

RESEARCH



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EFFECTIVENESS OF WILDLIFE FENCING AT REDUCING CRASHES

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Utah Department of Transportation
Research & Innovation Division

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16. Abstract Wildlife-vehicle collisions (WVCs) pose serious risks to motorist safety and contribute significantly to wildlife mortality. Wildlife fencing serves as a proven countermeasure to mitigate WVCs while promoting habitat connectivity. This study evaluates the safety effectiveness of wildlife fencing installed across Utah from 2011 to 2023, using traffic volume, herd size, migration patterns, and urban/rural context as explanatory variables. A total of 54 (138 miles) treated sites and 90 (583 miles) matched control sites were analyzed using safety performance functions and empirical Bayes methods. Results indicate a crash modification factor (CMF) of 0.25 for total wildlife-related crashes equating to a 75% reduction. CMFs for fatal/injury crashes and property damage-only (PDO) crashes were 0.15 and 0.26, respectively, demonstrating reductions of 85% and 74%. The CMF for total WVCs in only migration areas was 0.13, indicating a greater reduction compared to all sites taken together. It was seen that wildlife fencing creates a greater reduction in WVCs in migration areas of about 87% in these sensitive zones compared to other areas. Low standard errors and narrow 95% confidence intervals reinforce the statistical reliability of the results. Overall, the data strongly supports wildlife fencing as a highly effective safety countermeasure with consistent impact across all crash scenarios in this study. Findings support continued investment in targeted safety interventions across migration corridors. Economic analysis yielded a benefit-cost ratio of approximately 2.0 (at a 3% discount rate), confirming that wildlife fencing is a highly effective and cost-efficient strategy for improving roadway safety and supporting wildlife conservation.					
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UNIT CONVERSION FACTORS

Units used in this report and not conforming to the UDOT standard unit of measurement (U.S. Customary system) are given below with their U.S. Customary equivalents:

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. (Adapted from FHWA report template, Revised March 2003)

LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
AIC	Akaike Information Criterion
BACI	Before-After-Control-Impact
CMF	Crash Modification Factor
DVC	Deer-Vehicle Collision
DWR	Utah Division of Wildlife Resources
EB	Empirical Bayes
EVC	Elk-Vehicle Collisions
FHWA	Federal Highway Administration
GIS	Geographic Information System
GLM	Generalized Linear Models
MVC	Moose-Vehicle Collisions
NB	Negative Binomial
PDO	Property Damage Only
SPF	Safety Performance Function
UDOT	Utah Department of Transportation
UVC	Ungulate-Vehicle Collision
WVC	Wildlife-Vehicle Collision

EXECUTIVE SUMMARY

Wildlife-vehicle crashes (WVCs) are a significant safety concern for vehicle drivers and are a major source of wildlife mortality. Wildlife-fencing is a safety countermeasure to mitigate WVCs and enhance wildlife conservation efforts. The intent of this project is to determine the effectiveness of wildlife-fencing installation in the state of Utah, including the development of crash modification factors (CMFs) for WVCs.

A crash data analysis was conducted using Utah Department of Transportation (UDOT) crash data. Reported WVCs totaled 39,035 from 2010 to 2024, with a significant majority of crashes occurring in rural areas (24,730 or 63%), highlighting the elevated risk in areas where wildlife habitats are more prevalent, and roadways intersect migration corridors. It also revealed that most WVCs in the state of Utah were non-injury, however, a significant number of WVCs still resulted in injury or fatality.

Carcass data was obtained from UDOT for the years 2010 to 2024. The data shows a consistent gap between reported WVCs, and the number of carcasses removed from roadways. On average, carcass counts were 50 to 60% higher than crash counts, suggesting that many incidents involving minimal vehicle damage go unreported. The project team then identified highway locations and projects where wildlife-fencing has been installed, with emphasis on projects constructed between 2013 and 2020 such that adequate before/after data could be established. Additional comparison sites were also identified where wildlife-fencing has or is being considered. The project team then performed data collection of the project locations, which included gathering information about the type of fencing installed, locations of available animal crossings, crash history, carcass data, and traffic volume, among others. Finally, safety performance functions were developed, and CMFs were calculated using the empirical Bayes (EB) methodology for various crash types. Understanding the safety effectiveness of wildlife-fencing is essential for promoting both public safety and biodiversity and grows in importance as road networks increasingly intersect natural habitats. This study investigated the safety effectiveness of existing wildlife-fencing installed in the state of Utah between 2010 and 2023. Additionally, traffic volume, wildlife herd size, migration area usage type, and urban versus rural were included as explanatory variables for safety performance functions.

The study evaluated 54 treated sites with wildlife-fencing installations and 90 control sites with similar characteristics. A CMF is a numerical estimate that tells us how a safety treatment is expected to affect crash frequency. A CMF less than one means fewer crashes. A CMF greater than one means more crashes. A CMF of 0.251 for total WVCs was estimated showing that wildlife-fencing has the potential to reduce 74.9% of total wildlife related crashes. The CMFs for fatal and injury crashes and property damage only (PDO) crashes were also investigated. The CMF for fatal and injury crashes was found to be 0.154, showing that wildlife-fencing has a positive effect in reducing fatal and injury crashes by 84.6%. Similarly, it was observed that the CMF for the PDO crashes was 0.257, indicating a crash reduction of 74.3%.

The project team conducted a benefit-cost analysis for wildlife-fencing, offering a more empirical approach than previous methods. Traditionally, wildlife mitigation projects have been justified using only crash history and speculative assumptions about crash reduction benefits. The economic analysis indicates that the implementation of wildlife-fencing will yield benefit-cost ratios of approximately 2 with a 3% discount rate. The findings provide transportation agencies with robust, data-driven justification for investing in wildlife-fencing as a proven safety measure. The project enhanced the justification for wildlife-fencing, offered a framework for evaluating future projects, and contributed to both transportation safety and wildlife conservation efforts.

1.0 INTRODUCTION

1.1 Problem Statement

Approximately 29,000 injuries and 200 fatalities occur annually due to wildlife-vehicle collisions (WVCs) in the U.S. (IIHS, 2020; NHTSA, 2021). The estimated economic impact of these crashes is approximately \$8 billion annually (Huijser, M.P., et al., 2008). The consequences of WVCs extend beyond immediate human safety concerns. WVCs result in significant economic costs, including vehicle damage, medical expenses, and increased insurance premiums. The WVC Reduction Study, by the Federal Highway Administration (FHWA), found that 12 federally endangered or threatened species are directly imperiled by U.S. roadways. Over one million WVCs occur each year in the U.S. (Huijser, M.P., et al., 2008).

A general upward trend in deaths from collisions with animals occurred from 1975 to the mid-2000s. Deaths increased from 89 in 1975 to 223 in 2007, with the latest available data of 184 deaths in 2022. In 2022, the highest number of deaths from collisions with animals occurred July-September (IIHS, 2023). More recent data from State Farm suggests the most dangerous months for WVCs are, in order, November, October, and December (State Farm 2024).

The impact of WVCs on safety and on wildlife populations has been receiving increased attention. Mitigation efforts often focus on reducing collisions with large hooved mammals such as deer. Auto insurance estimates indicated that U.S. motorists had a 1 in 128 chance of colliding with an animal in 2024. State Farm estimated that over 1.8 million auto insurance claims involving WVCs were filed across the industry from July 1, 2023, to June 30, 2024. Deer-vehicle collisions (DVCs) are estimated to be among the costliest collision types in Virginia, averaging more than \$533 million per year (Donaldson, 2017).

Wildlife-fencing is a safety countermeasure to mitigate WVCs and enhance wildlife conservation efforts. Understanding the safety effectiveness of wildlife-fencing is essential for promoting public safety and biodiversity, and mitigation measures grow in importance as road networks increasingly intersect natural habitats. WVCs are a significant safety concern and a major source of wildlife mortality globally. Previous studies have evaluated the effectiveness of wildlife-fencing in reducing WVCs but have yet to produce a viable crash modification factor

(CMF). The implementation of wildlife-fencing aims to mitigate these crashes by preventing wildlife from accessing roadways, or guiding wildlife to grade-separated crossings, thereby protecting both human life and animal populations. WVCs are a significant and growing concern, posing risks to both human safety and wildlife populations. As road networks expand and urban areas encroach on natural habitats, understanding the patterns, impacts, and mitigation strategies related to WVCs has become increasingly important.

1.2 Objectives

The intent of this project is to establish a CMF for wildlife-fencing installation. The CMF was developed using the [CMF Clearinghouse guide](#) including accuracy, precision, and general applicability of results (FHWA, 2021). Common characteristics of a high-quality CMF include statistically rigorous reference groups, adequate sample size, diverse geographies and sites, small standard errors, and controls for potential bias.

The study analyzed historical data on wildlife-related crash severity in Utah. It examined the distribution of crash severities and compared wildlife crash outcomes to other crash type distributions and economic cost. The study also identified a benefit-cost ratio for installing wildlife fencing. Wildlife-fencing projects are currently identified and prioritized using only crash history with an expectation that crashes will reduce after installing the fencing. This project helps quantify the expected reduction in crashes and associated economic benefit, thus providing a comparison of safety benefits to other safety projects. The study also provides a historic severity distribution for wildlife crashes and compares that severity distribution to other crash types.

1.3 Scope

The project had three main activities. The project team first identified highway locations and projects where wildlife fencing has been installed, with emphasis on projects constructed between 2013 and 2020 such that adequate before/after data could be established. Additional comparison sites were also identified where wildlife fencing is not installed. The project team then performed data collection of the project locations, which included gathering information

about the type of fencing installed, locations of available animal crossings, crash history, carcass data, and traffic volume, among others. Finally, an empirical Bayes (EB) statistical analysis was performed as a before/after study to determine the CMF.

1.4 Outline of Report

This report includes six chapters. The Introduction outlines the research needs and objectives of this research. The Literature Review chapter reviews the existing research. The Data Collection chapter identifies the locations and data collected, as well as summary statistics. The Methodology and Results chapter describes the data utilization and statistical methodology along with the results from the analysis. The Conclusions chapter includes a summary of findings. A Recommendations and Implementation chapter provides an implementation strategy for using the CMF and results for prioritizing future wildlife-fencing projects.

2.0 LITERATURE REVIEW

2.1 Overview

This chapter includes a literature review of relevant research as well as a discussion of before/after studies that is the statistical methodology used for this research.

2.2 Literature Review

Much research has been devoted to determining the effectiveness of various countermeasures in reducing WVCs. This literature review examines the findings from various studies, and reports on the identified effectiveness of wildlife fencing in reducing crash rates.

Fencing is one of the most applied measures to separate wildlife from motorists (Romin et al., 1996). Wildlife fence typically consists of 6.0-8.0 foot- (2.0–2.4 m) high wire-mesh fence material. Several types of fence material are used, with page wire or cyclone fence material being the most common. Wooden or metal fence posts are typically used, and the latter is particularly important when fencing over rock substrates.

Wildlife fences are effective at reducing WVCs but may increase the barrier effect of the road. A 94 to 97% reduction in ungulate-vehicle collisions (UVCs) was observed along fenced sections of the Trans-Canada Highway (Woods, 1990). Other locations showed fencing was effective in reducing vehicle collisions with ungulates by 80% (Clevenger et al., 2001). Dodd and others found that wildlife fencing in combination with underpasses reduced elk-vehicle collisions (EVCs) by 86.8% (Dodd et al., 2007). Reed reported an average reduction of 78.5% for DVCs in Colorado, and Ward reported a reduction of greater than 90% for DVCs in Wyoming (Reed et al., 1982; Ward et al., 1982). Clevenger identified that WVCs were closer to fence ends than expected by chance; however, access points (fence gaps) were not WVC hotspots along the Trans-Canada Highway in Banff National Park, Alberta (Clevenger et al., 2002).

Adding fences along a highway to connect existing underpasses is an effective way to enhance existing infrastructure. Approximately 1.6 km (0.994 miles) of 2.4-m (7.87 feet) high wildlife fencing was added to connect two existing underpasses, situated approximately 8 km

apart on Interstate 64 in Virginia (Donaldson et al., 2021). The two underpasses consisted of a bridge underpass and a large box culvert. The study used cameras to monitor animal crossings for 2 years after the fence was installed and compared the crossing data with 2 years of collision data prior to the fence being installed. After the fence installation, DVCs were reduced by 96.5% at the box culvert and 88% at the bridge underpass, and there were no increases in DVCs within 1.6 km of the fence ends. Deer crossings increased 410% at the box culvert and 71% at the bridge underpass. Use of the culvert and bridge underpasses by other mammals increased by 81% and 165%, respectively.

Studies conducted in the southwestern United States have shown that fencing to connect existing underpasses is an effective means of reducing wildlife crashes regardless of whether the underpasses were designed for wildlife. The benefits from crash reduction exceeded the fencing costs in 1.8 years, and fencing resulted in an average savings of greater than \$2.3 million per site over the 25-year life expectancy of the fencing (Donaldson et al., 2020). The study found that the addition of wildlife fencing to certain existing isolated underpasses can be a highly cost-effective means of increasing driver safety and enhancing habitat connectivity for wildlife. Other studies show DVCs were reduced by 92% on average after fence installation, with deer crossings increasing significantly at the underpasses. EVCs were reduced by 85 to 97% in Arizona after fencing was constructed to connect wildlife crossing structures (Dodd et al., 2007; Gagnon et al., 2010). Similarly, EVCs decreased by 97% after the height of 0.9-m fencing was increased to 2.4 m between 2 large bridges and interchanges along I-17 in Arizona; the use of these bridges by elk increased by 217% and 54% (Gagnon et al., 2015).

The success of wildlife crossings (overpasses or underpasses) with fencing was studied to compare the costs of construction to effectiveness at reducing WVCs (Clevenger and Huijser, 2011; Kintsch et al., 2020). Implementation of wildlife crossings reduced vehicle collisions with deer and elk by more than 80%, and more than 90% in several studies (Kintsch et al., 2020).

Appropriate application of wildlife-fencing leads to substantial decreases in wildlife mortality and injury crashes, thereby enhancing road safety (Huijser et al., 2008). Wildlife fencing can be designed to prevent large animals from accessing the road right-of-way.

- **Height and Visibility:** Fences should typically be at least 8 feet (2.4 meters) high to prevent large mammals from jumping over. Visibility markers (e.g., flags or reflective tape) can help reduce accidental collisions with the fence, especially for birds and fast-moving animals.
- **Wildlife Crossings:** Dedicated wildlife underpasses or overpasses are preferred. These structures should be strategically placed based on known animal movement patterns and migration corridors, and fencing should funnel animals toward these safe crossing points.
- **Fence Design:** Use designs that minimize harm to wildlife. For example, post-and-rail fences are highly visible and allow for easy passage. Worm fences, also known as snake fences or zigzag fences, offer a rustic, attractive option that's kind to wildlife.
- **Location and Placement:** Analyze the landscape features and habitats that need to be reconnected to provide suitable locations for wildlife passages. Fencing should be provided in areas where collisions are particularly common and should guide animals to safe crossing points.
- **Materials and Maintenance:** Choose materials that match the target species' requirements and ensure the fence is properly anchored to the ground. Regular maintenance is essential to keep the fence effective and safe for wildlife.
- **Ecological Impact:** Assess the potential ecological impact of the fence, particularly in areas of major ecological interest, such as habitats of endangered species or ecological corridors. Mitigation measures should be implemented to avoid any adverse impacts.

By considering these factors, wildlife fencing can be designed to effectively reduce wildlife mortality and enhance road safety while maintaining ecological balance. Fence designs vary and may include shorter “drift” fences for amphibians or taller fences designed for large mammals (Boyle et al., 2021). Fencing may be accompanied by wildlife crossing structures, which maintain or restore safe wildlife movement across the highway. Because of cost, fencing is usually prioritized along particular road segments or WVC “hotspots” (Huijser et al., 2016).

Wildlife fencing has proven to be effective in reducing WVCs. Several factors influence performance, such as fence design and installation, wildlife crossing design, species-specific considerations, and maintenance and monitoring. The type of fence used, whether it is wiring mesh or solid barriers, and its height is critical for preventing wildlife from penetrating the

roadway. Crossings need to be designed to accommodate the size and behavior of the local species. Larger mammals, like deer, may be deterred by tight spaces or high fencing, whereas smaller animals may require culvert crossings and guide fencing with a smaller grid pattern. Additionally, fences can become damaged or degraded over time, reducing their effectiveness in preventing animal crossings. Regular maintenance and monitoring are essential to keeping the wildlife-fencing effective (Clevenger & Waltho, 2000; Huijser et al., 2016; McCollister & Van Manen, 2010).

Improving underpasses can mitigate WVCs and improve habitat connectivity. Adding fencing along the roadway to guide animals toward underpasses significantly reduces WVCs, with one study finding a 50-70% reduction in WVCs (Clevenger et al., 2001). The effectiveness of fencing was significantly enhanced when combined with wildlife crossings such as underpasses and overpasses. This enhancement protects wildlife and facilitates better movement between habitats, ultimately contributing to ecosystem health. Another study found that fencing led to a 90% reduction in WVCs (Huijser et al., 2008). Some studies highlight the importance of infrastructure modifications in wildlife conservation efforts, and in maintaining fences to prevent wildlife from entering the roadway. For example, research on the A50 highway in the Netherlands indicated a reduction in WVCs by as much as 70% after the installation of wildlife fencing (LiquiSearch, n.d.). The study also highlighted the importance of monitoring fence integrity and ensuring that fencing was continuous and without gaps. The distance between underpasses also influences animal habitat. Some animal species are less likely to reach an underpass when traveling along longer exclusionary fence lines (McCollister and Van Manen 2010). Wildlife fencing can adversely affect populations that access resources on both sides of the road when the fencing is not combined with an accessible underpass (Jaeger and Fahrig, 2003).

The design of fence ends is particularly important to minimize “end runs,” whereby an animal circumvents the fencing by traveling from the habitat side of the fence end to the roadside. Clevenger et al. (2001) found an increase in UVCs within one km of fence ends, although the authors concluded that major drainages near the fence end likely influenced these occurrences. Conversely, Bissonette and Rosa (2012) and Gagnon et al. (2015) found no increases in WVCs at fence ends. The risk of end runs can be minimized by tying the fence ends

into areas of steep topography or other obstacles that create difficulty for the animal to circumvent the fence end (Huijser et al., 2015; Jared et al., 2017).

In Sweden, fencing reduced moose-vehicle collisions (MVC) by 80%. Boarman et al. (1996) found 93% fewer tortoise carcasses and 88% fewer vertebrate carcasses along a fenced section compared to an unfenced section of highway. In British Columbia, exclusion fencing (2.4 m (8 ft) high on both sides) was 97 to 99% effective at reducing crashes with large wildlife. In Pennsylvania, Feldhamer and others determined that a 2.7-m (8.9-ft)-high fence was more effective than the 2.2-m (7.2-ft)-high fence. Pennsylvania saw that deer breached the fence despite changing the height of fences. Feldhamer suggested fencing may be effective if properly maintained to fix holes which were damaged by people, and by decreasing the size of the openings on the woven wire mesh.

Ahmed et al. 2022 estimated the CMFs for WVC countermeasures, crossing structures with fencing, and wildlife warning signs using cross-sectional analysis. The study used carcass removal data and traditional crash data and estimated CMFs of 0.66 and 0.55 using the carcass data and crash data, respectively. The results also suggested that implementing wildlife warning signs on WVC hotspots has been ineffective, but the crossing structures are found to be effective. Table 2-1 summarizes key literature related to wildlife fencing.

Table 2-1 Wildlife Fencing Literature Review List

	Study	Authors	Location	Findings
1	Wildlife-Vehicle Collision Reduction Study: Report to Congress	M.P. Huijser, P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith, and R. Ament	USA	Wildlife fences may reduce road mortality by 80–99%.
2	Enhancing Existing Isolated Underpasses with Fencing to Decrease Wildlife Crashes and Increase Habitat Connectivity	Bridget M. Donaldson and Kaitlyn E.M. Elliott	Arizona	After fencing installation, DVCs were reduced by 92% on average (96.5% and 88% at the box culvert and bridge underpass, respectively).
3	Investigating the Safety Effectiveness of Wildlife–Vehicle Crash Countermeasures Using a Bayesian Approach with a Comparison Between Carcass Removal Data and Traditional Crash Data	Irfan U. Ahmed and Mohamed M. Ahmed	Wyoming	The crossing structures with fencing are found to be effective, with an estimated CMF of 0.66 and 0.55 using carcass data and crash data, respectively.
4	Enhancing Existing Isolated Underpasses with Fencing Reduces Wildlife Crashes and Connects Habitat	Bridget M. Donaldson and Kaitlyn E. M. Elliott	Virginia	DVCs were reduced by 96.5% and 88% at the box culvert and bridge underpass, respectively. Valued a DVC at \$8,936. 99% of the deer carcasses as Property Damage Only (PDO) and 1% minor injury crashes.
5	Role of Fencing in Promoting Wildlife Underpass Use and Highway Permeability	Dodd, N. I., Gagnon, J. W., and Boe, S. et al.	Arizona	After fencing, the incidence of elk collisions declined by 87%. Used crossing rates and passage rates. The proportion of elk crossings that occurred along fenced highway stretches declined 50% while the proportion of crossings along unfenced highways increased 40%. Fencing plays an important role in reducing the incidence of WVCs and increasing the effectiveness of wildlife passage structures.
6	Advances in Wildlife Crossing Technologies	Mary Gray	NA	Latest tools to reduce animal-vehicle collisions and save the lives of both motorists and animals.
7	Impact of Road Fencing on Ungulate–Vehicle Collisions and Hotspot Patterns	Andrius Kucas and Linas Balciauskas	Lithuania	Assessed the effect of annual average daily traffic (AADT) and wildlife fencing on UVCs using regression analysis of changes in annual UVCs and UVC hotspots on different categories of roads.
8	Deer–Vehicle Collision Prevention Techniques	Lauren L. Mastro, Michael R. Conover, and S. Nicole Frey	Utah	Despite a limited amount of data, multiple studies have shown that properly installed and maintained fences combined with wildlife crossings are the most effective method of reducing DVCs.
9	Construction Guidelines for Wildlife-Fencing and Associated Escape and Lateral Access Control Measures	Marcel P. Huijser, Angela V. Kociolek, Tiffany D.H. Allen, and Patrick McGowen	Various	Describes the current state of knowledge and practice regarding the design, implementation, and maintenance of wildlife fencing and associated escape and lateral access control measures.
10	Implementing Wildlife Fences Along Highways at the Appropriate Spatial Scale: A Case Study of Reducing Road Mortality of Florida Key Deer	Marcel P. Huijser and James S. Begley	Florida	The (before-after-control-impact) BACI analysis showed that the wildlife fence and associated mitigation measures were highly effective (95%) in reducing deer-vehicle collisions along the mitigated highway section.

2.2.1 Patterns and Causes of WVCs

WVCs are more prevalent in certain geographic areas and at specific times of the year, particularly regions where wildlife habitats intersect with major roadways. Huijser et al. (2009) highlights that the rural areas with high wildlife populations, such as parts of the Midwest and West, experience higher rates of WVCs. Seasonal patterns also contribute to the occurrence of WVCs, with peaks observed during spring and fall, coinciding with animal migrations and breeding behaviors.

Key factors contributing to WVCs include roadway characteristics, vehicle speed, and wildlife behavior. High-speed roads increase the likelihood of fatal collisions, as the reaction time for drivers decreases. Additionally, certain species, such as deer, are more frequently involved in WVCs due to their behavior and habitat preferences.

2.2.2 Mitigation Strategies of Different States

In 2012, the Wyoming DOT completed construction of two wildlife overpasses and six underpasses, along with twelve miles of fencing to lead animals to these crossings above or below the highway. In the three years after construction, tens of thousands of animals used the structures and WVCs were reduced by 80%. The project also contributed to healthier populations of migrating animals by allowing them to safely cross the highway.

A Colorado project completed in 2016 included two wildlife overpasses, five underpasses, a widened shoulder, and fencing with “escape ramps” for animals. The changes reduced crashes by almost 90% on Highway 9 through the Blue River Valley by the second winter following construction. The study indicated the safety benefit of the project will pay for construction costs by around 2036.

California is working on the Wallis Annenberg Wildlife Crossing which will be the largest wildlife crossing in the world, scheduled to be completed in Fall 2026. The crossing will stretch across ten lanes of traffic that crisscross a habitat home to an abundance of wildlife including a protected species of mountain lion, twenty-five of which have been killed crossing these lanes prior to this project.

2.2.3 Cost-Benefit Analysis

Several studies have conducted cost-benefit analyses of wildlife-fencing. Huijser et al. (2008) found that the reduction in vehicle damage, medical costs, and human fatalities due to fewer crashes often outweighed the cost of installing wildlife fencing and crossings. The authors concluded that investing in wildlife fencing is economically justifiable in high-collision areas.

- **Direct Costs:** WVCs result in significant direct costs, including vehicle repair, medical expenses, and the loss of wildlife. These costs can be substantial, especially when larger animals like deer or elk are involved.
- **Indirect Costs:** Indirect costs include traffic delays, emergency response, secondary crashes, and the impact on local economies. These costs can be difficult to quantify but are nonetheless significant.
- **Cost-Benefit Analysis:** Cost-benefit analyses of various mitigation measures, such as wildlife crossings and fencing, can be conducted. These measures can be expensive to implement, but the long-term benefits, including reduced WVCs and reduced loss of wildlife, can outweigh the costs when crash frequency and severity is sufficiently reduced.

The estimated cost of the average WVC based on property damage, human injuries, and human fatalities is \$6,126. Over 95% of all WVCs result in property damage only (PDO) crashes as shown in Table 2-2, with the average cost per incident estimated at \$2,451.

Table 2-2 Average WVC Cost

Crash Severity	Crash Cost (\$)	Distribution of Collisions (%)	Contribution of Cost of Average WVC (\$)
Property damage only	2,570	95.4	2,451
Possible human injury	24,418	2.3	572
Evident human injury	46,266	1.8	809
Incapacitating/severe human injury	231,332	0.5	1,083
Human Fatality	3,341,468	0.04	1,210

One study estimated that WVCs result in an average of 0.05 human injuries when colliding with deer, 0.10 human injuries for elk, and 0.20 human injuries for moose (Huijser et

al., 2008). When these proportions are combined with the relative frequency for each of the three injury categories (51.4% for possible human injuries, 38.4% for evident human injuries, and 10.3% for incapacitating or severe human injuries), it results in the cost estimates for human injuries by species presented in Table 2-3. The research emphasizes investing in mitigation measures to reduce the economic impact of WVCs and improve safety for humans and wildlife.

Table 2-3 Cost Estimate per Crash for Human Injuries by Species

Type of Human Injury	Deer	Elk	Moose
Possible	\$627	\$1,254	\$2,508
Evident	\$887	\$1,775	\$3,550
Incapacitating/Severe	\$1,187	\$2,374	\$4,749
Total	\$2,702	\$5,403	\$10,807

2.3 Summary and Conclusion

Numerous studies have shown that wildlife fencing, especially when paired with crossing structures, is highly effective in reducing WVCs. Crash reductions range from 80% to 99%, with notable successes reported in states like Arizona, Virginia, Florida, and Wyoming. Wildlife fencing enhances motorist safety and promotes habitat connectivity by guiding animals to safe crossing points. Research approaches vary from crash data analysis and carcass removal tracking to hotspot modeling and EB evaluation, all pointing to the significant role fencing plays in minimizing roadkill and facilitating wildlife movement. Guidelines for design, implementation, and maintenance continue to evolve, supported by advancements in technology and best practices documented by experts like Huijser, Donaldson, and Gray.

Research confirms that wildlife fencing is one of the most effective countermeasures for reducing WVCs. Fencing, which is typically 2.0 to 2.4 meters high and made of wire mesh, is most effective when paired with underpasses or overpasses, which provide safe wildlife crossings and enhance habitat connectivity. Studies in Virginia, Colorado, Arizona, and Canada show dramatic reductions in deer and elk collisions when fencing connects existing underpasses, even those not originally designed for wildlife. Fence design and placement are critical; poorly maintained or improperly designed fences can inadvertently create hazard zones or obstruct wildlife movement. Effective wildlife fencing must consider species-specific needs, ecological context, and landscape features, incorporating elements like visibility markers, gates, and regular

maintenance. Combining fencing with crossing structures improves ecosystem health and road safety, but planners must ensure connectivity for all animals especially where exclusionary fences may limit access to essential resources. Wildlife fencing is a valuable strategy for mitigating the negative conflicts between wildlife and humans on roads..

3.0 DATA COLLECTION

3.1 Overview

This chapter describes the data sources for WVCs and for carcass data used in the project. The chapter also describes the extraction methodology used to identify and gather the data.

3.2 Data Sources

Two types of wildlife datasets were used in the analysis: police-reported crash data where the first harmful event identified a wildlife-related crash, and carcass removal data that includes geolocation of wildlife carcass location and is used as evidence of WVC.

Police-reported crash data are made when law enforcement responds to a crash. Reported WVCs are identified based on the first harmful event being contact with a wild animal, which excludes domestic or livestock animals from the crash dataset. The police reports offer detailed insight into the crash circumstances, vehicle and driver information, and location. However, police reports tend to underrepresent the frequency of WVCs. Incidents involving minor vehicle damage are often not reported to police, or if there is a response, the damage may not meet reporting thresholds. This type of non-reporting leads to data gaps and a bias toward more severe collisions. Furthermore, police reports rarely include ecological specifics such as animal species or behavior, which limits the usefulness in wildlife conservation analysis.

Carcass removal data is collected by agencies tasked with clearing wildlife carcasses from roadways. This data may capture events missed by police reports, offering additional spatial and ecological context, such as the frequency and distribution of species killed. However, carcass data is also incomplete. If an animal survives the crash or wanders off and dies elsewhere, it won't be accounted for. Similarly, carcasses may be removed or eaten by other animals before being logged. These limitations highlight that both data sets are imperfect and often fail to account for the full spectrum of wildlife incidents.

Integrating police reports and carcass data sources improves the accuracy and completeness of WVC analyses (Ahmed et al., 2022). Combining police and carcass data allows

researchers to identify reporting overlaps, estimate CMFs more reliably, and model crash patterns with greater precision. When police reports and carcass data are used together, the analysis provides a more holistic understanding of collision risk, ecological impact, and the effectiveness of mitigation strategies like wildlife fencing and crossing structures.

3.3 Reported Crash Data

WVC crash data from the Utah Department of Transportation (UDOT) was obtained for the years 2010 to 2024, as shown in

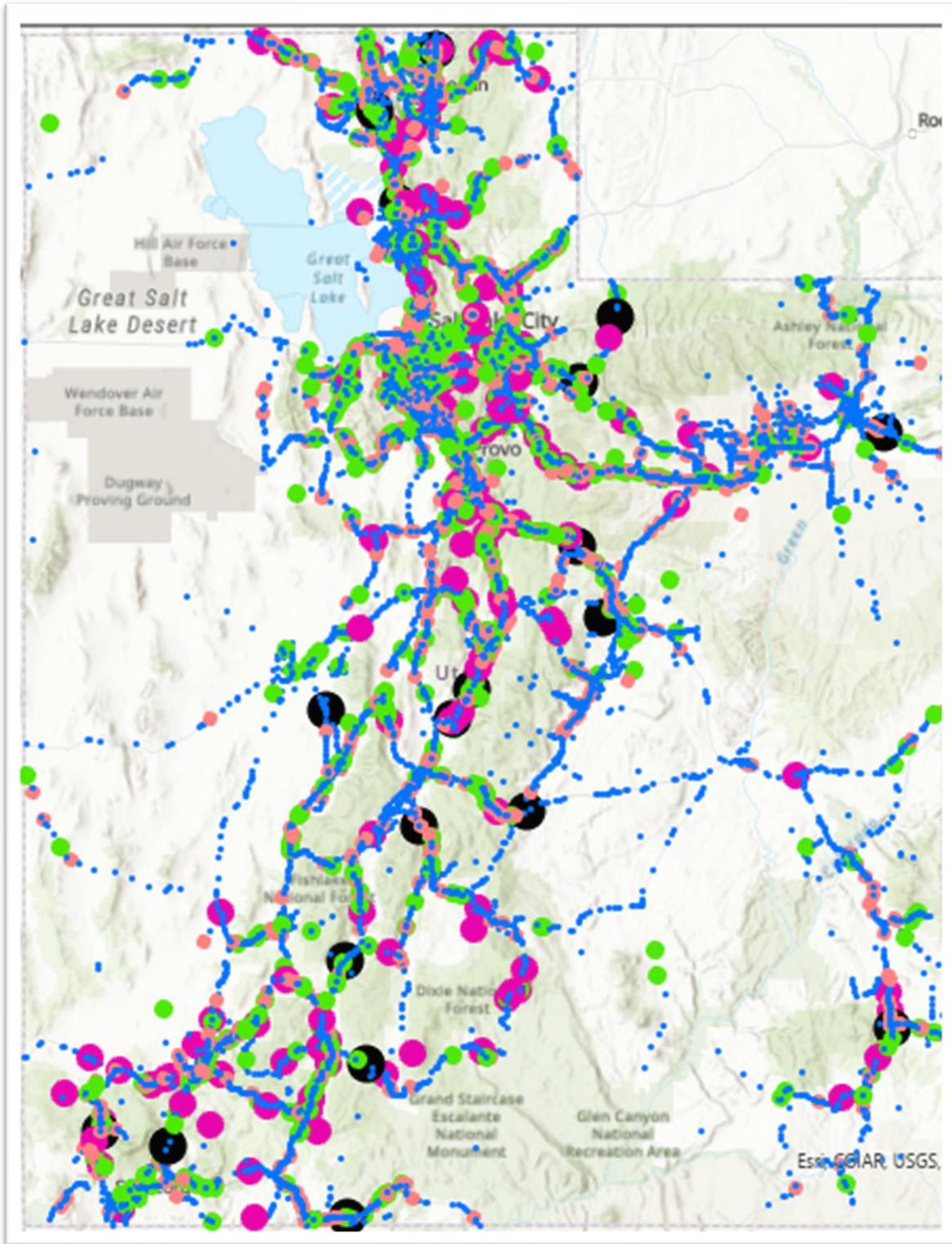


Figure 3.1. Domestic animal crashes were excluded from the study. Table 3-1 shows the count of crashes for the study period and crash severity distribution. The distribution highlights that most WVCs result in a PDO crash, however, a significant number of WVCs are injury and even fatal

crashes. Nearly all WVCs involved a single vehicle, accounting for 98.4% of the 39,035 total crashes. The crash type distribution of WVCs is shown in

Table 3-2, and the proportion of crashes by the number of vehicles involved is shown in Table 3-3. Multi-vehicle incidents such as front-to-rear, angle, sideswipe, and parked vehicle were rare, with just 532 crashes (1.4% of total WVC crashes) involving two vehicles and only 84 crashes (0.3%) involved three or more vehicles. This pattern reinforces that wildlife collisions typically occur in isolated incidents, often when a driver unexpectedly encounters an animal and other vehicles are not nearby. The minimal presence of multi-vehicle crashes highlights the importance of targeted mitigation strategies like fencing and wildlife crossings to prevent single-vehicle crashes.

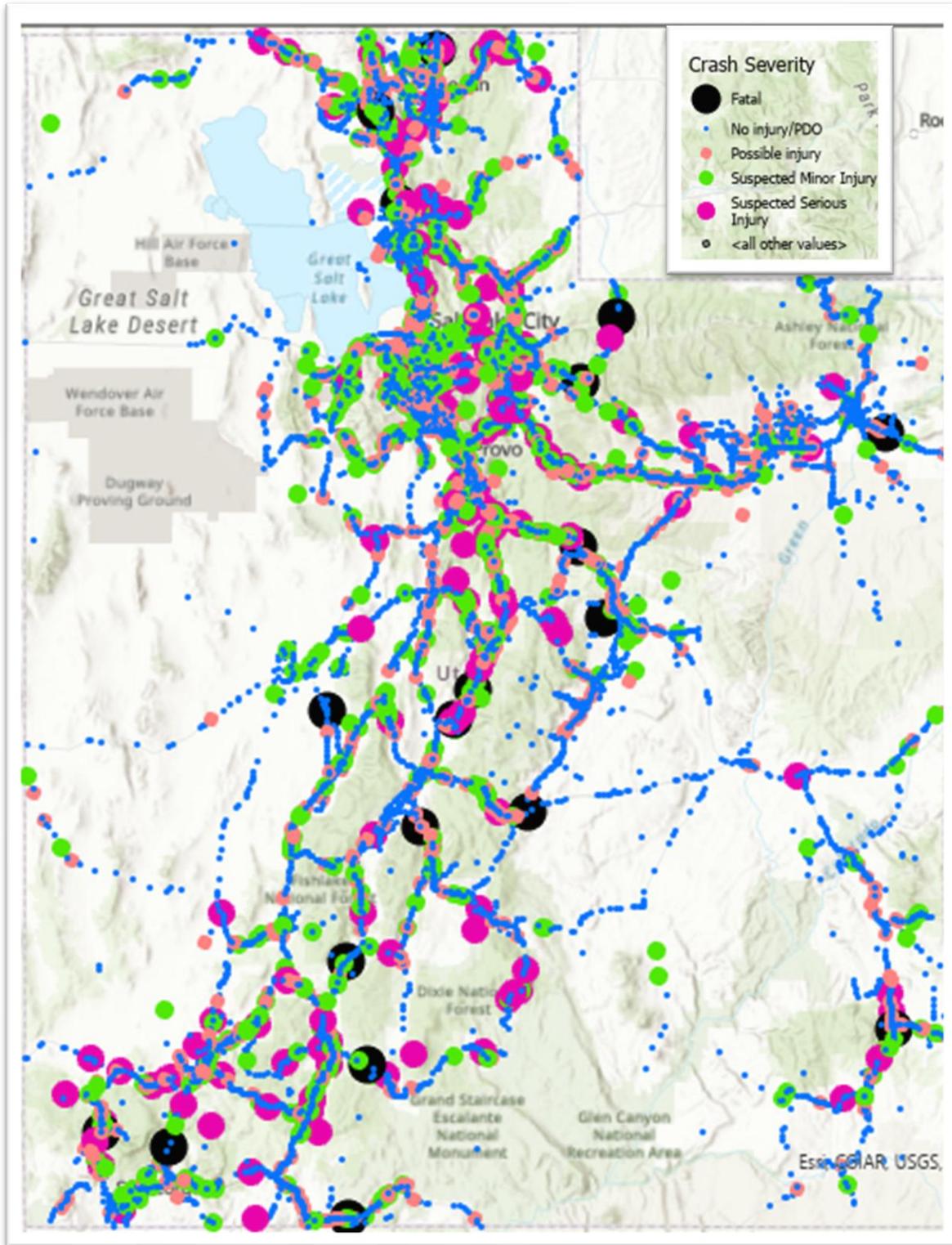


Figure 3.1 WVC data from 2010 to 2024

Table 3-1 Reported Wildlife Crashes by Injury Severity 2010-2024

Crash Severity	Crashes	Proportion
Fatal	19	0.05%
Suspected Serious Injury	157	0.40%
Suspected Minor Injury	964	2.47%
Possible Injury	1,465	3.75%
No injury/PDO	36,430	93.33%
Total	39,035	100.0%

Table 3-2 Crash Frequency of Wildlife Crashes by Crash Type

Manner of Collision	Crashes	Proportion
Rear to Side	1	0.00%
Rear to Rear	2	0.01%
Head On (front-to-front)	9	0.02%
Sideswipe Opposite Direction	11	0.03%
Sideswipe Same Direction	23	0.06%
Parked Vehicle	24	0.06%
Angle	38	0.10%
Unknown/Other	73	0.19%
Front to Rear	123	0.32%
Not Applicable/Single Vehicle	38,731	99.2%
Total	39,035	100%

Table 3-3 Crash Frequency of Wildlife Crashes Involving Multiple Vehicles

No of vehicles	Crashes	Proportion
1	38,419	98%
2	532	1.4%
3	66	0.17%
4	12	0.03%
5	3	0.01%
6	3	0.01%
Total	39,035	100%

Lighting conditions heavily influence WVCs with the highest number of crashes occurring in dark, unlighted conditions (23,405), shown in Figure 3.2. Decreased visibility significantly increases the risk of hitting wildlife. In contrast, daylight conditions accounted for 9,262 crashes, while dark but lighted areas saw 3,037 incidents. Collisions during dawn (2,035) and dusk (1,296) were less frequent but still notable, aligning with peak wildlife activity periods. These findings emphasize the importance of roadway lighting, driver awareness during low-light hours, and targeted mitigation strategies like wildlife fencing and signage in high-risk zones. Figure 3.3 shows that the proportion of fatal and suspected serious injury crashes is greater during the combined daylight and dawn/dusk categories compared to nighttime crashes. Even though there are a greater number of night-time wildlife crashes the probability of a serious or fatal WVC crash is higher during daylight and near daylight conditions.

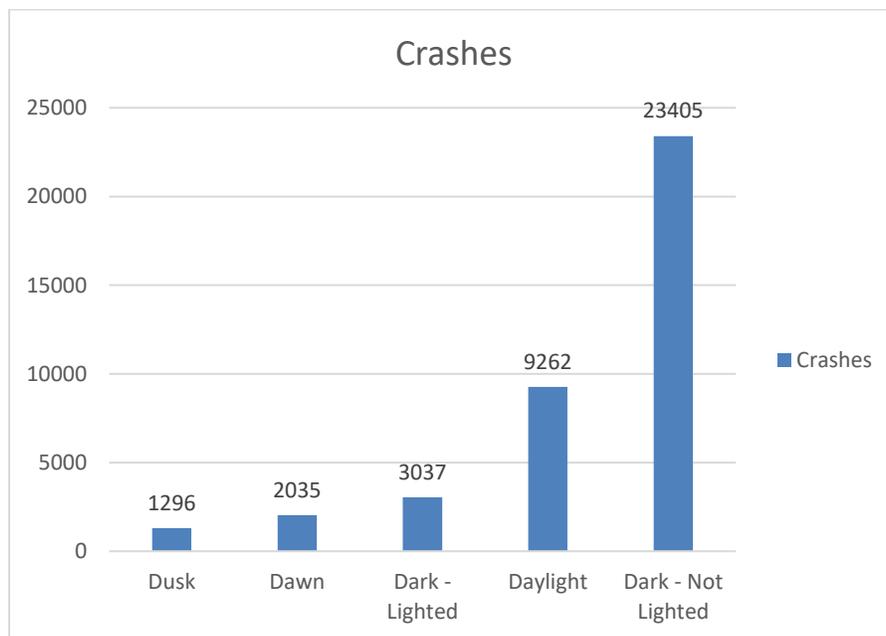


Figure 3.2 Distribution of WVC by lighting condition

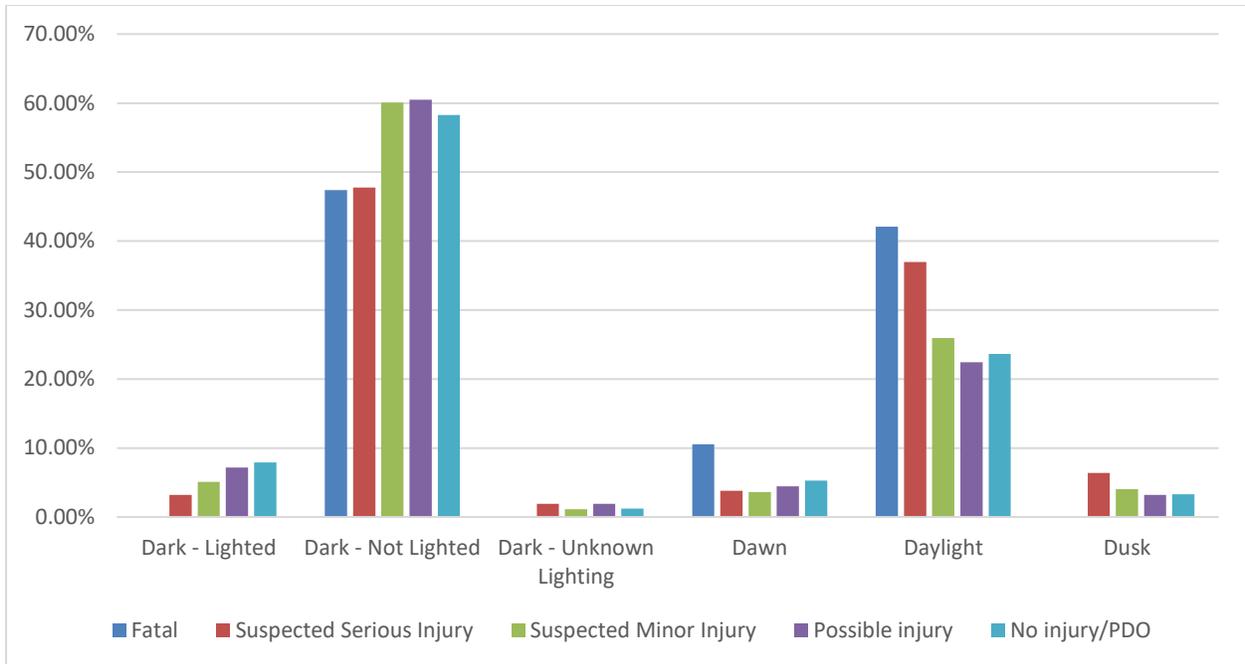


Figure 3.3 Crash severity distribution by lighting condition

Functional classification is a differentiator in identifying WVC patterns. The distribution of WVCs by functional classification is shown in Figure 3.4. Interstate freeways are classified as a principal arterial and account for 15.0% of WVCs. Nearly half of WVCs occur on other principal arterials, which do not include interstate freeways, but are still major highways with high traffic volumes and speeds. Minor Arterials observed 18.1% of reported WVCs and Other Freeway/Expressways observed 1.9%. Wildlife collisions are more prevalent on arterial type roadways, with an observed 78.7% of all WVCs. Major and Minor Collectors accounted for 12.6% and 1.4% of WVCs, respectively, while local roads made up 7.5%. These lower volume and lower speed roadways had a combined 21.5% of WVCs, indicating that lower volume and lower speed roadways are not immune to wildlife encounters. The WVC patterns highlight the need for targeted mitigation strategies such as fencing and crossing structures on principal arterial corridors where wildlife collisions are most frequent.

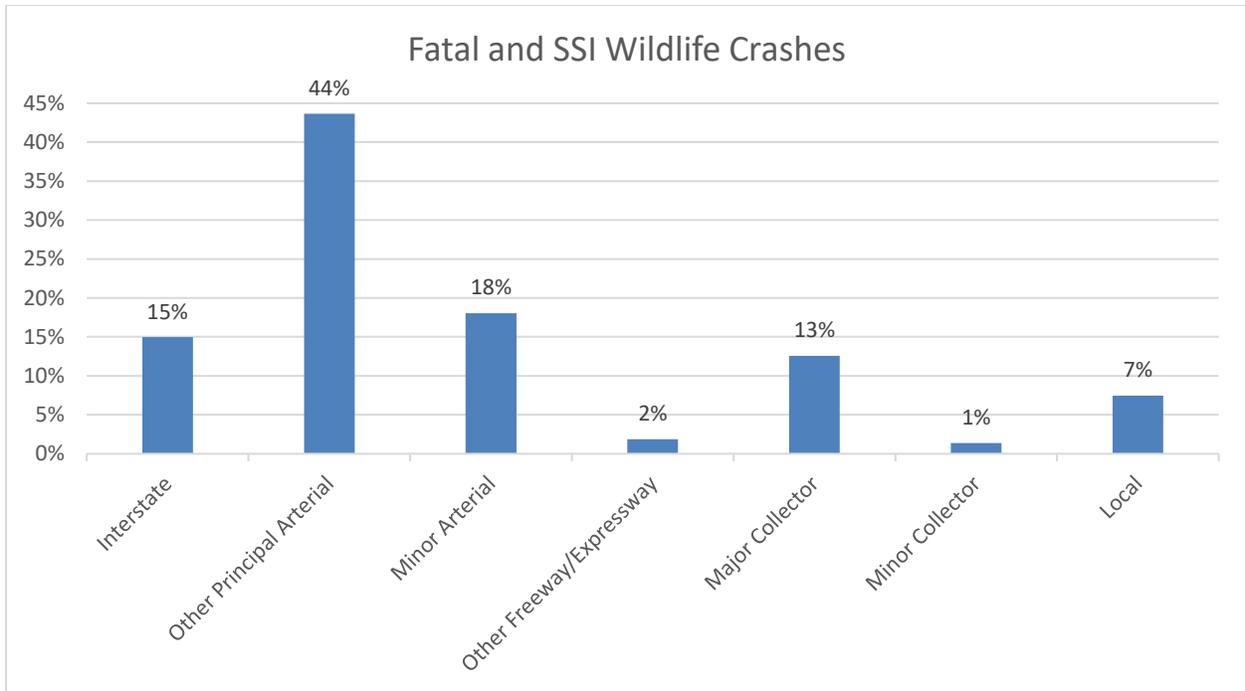


Figure 3.4 WVC distribution by roadway functional classification

A large proportion of fatal and suspected serious injury WVCs occur on interstates and other principal arterials. The severity distribution by roadway classification is shown in Figure 3.5. 12 of the total 19 (63%) reported fatal WVCs occurred on interstate roads, and 74 of the total 160 (46%) reported serious injury WVCs occurred on interstates or other principal arterials.

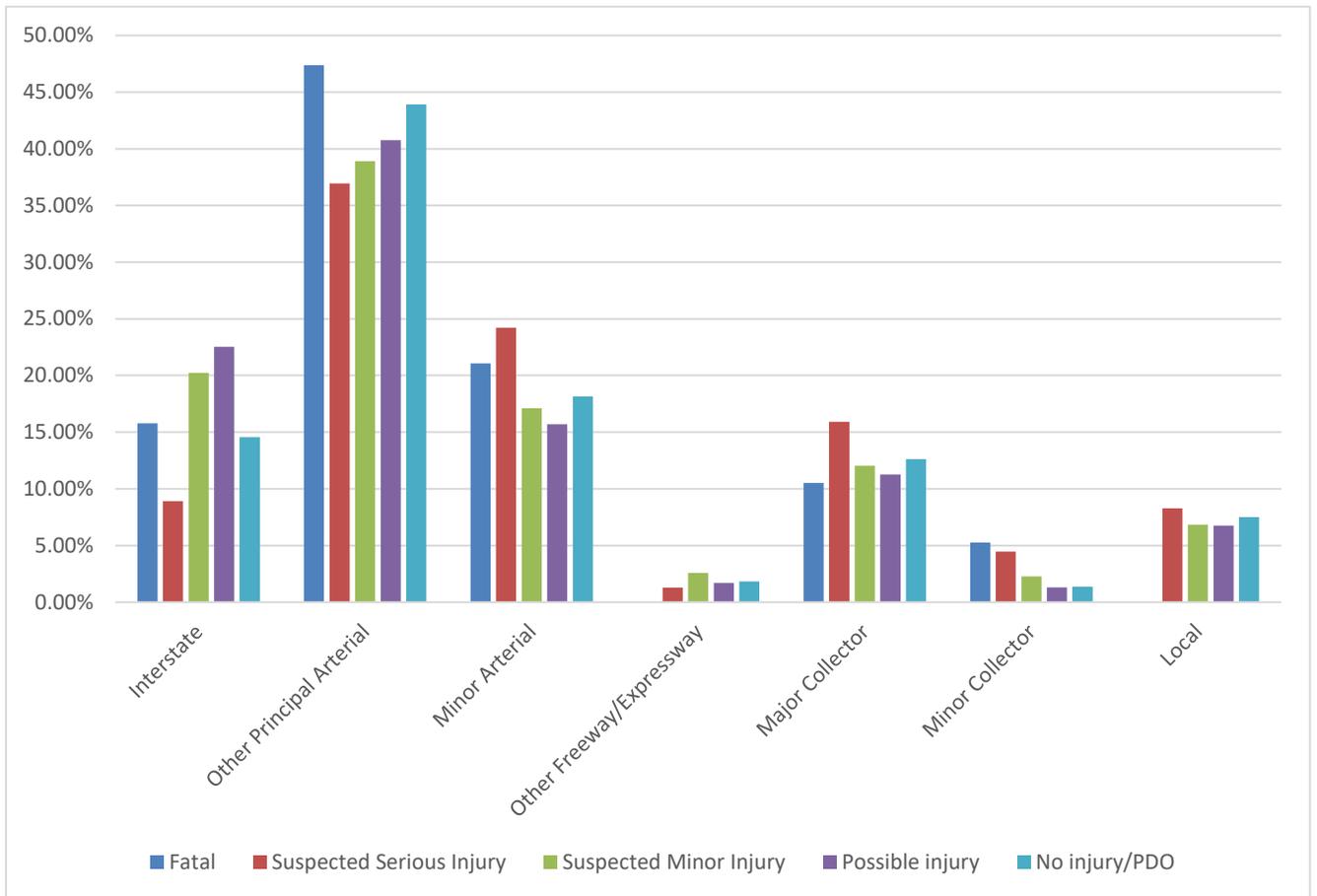


Figure 3.5 Severity distribution by roadway functional classification

Figure 3.6 shows the distribution of WVCs across rural and urban areas. The significant majority of WVCs (63%) occurred in rural areas, highlighting the elevated risk in areas where wildlife habitats are more prevalent, and roadways often intersect migration corridors. In contrast, urban areas accounted for 14,305 crashes in the 15 years of data (approximately 37%), which, while lower, still represent nearly 1,000 urban incidents a year on average. These figures underscore the importance of targeted mitigation strategies like wildlife fencing and crossing structures, particularly in rural zones where animal movement is more frequent and less restricted by development.

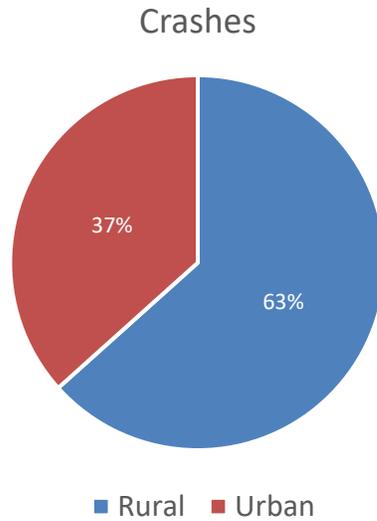


Figure 3.6 Distribution of WVCs by area type

3.4 Reported Carcass Data

Carcass data was obtained from UDOT for the years 2010 to 2024. Figure 3.7 compares data points between police-reported crash data (left) and carcass data (right). Table 3-4 provides the carcass count by animal type, highlighting the species most frequently involved in vehicle collisions. Mule deer dominate the list, with 101,661 carcasses (91%), underscoring their vulnerability and prevalence across the state’s highways. Elk (3,010 at 2.7%) and northern raccoons (2,342 at 2.1%) follow as the next most common species. A wide range of other wildlife including moose, pronghorn antelope, coyotes, and skunks also appear in significant numbers but at low overall percentage of carcasses.

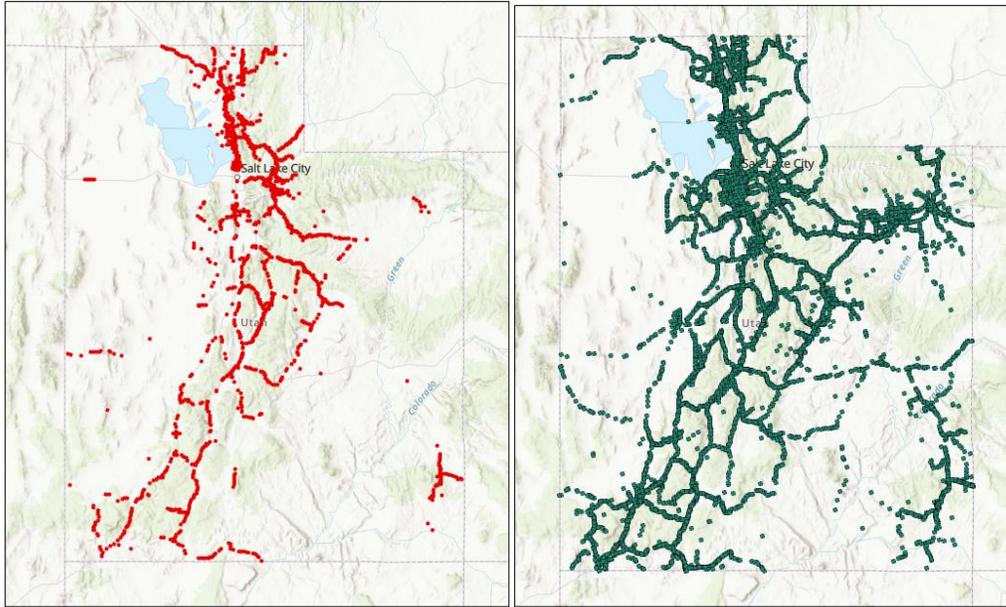


Figure 3.7 Comparison of crash data (left) and carcass data (right).

Table 3-4 2010-2024 Carcass Count

Animal Type	Carcass Count	Animal Type	Carcass Count
Mule Deer	101,661	Gray Fox	46
Elk	3,010	Jackrabbit	36
Northern Raccoon	2,342	Bobcat	34
others and unknown	764	Utah Prairie Dog	34
Domestic Cat	541	Muskrat	26
Pronghorn Antelope	487	Domestic Sheep	23
Moose	456	Black Bear	22
Striped Skunk	445	Golden Eagle	22
Domestic Dog	257	Great Horned Owl	19
Porcupine	256	Turkey Vulture	18
Coyote	245	Mojave Desert Tortoise	17
American Badger	239	Canada Goose	15
Red Fox	148	Ground Squirrel	15
Domestic Cow	122	Ring-Necked Pheasant	14
Beaver	84	Greater Sage Grouse	12
Cougar (Mountain Lion)	79	Domestic Horse	11
Kit Fox	77	Red-Tailed Hawk	11
Bighorn Sheep	49	Bison	10

3.5 Comparing Crash and Carcass Data

Utah saw a consistent gap between reported WVCs and the number of carcasses removed each year, shown in Table 3-5. Carcass data far exceeded reported WVCs, with differences ranging from 2,100 to over 4,500. On average, carcass counts were 50 to 60% higher than crash counts, indicating many incidents go unreported, especially if there are no human injuries. Figure 3.8 shows the yearly percentage difference between WVCs and carcass data. The negative trend line indicates the difference is reducing year over year.

Table 3-5 Reported WVCs to Carcass Count by Year 2010-2024

Year	Crash Count	Carcass Count	Difference	% Diff
2010	2,342	6,345	4,003	63.1
2011	2,279	4,889	2,610	53.4
2012	2,476	5,680	3,204	56.4
2013	2,615	7,196	4,581	63.7
2014	2,673	6,049	3,376	55.8
2015	3,116	6,936	3,820	55.1
2016	3,044	7,384	4,340	58.8
2017	2,869	6,610	3,741	56.6
2018	2,906	6,982	4,076	58.4
2019	2,832	6,481	3,649	56.3
2020	2,458	5,268	2,810	53.3
2021	2,391	4,839	2,448	50.6
2022	2,553	5,320	2,767	52.0
2023	2,492	4,603	2,111	45.9
2024	2,204	4,683	2,479	52.9

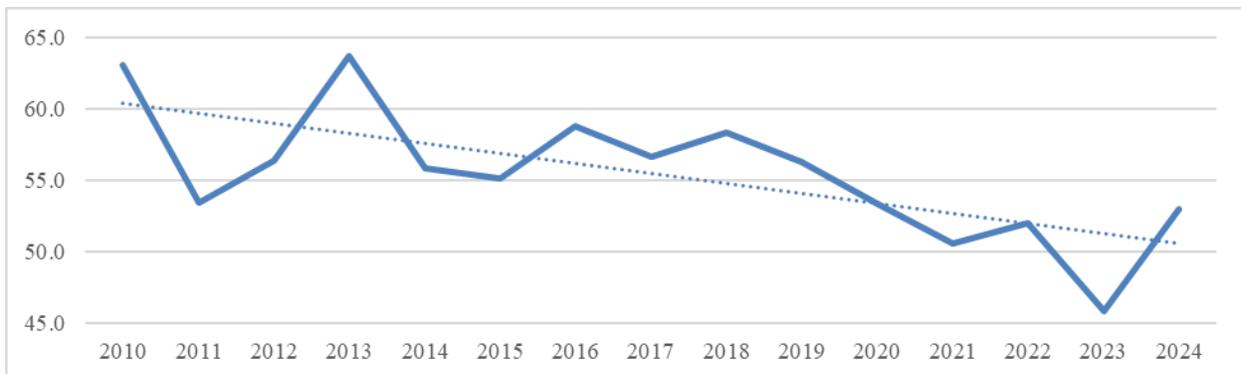


Figure 3.8 Percent difference in reported WVCs and carcass data by year

3.6 Crash Type and Crash Cost Comparisons

A comparison is made between the distribution of common crash types and the distribution of WVCs, shown in Table 3-6 for the years 2010 to 2024. Roadway departure crashes comprised 155,951 total crashes (18.3% of all crashes), with 7,695 fatal and serious injury crashes (35.0% of all fatal and serious injuries). Single-vehicle crashes accounted for the largest proportion of fatal and serious injuries, with 11,175 crashes (50.8%). Left-turn crashes at intersections are prominent, with 107,151 total crashes (12.6%) and 3,537 fatal and serious injuries (16.1%). Pedestrian and bicycle crashes represent a relatively small portion of the dataset (21,151 total), with 3,347 fatal and serious injuries. WVCs accounted for 39,539 of all crashes (4.6%) and 178 fatal and serious injury crashes (0.8%). Though infrequent, WVCs still contribute thousands of crashes each year.

The data supports mitigation strategies like wildlife fencing and crossing structures, which can reduce the frequency and severity of WVCs. Taken together, the data can help prioritize transportation safety interventions based on proportion of crashes by type and severity. It also highlights the importance of using detailed crash data to support infrastructure planning, policy decisions, and resource allocation.

Table 3-7 presents an economic evaluation of crashes by type and severity level (K for fatal, A for suspected serious injury, B for suspected minor injury, C for possible injury, and O for PDO). The total estimated crash costs across all categories amount to \$163.9 billion, underscoring the vast economic impact of traffic crashes in the state.

Despite a smaller overall crash cost, WVCs resulted in nearly \$1.88 billion in injury-related costs (K through C levels), suggesting a non-trivial safety and financial impact. PDO costs (O-level) from wildlife totaled over \$677 million, further supporting the value of wildlife mitigation measures like fencing and crossing infrastructure.

In summary, the cost analysis underscores the importance of targeted safety investments. Addressing crash types with high crash costs could yield economic and public health benefits, however additional benefits for lower-cost projects such as wildlife fencing and crossings should be considered which may provide higher benefit-cost ratios.

Table 3-6 Crash Data Comparisons (2010-2024)

Type:	Total	Roadway Departure	Ped/Bike	Left Turn at Intersections	SV	Wildlife
Fatal	3,642	1,740	681	356	2,056	19
Suspected Serious Injury	18,345	5,955	2,666	3,181	9,119	157
Suspected Minor Injury	90,418	19,345	9,961	17,367	31,016	964
Possible Injury	145,423	23,197	6,338	22,128	32,026	1,465
Property Damage Only	594,031	105,714	1,505	64,119	164,694	36,430
Total	851,859	155,951	21,151	107,151	238,911	39,035

Table 3-7 Economic Evaluation of Utah Crashes by Type and Severity (2010-2024)

Severity	Total	Roadway Departure	Ped/Bike	Left Turn at Intersections	SV	Wildlife
K	\$ 59,390,773,700	\$ 28,142,634,300	\$ 11,086,492,300	\$ 5,808,742,700	\$ 33,307,749,000	\$ 305,723,300
A	\$ 31,931,934,000	\$ 10,378,091,600	\$ 2,619,662,800	\$ 5,598,954,000	\$ 15,854,328,800	\$ 267,590,800
B	\$ 33,956,155,100	\$ 7,276,871,400	\$ 998,093,000	\$ 6,634,187,900	\$ 11,618,760,100	\$ 355,041,200
C	\$ 27,365,200,000	\$ 4,383,609,200	\$ 1,192,235,200	\$ 4,253,809,400	\$ 6,024,596,700	\$ 270,878,500
O	\$ 11,259,937,800	\$ 2,021,169,000	\$ 189,162,000	\$ 1,258,252,800	\$ 3,119,703,600	\$ 677,598,000
Total	\$ 163,904,000,600	\$ 52,202,375,500	\$ 16,085,645,300	\$ 23,553,946,800	\$ 69,925,138,200	\$ 1,876,831,800
Proportion by Crash Type		31.8%	9.8%	14.4%	42.7%	1.1%
Annual Cost		\$ 3,728,741,107.14	\$ 1,148,974,664.29	\$ 1,682,424,771.43	\$ 4,994,652,728.57	\$ 134,059,414.29
Avg Crash Cost		\$ 326,328.07	\$ 746,295.13	\$ 209,717.01	\$ 287,488.03	\$ 48,080.74

3.7 Study Location Identification

Historic UDOT projects were reviewed using keywords such as wildlife fencing, fence, fencing, and wildlife to identify projects with wildlife fencing. The search yielded 29 wildlife specific projects, while a broader search identified 53 projects that included wildlife fencing.

Study locations were gathered from the project listings, and milepost information was used to pinpoint fence installation areas. To verify and supplement project details, Google Street View was used to confirm the presence of fences and identify fencing not documented in the project records. Installation dates of wildlife fences were collected from two sources: 28 projects were confirmed by UDOT project managers, and the remaining dates were determined using historical Google Street View imagery. The latest Google Street View image showing the presence of wildlife fencing and the earliest available image showing its absence were manually identified using historical imagery. For example, if fencing was visible in November 2017 and all images back to 2014 also showed the fence, but the October 2012 image showed no fencing, it was concluded that installation occurred in 2013. That year was then assumed to be the installation date and used to define the “before” and “after” periods. In cases where historical imagery was missing for certain years, those years were excluded from the study. For instance, if images from 2014 to 2018 were unavailable, but the 2019 image showed fencing and the 2013 image showed no fencing, the “before” period was defined as 2011–2013 and the “after” period as 2020–2023. Installation timelines spanned from 2011 to 2023. This combination of official records, visual confirmation, and direct input from UDOT personnel provided the dataset for evaluating the effectiveness of wildlife fencing projects statewide. Locations were excluded when a fence had been installed before 2009, as crash data earlier than 2009 was not available. A 300-foot buffer was used to assign WVCs to roadway segments.

Roadways were divided into segments using Google Street View to identify locations where animals could potentially cross, shown in Figure 3.9. The top and middle images in Figure 3.9 show an example of wildlife fencing in Utah, and the bottom image shows the specification of type G fencing which is used as wildlife fencing in Utah. A study segment was identified between an available wildlife crossing such as a culvert, bridge, or interchange. The study

segments would also stop at fence terminations and were noted as a fence end. Segments shorter than 0.5 miles were merged with the closest adjacent segment to ensure consistency.

Control segments were selected based on how closely they matched treatment segments, especially in terms of roadway conditions and history of wildlife collisions. Wherever possible, control sites were placed near the treatment segments and included areas where animal crossings were likely to occur. For example, speed limits for treatment segments range between 35 mph and 80 mph with mean speed limit of 69 mph, and speed limits for control segments ranged from 30 mph to 80 mph with mean speed limit of 58 mph. Both treatment and control segments were mapped using the ArcMap geographic information system (GIS). 54 (138 miles) treatment segments and 90 (583 miles) control segments were incorporated into the analysis, as shown in Figure 3.10 and Figure 3.11.

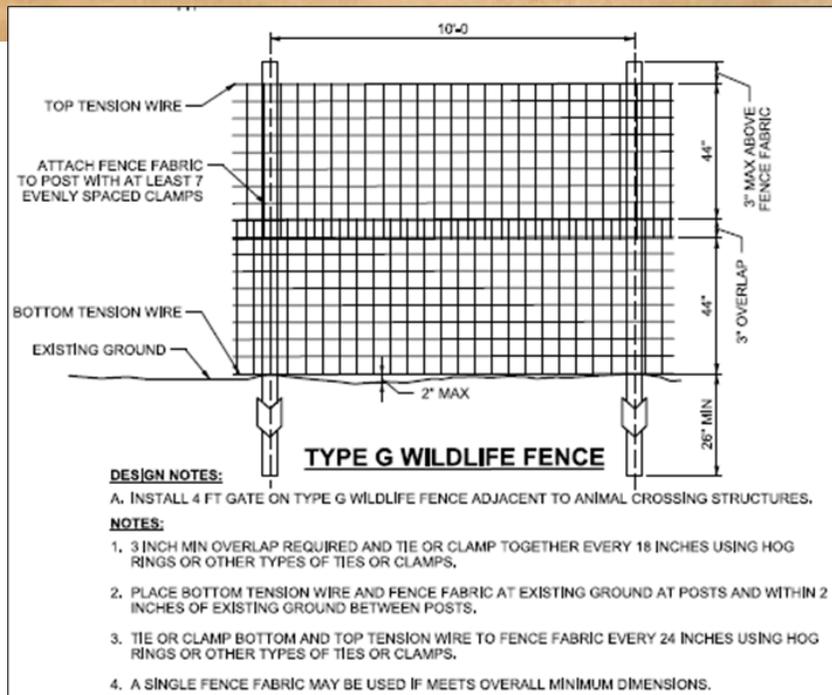
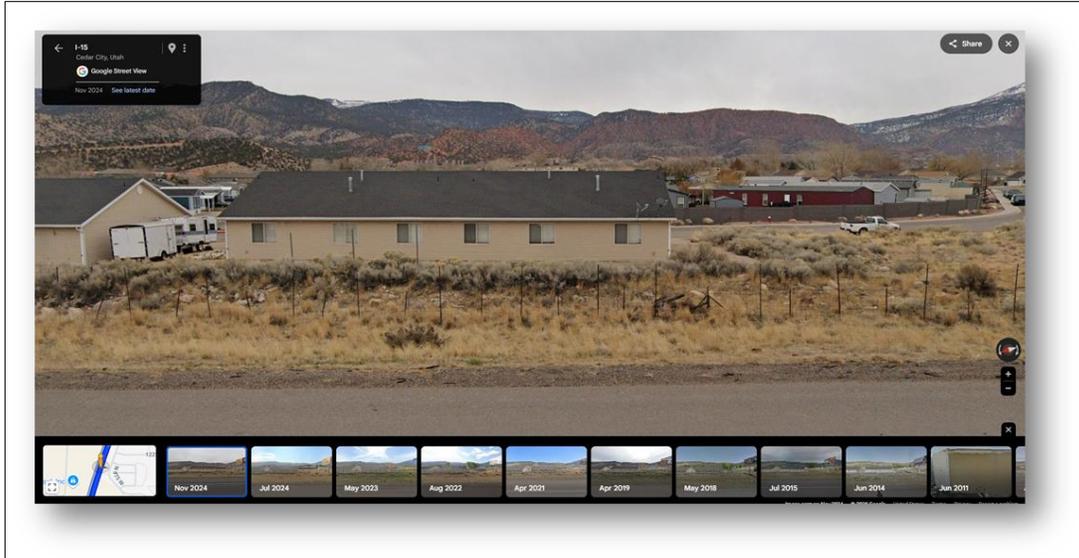


Figure 3.9 Identifying wildlife-fencing installations

The distribution of WVCs on Utah highways is shown in Table 3-8. Interstate 15 (I-15) accounted for the largest share, with 43% of all reported wildlife crashes. US-6 and SR-73 followed with 10% and 9%, respectively, identifying that these routes also experience frequent animal crossings. US-40 and I-80 each contributed 6%, while US-91 made up 5%. Other routes like US-189 and US-89 each represented 4%, and smaller shares were seen on US-89/91 (2%), I-70 (1%), and I-84 (1%). This breakdown helps identify priority areas for wildlife mitigation efforts, especially along I-15 and other high-impact corridors.

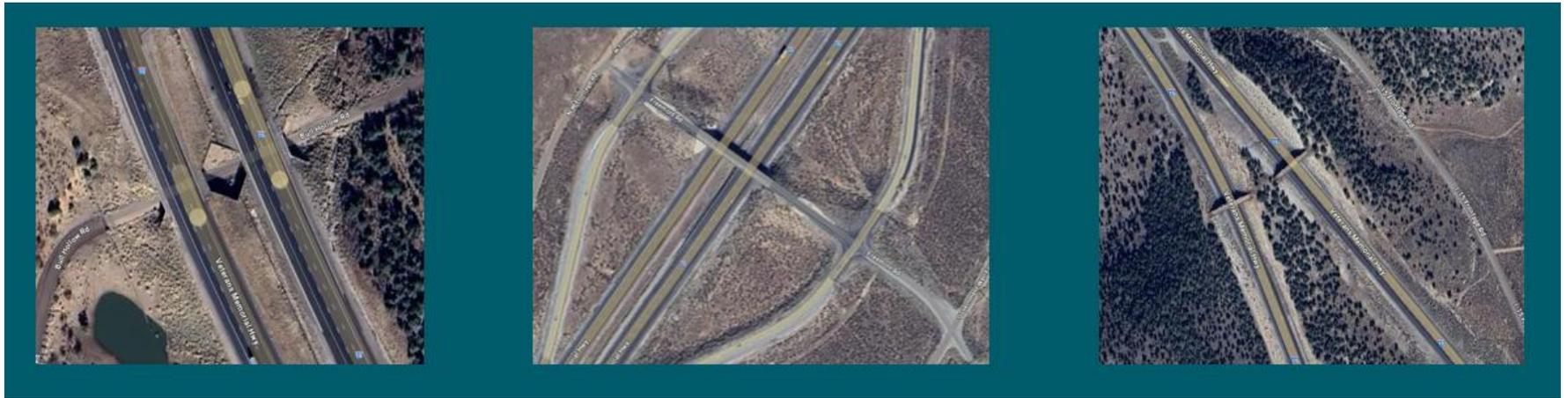


Figure 3.10 Example animal crossings along study segments



Figure 3.11 Treatment and control segments

Table 3-8 Distribution of Study Segment Locations

Location	Proportion
I-15	43%
US-6	10%
SR-73	9%
I-80	6%
US-40	6%
US-191	5%
US-189	4%
US-89	4%
US-89/91	2%
I-70	1%
I-84	1%

3.8 Migration Zone

Utah’s migration corridor GIS file was obtained from the Utah Division of Wildlife Resources (DWR). This GIS layer provided critical spatial data for understanding seasonal wildlife movement patterns, particularly for species such as mule deer, elk, and pronghorn. Migration corridors were identified by Utah DWR by attaching compact GPS tracking devices to wildlife, enabling the movement patterns of wildlife to be tracked over time. The interactive map shown in Figure 3.12 and Figure 3.13 provides the migration corridor locations and crashes throughout Utah. About 22% of all WVCs occurred near migration zones. The data shows migration type (high, medium, and low use) which positively correlates with herd size of the area.

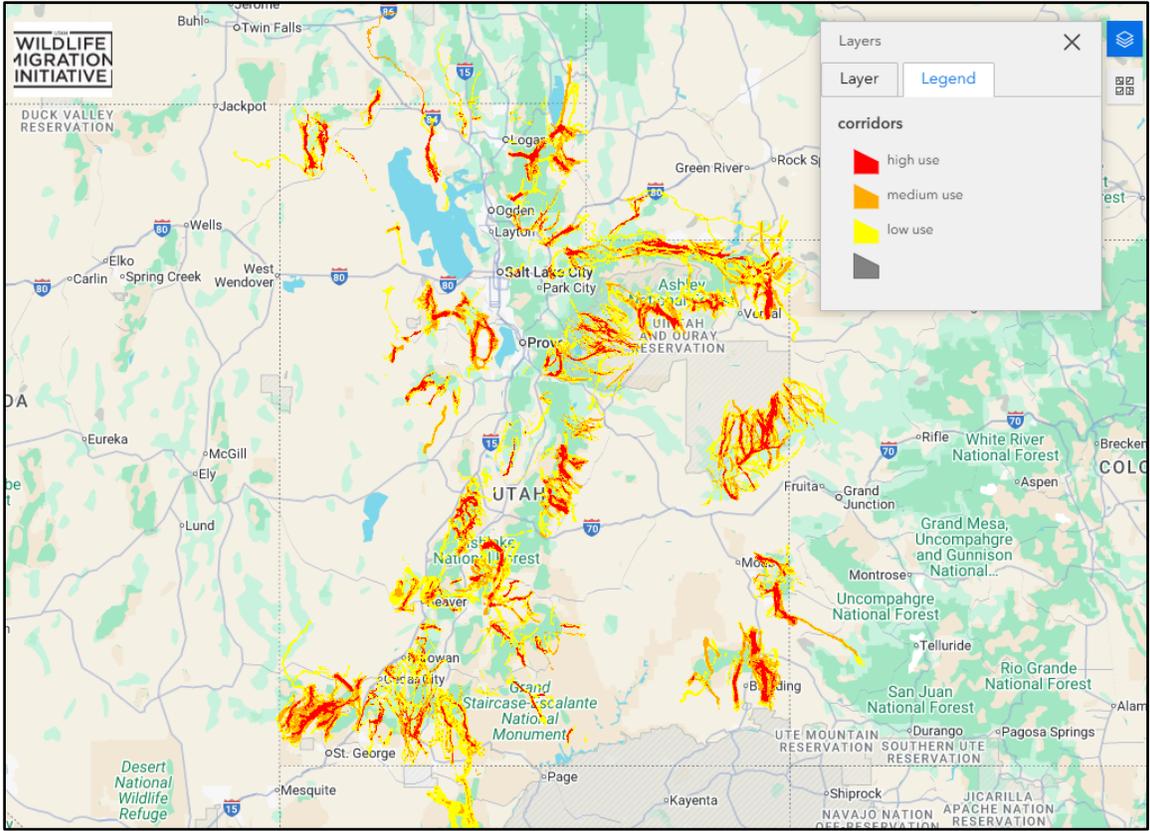


Figure 3.12 Wildlife migration zones

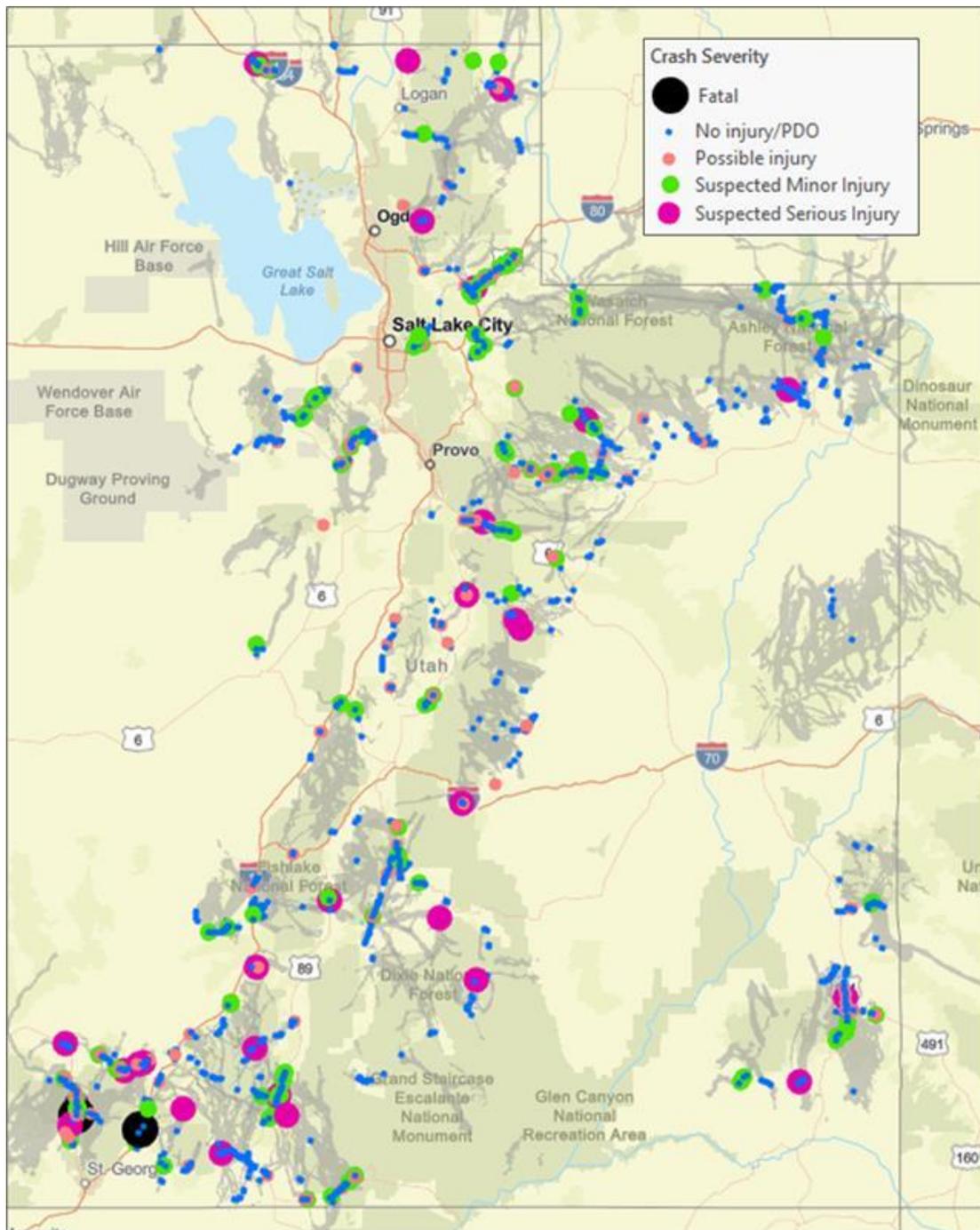


Figure 3.13 WVCs in migration zones

4.0 METHODOLOGY AND RESULTS

4.1 Overview

This chapter outlines how the study was conducted and provides crash reduction results, including the Safety Performance Functions (SPFs) and CMFs calculated in the study.

4.2 Descriptive Statistics

The before-and-after crash data for the effectiveness of wildlife fencing installation in reducing WVCs is shown in Table 4.1. Treatment segments averaged 87 WVCs per year before the fencing was installed, which dropped to 22 WVCs per year after, showing a 74% decrease. Injury-related crashes (KABC) fell from 8 to 3 per year, showing a 63% reduction, while PDO crashes declined from 79 to 20, marking a 75% decrease. These results demonstrate that wildlife fencing significantly improved road safety by lowering both injury and non-injury WVCs. Table 4.2 shows the crash severity distribution for before-and-after treatment. Most WVCs resulted in no injury, with 92.25% classified as PDO. A small portion of WVCs involved human injury with 4.35% labeled possible injury, 3.19% suspected minor injury, and 0.19% suspected serious injury.

Table 4-1 Descriptive statistics for treatment segments

Variable	Treatment Sites (n=54)			
	Total Before Yearly Crashes	Total After Yearly Crashes		
(2012-2019)				
Total Crashes	87	22		
KABC Crashes	8	3		
PDO crashes	79	20		
	Mean	Std Dev	Min	Max
No. of before years	6.05	3.36	1	11
No. of after years	7.36	3.76	2	13
Migration Zone	0.31	0.46	0	1
Urban	0.26	0.44	0	1
AADT before	16,278	7,023	1,054	23,428
AADT after	21,143	9,086	1,351	30,600
Length in Miles	138 total miles	1.3	0.16	7.42

Table 4-2 Descriptive statistics for control segments

Variable	Control Sites (n=90)			
(2012-2019)	Total Crashes			
Total WVCs	3,937			
KABC WVCs	277			
PDO WVCs	3,660			
	Mean	Std Dev	Min	Max
Migration Zone	0.1	0.3	0	1
Urban	0.38	0.49	0	1
AADT	9510	9471	292	54565
Length in Miles	Total 583 miles	6.63	6.54	43.73

4.3 Before-and-After Crash Evaluation

An observational before-and-after study using EB methodology was conducted. The analysis is a statistically accepted method to evaluate safety effects of treatments (Hauer et al., 1997). The effectiveness of a treatment is calculated by comparing the observed crashes to the expected crashes after the treatment has been installed. SPF models were developed for predicted wildlife crashes, which were grouped into models for “total fatal and injury” and “property damage only” crashes. The EB method accounts for regression-to-the-mean effects, the observed changes in crash frequency in the before-and-after periods, and the changes of traffic and roadway characteristics (Park et al., 2016).

A comparison was made of study segments before and after wildlife-fencing installations. Table 4-3 highlights the effectiveness of wildlife fencing in reducing WVCs. Study segments averaged 87 WVCs per year before the fencing was installed, which dropped to 22 WVCs per year after, showing a 75% decrease. Injury-related crashes (KABC) fell from 8 to 3 per year, showing a 63% reduction, while property damage only (PDO) crashes declined from 79 to 20, marking a 75% decrease. These results demonstrate that wildlife fencing significantly improved road safety by lowering WVCs. Table 4.4 shows the crash severity distribution for the treatment segments. No noticeable change in distribution is noted with the installation of wildlife fencing, as wildlife fencing reduces the frequency of crashes rather than the severity. Between 2010 and 2024, most WVCs along the treatment segments resulted in no reported injuries, with 92.25%

classified as PDO. A portion of crashes involved human injury, specifically 4.33% were labeled as possible injuries, 3.19% as suspected minor injuries, and 0.19% as suspected serious injuries. There were no reported fatal WVCs in the treatment study segments. This breakdown highlights that while most WVCs cause only vehicle damage, a notable number still pose risks to human safety.

The WVC frequency per mile for before and after wildlife-fencing installation was identified, shown in Figures 4.1 to 4.3. The frequency of WVCs reduces as the distance between animal crossings increases. However, WVC frequency remains low even for longer wildlife-fencing segments. Shorter segments likely create frequent locations where wildlife break through the fencing. All models in migration zones have a downward trend in the after period compared to the before period.

Table 4-3 Before and After WVC and Carcass Frequency Per Year

Crash Type	Before reports per year	After reports per year	% Decrease
Total	87	22	75%
KABC	8	3	63%
PDO	79	20	75%
Carcass Data	1,395	335	76%

Table 4-4 WVC Severity Distribution

Injury Severity	Distribution Before	Distribution After
Fatal	0.0%*	0.0%*
Suspected Serious Injury	0.19%	0.27%
Suspected Minor Injury	2.80%	2.43%
Possible injury	4.35%	4.04%
No injury/PDO	92.25%	93.26%
*Study segments had no reported fatal injury crashes in either the before or after periods.		

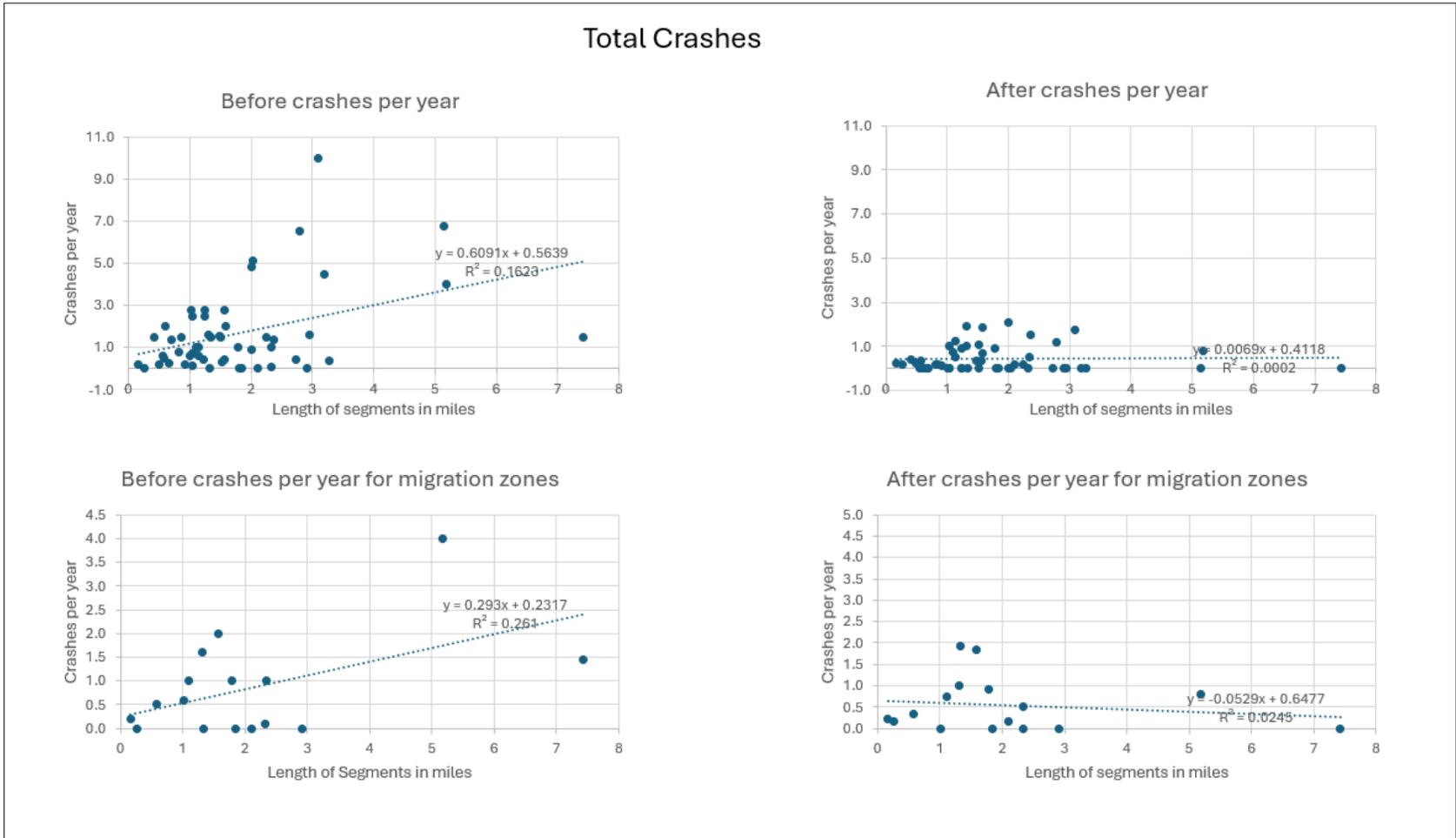


Figure 4.1 Before-and-after crashes per year for all crashes inside and outside of migration zones

KABC Crashes

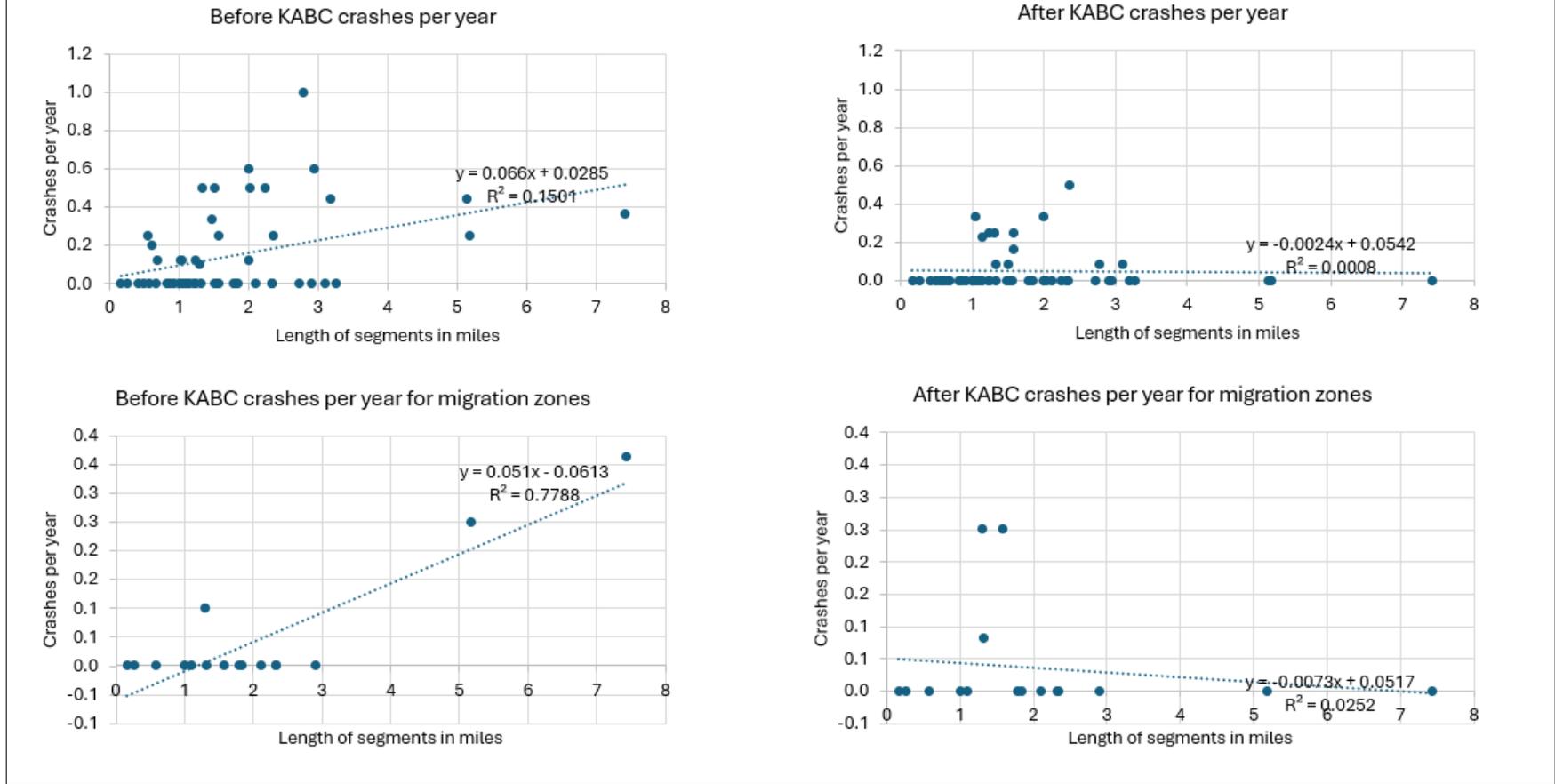


Figure 4.2 Before-and-after crashes per year for injury crashes inside and outside of migration zones

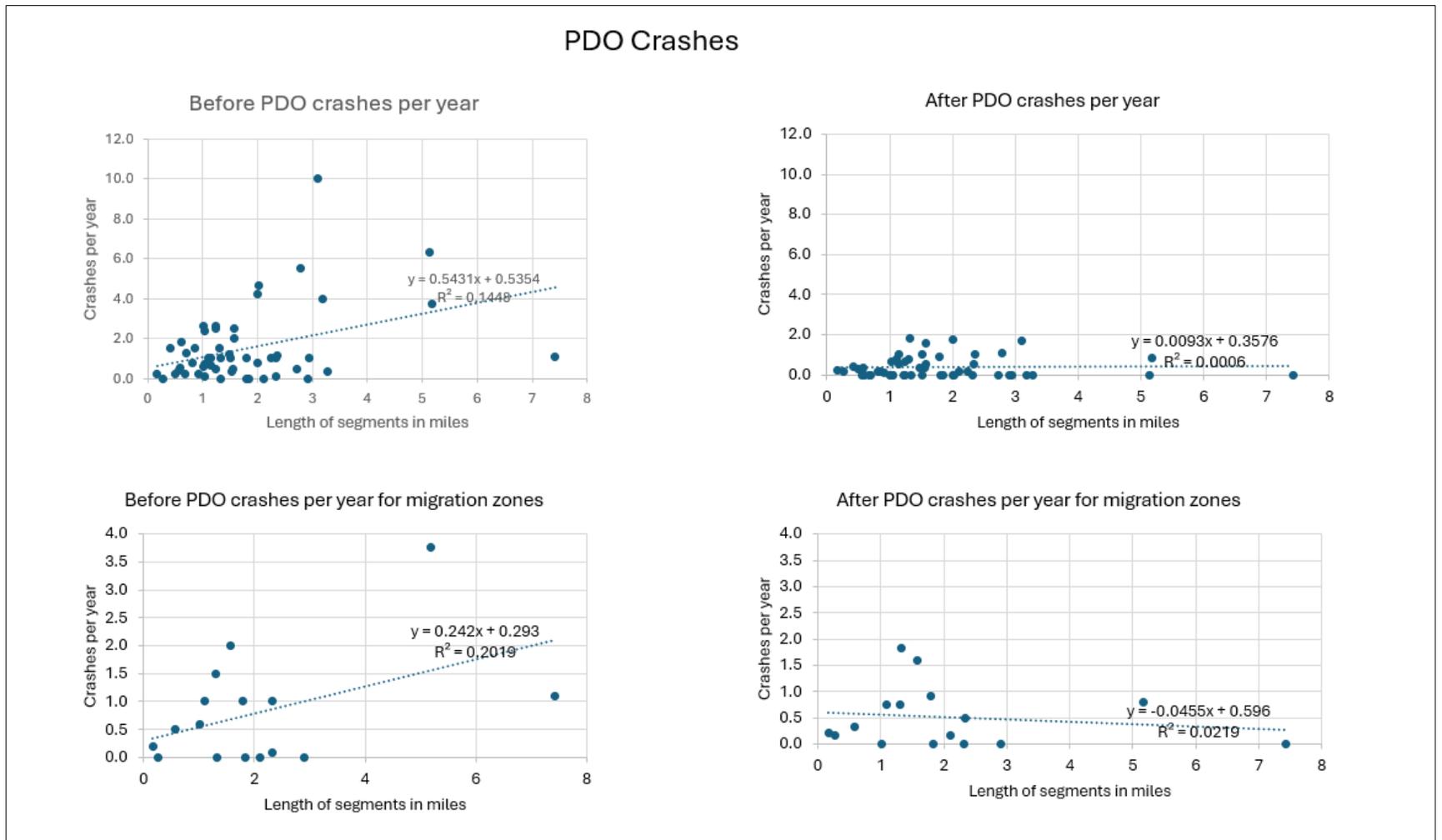


Figure 4.3 Before-and-after crashes per year for PDO crashes inside and outside of migration zones

4.4 Safety Performance Functions

An SPF is a crash prediction model that relates the crash frequency to traffic and other parameters. Data from the control sites and before period of the treatment segments was used to estimate the SPFs (Park et al., 2016). The estimated SPF predicts the crash frequency that would have occurred without the treatment (Hauer et al., 1997). The predicted crash frequency is compared to the observed after-period crash counts to develop a CMF.

SPFs were developed using negative binomial (NB) generalized linear models (GLM) (Park et al., 2016). The NB or the Poisson-gamma regression model is an extension of a Poisson model that addresses the over-dispersion in the data. The NB model assumes that the Poisson parameter (λ_i) follows a gamma probability distribution and the probability distribution function of the NB model for y_i , crashes occurring on segment i , can be written as equation 1.

$$f(y_i) = \frac{\Gamma(y_i + \phi)}{\Gamma(y_i + 1)\Gamma(\phi)} \left(\frac{\phi}{\phi + \lambda_i}\right)^\phi \left(\frac{\lambda_i}{\phi + \lambda_i}\right)^{y_i} \quad (1)$$

where, (Γ) is a gamma function, and ϕ is the dispersion factor.

If α which is a function of $(1/\phi)$ is the over-dispersion factor is significantly greater than zero, the data is over-dispersed. If α is equal to zero, the NB reduces to the Poisson distribution, and the mean number of crashes on segment i , λ_i , is a linear function of the covariates. The NB model is derived from rewriting the functional form of the Poisson parameter for each observation i , specified as equation 2.

$$\lambda_i = \text{EXP}(\beta X_i + \varepsilon_i) \quad (2)$$

where, $\text{EXP}(\varepsilon_i)$ is the gamma-distributed error term with mean 1 and variance α .

The addition of this term allows the variance to differ from the mean. The variance can be calculated using equation 3.

$$\text{Var}(y_i) = \lambda_i + \frac{\lambda_i^2}{\phi} \quad \text{or} \quad \text{Var}(y_i) = \lambda_i + \alpha \lambda_i^2 \quad (3)$$

Table 4-5 provides the SPFs for WVCs with statistically significant variables by severity group. Each SPF uses the exponential function of a linear combination involving the natural log of AADT represented as $\text{Ln}(\text{AADT})$ and an urban area indicator which is Boolean (1 for urban and 0 for rural). The study segments had a minimum of 1,000 AADT and a maximum of 30,000 AADT. For total WVCs, the model predicts higher WVCs with increased traffic but fewer in urban areas. The fatal and injury crash SPF follows a similar pattern, though the overall predicted rate is lower due to a more negative intercept, indicating WVCs are less frequent. The PDO crash model shows a rise in WVCs as traffic increases but a drop in urban settings. For Total WVCs in migration areas, areas with smaller wildlife populations have fewer WVCs, and zones with moderate wildlife activity show fewer WVCs compared to high-use zones. Data availability did not allow for creation of SPFs for injury and PDO crashes in migration areas. Dispersion parameters range from 0.5865 to 0.6229 which indicates moderate variability in the data and accounts for random fluctuations in crash counts. The models provide a statistical foundation for estimating expected crash rates and assessing the effectiveness of wildlife fencing.

Table 4-5 Final models developed for SPFs

Crash Severity	Safety Performance Functions	Dispersion Parameter* (ϕ)
Total WVCs	EXP $\{0.3683 + (0.2271 \times \text{Ln}(\text{AADT}) + (-1.4512 \times \text{Urban})\}$	0.5865
Fatal and injury WVCs	EXP $\{-4.4522 + (0.4794 \times \text{Ln}(\text{AADT}) + (-1.9263 \times \text{Urban})\}$	0.6229
PDO WVCs	EXP $\{0.4476 + (0.2089 \times \text{Ln}(\text{AADT}) + (-1.4130 \times \text{Urban})\}$	0.5922
Total WVCs in Migration Area	EXP $\{2.459 + 0.156 \times \text{Ln}(\text{AADT}) + 0.291 \times \text{Ln}(\text{Length}) - 0.352 \times (\text{Herd Size} < 10\text{K}) + - 0.137 \times (\text{Medium Use Zone})\}$	0.8395

*Dispersion parameter for the NB model

Measures of goodness-of-fit, including Log-Likelihood and Akaike Information Criterion (AIC), were used to ascertain the best fitted model. The best fitted model that displayed the maximum value of the log-likelihood function was chosen to obtain the parameter estimates that made the data most likely. AIC value was used to compare the performances of the GLMs. The

preferred model is the one with the minimum AIC value. The AIC value is evaluated using equation 4.

$$AIC = 2k - 2\ln(L) \tag{4}$$

where, k = The number of estimated parameters in the model, and L = The maximum value of the likelihood function for the model. Model parameters including goodness-of-fit statistics are shown in Table 4-6 The AIC introduces a penalty term that is represented by the parameter number in the AIC. The models were compared and models with lower AIC values were used. Table 4-6 also presents the statistical results of the three WVC severity groups. Each SPF includes an intercept, coefficients for traffic volume Ln(AADT), and an indicator variable for urban location, along with standard errors and p-values indicating statistical significance.

The Ln(AADT) coefficient (0.2271) suggests that higher traffic volumes are associated with higher WVCs, although the p-value (0.075) is marginally significant. The urban coefficient (-1.4512) is statistically significant (p = 0.006), indicating fewer crashes in urban areas. The model’s AIC (823.8) and over-dispersion parameter ($\alpha = 0.5865$) reflect its fit and variability.

Table 4-6 Parameter Estimates and Model Statistics

Crash Type	Parameter	SPFs			AIC
		Estimate (β)	Std. Error	P-Value	
Total WVCs	Intercept	0.368	1.088	0.735	823.800
	Ln(AADT)	0.227	0.127	0.075	
	Urban	-1.451	0.537	0.006	
	α^*	0.587			
Fatal and Injury WVCs	Intercept	-4.452	1.182	0.000	398.620
	Ln(AADT)	0.479	0.138	0.000	
	Urban	-1.926	0.889	0.030	
	α^*	0.623			
PDO WVCs	Intercept	0.448	1.084	0.680	811.69
	Ln(AADT)	0.209	0.127	0.100	
	Urban	-1.413	0.537	0.009	
	α^*	0.592			
Total WVCs in Migration Area	Intercept	2.459	0.203	0.000	1834.4
	Ln(AADT)	0.156	0.021	0.000	
	LnLength	0.291	0.035	0.000	

	Less than 10K Herd Size	-0.352	0.048	0.000
	Medium Use of Zone	-0.137	0.064	0.032
	α^*	0.839		

* Dispersion parameter of the NB model

For fatal and injury crashes, both Ln(AADT) (0.4794) and urban (-1.9263) coefficients are statistically significant ($p < 0.05$), showing a strong relationship between traffic volume and crash severity, and fewer severe crashes in urban areas. This model has a lower AIC (398.62), suggesting better fit, and a dispersion parameter of 0.6229.

For PDO crashes, the Ln(AADT) coefficient (0.2089) is not statistically significant ($p = 0.0995$), while the urban coefficient (-1.4130) is highly significant. The AIC and over-dispersion values ($\alpha = 0.5922$) are similar to the total crash model.

Overall, the models show that traffic volume tends to increase WVCs, while urban settings are consistently associated with fewer incidents. The fatal and injury crash model demonstrates the strongest statistical significance and best fit.

4.5 Calculation of Before-and-After Predicted Crashes

SPFs were used to calculate annual predicted crashes for both the before-and-after periods per unit length for each of the treatment sites. The relative weight given to the before predicted crashes was calculated using the dispersion factor from the NB model as in equation 5.

$$w = \frac{1}{(1 + \alpha \times N_{bp})} \quad (5)$$

where, α = estimated NB model over dispersion parameter; N_{bp} = before predicted crash frequency

An estimate of the expected number of crashes before implementation of treatment at each treatment site (shown in equation 6) was computed using the developed SPFs.

$$N_{eb} = (w \times N_{bp}) + (1 - w) \times (N_b) \quad (6)$$

where, N_{eb} = expected annual before crash frequency; w = weight; N_b = annual crash counts during the before period

4.6 Calculating Crash Modification Factor

The SPFs developed based on the control group were used to account for traffic volume changes. SPFs were calibrated to each period, and these calibration factors (multipliers) reflect differences in crash frequency and traffic volume between the before-and-after periods. The correction is done using the ratio of annual predicted crashes calculated from the changes of AADT in the before-after periods. The ratio was calculated using equation 7.

$$R_1 = \frac{(N_{ap})}{(N_{bp})} \quad (7)$$

where, N_{ap} = after predicted crash frequency; N_{bp} = before predicted crash frequency

The expected number of after-period crashes that would have occurred without wildlife fencing was computed using equation 8.

$$N_{ea} = R_1 \times (N_{eb}) \quad (8)$$

where, N_{ea} = expected after crash frequency

Changes in traffic volumes are reflected in the EB method leaving other factors such as weather, vehicle performance, and driver behaviors unchanged. Thus, the number of crashes per site that would have occurred in the after period without the countermeasure is given by N_{EA} .

$$N_{EA} = A \times (N_{ea}) \quad (9)$$

where, A = length of the after period in years

The variance of N_{EA} is calculated by equation 10.

$$\text{Var}(N_{EA}) = \frac{\{(N_{eb}) \times (R_1 \times A)^2\}}{\left\{B + \left(\frac{\alpha}{N_{bp}}\right)\right\}} \quad (10)$$

where, B = length of the before period in years

The ratio of the total number of observed crashes in the after period ($\sum N_a$) to the total number of expected crashes in the after period had there been no countermeasure ($\sum N_{EA}$) was calculated. This would be a biased estimate of the CMF. The ratio is given by equation 11.

$$R_2 = \frac{(\sum N_a)}{(\sum N_{EA})} \quad (11)$$

where, N_a = crash counts during the after period

CMFs for the wildlife fence countermeasure were calculated using equation 12.

$$\text{CMF}(\Theta) = \frac{R_2}{\left\{1 + \frac{\{\sum \text{Var}(N_{EA})\}}{(\sum N_{EA})^2}\right\}} \quad (12)$$

The variance of $\text{CMF}(\Theta)$ was calculated using equation 13.

$$\text{Var}(\Theta) = \frac{\theta^2 \times \left\{ \frac{\text{Var}(\sum N_a)}{(\sum N_a)^2} + \frac{\sum \text{Var}(N_{EA})}{(\sum N_{EA})^2} \right\}}{\left\{ 1 + \frac{\sum \text{Var}(N_{EA})}{(\sum N_{EA})^2} \right\}} \quad (13)$$

The standard error, which is the standard deviation of a sample mean, provides a measure of certainty (or uncertainty) in the CMF. A relatively small standard error, with respect to the magnitude of the CMF estimate, indicates greater certainty in the estimate of the CMF, while a relatively large standard error indicates less certainty in the estimate of the CMF. The standard error is used in the calculation of the confidence interval. The standard error is simply the square root of the variance as shown in equation 14.

$$\text{S. E.}(\Theta) = \sqrt{\text{Var}(\Theta)} \quad (14)$$

4.7 Crash Modification Factors Results

CMFs were calculated for total, fatal and injury, and PDO WVCs. Summary information is provided in Table 4-7. A CMF of 0.25 for total wildlife-related crashes was estimated showing that wildlife fencing has the potential to reduce 75% of total wildlife-related crashes. CMFs for fatal and injury crashes and PDO crashes were also investigated. The CMF for fatal and injury crashes was found to be 0.15, showing that wildlife fencing has a positive effect in reducing fatal and injury crashes by 85%. Similarly, it was observed that the CMF for the PDO crashes was 0.26, indicating a crash reduction of 74%. Results show that wildlife fencing can be effective in reducing wildlife-related crashes. Total WVCs dropped from an expected 867 to 219, injury-related crashes (KABC) fell from 146 to just 23, and PDO crashes decreased from 767 to 196. In migration areas, total WVCs declined from 1317 expected to 173 observed, with a CMF of 0.13, indicating an 87% reduction in these sensitive zones. Low standard errors and narrow 95% confidence intervals reinforce the statistical reliability of the results. Overall, the data strongly supports wildlife fencing as a highly effective safety countermeasure with consistent impact across crash types. Wildlife fencing led to a greater reduction in WVCs in migration areas compared to all areas. These findings support continued investment in targeted safety interventions across migration corridors.

Table 4-7 CMF Statistics

Empirical Bayes	Total WVCs	KABC WVCs	PDO WVCs	Total WVCs in Migration Area
Expected (EB)	867	146	767	1317
Observed (After)	219	23	196	173
CMF	0.25	0.15	0.26	0.13
Standard Error	0.024	0.039	0.026	0.013
95% confidence interval	(0.20, 0.30)	(0.08, 0.23)	(0.21, 0.31)	(0.11, 0.16)

4.8 Cost-Benefit Analysis

An economic cost-benefit analysis of the treatment segments was performed. The average cost associated with wildlife-fencing projects for all the treatment segments in the study was determined to be \$216,480 per mile. Some representative projects that installed wildlife fences were selected from Utah DOT project pages to determine the cost per mile as shown in Table 4-8. Together, these projects illustrated the typical range of costs per mile for wildlife-fencing installations and maintenance across different routes and years. The average cost represented by installing wildlife fencing was calculated to be \$20.5 a linear foot.

Table 4-8 Representative Projects for Cost Estimation for Installation of Wildlife Fences

Project Name	Wildlife fence on I-15 - Pin: 20010	I-15; Wildlife Fencing, Phase 2 - Pin: 16426	I-15; MP 188.44-193.00, Install Wildlife Fencing 12868	US-40; Wildlife Fencing MP 58 to 81 - Pin: 22804	I-80; MP 145.4-146.9 Wildlife Fencing - Pin: 22938
Cost	\$ 1,318,633.62	\$ 612,282.03	\$ 125,000.00	\$ 12,011,000.00	\$ 250,000.00
MP Start	387.7	78	188.44	58	145.4
MP End	392.4	85.25	193	81	146.9
Roadway MP	4.7	7.25	4.56	23	1.5
Total Fencing Length (miles with both sides)	9.4	14.5	9.12	46	3
Cost/Roadway Mile:	\$ 280,560.35	\$ 84,452.69	\$ 27,412.28	\$ 522,217.39	\$ 166,666.67

Cost/Fence Mile each side	\$ 140,280.17	\$ 42,226.35	\$ 13,706.14	\$ 261,108.70	\$ 83,333.33
Cost/linear foot	\$ 26.57	\$ 8.00	\$ 2.60	\$ 49.45	\$ 15.78
Average Cost per mile	\$20.50				
Includes Escape Ramp:		yes	yes	yes	yes

The estimated safety benefits for wildlife fencing projects were based on Utah’s average annual crash costs for WVCs. The average annual cost for WVCs in Utah was \$134,059,414 per year (shown in Table 3-7). The weighted crash unit cost of injury crashes (KABC) was used for analysis, with a crash cost of \$460,360 and a unit cost of \$18,600 for PDO crashes.

The cost-benefit analysis requires estimating the number of expected crashes after implementation. Eight injury WVCs per year were identified in segments without wildlife fencing, and using a CMF of 0.15 for injury crashes, the expected crashes is reduced to one injury crash as shown in Table 4-10. A total of 80 PDO wildlife-related crashes were identified for the “Before” period, and a total of 20 was calculated using a CMF of 0.26 in the “After” period. An estimated total safety benefit of approximately \$65,715,592 over 20 years was calculated as shown in Table 4-11. The economic analysis indicates wildlife fencing will yield a benefit-cost ratio of approximately 3.0, using a 3% discount rate. The service life of the fence is assumed to be 20 years.

Table 4-9 Average Annual WVC Cost (2010-2024)

Injury	Crash Cost
KABC	\$460,358.46
PDO	\$18,600.00

Table 4-10 Study Treatment Segments Cost Calculation

Crash Severity	Observed Crashes Before implementation per year	Expected Crashes After implementation per year	CMF
Fatal and injury	8	1	0.15
Property damage only	80	20	0.25

Countermeasure	Miles	Cost (\$) /mile	Cost (\$)
Wildlife fence installation	138	216480	29874240
Assumptions:	Total Crash Cost		
Fatal and Injury Cost assumed=	\$460,360		
PDO Crash Cost assumed=	\$18,600		
Discount rate =	3 percent		

Table 4-11 Benefit-Cost Ratio

Year	Before Yearly Fatal and Injury Crashes	After Yearly Fatal and Injury Crashes	Reduction in Fatal & Injury Crashes	Annual Monetary Value of FI Crashes (\$)	Before Yearly PDO Crashes	After Yearly PDO Crashes	Reduction in PDO Crashes	Annual Monetary Value of PDO crashes (\$)	Total Benefit (\$)	Present Value Ratio	Present Value Saved (Year 0) (\$)
1	8.0	1.2	6.8	3130448	80.0	20.8	59.2	1101120	4231568	0.971	4108318
2	8.0	1.2	6.8	3146100	80.4	20.9	59.5	1106626	4252726	0.943	4008602
3	8.1	1.2	6.9	3161831	80.8	21.0	59.8	1112159	4273989	0.915	3911306
4	8.1	1.2	6.9	3177640	81.2	21.1	60.1	1117720	4295359	0.888	3816371
5	8.2	1.2	6.9	3193528	81.6	21.2	60.4	1123308	4316836	0.863	3723741
6	8.2	1.2	7.0	3209496	82.0	21.3	60.7	1128925	4338420	0.837	3633359
7	8.2	1.2	7.0	3225543	82.4	21.4	61.0	1134569	4360112	0.813	3545170
8	8.3	1.2	7.0	3241671	82.8	21.5	61.3	1140242	4381913	0.789	3459123
9	8.3	1.2	7.1	3257879	83.3	21.6	61.6	1145943	4403823	0.766	3375163
10	8.4	1.3	7.1	3274169	83.7	21.8	61.9	1151673	4425842	0.744	3293242
11	8.4	1.3	7.1	3290540	84.1	21.9	62.2	1157431	4447971	0.722	3213309
12	8.5	1.3	7.2	3306992	84.5	22.0	62.5	1163219	4470211	0.701	3135316
13	8.5	1.3	7.2	3323527	84.9	22.1	62.9	1169035	4492562	0.681	3059216
14	8.5	1.3	7.3	3340145	85.4	22.2	63.2	1174880	4515025	0.661	2984963
15	8.6	1.3	7.3	3356846	85.8	22.3	63.5	1180754	4537600	0.642	2912513
16	8.6	1.3	7.3	3373630	86.2	22.4	63.8	1186658	4560288	0.623	2841821
17	8.7	1.3	7.4	3390498	86.6	22.5	64.1	1192591	4583089	0.605	2772844
18	8.7	1.3	7.4	3407450	87.1	22.6	64.4	1198554	4606005	0.587	2705542
19	8.8	1.3	7.4	3424488	87.5	22.8	64.8	1204547	4629035	0.570	2639874
20	8.8	1.3	7.5	3441610	88.0	22.9	65.1	1210570	4652180	0.554	2575799
Benefit Cost Ratio								2.0	Total Present Value Saved	\$ 65715592	

4.9 Mitigation and Implementation Thresholds

Wildlife-fencing mitigation projects can be justified and implemented when they meet an expected cost-benefit threshold. A historic cost benefit for wildlife-fencing projects was determined by calculating the safety benefit achieved by other wildlife-fencing projects. The average cost of wildlife-fencing installation in Utah is \$ 216,480 per mile, based on actual contractor bid costs for projects, with the most recent project from 2024 and the oldest from 2008. The historic 20-year lifetime benefit-cost ratio was determined to be 2.0, determined by a predicted lifetime benefit of \$65,715,592 from 138 miles of wildlife fencing. To reach a cost benefit of 2.0, the lifetime benefit would exceed $2 \times \$ 216,480$ or \$432,960. A study segment that has an observed 20-year PDO crash frequency of 36.3 crashes per mile without wildlife fencing is expected to experience a 26.9 crash reduction in PDO WVCs after wildlife-fencing installation. The 26.9 lifetime crash reduction at \$18,600 benefit per crash yields the \$500,000 benefit. The historic average safety benefit is met and would thus meet the threshold of similar wildlife-fencing projects, when 36.3 PDO crashes, or 1.8 PDO crashes per year per mile, are observed in a candidate segment. Similarly, the historic average crash benefit is met with a lifetime reduction of 1.03 injury crashes, or a reported lifetime injury crash rate of 1.2 injury crashes per mile. A combination of PDO and injury crashes per mile would also provide a combined crash benefit. Mitigation locations for installing wildlife fencing could be identified by using the implementation thresholds identified, or agencies could set higher cost-benefit goals beyond the 3.0 ratio to prioritize locations with greatest benefit or to match other safety mitigation priorities.

Mitigation measures that include other infrastructures to protect wildlife, such as wildlife crossings, can also be justified using this method. The expected safety benefit can be determined by taking the average observed WVCs for injury and PDO crashes per year and multiplying each number by the corresponding CMF for injury (0.15) and PDO (0.26) crashes to calculate the reduction in WVCs and corresponding safety benefit per year. The sum of the crash benefit, multiplied by the expected years based on the lifespan of the project will determine the lifetime crash benefit. The project is viable when the crash benefit divided by the 2.0 benefit cost exceeds the lifetime cost of constructing and maintaining the infrastructure. When the implementation

threshold provides the target safety benefit value for the project that meets or exceeds the benefits of similar projects, then the project becomes viable and should be considered for implementation.

5.0 CONCLUSIONS

5.1 Overview

This chapter summarizes the findings of the study, explains data and evaluation methods along with the results and conclusions, and addresses the objectives of the research.

5.2 Summary

WVCs are a significant safety concern and a major source of wildlife mortality. Wildlife fencing is a safety countermeasure to mitigate WVCs and enhance wildlife conservation efforts. The intent of this project was to establish a CMF for wildlife-fencing installation in Utah. The CMF was developed using the CMF Clearinghouse guidance regarding accuracy, precision, and general applicability of results. Common characteristics of a high-quality CMF include a statistically rigorous reference group, adequate sample size, diverse geographies and sites, small standard errors, and controls for potential bias.

This study investigated the safety effectiveness of wildlife fencing installed in Utah between 2010 and 2023. The study evaluated 54 treated sites (138 miles) with wildlife-fencing installations and 90 control sites (583 miles) with similar characteristics. Traffic volume, wildlife herd size, migration area usage type, and urban versus rural were included as explanatory variables for SPFs. SPFs were developed, and CMFs calculated, using the EB methodology for various crash types. A CMF of 0.25 for total wildlife-related crashes was estimated showing that wildlife fencing has the potential to reduce 75% of total wildlife-related crashes. A CMF for fatal and injury crashes and PDO crashes was also investigated and found to be 0.15, showing that wildlife fencing has a significant effect in reducing fatal and injury crashes by 85%. Similarly, a CMF of 0.26 for the PDO crashes was calculated, indicating a crash reduction of 74%. It was seen that wildlife fencing creates a greater reduction (about 87%) in WVCs in sensitive migration areas compared to other areas because these areas concentrate animal movement across roads, increasing the probability for WVCs. Low standard errors and narrow 95% confidence intervals reinforce the statistical reliability of the results. Overall, the data strongly supports wildlife fencing as a highly effective safety countermeasure with consistent impact

across all crash scenarios in this study. The economic analysis indicates the implementation of wildlife fencing will yield benefit-to-cost ratios of approximately 2.0 with a 3% discount rate.

5.3 Limitations and Future Research

This project utilizes locations in the state of Utah and has limitations in sample size. More data should provide better results with more variables being statistically significant in the SPFs. With a larger data pool, we could consider more of the severities for injury crashes instead of KABC all together. This study could only incorporate 54 treated segments (138 miles), which could be increased if information on wildlife fence installations is available for other states with wildlife crashes. Similarly, more control segments will be available to be added.

Additional data limitations include if a vehicle crashes after swerving to avoid an animal but does not actually hit the animal. Police reports may or may not indicate the crash as wildlife-involved. Training to police officers and data managers should include guidance to mark a crash as wildlife-involved if the animal was a contributing factor.

Establishing a larger data pool for calculating CMFs offers several key benefits. It allows for more accurate and reliable estimates of safety countermeasure effectiveness. A larger dataset will also improve the ability to identify trends and patterns in crash data, leading to a better understanding of the factors contributing to crashes. Given that data collection methodology, utilization framework, and statistical modeling and analysis processes have already been established in the current study, expanding Utah's study into a broader region and multiple states presents a valuable opportunity for regional integration. This expansion would leverage existing analytical foundations, requiring primarily the incorporation of additional datasets.

By utilizing the well-structured framework already in place, the transition to a regional study would enhance comparative analysis across multiple jurisdictions, providing a more comprehensive understanding of transportation trends and safety factors across the region. This approach would streamline implementation, maximize resource efficiency, and enable data-driven policy decisions informed by a larger, more diverse dataset. Such an expansion would also strengthen collaboration among regional transportation agencies, fostering a unified strategy for addressing key challenges in infrastructure, traffic management, and safety improvements.

The scalability and adaptability of the existing model ensure that this initiative can be executed efficiently while maintaining methodological consistency and analytical rigor. Larger datasets will provide more robust statistical analysis, leading to more precise CMF estimates. This will reduce the potential for bias and error in the calculations, making the CMFs more reliable. As accurate and reliable CMFs enable agencies to make more informed decisions about where and how to invest in safety improvements, agencies can prioritize projects that offer the greatest potential for reducing crashes.

Due to smaller sample size, variables indicating migration area and herd sizes are not significant in the SPFs, so exposure of wildlife could not be fully understood from this study. Future efforts will include wildlife population densities adjacent to the roadways obtained from wildlife estimates.

6.0 RECOMMENDATIONS AND IMPLEMENTATION

6.1 Recommendations

Future research should expand the dataset beyond Utah to include wildlife-fencing projects from other states, to enhance the reliability of safety estimates and allow for broader comparisons. Increasing the number of treated and control segments would improve the statistical strength of SPFs and enable more detailed analysis of crash severities beyond the KABC classification. Utilizing the established modeling framework, a regional or multi-state initiative would promote greater collaboration among transportation agencies and lead to more consistent, data-driven decisions. Incorporating diverse datasets would also help refine CMFs, reducing bias and improving accuracy in evaluating safety countermeasures. Ultimately, these steps would support effective prioritization of mitigation strategies, maximize resource efficiency, and strengthen wildlife and roadway safety across broader networks.

6.2 Implementation Plan

An implementation plan should begin with identifying high-priority segments of roadways using crash data, migration patterns, and ecological features to target wildlife-fencing installations. The crash benefit ratio and CMFs provided in the report indicate that roadway segments with an average WVC frequency of 1.8 per year will provide the same or greater safety benefits when installing wildlife fencing. Engineering designs should include fencing specifications and wildlife crossings, while minimizing disruption to habitats. Collaboration with UDOT engineers, wildlife experts, local agencies, and the public will benefit project planning. Post-installation, crash data, and carcass counts should be monitored to evaluate effectiveness through SPFs and CMFs. As success data accumulates, Utah's framework can be scaled across the region, using centralized databases to share insights and streamline decision-making. Funding opportunities through federal grants and local partnerships should be pursued, with maintenance and monitoring integrated into long-term budgets to ensure sustainability.

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