, equipment, etc.</td>
<td>$693.80</td>
</tr>
<tr>
<td>Injury Cost (IC) (2011)</td>
<td>$91,091.70</td>
</tr>
<tr>
<td>Fatality Cost (FC) (2011)</td>
<td>$3,068,359.10</td>
</tr>
<tr>
<td><strong>Total Collision Cost</strong></td>
<td><strong>$3,174,701.00</strong></td>
</tr>
<tr>
<td><strong>Total (Construction + Collision Cost)</strong></td>
<td><strong>$5,635,456.00</strong></td>
</tr>
</tbody>
</table>
4.1.3.4 Other Costs

Costs that are not easily quantifiable and excluded from the analysis are the costs associated with emotional distress of deer-vehicle collision victims and expenses involved with conservation efforts for threatened or endangered species.
Table 4-3 Contract Bids and Initial Costs

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>QUANTITY</th>
<th>UNIT</th>
<th>DESCRIPTION</th>
<th>BID BOND 5%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RAFAEL CONSTRUCTION INC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7120 RAFAEL RIDGE WAY</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LAS VEGAS NV 89118</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Q &amp; R CONSTRUCTION INC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PO BOX 10865</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RENO NV 89510</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MKD CONSTRUCTION INC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PO BOX 22070</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CARSON CITY NV 89721</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>FREHNER CONSTRUCTION</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>COMPANY INC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>522 OSHO #8 ELKO NV 89801</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>UNIT</td>
</tr>
<tr>
<td>211 0500</td>
<td>1,400</td>
<td>CU YD</td>
<td>TOP SOIL</td>
<td>-</td>
</tr>
<tr>
<td>211 0552</td>
<td>5,400</td>
<td>SQ YD</td>
<td>MULCHING</td>
<td>-</td>
</tr>
<tr>
<td>212 1301</td>
<td>22</td>
<td>EACH</td>
<td>IMAGE PANEL</td>
<td>-</td>
</tr>
<tr>
<td>214 0088</td>
<td>1</td>
<td>EACH</td>
<td>INFORMATION SIGN</td>
<td>-</td>
</tr>
<tr>
<td>502 0113</td>
<td>LS</td>
<td>-</td>
<td>CONCRETE BRIDGE</td>
<td>-</td>
</tr>
<tr>
<td>604 2180</td>
<td>6</td>
<td>EACH</td>
<td>18-INCH METAL END SECTION</td>
<td>-</td>
</tr>
<tr>
<td>605 1220</td>
<td>364</td>
<td>LINFT</td>
<td>15-INCH HIGH DENSITY POLYETHYLENE PIPE, TYPES</td>
<td>-</td>
</tr>
<tr>
<td>616 0752</td>
<td>796</td>
<td>LINFT</td>
<td>96-IN CHAIN LINK FENCE</td>
<td>-</td>
</tr>
<tr>
<td>618 0073</td>
<td>4</td>
<td>EACH</td>
<td>GUARDRAIL TERMINAL (FLARED)</td>
<td>-</td>
</tr>
<tr>
<td>618 0528</td>
<td>1,100</td>
<td>LINFT</td>
<td>GALVANIZED GUARDRAIL (TRIPLE CORRUGATION)</td>
<td>-</td>
</tr>
<tr>
<td>624 0016</td>
<td>60</td>
<td>DAY</td>
<td>TRAFFIC CONTROL SUPERVISOR</td>
<td>-</td>
</tr>
<tr>
<td>625 0120</td>
<td>LS</td>
<td>-</td>
<td>RENT TRAFFIC CONTROL DEVICES</td>
<td>-</td>
</tr>
<tr>
<td>628 0004</td>
<td>LS</td>
<td>-</td>
<td>MOBILIZATION</td>
<td>-</td>
</tr>
<tr>
<td>637 0003</td>
<td>LS</td>
<td>-</td>
<td>TEMPORARY POLLUTION CONTROL</td>
<td>-</td>
</tr>
<tr>
<td>637 0000</td>
<td>LS</td>
<td>-</td>
<td>DUST CONTROL</td>
<td>-</td>
</tr>
<tr>
<td>685 0100</td>
<td>FA</td>
<td>-</td>
<td>PARTNERING</td>
<td>-</td>
</tr>
</tbody>
</table>

**TOTAL** 2,856,890.00 1,862,862.00 2,025,024.00 2,050,000.00 2,199,999.00
4.2 BENEFIT-COST ANALYSIS PROCESS

Below are the assumptions outlined and the procedures involved to perform the analysis. In this analysis, the cost for an average collision with a deer was estimated and all costs and benefits are in real terms.

4.2.1 Assumptions

The following list comprises the assumptions used in illustrating the Benefit-Cost estimate.

1) With extensive exclusionary fencing (3 miles on each side), 90% of deer-vehicle collisions will be eliminated within the segment. (For actual B/C determination, reduction will be based on actual deer related crashes reduced over a minimum of two years).

2) The number of reported deer-vehicle collisions is 29% (Error! Bookmark not defined.), which was based on field data collected along a 10-mile segment of I-80 that included Pequop Summit by NDOW in the fall of 2005, which would factor the crashes to the analysis years. Again, this is reported data; therefore, the actual number of collisions is approximately 3.5 times greater.

3) All costs were adjusted to 2011 dollars based on Consumer Price Index.

4) The value of the wildlife overpass at the end of 40 years was zero.

5) The value of deer was based on the average of 2001-2005 (Error! Bookmark not defined.) data and included the cost of non-resident tags, license fees, travel, food, lodging, equipment, etc., incurred by hunters divided by the total number of deer killed by hunters. For this analysis, it was assumed that an AVC always resulted in the eventual death of the animal, regardless of the species.
6) The 2003 Utah vehicle damage cost ($1,574) was used because the 2002 statewide Nevada cost of $3500 was the average for all property damage. This categorizes the types of collisions and deer collisions that are probably less severe, implied by the 29% reporting rate.

7) For the injury cost the 2002 statewide Nevada data for ‘stuck animal’ collision cost was reduced since 35% of animal collisions were animals larger than deer. The rural cost of $144,400 was reduced by 50% to $72,200.

8) For the average deer carcass removal and disposal, there was no apparent cost involved.

9) The 2002 statewide Nevada data of $2,432,000 was used for fatal collisions.

10) The Upper Midwest data was used as the portion of fatal collisions. Nevada data had one fatal in five years giving a probability of 0.001, which was about 5 times higher than the published data. The Nevada sample was too small to be statistically reliable.

11) For towing, incident attendance and investigation, not all deer-vehicle collisions require the towing of a vehicle and attendance or investigation by medical personnel, fire department or police. The cost for the actual medical assistance is included in the cost estimates for human injuries. These assumptions result in an average cost for towing, incident attendance, and investigation of $125 for deer.

Listed below are the probability factors applied to its corresponding categories of crash severities to account for the probability of each occurrence:

Probability of Collision (Portion of total crashes)

Prob. of damage (PD) - 0.9591
Prob. of Injury (PI) - 0.0407 (Nevada data)

Prob. of Fatality (PF) - 0.00021 (Upper Midwest data)

Collision Data = 10.3/year (10 years for the 4.1 mile segment, annual amount increased by 3.5 because of the 29 percent reporting rate).

Interest Rate (i) - 4% (Based on the approximate average for the past 40 years)

Life of Project (n) - 40 years (Reinforced concrete bridge structure).

Assuming a 4% discount rate and a design life of 40 years (2):

$$\text{NPW} = \{(\text{DC}) \cdot (\text{PD}) + (\text{IC}) \cdot (\text{PI}) + (\text{FC}) \cdot (\text{PF})\} \cdot (\text{N}) \cdot (\text{PWF}) - \{(\text{CC}) + (\text{MC}) \cdot (\text{PWF})\},$$

where

PWF – present worth factor (i = 4%, n = 40 years)

N – Number of collision reduced (90% reduction factor) and all other factors as previously defined.

Calculations (All costs are 2011):

$$\text{PWF} = (1 - \frac{1}{(1+i)^n})/[\ln(1 + i)]$$

$$= (1 - \frac{1}{(1+0.04)^{40}})/[\ln(1 + 0.04)] = 20.19$$

$$\text{NPW} = \{(\text{DC}) \cdot (\text{PD}) + (\text{IC}) \cdot (\text{PI}) + (\text{FC}) \cdot (\text{PF})\} \cdot (\text{N}) \cdot (\text{PWF}) - \{(\text{CC}) + (\text{MC}) \cdot (\text{PWF})\}$$

$$= \{(7625.16 \times 0.9591) + (91,091.74 \times 0.0407) + (3,068,359.10 \times 0.0002)\}$$

$$(10.3 \times 4.1 \times 0.90) \times 20.19 - \{2,326,235.00 + 134,520 \times 20.19\}$$
NPW = \{7313.29 + 3707.43 + 613.67\} (38.00) (20.19) – \{2,326,235 + $2,715,958.80\}

NPW = 8,927,780.98 – $5,042,193.80

NPW = $3,885,587\text{million}

\[\text{B/C} = \frac{3,885,587}{2,460,755.00}\]

\[\text{B/C ratio} = 1.58\]

### 4.3 CONCLUSIONS

The benefits and costs estimated over the analysis period were discounted to calculate the net present value of benefits and costs. The wildlife overpass has a Net Present Worth of approximately $3,972,269 million and a Benefit-Cost Ratio of 1.58. Benefit-cost ratios greater than one identify projects worth investing in. A B/C ratio of 1.58 indicates that the question of having wildlife crossings at high DVC locations is economically justified.
CHAPTER 5

DEER VEHICLE COLLISIONS DATA ANALYSIS

5.1 INTRODUCTION

Roadway conflicts tend to be complicated and problematic for ungulates such as the mule deer when road use coincides with winter ranges or migration routes, where animal densities are high during certain times of the year. This has resulted in several animal-vehicle collisions especially with the mule deer. Mule deer-vehicle collisions have historically been high along the 4.1 segment of the 10-mile summit study site along the U.S. 93 Highway located in Elko County. Despite a variety of mitigation measures implemented, aimed at slowing traffic and warning motorists of potential collisions with wildlife (e.g., signs, reflectors, flashing lights), dozens of deer-vehicle collisions continued to occur each year in this 4.1-mile segment (milepost EL 81.6 to EL 85.7) of highway. This chapter analyzes and discusses deer-vehicle collision data from the Nevada Department of Transportation along the U.S. 93 Highway, between Wells and Jackpot (10 Mile Summit).

Deer-vehicle collision (DVC) data comes in two major forms: reported DVC data and carcass removal data. Previous studies found that these two data sets have discrepancies and are significantly different. This is mainly because most deer-vehicle collisions go unreported, thus underestimating the magnitudes of these collisions, which explains the different magnitudes and patterns of reported DVCs and deer carcass removal data as they typically exist at Department of Transportation agencies (5). This implies that not all deer involved in DVCs died on the roadway and not all deer carcasses were removed and properly reported and recorded by transportation
agencies (56). These two types of data sets have been used in the past by several researchers and analysts, but these differences could lead to varying and possible ineffective or inefficient DVC-related policy and countermeasure decision making.

5.1.1 Data Sources

Two different databases were used to compare the magnitude and patterns of DVCs and deer carcass removals in the State of Nevada. The first dataset includes ten years before construction of the overpass and one year after construction of the overpass from the Nevada Department of Transportation (NDOT). The second dataset was acquired from the Nevada Highway Patrol (NHP). The data included information provided on the police reports (e.g., severity, weather conditions, lighting conditions, roadway factors, time of day and crash date and year) and the location (mile post) of the DVCs. However, there were no similarities between the two datasets as previously mentioned. The data requested from NDOT seemed to be more reliable compared to that obtained from the NHP office. Carcass removal data was obtained from Nova Simpson, a UNR student monitoring deer movement at the study site between Fall 2010 through autumn 2011. Carcass removal data did not include any information such as the location and mile post except for the carcass counts.

5.1.2 Objectives and Scope

The main objectives of this chapter include:

- Perform statistical analysis on deer-related crash data to identify trends in crash patterns.
- Quantify the number of mule deer that used the overpass as well as providing an estimate of the success rates of the overpass.
• Analyze reported deer-vehicle collisions and carcass removal data to identify discrepancies between the two sets of data.

5.2 COLLISION DATA ANALYSIS

5.2.1 U.S. 93 Highway Collision Data

Historic deer-vehicle collision data along a 65-mile section of U.S. 93 Highway, between Wells and Jackpot from 2000 through 2004 includes reported deer kills and collisions. It begins at milepost 76, north of Wells and ends at milepost 140 (64miles), near the Nevada-Idaho border. Table 5-1 shows the reported number of deer killed (388) in 290 deer-vehicle collisions over a 65-mile segment (Error! Bookmark not defined.). Table 5-1 also shows that 388 deer were reported killed in 290 deer-vehicle collisions, which average almost 80 reported deer killed per year. Using the 29% statistic for unreported deer collisions, this annual figure is really closer to 300 as shown in Table 5-1.

Table 5-1: Deer Collisions by Month on U.S. 93 Highway in Wells, NV from 2000-2004 (2)

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>17</td>
<td>49</td>
<td>33</td>
<td>43</td>
<td>6</td>
<td>3</td>
<td>9</td>
<td>6</td>
<td>5</td>
<td>70</td>
<td>25</td>
<td>24</td>
<td>290</td>
</tr>
<tr>
<td>Mortalities</td>
<td>23</td>
<td>65</td>
<td>39</td>
<td>50</td>
<td>6</td>
<td>3</td>
<td>11</td>
<td>6</td>
<td>5</td>
<td>106</td>
<td>49</td>
<td>25</td>
<td>388</td>
</tr>
</tbody>
</table>

The collision pattern in Figure 5-1 indicates that the months of October through April are when the migration of the deer herds occurs, with October and November, and February through April being the most severe months.
Figure 5-1: Deer Collisions by Month on U.S. 93 Highway in Wells, NV from 2000-2004

Crash data and AADT requested from NDOT from the year 2000 through 2011 for the 4.1-mile segment (study site) of the 10 mile study site are as shown in Table 5-2. The highest number of crashes recorded was in the year 2005 with no crash reports for the years 2001 and 2003. In total, 30 crashes were reported in the study area over the 10-year period. Figure 5-2 is a graphical representation of the crash data. In the chart, it can be seen that deer crashes fluctuate from year to year. Upon analyzing the data, no obvious trends between crash year and frequencies were observed, although each year had an observable decrease in crashes between 2007 and 2010.
Table 5-2 Deer Collisions by Year on Wells, NV for 2000-2010

<table>
<thead>
<tr>
<th>Year</th>
<th>ADT</th>
<th>Crash Frequency (DVCs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>5060</td>
<td>0</td>
</tr>
<tr>
<td>2002</td>
<td>5270</td>
<td>4</td>
</tr>
<tr>
<td>2003</td>
<td>5350</td>
<td>0</td>
</tr>
<tr>
<td>2004</td>
<td>5200</td>
<td>1</td>
</tr>
<tr>
<td>2005</td>
<td>5200</td>
<td>8</td>
</tr>
<tr>
<td>2006</td>
<td>5050</td>
<td>2</td>
</tr>
<tr>
<td>2007</td>
<td>5500</td>
<td>6</td>
</tr>
<tr>
<td>2008</td>
<td>5400</td>
<td>4</td>
</tr>
<tr>
<td>2009</td>
<td>5200</td>
<td>2</td>
</tr>
<tr>
<td>2010</td>
<td>5200</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 5-2 Deer-Vehicle Collisions by Year
Major changes in traffic volume, deer population size or changes to the road or landscape may result in an increase or decrease in the number of deer-vehicle collisions. Deer-vehicle collisions and AADTs were analyzed as shown in figure below. AADTs were plotted against crash frequencies to identify the impact of AADT on deer-vehicle collisions as shown in Figure 5-3. As can be seen, crash frequency is relatively low when AADT is lower and shows a declining trend from AADT= 5500, except for AADTs = 5060 and 5350 due to smaller sample size. Further research is recommended to collect more data to investigate this issue.

Figure 5-3 Crash Frequency vs. AADT

DVCs per each mile post were plotted to identify how many crashes occurred at each mile within the study segment. The segment between mile posts 83 to 84 recorded the highest number of crashes (11 crashes) with the least between mile posts 81 to 82 as shown in Table 5-3 and Figure 5-4.
Table 5-3 Crash Frequencies per Mile Post from 2010-2012

<table>
<thead>
<tr>
<th>Mile Post</th>
<th>Crash Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>81-82</td>
<td>4</td>
</tr>
<tr>
<td>82-83</td>
<td>7</td>
</tr>
<tr>
<td>83-84</td>
<td>11</td>
</tr>
<tr>
<td>84-85</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
</tr>
</tbody>
</table>

Figure 5-4 Crash Frequencies per Mile Post from 2010-2012

5.2.2 Deer Carcass Removal Data

Deer carcass counts that were picked up by maintenance crews were obtained from Nova Simpson, a UNR student monitoring deer behavior towards wildlife crossings (unpublished
These records were sorted by mile post number from segment 81.6 to 85.7 and recorded to the nearest tenth of a milepost by the maintenance crews. Seasonal carcass removal data is as shown in Table 5-4. The carcass data ranges from fall 2010 through autumn 2011. For the purpose of this study, the crash data and the carcass removal data were not combined due to data limitations and sample size. Instead, the two separate datasets were used to identify potential patterns in the individual data sets, rather than conducting final analyses based on a potential reduction in DVCs. Considering the mile segment under study (EL 81.6 to EL 85.7), obtaining deer carcass counts of 8 and DVC count of 0 for spring 2010 as shown in Table 5-4 indicates a significant contrast between the two datasets. This may be due to the issue of DVC under-reporting where most DVCs go unreported depending on the threshold for crash data (e.g. at least $1,000 in vehicle repair costs), carcasses of small or medium sized species (e.g. tortoise) that are not removed, and carcasses of larger species that are not on the actual road surface and not highly visible to drivers in the right-of-way which may also not have been removed and remain unrecorded. A correlation may exist between these two data sets if appropriately reported. However, analyzing both data sets with discrepancies may result in erroneous inferences since no correlation between the two datasets was identified.

**Table 5-4 Comparing Carcass Removal Data and Reported DVCs**

<table>
<thead>
<tr>
<th>Season</th>
<th>Reported DVC</th>
<th>Carcass Removal Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn 2010</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Spring 2011</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Autumn 2011</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
5.3 Success Rates for Overpass Use by Mule Deer

Wildlife overpass, used in conjunction with fencing was found to tremendously reduce DVCs. Out of a total of 16,503 total successful migrations (includes deer moving both east and west for each migration) of mule deer documented so far for all five wildlife crossings (3 underpasses and 2 overpasses), 12,522 of the migrations occurred on the wildlife overpass located at the 10-mile Summit site (unpublished data). The amount of overpass use by deer increased steadily between fall and spring migrations. For example, comparing deer crossing for spring 2011 to spring 2012, numbers increased from 2735 to 3331 which is completely opposite for underpass use as shown in Table 5-5. This constitutes about 76% of all the migration counts, thus justifying the conclusions that mule deer easily adapts to overpasses compared to underpasses.

Total successful crossings by mule deer are based on mule deer that approached a structure and used it rather than turning back in the direction they originally came from. It includes the individuals that approached from the side of the road considered to be the entrance during a particular seasonal migration (east or west) (i.e. for spring migration deer moved from east to west, thus approaching the east side of the structure. Therefore only deer traveling from the east were used to calculate this proportion).
Table 5-5 Total Successful Crossings by Mule Deer

<table>
<thead>
<tr>
<th>Location</th>
<th>Structure Number</th>
<th>Structure Type</th>
<th>Autumn 2010</th>
<th>Spring 2011</th>
<th>Autumn 2011</th>
<th>Spring 2012</th>
<th>All Migrations Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Mile</td>
<td>1</td>
<td>Underpass</td>
<td>156</td>
<td>220</td>
<td>138</td>
<td>82</td>
<td>596</td>
</tr>
<tr>
<td>10 Mile</td>
<td>2</td>
<td>Overpass</td>
<td>2911</td>
<td>2735</td>
<td>3545</td>
<td>3331</td>
<td>12522</td>
</tr>
<tr>
<td>10 Mile</td>
<td>3</td>
<td>Underpass</td>
<td>331</td>
<td>477</td>
<td>275</td>
<td>345</td>
<td>1428</td>
</tr>
<tr>
<td>HD Summit</td>
<td>4</td>
<td>Underpass</td>
<td>196</td>
<td>54</td>
<td>527</td>
<td>367</td>
<td>1144</td>
</tr>
<tr>
<td>HD Summit</td>
<td>5</td>
<td>Overpass</td>
<td>NA</td>
<td>NA</td>
<td>575</td>
<td>238</td>
<td>813</td>
</tr>
</tbody>
</table>

The proportions of successful crossings are as shown in Table 5-6. The study site (U.S. 93 Highway Wildlife Overpass) and the HD Summit overpass recorded the highest percentage of total migrations combined (95.75%). It also shows the proportions of successful deer crossings by mule deer during seasonal ranges.

Table 5-6 Proportions of Successful Crossings by Mule Deer

<table>
<thead>
<tr>
<th>Location</th>
<th>Structure Number</th>
<th>Structure Type</th>
<th>Autumn 2010</th>
<th>Spring 2011</th>
<th>Autumn 2011</th>
<th>Spring 2012</th>
<th>All Migrations Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Mile</td>
<td>1</td>
<td>Underpass</td>
<td>34%</td>
<td>56%</td>
<td>64%</td>
<td>34%</td>
<td>47.00%</td>
</tr>
<tr>
<td>10 Mile</td>
<td>2</td>
<td>Overpass</td>
<td>96%</td>
<td>98%</td>
<td>95%</td>
<td>94%</td>
<td>95.75%</td>
</tr>
<tr>
<td>10 Mile</td>
<td>3</td>
<td>Underpass</td>
<td>27%</td>
<td>49%</td>
<td>48%</td>
<td>34%</td>
<td>39.50%</td>
</tr>
<tr>
<td>HD Summit</td>
<td>4</td>
<td>Underpass</td>
<td>23%</td>
<td>69%</td>
<td>48%</td>
<td>61%</td>
<td>50.25%</td>
</tr>
<tr>
<td>HD Summit</td>
<td>5</td>
<td>Overpass</td>
<td>NA</td>
<td>NA</td>
<td>95%</td>
<td>96%</td>
<td>95.50%</td>
</tr>
</tbody>
</table>
CHAPTER 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY AND CONCLUSIONS

The research concerned evaluation of the effectiveness of wildlife overpasses in reducing deer-vehicle collisions. An overview of the different types of before-after studies with an emphasis on the comparison group before-after study and the Empirical Bayes before-after study were included. Using the case of U.S. 93 Highway, a Benefit-Cost analysis was performed to calculate the net present value of benefits and costs. DVC and Carcass Removal Data were analyzed to identify the different magnitudes and patterns of reported DVCs and deer carcass removal data as they typically exist.

The concept behind the Before-After (B-A) studies is comparing the crash prevalence associated with a facility before and after the treatment was implemented to estimate the effectiveness of a safety improvement. The three main types discussed include the Naïve B-A study, Comparison B-A study and the Empirical Bayes B-A study. While the Naïve B-A study uses crash counts in the before period to predict the expected number of crashes in the after period had the treatment not been implemented, the Comparison B-A study uses a group of control sites selected as being similar to the treatment site if no treatment had been implemented. Expected number of crashes obtained for the 10-mile summit study site within the period 2001-2010 was 24.72 using the Empirical Bayes B-A Study whereas the Comparison group B-A Study yielded a reduction in the expected number of crashes by 2.53 per year.
The main objective of performing a Benefit-Cost analysis (BCA) on the U.S. 93 Highway Wildlife Overpass was to determine whether the question of having wildlife crossings at high DVC locations is economically justifiable. Moreover, there was the need to identify its effect on mule deer population levels due to high levels of mortalities as a result of DVCs. ‘Benefits’, which includes both monetary and safety appeared to outweigh the cost of construction and maintenance. ‘Costs’ which are generally easier to quantify includes resources expended on the project (right-of-way, labor, equipment and materials), design, implementation, maintenance and removal efforts, initial cost and costs associated with deer-vehicle collisions. Applying a present worth factor model yielded a Net Present Worth of approximately $3,972,269 million and a Benefit-Cost ratio of 1.58. A Benefit-Cost ratio greater than one signifies a project worth investing in.

Deer-vehicle collision data and carcass removal data were analyzed to identify the discrepancies between the two dataset. Crash data and the carcass removal data were not combined due to data limitations and sample size. Separate analysis was made to identify patterns that exist between them. A correlation might exist between these two data sets if appropriately reported. However, no correlation between the two datasets was identified upon analyzing the datasets. A tremendous success rate for overpass use by mule deer was identified. Out of the 16,503 total successful migrations of mule deer documented for all five wildlife crossings, 12,522 of the migrations occurred on the wildlife overpass located at the 10-mile Summit site.

An analysis of the proportions of successful crossings was made on each facility and it was found that 95.75 percent of all total migrations combined were recorded from the wildlife overpass under study as indicated in Table 5-6. Previous studies showed that deer
naturally avoid confining spaces where a means of escape does not appear to be clear. However, underpasses have been found to be effective tools in reducing highway mortalities as well (11). In conclusion, wildlife overpasses in conjunction with fencing is highly effective in reducing deer-vehicle collisions.

6.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the outcome of this research, several areas were identified for further research:

1. For more accurate and precise results for an Empirical Bayes estimate, a Nevada specific Safety Performance Function (SPF) is recommended. Thus, it is recommended that SPFs and Accident Modification Factors (AMFs) be developed for the State of Nevada.

2. It is recommended that when feasible and available, DVCs and large-animal carcass removal data and locations are used in combination to help define the magnitude and patterns of this safety concern both statewide and along specific corridors.

3. Double counting of animal–vehicle collisions should be avoided; e.g., one should ignore deer carcass removals that occur at the same time and location as a reported DVC. In this case, the attributes collected with the animal or deer removal (e.g., gender, estimated age, and species) might be transferred, if possible, to the reported DVC database.

4. Plans for new highways should avoid bisecting high quality animal habitats. Highways going through high quality animal habitats have negative effects on animal activities and ecology. In addition, animal movements between bisected habitats increase highway-crossing activities and hence increase the probability of AVCs.
5. Development and implementation of specific guidelines and standards for collecting and reporting DVCs as well as evaluation of mitigation measures is recommended.
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