The Impact of Wildlife Crossing Structures on Wildlife-Vehicle Collisions

Wisnu Sugiarto[1]
Ph.D. Student
School of Economic Sciences
Washington State University
wisnu.sugiarto@wsu.edu

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Abstract

This paper examines whether wildlife crossing structures reduce the number of wildlife-vehicle collisions. Using Washington state crash data from 2011 to 2020, I employ a difference-in-differences methodology at the year level on each of 13 observed wildlife crossing structures in Washington. The treatment area consists of wildlife-vehicle collisions within 10 miles of a wildlife crossing structure, and the control area includes wildlife-vehicle collisions that are 60-70 miles away from the same wildlife crossing structure. I find evidence that wildlife crossing structures result in one to three fewer wildlife-vehicle collisions on average per mile per year. The marginal treatment effect also holds within a 5-mile treatment, 15-mile treatment, and when controlling for the presence of other structures within the baseline of 10-mile treatment area. However, the collision reductions are more consistent among wildlife bridges than culverts, suggesting that not all wildlife crossing structures have the same effects in reducing accidents involving wildlife. Using a back-of-the-envelope approach, each wildlife crossing structure yields annual benefits of $235,000-443,000 in 2021 U.S. dollars.

The number of wildlife-vehicle collisions in the United States poses a safety concern, as one to two million collisions between vehicles and large animals occur every year (Huijser et al., 2017). In the state of Washington, highway U.S. 97 in Okanogan Valley alone has more than 350 deer carcasses each year in a 12.5 mile stretch of the highway (*Safe Passage Highway 97*, 2021). Presence of wildlife animals on the roads poses a danger to not only motorist safety, but also to wildlife survival. Additionally, collisions involving wildlife are costly. The estimated annual costs associated with wildlife-vehicle collisions are between US$ 6.2 and US$ 12.4 billion (2007 dollars) (Huijser et al., 2009). Meanwhile, people continue to rely on highways for commerce and travel, and animals continue to have mobility needs for food, mating, and migration. Thus, identification of an effective mitigation strategy on reducing wildlife-vehicle collisions is essential for transportation safety.

One strategy to keep animals away from the roads is to construct wildlife crossing structures. Wildlife crossing structures are public goods that can improve animal connectivity and motorist safety. However, the construction of a wildlife crossing structure is costly, and it is important to justify allocation of resources, including tax dollars. Notably, the Infrastructure Investment and Jobs Act includes an unprecedented, dedicated funding of US$350 million over five years for wildlife crossing structure construction (*Infrastructure Bill Passes House, Signed into Law*, 2021).

This paper studies the effectiveness of wildlife crossing structures on reducing the number of reported wildlife-vehicle collisions. In addition, I include a back-of-the-envelope monetized benefits of collision[2] reductions by relating the findings to the value of statistical life (VSL) literature and a cost-benefit study by Huijser et al. (2009). Analyses in this study use crash data and wildlife crossing structure information from the Washington State Department of Transportation (WSDOT). I hypothesize that wildlife crossing structures can lower the number of wildlife-vehicle collisions, but not all structures[3] have the same effects. The

[2]All collisions refer to wildlife-vehicle collisions. Otherwise, they will be explicitly noted.

[3]I use ”wildlife crossing structures”, ”crossing structures”, and ”structures” interchangeably. Other

proposed hypothesis is based on two motivating reasons. First, there is a photo evidence from WSDOT (appendix Figure B1) that animals use wildlife crossing structures. The use of wildlife crossing structures signals a possible reduction in wildlife-vehicle collisions because animals are off the roads. Second, on the other hand, wildlife crossing structures may be constructed in areas that do not historically have many wildlife-vehicle collisions. Their construction may be due to a focus on wildlife connectivity, rather than motorist safety. In such cases, the presence of structures may not affect the number of collisions. These two opposing reasons motivate the empirical research in this paper.

The identification strategy uses a difference-in-differences (DID) approach to test the impact of each wildlife crossing structure on the number of wildlife-vehicle collisions. I compare the annual number of wildlife-vehicle accidents before and after the construction of a wildlife crossing structure between a treatment area and a control area. The treatment area covers all reported accidents involving wildlife that occur within 10 miles of a crossing structure. The choice of a 10-mile bandwidth treatment comes from a study by Nelson, Mech, and Frame (2004). The researchers use global positioning system (GPS) radio collars on female white-tailed deer and find that deer migrate a minimum of 2.1-18.6 km/day, or approximately 1.3-11.6 miles, in spring[4]. The control area consists of all reported accidents involving wildlife that occur between 60 and 70 miles away from a crossing structure. There is a 60-mile gap between the treatment and control areas for two reasons. First, it is difficult to disentangle the treatment effect from the control group if the location of treated and controlled areas are too close to each other. Second, the 60-70 mile distance ensures that each control area is situated outside the treatment area of all other wildlife crossing structures.

There are 22 wildlife crossing structures in Washington, and most structures are supported with well-maintained fencing. I observe 13 of 22 structures in this study for two reasons. First, the analysis uses historical crash data from 2011 to 2020. As a result, there

meanings will be clearly noted.

[4]Deer migrate similar distances in autumn.

are no pre-treatment crash data among wildlife crossing structures that were completed prior to 2011. The identification approach of applying DID method on each wildlife crossing structure relies on having pre- and post-treatment information for each corresponding structure, so structures completed prior to 2011 are excluded from this study. Second, not all structures are qualified for the control group design. For example, some wildlife crossing structures are 74 miles (appendix Table A7) from each other. This implies that the control group for a structure may be affected by a treatment effect of another structure. Thus, each of the 13 wildlife crossing structures has corresponding pre- and post-treatment crash data and is qualified for a clean control group.

The findings report evidence that wildlife crossing structures reduce the number of wildlife-vehicle collisions by one to three accidents on average per mile per year, but not all structures have statistically significant effects. Reductions in wildlife-vehicle collisions are more consistent among wildlife bridges than wildlife culverts[5]. In addition, I employ several sensitivity checks such as changing the treatment radius and controlling for the presence of other wildlife crossing structures within the baseline of a 10-mile treatment radius. Presence of wildlife crossing structures also lowers the number of wildlife-vehicle collisions that are both within a 5-mile and 15-mile radius of a structure, and the statistical results hold when controlling for the presence of other structures. Relating the findings to the value of statistical life (VSL) literature and Huijser et al. (2009), a wildlife crossing structure generates an annual benefit of US$235,000-443,000 in 2021 dollars.

Previous studies focus on wildlife crossing structures in North Carolina (McCollister & Van Manen, 2010), Utah (Bissonette & Rosa, 2012), and Wyoming (Sawyer et al., 2012). They find that wildlife underpasses and fencing improve road safety. Nonetheless, in their report to congress, Huijser et al. (2017) state a need to address knowledge gaps, insufficient

[5]The WSDOT defines bridges as structures that are greater than 20 feet long (measured parallel to the highway) that convey water under the highway. Culverts are structures that are less than 20 feet long (measured parallel to the highway) that convey water under the highway.

information, and statistical methods to analyze the data associated with the study of wildlife-vehicle collision reduction. There are no standards for collecting wildlife-vehicle collision data, and methods vary between states and agencies. As a result, more research on the topic is needed, including empirical work involving statistical analysis. This paper answers the call and contributes to more empirical work of the topic.

This paper complements the literature with four contributions. First, I examine wildlife crossing structures in Washington and utilize Washington state crash data. Evaluating wildlife crossing structures at various locations is useful because animal types as well as structural and location attributes may differ. Second, this study includes the use of time and location fixed effects to help with capturing the underlying unobservable systematic differences between observed time units and locations. Third, I use the data to address an endogeneity concern associated with the placement of wildlife crossing structures to improve the robustness of this causality study. The data suggest that locations with high wildlife-vehicle collisions do not dictate the placement of wildlife crossing structures. Fourth, I examine 13 wildlife crossing structures that consist of multiple types, different completion years, and varying locations and distances between one another. Few studies have simultaneously examined responses to multiple structure types that may be close to one another, and the effects on collision reductions are likely to vary depending on structure type and wildlife preferences (Dodd et al., 2007); (Gagnon et al., 2011); (Simpson et al., 2016).

The findings from this study are directly relevant to multiple stakeholders including transportation planners and road ecologists. One limitation of this work is that it does not address any impact of wildlife crossing structures on wildlife connectivity. Questions related to whether wildlife crossing structures improve adjacent ecosystems are beyond the scope of this paper. In addition, reported collisions involving wildlife are only one dimension of road safety. Many wildlife-vehicle collisions are likely not reported. Future research may consider using animal carcass data or insurance claims. Overall, this study contributes to a continuous evaluation and improvement of road safety, and supports the importance of wildlife crossing structures.

Background

I. Wildlife-Vehicle Collisions

An obvious reason why road safety is so important is that many lives are at stake when people are on the road. In the most of the twentieth century, considerations of road constructions focused on the ease of terrain, logistics, and cost. The importance of wildlife habitat in relation to road construction and maintenance did not appear until late in the twentieth century (Forman et al., 2003). Consequently, many roadways pass through habitats for numerous species and disrupt wildlife's mobility.

Wildlife-vehicle collisions are a concern in Washington because there are many highways that cross significant wildlife-use areas, such as deer or elk wintering areas or migration routes (Kalisz, 2021). In eastern Washington, state highways north of Spokane intersect with white-tailed deer wintering grounds. In southeastern Washington, state route 124 and U.S. 12 follow the Touchet River Valley, which has abundant white-tailed deer. In western Washington, a high rate of deer-vehicle collisions occurs on Whidbey Island, along State Route 20 and State Route 525. Highways intersecting the Cascade Mountains, such as the Packwood-Randle vicinity and on I-90 near North Bend also have a high number of elk-vehicle collisions.

Not only is the safety of humans and animals at stake, wildlife-vehicle collisions are also costly. A typical collision incurs various expenses from vehicle repair costs, human injuries or fatalities, towing, emergency responders, investigation, and carcass removal and disposal. Huijser et al. (2009) estimate the average cost of a vehicle collision with deer to be US$6,617

(2007) (US$10,723.89 in 2021)[6]. Most wildlife-vehicle collisions involve deer, but accidents with larger and heavier animals occur and are even more costly. In 2007 US dollars, the average estimated costs for elk-vehicle and moose-vehicle collisions are US$17,483 ($28,333.96 in 2021 USD) and US$30,760 ($49,851.43 in 2021 USD), respectively (Huijser et al., 2009). In the state of Washington, Highway 97 in the Okanogan Valley alone costs drivers, insurers, and taxpayers more than US$2.2 millon annually (*Safe Passage Highway 97*, 2021).

II. Mitigation Strategies to Keep Wildlife Off the Road

A number of methods to reduce the risk of collisions with wildlife on highways are available, but not all methods yield the same benefits or have the same costs. Fencing is a popular method, but it can be costly to install and maintain, and cannot be used everywhere. On U.S. Highway 93 on the Flathead Reservation in Montana, the costs of wildlife fencing are US$7.9, US$11.6, or US$12.5 per foot, depending on the road section (Huijser et al., 2017). The authors also mention that fencing is impractical in dense vegetation areas where there is not much public roadside right of way. Highly motivated wildlife can find their way around the ends of a fenced highway segment, and fencing does not connect wildlife habitat from one side of a highway to another.

Road signs and flashing signs are also common tools to warn motorists of the possibility of wildlife presence in the area. However, signs do not stop wildlife from entering highways, nor do they provide any alternative for animals to cross safely. Another alternative is to lower the speed limit in areas where animals often cross the highway. But, the reduction in speed limit is not an effective way to reduce wildlife-vehicle collisions because drivers are apathetic to the lowered speed limits (Kalisz, 2021); (Riginos et al. 2022).

Furthermore, WSDOT has evaluated technologies such as deer reflectors, a laser detec-

[6]I use CPI Inflation Calculator from the U.S. Bureau of Labor Statistics for all inflation adjusted dollars in this paper.

tion system, and animal activated warning signs, but most of these have not proven to be effective because they can easily trigger false alarms. The only technology still in use since 2000 is the animal activated warning signs to notify motorists when elk are near U.S. 101 in Sequim (Kalisz, 2021). It relies on radio telemetry collars placed on elk to trigger a flashing elk crossing sign. The drawbacks of such a method are the need to place radio collars on the elk, and presence of elk nearby will trigger the receiver even though they are not crossing the road (Kalisz, 2021).

Another method to mitigate the presence of animals on roads is to provide wildlife crossing structures. Wildlife crossing structures include a variety of types, each with its own advantages and drawbacks. Wildlife overpasses are less confining than underpasses, and they have temperature and light exposure which makes them suitable to maintain ambient conditions of rainfall. However, they are usually more costly than underpasses. Overpasses are less effective for semi-aquatic species, such as muskrats, beavers, and alligators (Jackson & Griffin, 2000). Some other crossing structures include viaducts, expanded bridges, oversize stream culverts, upland culverts, and dry drainage culverts. A notable crossing structure in Washington is the large wildlife overpass arching above seven[7] lanes of traffic on I-90 over Snoqualmie Pass, near the east end of Keechelus Lake. However, the use of wildlife crossing structures is not exclusive to Washington. Wildlife crossing structures are also available in other US states and other countries.

Finally, mitigation measures on reducing wildlife-vehicle collisions do not have to use physical structures such as wildlife overcrossings, bridges, culverts, or even road signs. One effective alternative is to capitalize on the presence of predators. Gilbert et al. (2017) find that cougar recolonization in the eastern United States reduces deer-vehicle collisions by 22%. This large carnivore recolonization prevents 21,400 human injuries, 155 fatalities, and US$ 2.13 billion in savings within 30 years of the method establishment. A similar

[7]Technically, the overpass spans six travel lanes and one additional lane for pulling over and installing tire chains in the winter.

mitigation approach, Raynor, Grainger, and Parker (2021) quantify the effects of restoring wolf populations in Wisconsin and find that wolf entry reduces deer-vehicle collisions by 24% for the average county. Additionally, the authors report that reductions in collisions are mostly due to a behavioral response that deer are afraid of the wolves rather than through a decline in deer population from wolf predation.

Literature Review and Contributions

Multiple approaches are available to examine the effectiveness of wildlife crossing structures. One approach is to define effectiveness based on the frequency of wildlife crossing. Learning about wildlife movement and their crossing frequency on wildlife crossing structures is important for assessing wildlife connectivity in many countries and multiple US states. For example, Olsson, Widén, and Larkin (2008) find that five to seven individual moose used an overpass in southwestern Sweden annually, which was sufficient to maintain gene flow between otherwise disjoined subpopulations. In the Changbai mountainous area, China, 13 medium- and large-sized wildlife species used tunnels, bridges, and culverts to cross highways (Wang et al., 2017). In the United States, P. Cramer, Center, et al. (2012) document over 23,000 mule deer passages on wildlife crossing structures in Utah; P. C. Cramer and Hamlin (2016) report white-tailed deer moved through wildlife crossing structures on over 24,000 occasions in Montana.

A number of studies have also explored wildlife preferences for crossing structure type. The response of particular species to wildlife crossing structures varies across North America (Clevenger & Huijser, 2009). For example, cougars tend to use more constricted structures, such as underpasses (Gloyne & Clevenger, 2001); (Clevenger & Waltho, 2005). Grizzly bears, wolves, elk, and deer favor structures that are high, wide, and short in length (Clevenger & Waltho, 2005). Sawyer, Rodgers, and Hart (2016) report 79% of 40,251 mule deer crossings were on underpasses and 93% of 19,290 pronghorn crossings were on overpasses. Furthermore, other studies examine factors that influence wildlife uses of crossing structures. Season has the greatest effect on underpasses uses by elk; summer use is more favorable than winter (Dodd et al., 2007). Moose and roe deer use an overpass mostly during night time when traffic volume decreases (Olsson et al., 2008). Also, artificial light can deter some animals to use crossing structures (Bliss-Ketchum et al, 2016).

A second approach in defining the effectiveness of wildlife crossing structures is from the road safety perspective. The second approach is what I pursue in this research, particularly the impact of wildlife crossing structures on wildlife-vehicle collisions. This empirical research shares a similar motivation with several existing studies. McCollister and Van Manen (2010) study the effectiveness of underpasses and fencing to reduce wildlife-vehicle collisions on U.S. Highway 64 in North Carolina. The study area consists of three stretches of the highway with underpasses and fencing, and four stretches of the highway without the mitigation measures. Using collision reports from adjacent highway sections, the researchers find that underpasses and fencing reduce the number of deer-vehicle collisions, resulting in 58% fewer wildlife mortalities. Bissonette and Rosa (2012) study the effectiveness of mitigation measures on deer-vehicle collisions in southwest Utah. The authors compare six years of pre-construction on mortality with two years of post-construction data on mortality. They find a 98.5% decline in deer mortalities in the treatment area with fencing, jump-outs, and underpasses, whereas the control area experiences a 2.9% decline. Sawyer et al. (2012) investigate whether underpasses and associated fencing reduce deer-vehicle collisions in southwest Wyoming. The authors find the mitigation measures reduce deer-vehicle collisions by 81%.

The first contribution relates to complementing existing studies by using Washington state data. Previous studies in the U.S. have assessed the impact of wildlife crossing structures on wildlife-vehicle collisions in North Carolina, Utah, and Wyoming. The studies find that wildlife underpasses and fencing improve road safety through reductions in deer-vehicle collisions. It is useful to examine the effectiveness of wildlife crossing structures at different locations because structural and location attributes may differ across areas, which suggests that the use of structures can vary. For example, black bears have multiple size preferences for underpasses (Donaldson, 2007); (Clevenger & Waltho, 2005).

Second, this study uses time and location fixed effects in addition to having pre- and post-treatment data, and a control group. Previous studies have used pre- and post-treatment data as well as a control group. I supplement the statistical analysis with time and location fixed effects, while also using baseline data and a control group. Using time and location fixed effects help with capturing changes that may occur through time and differences attributed to locations. It is possible that the reductions in wildlife-vehicle collisions are from factors other than the presence of wildlife crossing structures. For example, floods, wildfires, and severe winters can affect wildlife population and behavior (Hardy et al., 2003). Also, the reductions in wildlife-vehicle collisions happen because fewer people are traveling due to the Covid-19 pandemic (Shilling et al., 2021). Thus, it is important to control for unobserved factors that might influence the effects of wildlife crossing structures on wildlife-vehicle collisions.

Third, I use the data to address an endogeneity concern associated with the placement of wildlife crossing structures. For example, locations with high wildlife-vehicle collisions dictate the placement of wildlife crossing structures. Thus, the presence of randomness may be missing, which is crucial for identifying causal effect (Cunningham, 2021). If the placement of wildlife crossing structures were determined by the frequency of wildlife-vehicle collisions, then the locations with high number of wildlife-vehicle collisions should have been equipped with the structures. However, the data show that locations with high wildlife-vehicle collisions do not dictate the placement of wildlife crossing structures.

Finally, I examine 13 wildlife crossing structures that consist of multiple types, different completion years, and varying distances between one another. Because there are wildlife preferences for structure type, I categorize my results into wildlife bridges and culverts.

The newest structures were completed in 2018 and the oldest ones examined in this study were completed in 2012. Also, few studies have documented responses to multiple structure types that may be close to one another (Simpson et al., 2016). The researchers hypothesize that there is no difference in the numbers of mule deer crossing between on overpasses and underpasses, and find that greater passage rates occur at overpasses than underpasses. There are structures in Washington that are adjacent to one another, and other structures can be over 100 miles apart from each other (appendix Table A7). This paper examines structures that are both near and far from each other.

Data

The collected data in this study consists of two components: 1) location and information of each wildlife crossing structure, and 2) reported vehicle crash data. The following sections clarify each data set further and report some summary statistics of the data sets.

I. Wildlife Crossing Structures

The data collection of wildlife crossing structures involves communication with multiple WSDOT team members or offices, such as WSDOT habitat connectivity biologists, bridge inspectors, engineers, maintenance specialists, and the communications office. The wildlife crossing structures are available across the state of Washington, with half of them located on interstate 90 in Kittitas county. Figure 1 below maps out the locations of each wildlife crossing structure in Washington. Every triangle represents a wildlife crossing structure location[8].

Table 1 summarizes the information of each wildlife crossing structure, starting with the oldest structures. There are 22 structures in total; 12 of them are considered bridges

[8]A number of triangles are stacked on top of one another due to the close proximity of wildlife crossing structures.

Figure 1: Locations of Wildlife Crossing Structures in Washington

and 10 of them are culverts. The *Structure Comp.* column refers to the completion year of a structure, which may be different from the completed project time. Construction of a wildlife crossing structure is typically part of a larger highway project. A completed wildlife crossing structure is immediately available for animals to use, but its highway project is not necessarily over. Landscaping and drainage projects usually follow the completion of a structure. The oldest two structures have been present since 1976 in King County. Both structures also have fencing, but they are in poor condition. Almost all wildlife crossing structures have fencing support, and most fences are in good condition.

A structure completion year may have a different short-term treatment effect than the year when an overall project is complete. For example, noises and human activities from a highway construction deter animals from using a crossing structure, even though it is ready for use. This means a finished structure may not have any immediate effects on reducing the number of wildlife-vehicle collisions; animals are still crossing on roads rather than on wildlife crossing structures. However, the long-term treatment effects between a structure completion year and its overall project completion year should be identical. Animals learn about the presence of crossing structures and adapt over time. In this paper, I assume the treatment effect begins on structure completion year since a completed wildlife crossing structure is immediately available for animals to use. Evidence also suggests that wildlife such as mule deer use crossing structures immediately following a completed construction (Simpson et al., 2016).

Type	Name	County	Structure Comp.	Project Comp.	Fencing	Fencing Cond.
Bridge	MP 27 Wildlife Bridge	King	1976	1979	Yes	Bad
Culvert	MP 29 Steel Pate Arch Culvert	King	1976	1979	Yes	Bad
Bridge	Little Hoquiam River Bridge	Grays Harbor	1988	1988	Yes	Fair
Culvert	Spur 109 Wildlife Culvert MP 3.00	Grays Harbor	1993	1993	Yes	Fair
Culvert	Spur 109 Wildlife Culvert MP 2.80	Grays Harbor	1995	1995	Yes	Fair
Culvert	McNary Wildlife Crossing	Benton	2007	2007	Yes	Unknown
Culvert	Deadman Creek Fish and Wildlife Crossing	Spokane	2010	2012	Yes	Good
Culvert	Monroe Wildlife Crossing	Snohomish	2012	2017	Yes	Good
Culvert	River Otter Crossing Culvert	Walla Walla	2012	2013	Unknown	Unknown
Bridge	Rocky Run Creek Bridge (MP 56.8)	Kittitas	2012	2015	Yes	Good
Bridge	Gold Creek Bridge	Kittitas	2012	2015	Yes	Good
Bridge	Hyak Underpass (MP 55.3)	Kittitas	2012	2015	Yes	Good
Bridge	Butler Creek Bridge	Klickitat	2012	2012	Yes	Good
Culvert	Wolfe Creek	Kittitas	2013	2015	Yes	Good
Bridge	Butler Creek Fish and Wildlife Crossing	Klickitat	2014	2015	Yes	Fair
Bridge	Resort Creek Bridge (MP 59.5)	Kittitas	2015	2019	Yes	Good
Culvert	Townsend Creek (MP 60.6)	Kittitas	2017	2019	Yes	Good
Culvert	Unnamed Creek (MP 59.7)	Kittitas	2017	2019	Yes	Good
Bridge	Price Creek Bridge (MP 61.3)	Kittitas	2018	2019	Yes	Good
Bridge	Noble Creek Bridge (MP 61.4)	Kittitas	2018	2019	Yes	Good
Bridge	Unnamed Creek Bridge (MP 60.9)	Kittitas	2018	2019	Yes	Good
Bridge	Wildlife Overcrossing (MP 61.5)	Kittitas	2018	2019	Yes	Good

Table 1: Information of wildlife crossing structures in Washington

II. Crash

In the state of Washington, police officers have to submit collision reports to WSDOT when there is a human injury or fatality or property damage exceeding US$1,000 (Kalisz, 2021). The collected crash data are from 2010 to 2020[9], but the primary analysis in this paper relies on 2011-2020 crash data. A drawback of using 2010 data is that it weakens the

[9] WSDOT has crash data starting in 2006, but location coordinates for each accident are available in 2010 and forward.

parallel trend assumption (appendix Figure B4 and Figure B5). However, inclusion of 2010 crashes serves as a robustness check, and the findings remain the same.

Table 2 reports accidents involving wildlife in Washington between 2011 and 2020. Over 1,600 collisions are reported each year, and most of them involve deer. The number of injuries include possible, minor, and serious injury categories. In total, approximately 10% of wildlife-vehicle collisions result in the *injured* category. The number of fatalities includes deaths at scene, deaths after emergency responders arrive, and deaths in hospital. While the number of fatalities is low relative to the number of collisions, the fact that there are over 1,600 vehicle accidents involving wildlife is still concerning. Besides physical conditions, accidents may affect motorists' mental well-being and cause trauma, which are not observable in the data. Another limitation of using a crash data set is that not all accidents are reported. There are under reporting issues because collisions with wildlife can be a hit-and-run or the property damage is incorrectly perceived to be less than US$ 1,000. As further evidence of under reporting, the Insurance Information Institute cites information from a major insurance company, State Farm, that there were over 1.9 million animal collision insurance claims in the U.S. between July 1, 2019 and June 30, 2020 (*Facts + Statistics: Deer vehicle collisions*, 2021).

Year	Wildlife-Vehicle Collisions	Deer-Vehicle Collisions	Injured	Fatality
2011	1,681	1,500	175	0
2012	1,805	1,564	193	1
2013	1,773	1,584	191	3
2014	2,001	1,788	206	2
2015	2,128	1,869	227	1
2016	1,958	1,754	180	3
2017	1,797	1,610	204	4
2018	2,012	1,775	174	2
2019	1,960	1,696	195	0
2020	1,776	1,536	169	7

Table 2: Reported crashes involving wildlife in Washington

III. Summary Statistics

Table 3 reports summary statistics of total annual wildlife-vehicle collisions between 2011 and 2020 that are within 10 miles for each of the thirteen wildlife crossing structures. Some of the wildlife crossing structures are in a close proximity to one another, resulting in identical summary statistics. The total number of wildlife-vehicle collisions ranges from 46 to 228 accidents. Rocky Run Creek Bridge has the lowest number of wildlife-vehicle collisions and Monroe Wildlife Crossing has the highest.

Structure Name	Total	Mean	Std. Dev.	Min	Max
Gold Creek Bridge	47	4.7	2.0	2	8
Monroe Wildlife Crossing	228	22.8	5.0	17	32
Noble Creek Bridge (MP 61.4)	87	8.7	3.5	4	14
Price Creek Bridge (MP 61.3)	86	8.6	3.6	4	14
Resort Creek Bridge (MP 59.5)	77	7.7	3.2	5	14
River Otter Crossing Culvert	94	9.4	2.9	5	15
Rocky Run Creek Bridge (MP 56.8)	46	4.6	2.1	2	9
Townsend Creek (MP 60.6)	80	8.0	3.5	4	14
Unnamed Creek (MP 59.7)	79	7.9	3.3	5	14
Unnamed Creek Bridge (MP 60.9)	83	8.3	3.7	4	14
Hyak Underpass (MP 55.3)	47	4.7	2.0	2	8
Wildlife Overcrossing (MP 61.5)	87	8.7	3.5	4	14
Wolfe Creek	51	5.1	2.5	2	10

Table 3: Summary statistics of total vehicle-wildlife collisions per year

Identification Strategy

The location coordinates in both data sets come in the format of Washington State Plane South. Using ArcMap, I convert all data sets to WGS 1984 format for compatibility with the geodistance calculation feature in Stata. Furthermore, I convert the data sets from WGS 1984 to Web Mercator format for mapping purposes. I append the wildlife crossing structure data set to the crash data set to obtain the distance between each wildlife-vehicle collision and each wildlife crossing structure.

Using the difference-in-differences (DID) method, I compare the annual changes in the number of wildlife-vehicle collisions within 10 miles of a wildlife crossing structure with the number of wildlife-vehicle collisions that occur between 60 and 70 miles away from the same wildlife crossing structure. The choice of the treatment and control areas is not arbitrary. Nelson et al. (2004) use global positioning system (GPS) radio collars on female white-tailed deer and find that deer migrate a minimum of 2.1-18.6 km/day, or 1.3-11.6 miles/day, in spring. The researchers also find that deer migration in fall have similar distances, as well as comparable rates and travel patterns. Using this study as a guide, I apply a 10-mile treatment to examine the effect of wildlife crossing structures on reducing the number of wildlife-vehicle collisions. The control area is chosen because there is no other wildlife crossing structure present within 60-70 miles of a particular structure, and that distance does not fall within the treatment area of another structure. Additionally, a control area that is 60-70 miles away is more likely to have similar temperatures, weather patterns, climates, and topography conditions. Another option would be to use a control area that is greater than 250 miles away from a structure. However, this alternative is less appealing given that the distance between the treatment and control group is quite far, which means they are less likely to share similar characteristics.

I conduct a DID analysis for each of the 13 wildlife crossing structures that have a structure completion year between 2012 and 2020 to ensure each structure has pre- and post-treatment data. In addition, each of the 13 structures must have a control group that meets the criteria of the study. One drawback of doing a DID analysis at the year level is that the data has only 10 years. To increase the number of observations, I create a *distant point* variable for every mile away from a wildlife crossing structure. For example, *distant point = 1* if an accident location is within the first mile of a wildlife crossing structure. *distant point = 2* if an accident location is beyond one mile and less than or equal to two miles away from a wildlife crossing structure. Each *distant point* value serves as a location identifier. As a result, I have ten locations in the treatment group because the treated area covers 0-10 miles away from a wildlife crossing structure. Similarly, there are ten locations in the control group because the controlled area is between 60 and 70 miles away from a wildlife crossing structure. The creation of the *distant point* variable as a location identifier results in a panel data setup because I observe the same distant points over time.

The following equation (1) provides the DID regression specification:

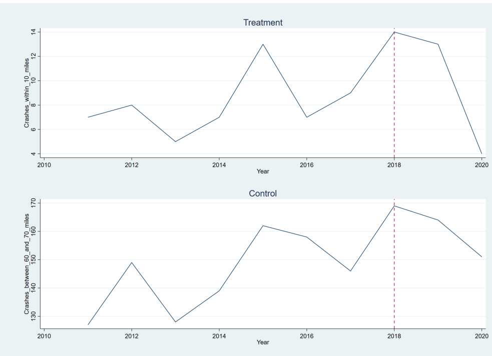
$$Crash_{it} = \alpha + \beta(Structure\_Year) + \lambda(Structure) + \theta(Year) + \omega_i + \delta_t + \epsilon_{it} \tag{1}$$

The dependent variable $Crash_{it}$ represents the number of wildlife-vehicle collisions at distant point i in year t. α is the equation intercept, and β is the primary coefficient estimate of interest. The variable $Structure\_Year$ is a dummy variable obtained by multiplying the *Structure* and *Year* dummy variables. $\lambda(Structure)$ measures the location effect that is not due to the presence of a wildlife crossing structure. $\theta(Year)$ captures changes in all wildlife-vehicle collisions between and after the years a wildlife crossing structure exists. ω_i represents location fixed effects and δ_t accounts for time fixed effects. ϵ_{it} is an error term.

Considering the panel data setup in the identification strategy, the definition of "every mile" refers to each distant point from a wildlife crossing structure. There are some distant points within a particular year that have missing information. However, the information is not actually missing; there are no reported accidents involving wildlife at the distant points in the particular year. Thus, the missing information implies zero reported wildlife-vehicle collisions. This results in a balanced panel data with 200 observations for every regression. The coefficient estimates on the treatment location on all structures are zero and are omitted from the result tables. There is no variation within each unit of the treatment, and the panel data regression fixed effects absorb the coefficients. All regressions apply year and distant point fixed effects, and they are clustered at distant point level.

The parallel trend assumption is a critical assumption to ensure internal validity of using the DID methodology. Figures (2) and (3) show the pre-trends of wildlife-vehicle collisions for each of the 13 wildlife crossing structures. To be consistent with how I present the regression results in the next section, I separate the structures into two categories: bridge and culvert. Figure (2) provides a visual inspection of pre-trends of eight wildlife bridges, and figure (3) shows pre-trends of five wildlife culverts. There are two graphs in each sub-figure. The top graph represents the treatment group and the bottom graph represents the control group. The vertical dashed red line indicates when a treatment effect begins. Some of the wildlife crossing structures were completed in 2012, resulting in only one year of pre-trend data. Comparing each treatment and control group, they appear to have parallel trends in most cases, but they are not perfect. For example, sub-figure (b) in figure (2) shows an increase in wildlife-vehicle collisions from 2016 to 2017 in the treatment group, but a decrease for the control group. In figure (3), sub-figures (a), (b), and (d) do not have the same pre-trends. However, the pre-trends consist of only one year due to data limitation, and it would be incorrect to conclude that the treatment and control groups do not have comparable pre-trends over time. Figures (2) and (3) also suggest that not all completions of wildlife crossing structures have the same impact on motorist safety, thus heterogeneity of treatment effect exists.

(a) Gold Creek Bridge



(b) Noble Creek Bridge

(c) Price Creek Bridge

(d) Resort Creek Bridge

(e) Rocky Run Creek Bridge

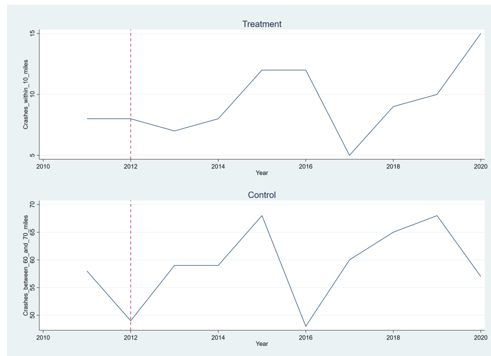
(f) Unnamed Creek Bridge (MP 60.9)

(g) Hyak Underpass

(h) Wildlife Overcrossing

Figure 2: Wildlife Bridge Structures

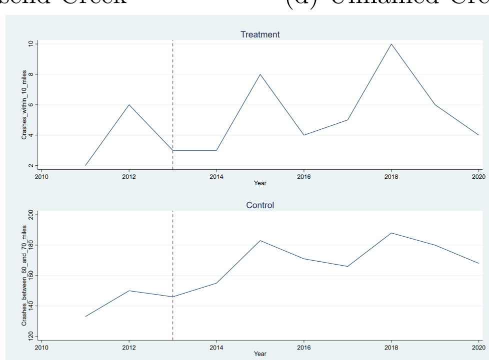
(a) Monroe Wildlife Crossing



(b) River Otter Crossing Culvert

(c) Townsend Creek

(d) Unnamed Creek Culvert (MP59.7)



(e) Wolfe Creek

Figure 3: Wildlife Culvert Structures

Results

Table 4 reports the impact of wildlife bridges on the number of wildlife-vehicle collisions at the year level for every mile away from a specified wildlife bridge. There are eight wildlife crossing structures in the bridge category, and each column represents a specific structure. For example, column 1 reports coefficient estimates for Gold Creek Bridge, column 2 corresponds to Noble Creek Bridge, and so on. Variable *Structure_Year* reports the primary coefficient estimates of interest. The results show that wildlife bridges reduce the number of wildlife-vehicle collisions by one to three accidents on average per mile every year. The reductions in wildlife-vehicle collisions are statistically significant on seven of eight bridges. The presence of Price Creek Bridge does not yield statistically significant reduction in wildlife-vehicle collisions, but the relationship is negative. Variable *Year* captures changes in all wildlife-vehicle collisions before and after the completion of a wildlife bridge structure that are not attributed to the structure's presence. The estimates suggest that vehicle collisions involving wildlife increase after a structure exists.

The reduction effects occur on both relatively older and newer wildlife bridges. Gold Creek, Rocky Run, and Wildlife Bridge were completed in 2012. Resort Creek was completed in 2015, and the remaining bridge structures were completed in 2018. All eight bridges are located on Interstate-90 and are supported with good fencing, which were all completed in 2019.

Table 5 reports the impact of wildlife culverts on the number of wildlife-vehicle collisions at the year level for every mile away from a specified wildlife culvert. There are five wildlife crossing structures in the culvert category, and each column represents a specific structure. For example, column 1 reports coefficient estimates for Monroe Wildlife Crossing Culvert, column 2 corresponds to River Otter Crossing Culvert, and so on. Similar to Table 4, variable *Structure_Year* reports the *DID* estimates. The results show that Monroe, River Otter

Crossing, and Unnamed (MP 59.7) Culverts do not have effects on reducing the number of wildlife-vehicle collisions. However, the presence of Townsend Creek and Wolfe Creek structures reduces wildlife-vehicle collisions by one to three accidents on average per mile every year. Coefficient estimates for variable *Structure* are omitted from the tables because they are collinear with individual structure fixed effects.

Looking at some characteristics of the wildlife culverts, Monroe Wildlife Crossing and River Otter Crossing Culvert were completed in 2012. Neither structure is located on I-90. Monroe Wildlife Crossing is supported with good fencing, but it is unknown whether River Otter Crossing Culvert is equipped with fencing or its condition. The remaining three wildlife culverts have good fencing and can be found on I-90. Wolfe Creek was completed in 2013, and Townsend Creek and Unnamed Culverts were completed in 2017.

Overall, there is evidence that wildlife crossing structures reduce the annual number of wildlife-vehicle collisions, but not all structures have the same effects. The results suggest that reductions in wildlife-vehicle collisions are more consistent among wildlife bridges (include overcrossing) than wildlife culverts.

Table 4: Impact of Wildlife Bridges on Vehicle-Wildlife Collisions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Crash Gold	Crash Noble	Crash Price	Crash Resort	Crash Rocky	Crash Unnamed (MP 60.9)	Crash Hyak Under.	Crash Wild. Over.
Structure_Year	-2.556**	-1.486*	-1.376	-1.808***	-3.089***	-1.538**	-2.656*	-1.557*
	(-2.20)	(-1.76)	(-1.51)	(-3.08)	(-3.18)	(-2.42)	(-2.08)	(-1.98)
Year	2.878**	1.793*	1.588	2.104***	3.494**	1.969**	2.978*	1.779*
	(2.15)	(1.86)	(1.64)	(3.09)	(2.81)	(2.23)	(1.93)	(1.80)
Constant	7.100***	6.700***	6.800***	6.850***	6.800***	6.850***	7.050***	6.750***
	(13.59)	(17.56)	(15.70)	(15.17)	(15.56)	(16.04)	(12.29)	(19.30)
Observations	200	200	200	200	200	200	200	200

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Impact of Wildlife Culverts on Vehicle-Wildlife Collisions

	(1)	(2)	(3)	(4)	(5)
	Crash Monroe	Crash River Otter	Crash Townsend	Crash Unnamed (MP 59.7)	Crash Wolfe
Structure_Year	0.844	0.0333	-1.042*	-1.250	-2.675***
	(0.68)	(0.03)	(-1.77)	(-1.09)	(-4.63)
Year	-1.022	0.283	1.821*	2.075	3.188***
	(-0.94)	(0.21)	(1.94)	(1.63)	(3.32)
Constant	8.150***	3.300***	6.850***	6.800***	6.750***
	(14.65)	(5.77)	(13.15)	(13.29)	(11.76)

Observations	200	200	200	200	200

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Sensitivity Analysis

To test whether the findings hold in other scenarios, I employ four sensitivity analyses for robustness checks. The first sensitivity check uses the 2010 data that is excluded from the baseline results. The inclusion of 2010 data does not alter the conclusion of the findings; wildlife crossing structures can reduce the annual number of wildlife-vehicle collisions. Table A1 and Table A2 in the appendix report the reductions in accidents involving wildlife associated with wildlife bridges and culverts, respectively. Compared to the baseline results, including 2010 data amplifies the average treatment effects. For example, all *Structure_Year* coefficient estimates for wildlife bridges on Table A1 are greater than the baseline results and are statistically significant. The findings on Table A2 for wildlife culverts are also compatible to the Table 5, only Townsend Creek and Wolfe Creek culverts have effects on reducing the number of wildlife-vehicle collisions.

The second sensitivity check examines whether the presence of a wildlife crossing structure has an effect on reducing the number of wildlife-vehicle collisions within a 5-mile treatment radius. Table A3 in the appendix reports that seven of eight wildlife bridges are effective in reducing the annual number of wildlife-vehicle collisions. Similar to the baseline results, there are two to three fewer vehicle accidents involving wildlife on average per mile every year. Table A4 shows that Townsend Creek and Wolfe Creek culverts reduce the annual number of wildlife-vehicle collisions, whereas the remaining three culverts have no effects. These findings within the 5-mile treatment are consistent with the baseline results and are rather unsurprising. Intuitively, an effective wildlife crossing structure in a 10-mile treatment should also have an effect in wildlife-vehicle collision reduction in a 5-mile treatment, considering the treatment location is closer to the structure.

The third sensitivity check investigates the effects of wildlife crossing structures if the treatment area expands to a 15-mile radius. Considering that deer migrate a minimum of 1.3-11.6 miles/day (Nelson et al., 2004), the treatment effect may occur beyond a 10-mile radius. Table A5 reports evidence that wildlife bridges reduce the annual number of wildlife-vehicle collisions by approximately two to three collisions on average per mile. The findings on wildlife culverts are also comparable to the baseline results. Only two of five wildlife culverts have statistically significant effects on reducing wildlife-vehicle collisions.

The fourth sensitivity check controls for the presence of other crossing structures within the 10-mile treatment area. I created a dummy variable, *Other_Structure*, where the value is one if there is at least one wildlife crossing structure present in the treatment area, and it is also conditioned on the oldest year since multiple structures are present. For example, structure Gold Creek Bridge has 10 other wildlife crossing structures within the 10-mile radius, and the oldest structure was completed in 2012. Hence, the dummy variable is equal to one if the year is 2012 and beyond and for all accidents that are within the treatment area. Table A7 reports the impact of wildlife bridge structures on wildlife-vehicle collisions controlling for the presence of other structures. There are no marginal effects on *Noble, Price, Resort, and Wildlife Overcrossing*, but the corresponding presence of other structures has a statistically significant effect on reducing wildlife-vehicle collisions. Some of the coefficient estimates are zero due to collinearity with the primary coefficient estimate of interest, *Structure_Year*. Table A8 reports the impact of wildlife culvert structures on wildlife-vehicle collisions controlling for the presence of other structures. Only three of five examined wildlife culverts have another wildlife crossing structure present within the 10-mile treatment area. Culverts *Townsend* and *Unnamed (MP 59.7)* do not have marginal effects, but the corresponding presence of other structures does.

All sensitivity checks consistently report evidence that wildlife crossing structures reduce the number of wildlife-vehicle collisions, but not all structures have the same effects. Wildlife bridges are more consistently effective in collision reductions than wildlife culverts, though there are some wildlife culverts that have significant effects.

Benefits of Wildlife Crossing Structures

Another goal of this paper is to examine a back-of-the-envelope benefit of wildlife crossing structures. Policymakers and transportation planners may wonder whether retrofitting a wildlife crossing structure to a highway project passes a cost and benefit assessment. It is important to note that the costs of wildlife crossing structures vary by types, lengths, materials, and other factors associated with construction. In Florida, the estimated construction costs for one overpass and two underpasses on I-4 in Volusia County are US$2.7 million each (Neal et al., 2003). The construction of 3 underpasses on U.S. Highway 64 between Roper and Creswell in North Carolina cost US$ 3.6 million, representing 1.85% of the total cost of the new section of highway (Jones, Van Manen, Wilson, & Cox, 2010); (McCollister & Van Manen, 2010). The information suggests that the average cost for an underpass is US$1.2 million. On U.S. Highway 30 in southwest Wyoming, construction of six new underpasses and 10 km (6.2 miles) of fencing in 2008 cost US$ 4.1 million, with US$ 2.8 million allocated for underpasses and US$ 1.3 million for fencing (Sawyer et al., 2012). This implies the average cost for each underpass is almost US$500,000. In the state of Washington, the wildlife overcrossing on I-90 costs US$6.2 million (Bush, 2018). To summarize, the cost for each underpass can range from US$500,000 to US$2.7 million. The cost for an overpass can range from US$2.7 million to $6.2 million.

I monetize the reductions in wildlife-vehicle collisions by considering both fatality and collision costs. First, I provide a simple, quick, and rough benefit estimation by using information from the existing value of statistical life (VSL) literature. Ashenfelter and Greenstone

(2004) discuss the value of a statistical life from a transportation safety perspective. The authors measure revealed preferences for safety risks from public choices about speed limits. If there is an increase in a speed limit, then the adopters must have valued the time saved more than the safety threats associated with faster traffic. The authors value the time saved by using the average hourly wage, and they find that the increase of speed limit from 55 mph to 65 mph resulted in a savings of US$1.54 million (1997)(US$2.65 million in 2021) per fatality, with a sampling error of about one-third of the value.

Aldy and Viscusi (2008) use a pooled series of cross sections data to examine how VSL varies with age across populations and how differences in cohorts affect the relationship between age and VSL. The authors find that VSL exhibits an inverted U-shaped relationship with age. Based on 2000 US dollars, ages 18-24 workers' VSL rises from US$3.7 million (US$6 million in 2021) to US$9.7 million (US$15.7 million in 2021) among 35-44 workers, and declines to US$3.4 million (US$5.5 million in 2021) among ages 55-62 workers. They also control for birth-year cohort effects and find that VSL peaks at age 46 of US$7.8 million (US$12.6 million in 2021). Kniesner et al. (2012) contribute to the VSL literature through improved econometric practices to address issues that are related to measurement error, endogeneity, latent individual heterogeneity possibly correlated with regressors, state dependence, and sample composition. Using a panel data setup, the authors find that VSL ranges between US$4 million and US$10 million.

Based on the results that wildlife crossing structures can effectively reduce one to three wildlife-vehicle collisions on average per mile every year, I assume the reductions in collisions are 20 fewer accidents on average every year within a 10-mile radius of a structure. The collected information from the literature yields a range of VSL estimates from $2.65 million (Ashenfelter & Greenstone, 2004) to $12.6 million (Aldy & Viscusi, 2008). It is important to note that these VSL estimates represent the tradeoffs between fatalities and earnings, whereas most wildlife-vehicle collisions do not have any fatalities. Looking at the summary statistics on Table 2, there are approximately 1,900 wildlife-vehicle collisions on average each year with about 2 fatalities on average annually. As a result, I assume a fatality occurs once every 950 wildlife-vehicle collisions. If the collision reductions are 20 fewer accidents per year, it takes 47.5 years to reach 950 wildlife-vehicle collisions. This suggests that a wildlife crossing structure generates a benefit between US$2.65-12.6 million per 48 years from avoiding a fatality, or about US$55,000-263,000 per year. However, the estimation using only VSL undervalues the monetized benefits of wildlife crossing structures because it does not consider savings from the number of collisions avoided, including costs associated with injury and property damage.

Additionally, I consider savings from the average cost of deer-vehicle collisions because most wildlife-vehicle collisions involve deer. Huijser et al. (2009) estimate the average cost of a deer-vehicle collision is US$6,617 in 2007 dollars or about US$9,000 in 2021. Multiplying the annual reductions of 20 collisions with the average cost, the estimated savings are US$180,000 per year. Finally, I combine savings from both deer-vehicle collisions and fatalities; a wildlife crossing structure generates annual savings of US$235,000-443,000 in 2021 dollars. It is important to note that the estimates are likely to undervalue the actual benefits of a wildlife crossing structure. The estimated collision reductions are only based on reported crash data. In addition, the estimated savings do not consider any ecological benefits that a wildlife crossing structure provides.

Discussions

While the findings suggest that wildlife bridges are more consistent in reducing wildlife-vehicle collisions than the culverts, they do not imply that wildlife culverts are less important. There are other factors to consider when selecting what structures to build, including wildlife preferences, topography conditions, and funding. Aquatic and semi-aquatic animals benefit from wildlife culverts. For example, frogs and turtles can use streams and streambanks for daily and seasonal movement (Reshetiloff, 2021). This prevents them from having to move over land and across roadways, which exposes them to vehicles and predators.

One concern of this study is that the presence of a wildlife crossing structure is endogenous. It is possible that areas with more frequent wildlife-vehicle collisions dictate the locations of wildlife crossing structures, and in return, wildlife crossing structures reduce the number of collisions. I address the concern in two ways. First, I compare the number of wildlife-vehicle collisions between the treatment and control areas. Table A9 (appendix) shows that the number of wildlife-vehicle collisions in the control group is much higher than the number of collisions within 10 miles (treatment) of a wildlife crossing structure. If the location with a higher number of wildlife-vehicle collisions had truly determined the placement of wildlife crossing structures, the structures would have been built in the control area. Second, the construction of a wildlife crossing structure often focuses on wildlife connectivity. The placement of a structure can occur in areas where there are historically not many wildlife-vehicle accidents. Land management plan, source of funding, success rate of a wildlife crossing structure construction campaign, and state and local politics may also influence the decisions involved in constructing a wildlife crossing structure. Consequently, the placement of wildlife crossing structures may be more random than expected.

Other potential factors that may influence wildlife-vehicle collisions include weather condition, lighting condition, speed limit, and driving under the influence of alcohol or drugs. The 10-year data consists of 18,891 observations. Most of the accidents, 73% of them, occurred on clear or partly cloudy days. This suggests that weather condition is unlikely to negatively impact driving condition. Approximately half of total wildlife-vehicle collisions occurred in dark with no street lights, and 31% happened in daylight. Only very few accidents, 0.12%, are reported to exceed stated speed limits. Similarly, very few wildlife-vehicle collisions, 0.21%, involve drivers who were under the influence of alcohol or drugs. Most drivers (89%) who experienced vehicle collisions with wildlife were driving without any distractions. The descriptive statistics highlight the importance of mitigation measures on reducing wildlife-vehicle collisions. Many wildlife-vehicle collisions involved safe drivers who were driving under appropriate driving conditions, yet accidents happened due to wildlife presence on the roads.

Conclusion

This study finds evidence that wildlife crossing structures reduce the annual number of wildlife-vehicle collisions, with wildlife bridges having more consistent effects than wildlife culverts. The results complement findings from previous studies that wildlife crossing structures are effective measures to increase road safety (McCollister & Van Manen, 2010); (Bissonette & Rosa, 2012); (Sawyer et al., 2012). Additionally, a wildlife crossing structure generates annual savings of US$235,000-443,000 in 2021 dollars. Nonetheless, this study has limitations, but it also stimulates future research ideas. One limitation is that the study does not consider the impacts of wildlife crossing structures on wildlife connectivity and surrounding ecosystems. Future work may consider a more comprehensive benefit analysis of wildlife crossing structures, such as quantifying their ecological impacts. Another idea relates to the incentives of constructing wildlife crossing structures. Reductions in wildlife-vehicle collisions benefit private insurance companies, but highway projects that include the construction of wildlife crossing structures are the responsibility of public transportation agencies (Huijser et al., 2017). Future work can utilize insurance claims information and attract insurance companies to invest in wildlife crossing structures as a cost-saving strategy.

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Appendix

Table A1: Impact of Wildlife Bridge Structures on Vehicle-Wildlife Collisions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Crash	Crash	Crash	Crash	Crash	Crash	Crash	Crash
	Gold	Noble	Price	Resort	Rocky	Unnamed	Hyak	Wild.
						(MP 60.9)	Under.	Over.
Structure_Year	-3.856***	-1.888**	-1.796*	-2.413***	-4.189***	-1.967***	-3.856***	-1.950**
	(-10.26)	(-2.24)	(-1.90)	(-4.00)	(-8.83)	(-3.09)	(-8.70)	(-2.55)
Year	4.428***	2.394**	2.298*	2.707**	4.544***	2.633**	4.378***	2.425**
	(4.46)	(2.54)	(2.08)	(2.14)	(5.11)	(2.59)	(4.45)	(2.60)
Constant	6.200***	6.300***	6.300***	6.550***	6.300***	6.400***	6.250***	6.300***
	(10.00)	(11.43)	(11.05)	(9.14)	(13.97)	(11.51)	(11.51)	(11.80)
Observations	220	220	220	220	220	220	220	220

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2: Impact of Wildlife Culvert Structures on Vehicle-Wildlife Collisions

	(1)	(2)	(3)	(4)	(5)
	Crash	Crash	Crash	Crash	Crash
	Monroe	River Otter	Townsend	Unnamed	Wolfe
				(MP 59.7)	
Structure_Year	-0.506	-1.017	-1.611***	-1.821	-3.525***
	(-0.45)	(-1.28)	(-2.88)	(-1.65)	(-12.72)
Year	1.503	1.758**	2.755**	2.761*	3.963***
	(1.21)	(2.23)	(2.66)	(1.81)	(5.09)

Constant	6.300***	2.350***	6.200***	6.400***	6.400***
	(10.12)	(7.07)	(9.73)	(9.90)	(11.81)
Observations	220	220	220	220	220

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A3: Impact of Wildlife Bridge Structures on Vehicle-Wildlife Collisions (5-mile Treatment)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Crash	Crash	Crash	Crash	Crash	Crash	Crash	Crash
	Gold	Noble	Price	Resort	Rocky	Unnamed	Hyak	Wild.
						(MP 60.9)	Under.	Over.
Structure_Year	-2.478*	-1.671*	-1.576	-2.050***	-3.022***	-1.781**	-2.622*	-1.743**
	(-2.11)	(-1.95)	(-1.73)	(-3.36)	(-3.06)	(-2.67)	(-2.03)	(-2.19)
Year	2.893*	2.157*	1.925*	2.350**	3.474**	2.394**	3.007	2.114*
	(1.98)	(2.03)	(1.82)	(2.82)	(2.46)	(2.43)	(1.76)	(1.90)
Constant	9.333***	8.600***	8.733***	8.800***	9.000***	8.800***	9.267***	8.667***
	(13.25)	(17.99)	(15.33)	(15.87)	(15.32)	(16.30)	(11.98)	(20.17)
Observations	150	150	150	150	150	150	150	150

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A4: Impact of Wildlife Culvert Structures on Vehicle-Wildlife Collisions (5-mile Treatment)

	(1)	(2)	(3)	(4)	(5)
	Crash	Crash	Crash	Crash	Crash

	Monroe	River Otter	Townsend	Unnamed (MP 59.7)	Wolfe
Structure_Year	0.333	0.122	-1.258*	-1.392	-2.713***
	(0.28)	(0.09)	(-1.99)	(-1.17)	(-4.41)
Year	-1.511	0.226	2.219*	2.464	3.304**
	(-1.34)	(0.16)	(1.90)	(1.74)	(2.91)
Constant	10.20***	4***	8.867***	8.733***	8.933***
	(14.67)	(5.19)	(13.33)	(13.66)	(11.60)
Observations	150	150	150	150	150

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A5: Impact of Wildlife Bridges on Vehicle-Wildlife Collisions (15-mile Treatment)

	(1) Crash Gold	(2) Crash Noble	(3) Crash Price	(4) Crash Resort	(5) Crash Rocky	(6) Crash Unnamed (MP 60.9)	(7) Crash Hyak Under.	(8) Crash Wild. Over.
Structure_Year	-2.870**	-1.773**	-1.659*	-1.911***	-3.615***	-1.787***	-2.970**	-1.851**
	(-2.46)	(-2.11)	(-1.85)	(-3.23)	(-3.55)	(-2.86)	(-2.29)	(-2.35)
Year	2.842**	1.864*	1.675*	2.067***	3.449***	2.072**	2.942*	1.910**
	(2.23)	(2.05)	(1.81)	(3.42)	(2.98)	(2.55)	(2.02)	(2.08)
Constant	6.080***	5.680***	5.760***	5.720***	6.000***	5.720***	6.040***	5.720***
	(14.04)	(16.95)	(15.34)	(15.07)	(15.16)	(16.25)	(12.44)	(18.57)
Observations	250	250	250	250	250	250	250	250

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A6: Impact of Wildlife Culverts on Vehicle-Wildlife Collisions (15-mile Treatment)

	(1)	(2)	(3)	(4)	(5)
	Crash	Crash	Crash	Crash	Crash
	Monroe	River Otter	Townsend	Unnamed (MP 59.7)	Wolfe
Structure_Year	1.252	0.359	-1.175*	-1.464	-2.963***
	(1.03)	(0.28)	(-2.06)	(-1.29)	(-4.85)
Year	-0.671	0.264	1.745**	1.998	2.978***
	(-0.60)	(0.20)	(2.15)	(1.67)	(3.42)
Constant	7.160***	3.080***	5.760***	5.640***	5.960***
	(15.08)	(6.43)	(13.12)	(13.28)	(11.89)
Observations	250	250	250	250	250

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A7: Impact of Wildlife Bridge Structures on Vehicle-Wildlife Collisions Controlling for Presence of Other Structures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Crash	Crash	Crash	Crash	Crash	Crash	Crash	Crash
	Gold	Noble	Price	Resort	Rocky	Unnamed (MP 60.9)	Hyak Under.	Wild. Over.
Structure_Year	-2.556**	-1.217	-1.117	-1.333	-3.089***	-1.217*	-2.656*	-1.317
	(-2.20)	(-1.40)	(-1.21)	(-1.65)	(-3.18)	(-1.84)	(-2.08)	(-1.57)
Year	2.878**	2.600**	2.367**	2.817***	3.494**	2.933***	2.978*	2.500**
	(2.15)	(2.60)	(2.17)	(3.31)	(2.81)	(3.05)	(1.93)	(2.52)
Other_Structure	0	-1.883**	-1.817**	-1.900	0	-2.250**	0	-1.683**

	(.)	(-2.47)	(-2.10)	(-1.46)	(.)	(-2.68)	(.)	(-2.16)
Constant	7.100***	6.700***	6.800***	6.850***	6.800***	6.850***	7.050***	6.750***
	(13.59)	(20.19)	(17.28)	(16.29)	(15.56)	(18.89)	(12.29)	(22.01)
Observations	200	200	200	200	200	200	200	200

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A8: Impact of Wildlife Culvert Structures on Vehicle-Wildlife Collisions Controlling for Presence of Other Structures

	(1)	(2)	(3)
	Crash	Crash	Crash
	(1)	(2)	(3)
	Townsend	Unnamed (MP 59.7)	Wolfe
Structure_Year	-0.665	-0.810	-2.025**
	(-0.91)	(-0.63)	(-2.25)
Year	2.763**	3.175**	3.513***
	(2.37)	(2.48)	(2.92)
Other_Structure	-2.260*	-2.640**	-1.300
	(-1.79)	(-2.10)	(-0.72)
Constant	6.850***	6.800***	6.750***
	(14.49)	(15.36)	(11.83)
Observations	200	200	200

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Structure Name	Collisions in Treatment Area	Collisions in Control Area
Gold Creek Bridge	47	1,657
Monroe Wildlife Crossing	228	1,442
Noble Creek Bridge (MP 61.4)	87	1,493
Price Creek Bridge (MP 61.3)	86	1,503
Resort Creek Bridge (MP 59.5)	77	1,578
River Otter Crossing Culvert	94	591
Rocky Run Creek Bridge (MP 56.8)	46	1,644
Townsend Creek (MP 60.6)	80	1,560
Unnamed Creek (MP 59.7)	79	1,589
Unnamed Creek Bridge (MP 60.9)	83	1,552
Hyak Underpass (MP 55.3)	47	1,656
Wildlife Overcrossing (MP 61.5)	87	1,488
Wolfe Creek	51	1,640

Table A9: Comparison of vehicle-wildlife collisions between treatment and control areas

Structure	Butler Creek Bridge	Butler Creek Fish and Wildlife Crossing	Deadman Creek Fish and Wildlife Crossing	Gold Creek Bridge	Little Hoquiam River Bridge	MP 27 Wildlife Bridge	MP 29 Steel Pate Arch Culvert	McNary Wildlife Crossing	Monroe Wildlife Crossing	Noble Creek Bridge (MP 61.4)	Price Creek Bridge (MP 61.3)	Resort Creek (MP 59.5)	River Otter Crossing Structure	Rocky Run Creek Bridge (MP 56.8)	Spur 109 Wildlife Culvert MP 3.00	Spur 109 Wildlife Culvert MP 2.80	Townsend Creek (MP 60.6)	Unnamed Creek (MP 59.7)	Unnamed Creek Bridge (MP 60.9)	Hyak Underpass (MP 55.3)	Wildlife Overcrossing (MP 61.5)	Wolfe Creek
Butler Creek Bridge	0	0.1	204.1	106.9	170.4	123.1	122	73.6	146.5	101.7	101.7	103.2	84.2	105.6	169.9	170.1	102.3	103.1	102.1	107.1	101.6	105.2
Butler Creek Fish and Wildlife Crossing	0.1	0	204.1	107	170.5	123.1	122	73.6	146.5	101.7	101.8	103.3	84.1	105.7	169.9	170.1	102.3	103.1	102.1	107.1	101.6	105.3
Deadman Creek Fish and Wildlife Crossing	204.1	204.1	0	189.7	312.3	210.5	209	138.3	216.8	187.9	187.9	189.1	133.3	189.6	311.6	311.9	188.5	188.8	188.3	189.8	187.9	189.5
Gold Creek Bridge	106.9	107	189.7	0	122.6	23.7	22.1	128.1	42.7	5.4	5.3	3.7	139	1.3	122	122.2	4.7	3.9	4.9	0.1	5.5	1.7
Little Hoquiam River Bridge	170.4	170.5	312.3	122.6	0	103.6	104.9	227.9	106.5	124.4	124.4	123.2	239.9	122.7	0.7	0.5	123.8	123.5	124.1	122.5	124.5	122.8
MP 27 Wildlife Bridge	123.1	123.1	210.5	23.7	103.6	0	1.6	151	23.6	28.1	28	26.3	162	24.4	102.9	103.1	27.3	26.5	27.5	23.5	28.1	24.7
MP 29 Steel Pate Arch Culvert	122	122	209	22.1	104.9	1.6	0	149.4	24.6	26.5	26.4	24.7	160.5	22.9	104.2	104.4	25.7	24.9	26	21.9	26.6	23.2
McNary Wildlife Crossing	73.6	73.6	138.3	128.1	227.9	151	149.4	0	170.5	123.1	123.2	125	12	127.1	227.3	227.5	124	124.8	123.7	128.3	123.1	126.7
Monroe Wildlife Crossing	146.5	146.5	216.8	42.7	106.5	23.6	24.6	170.5	0	48	48	46.2	181.1	43.9	105.9	106.1	47.2	46.4	47.5	42.6	48.1	44.3
Noble Creek Bridge (MP 61.4)	101.7	101.7	187.9	5.4	124.4	28.1	26.5	123.1	48	0	0.1	1.9	134.1	4.2	123.8	124	0.8	1.6	0.6	5.6	0.1	3.8
Price Creek Bridge (MP 61.3)	101.7	101.8	187.9	5.3	124.4	28	26.4	123.2	48	0.1	0	1.8	134.1	4.1	123.7	124	0.8	1.6	0.5	5.5	0.1	3.7
Resort Creek (MP 59.5)	103.2	103.3	189.1	3.7	123.2	26.3	24.7	125	46.2	1.9	1.8	0	135.9	2.4	122.6	122.8	1.1	0.3	1.3	3.8	1.9	2
River Otter Crossing Culvert	84.2	84.1	133.3	139	239.9	162	160.5	12	181.1	134.1	134.1	135.9	0	138	239.2	239.5	134.9	135.7	134.6	139.1	134	137.6
Rocky Run Creek Bridge (MP 56.8)	105.6	105.7	189.6	1.3	122.7	24.4	22.9	127.1	43.9	4.2	4.1	2.4	138	0	122.1	122.3	3.4	2.6	3.7	1.4	4.2	0.4
Spur 109 Wildlife Culvert MP 3.00	169.9	169.9	311.6	122	0.7	102.9	104.2	227.3	105.9	123.8	123.7	122.6	239.2	122.1	0	0.2	123.2	122.8	123.4	121.9	123. 8	122.2
Spur 109 Wildlife Culvert MP 2.80	170.1	170.1	311.9	122.2	0.5	103.1	104.4	227.5	106.1	124	124	122.8	239.5	122.3	0.2	0	123.4	123	123.6	122.1	124	122.4
Townsend Creek (MP 60.6)	102.3	102.3	188.5	4.7	123.8	27.3	25.7	124	47.2	0.8	0.8	1.1	134.9	3.4	123.2	123.4	0	0.8	0.3	4.8	0.9	3
Unnamed Creek (MP 59.7)	103.1	103.1	188.8	3.9	123.5	26.5	24.9	124.8	46.4	1.6	1.6	0.3	135.7	2.6	122.8	123	0.8	0	1.1	4	1.7	2.2
Unnamed Creek Bridge (MP 60.9)	102.1	102.1	188.3	4.9	124.1	27.5	26	123.7	47.5	0.6	0.5	1.3	134.6	3.7	123.4	123.6	0.3	1.1	0	5.1	0.6	3.3
Hyak Underpass (MP 55.3)	107.1	107.1	189.8	0.1	122.6	23.5	21.9	128.3	42.6	5.6	5.5	3.8	139.1	1.4	121.9	122.1	4.8	4	5.1	0	5.6	1.8
Wildlife Overcrossing (MP 61.5)	101.6	101.6	187.9	5.5	124.5	28.1	26.6	123.1	48.1	0.1	0.1	1.9	134	4.2	123.8	124	0.9	1.7	0.6	5.6	0	3.9
Wolfe Creek	105.3	105.3	189.5	1.7	122.8	24.8	23.2	126.7	44.3	3.8	3.7	2	137.6	0.4	122.2	122.4	3	2.2	3.3	1.8	3.9	0

Table A10: Distance of each wildlife crossing structure to another in miles

Figure B1: Noble Creek Bridge