Cost-Benefit Analyses Animal Detection System, US Hwy 89 near Livingston, Montana, USA

by

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16. Abstract

US Hwy 89 just south of Livingston, Montana, is known for its relatively high concentration of deer-vehicle collisions. The Montana Department of Transportation is evaluating the potential implementation of an animal detection system, and this project is focused on exploratory cost-benefit analyses for this mitigation measure. The road section considered for the implementation of an animal detection system is US Hwy 89 just south of Livingston between Cedar Bluff Road (mile reference post 51.3) and Merrill Lane (mile reference post 52.5). For large wild mammal carcass removal data, the cost associated with "no action" was higher than the economic thresholds for an animal detection system. For animal-vehicle crash data, the cost associated with "no action" was similar to the economic thresholds for an animal detection system. The minimum percentage reduction in large wild mammal carcasses and animal-vehicle crashes that needs to be achieved in order to have the animal detection system pay for itself was also calculated. This "break-even percentage" was 32.10% for large wild mammal carcasses, assuming a 15-year life span of the animal detection system. For a 20-year life span, the break-even percentage was 26.52%. For animal-vehicle crashes, the thresholds were 92.74% (15-year life span) and 76.61% (20-year life span). If the system is more effective than these thresholds in reducing large mammal collisions, the economic benefits of the system exceed the costs. If the system is to still "break-even" with an effectiveness that is lower than the thresholds, the system would have to remain operational for longer than its assumed life span of 15 or 20 years. However, because of the emphasis on parameters related to human safety, and the model not including parameters associated with biological conservation, the cost-benefit analyses conducted, are by definition limited in scope, and the outcomes should not be used as a litmus test for implementing mitigation measures. Rather, the outcome of the cost-benefit analyses should be one of the parameters that should be considered in the decision process.

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SUMMARY

US Hwy 89 just south of Livingston, Montana, is known for its relatively high concentration of deer-vehicle collisions. The Montana Department of Transportation is evaluating the potential implementation of an animal detection system, and this project is focused on exploratory cost-benefit analyses for this mitigation measure. The road section considered for the implementation of an animal detection system is US Hwy 89 just south of Livingston between Cedar Bluff Road (mile reference post 51.3) and Merrill Lane (mile reference post 52.5).

Along the road section of interest, animal-vehicle crashes represented 83.01% of the total number of crashes (all types combined). The carcass removal data were dominated by white-tailed deer (90.37%), followed by mule deer (8.89%), and elk (0.74%). The number of reported animal-vehicle crashes was approximately one-third of the number of large wild mammal carcasses; 32.59%. Most of the collisions occurred between August through January, though carcass observations remained high through April. Most animal-vehicle crashes occurred at the end of the afternoon and in the evening (5 pm - 10 pm) and in the early morning (6 am - 8 am).

The animal-vehicle crashes along the road section of interest were mostly in the category “No apparent (human) injury, property damage only” with one in the category “suspected minor (human) injury”. For the purpose of the cost-benefit analyses in this report, the average animal-vehicle crash costs associated with property damage, the occasional suspected human injury, and carcass removal was set at US$ 13,382 (in 2019 US$). The same cost estimate was applied to each large wild mammal carcass (i.e. deer and elk). The costs for an animal detection system were provided by MDT and calculated for both a 15- and 20-year life span. The values were corrected for a discount rate of 3%, and a “break-even” threshold was calculated. The break-even threshold reflects the dollar amount that needs to be “earned” by the system through reducing collisions to make it pay for itself. The break-even threshold based on a 15-year life span was US$ 44,678 per year, whereas it was US$ 36,907 per year based on a 20-year life span.

For large wild mammal carcass removal data, the cost associated with “no action” was higher than the economic thresholds for an animal detection system. For animal-vehicle crash data, the cost associated with “no action” was similar to the economic thresholds for an animal detection system. The minimum percentage reduction in large wild mammal carcasses and animal-vehicle crashes that needs to be achieved in order to have the animal detection system pay for itself was also calculated. This “break-even percentage” was 32.10% for large wild mammal carcasses, assuming a 15-year life span of the animal detection system. For a 20-year life span, the break-even percentage was 26.52%. For animal-vehicle crashes, the thresholds were 92.74% (15-year life span) and 76.61% (20-year life span). If the system is more effective than these thresholds in reducing large mammal collisions, the economic benefits of the system exceed the costs. If the system is to still “break-even” with an effectiveness that is lower than these thresholds, the system would have to remain operational for longer than its assumed life span of 15 or 20 years.

Because of the emphasis on parameters related to human safety, and the model not including parameters associated with biological conservation, the cost-benefit analyses conducted are by definition limited in scope, and the outcomes should not be used as a litmus test for implementing mitigation measures. Rather, the outcome of the cost-benefit analyses should be one of the parameters that should be considered in the decision process.

1. INTRODUCTION

1.1. Background

The Montana Department of Transportation (MDT) has proposed reconstructing US Hwy 89 just south of Livingston, Montana (between mile reference posts 49.8 through 52.5). The proposed reconstruction includes minor shifts in alignment, changes in the approaches, partial reconstruction of the adjacent multi-use path, installation of a retaining wall along segments of the Livingston Canal, and an extension of a left turn lane. This section of US Hwy 89 is known for its relatively high concentration of deer-vehicle collisions. Wildlife-fences in combination with wildlife underpasses and overpasses is the most robust and effective combination of measures to reduce collisions with large wild mammals and to maintain habitat connectivity through safe crossing opportunities (Clevenger & Huijser, 2011; Huijser et al., 2016a; b). However, the number of access roads and driveways, the proximity and density of adjacent private and commercial development, irrigation facilities, flat road grade, and high ground water table, made MDT conclude that the implementation of wildlife fences and wildlife crossing structures is not feasible (Personal communication, Deb Wambach, Montana Department of Transportation). Therefore, MDT is evaluating the potential implementation of an animal detection system along a portion of the road section that will be reconstructed. See Huijser et al. (2015) for a detailed description of animal detection systems, and what was known about their reliability and effectiveness at the time of publication.

1.2. This Project

For this project, the Western Transportation Institute at Montana State University conducted cost-benefit analyses for the potential implementation of an animal detection system. The road section considered for the implementation of an animal detection system is US Hwy 89 just south of Livingston between Cedar Bluff Road (mile reference post 51.3) and Merrill Lane (mile reference posts 52.5) (Figure 1).

Figure 1: The section of US Hwy 89 just south of Livingston between Cedar Bluff Road (south end red oval, mile reference post 51.3) and Merrill Lane (north end red oval, mile reference posts 52.5) for which an animal detection system is considered.

2. ANIMAL-VEHICLE COLLISION DATA

2.1. Introduction

This chapter contains a summary of the animal-vehicle collision data. For this report, the term "collision data" refers to both animal carcass data and animal-vehicle crash data. However, rather than attempting to identify possible duplicates when combining animal carcass data and animal-vehicle crash data, and removing them, the two data sets were kept separate for all analyses. Since the carcass removal data and animal-vehicle crash data were collected independently, potential similarities in spatial or temporal patterns between the two data sources strengthen the conclusions.

The road section for which the collision data were summarized covered the 1.2 mile long road section with the proposed animal detection system between Cedar Bluff Road (mile reference post 51.3) and Merrill Lane (mile reference post 52.5), as well as immediately adjacent road sections extending another 0.5 miles (mile reference posts 50.8 through 53.0 (2.2 miles of road with twenty-three 0.1 mile reference posts). The additional 0.5 mile from each end of the road section with the proposed animal detection system was included because the cost-benefit analyses require a buffer zone of at least 0.5 mile from each end of a road section under evaluation for the implementation of an animal detection system (see Chapter 3).

2.2. Methods

2.2.1. Data Sources

This chapter relates to the following data sources:

- Carcass removal data
  Animal carcass removal data are collected by road maintenance personnel and typically relate to large wild mammals, especially ungulates such as "deer". For this report the carcass removal data related to 10 calendar years (1 January 2009 through 31 December 2018), and covered the road section of the proposed animal detection system and an additional five 0.1 mile long segments from each end (mile reference posts 50.8-53.0).

- Crash data
  Crash data are collected by law enforcement personnel. For this report, the crash data related to 10 calendar years (1 January 2009 through 31 December 2018), and covered the road section of the proposed animal detection system and an additional five 0.1 mile long segments from each end (mile reference posts 50.8-53.0). The author selected crashes where animals were a contributing factor. These "animal-vehicle crashes" (n=44) represented 83.01% of the total number of crashes for this road section (n=53).

2.2.2. Analyses

The carcass removal data were used to identify the species concerned. Both the carcass removal data and the animal-vehicle crash data were used to identify collision trends over the 10-year period as well as the distribution of the collisions within a year (by month). Finally, the animal-vehicle crash data were used to investigate the distribution by hour of day.

2.3. Results

The carcass removal data were dominated by white-tailed deer (90.37%), followed by mule deer (8.89%), and elk (0.74%) (Total sample size n=135) (Table 1).

Table 1: The number of large wild mammal carcass observations for each species (2009-2018) for mile reference posts 50.8-53.0.

Species	N	%
White-tailed deer (*Odocoileus virginianus*)	122	90.37
Mule deer (*Odocoileus hemionus*)	12	8.89
Elk (*Cervus canadensis*)	1	0.74
Total	135	100.00

There was no consistent increase or decrease over the 10-year period in collisions (Figure 2). The average number of reported carcasses per year was 13.50 (SD = 8.22). However, two years had relatively few observations (2009 and 2013), suggesting lower search and reporting effort in those years compared to the other years. The number of reported carcasses (n=135 over 10 years over twenty-three 0.1 mile reference posts) was on average 5.87 carcasses per mile per year. The average number of reported animal-vehicle crashes per year was 4.40 (SD = 3.13) and less variable between years compared to the carcass removal data (Figure 2). The number of reported animal-vehicle crashes (n=44 over 10 years over 2.3 miles) was on average 1.91 crashes per mile per year. Animal-vehicle crashes (n=44 in 10 years) were 32.59% of the number of large wild mammal carcasses (n=135 in 10 years).

Most (n=43, 97.73%) of the animal-vehicle crashes resulted in “no apparent injury / property damage only” (i.e. vehicle repair costs and no human injuries or human fatalities). Only one (n=1, 2.27%) of the animal-vehicle crashes resulted in “suspected minor human injuries”.

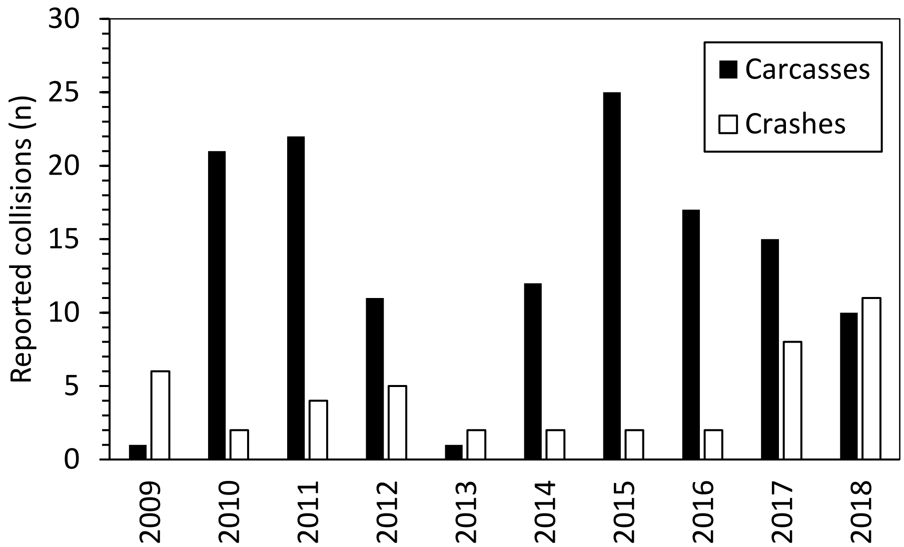

Figure 2: The number of reported large wild mammal carcasses and animal-vehicle crashes per year (2009-2018) for mile reference posts 50.8-53.0.

More carcasses were reported in late summer through early spring (August through April) with fewer carcasses reported in May through July) (Figure 3). Animal-vehicle crashes followed a similar pattern, but higher numbers were reported from June through January, with October as an exception) (Figure 3). Interestingly, in contrast to all other months, there were more reported crashes than carcasses in the month of June.

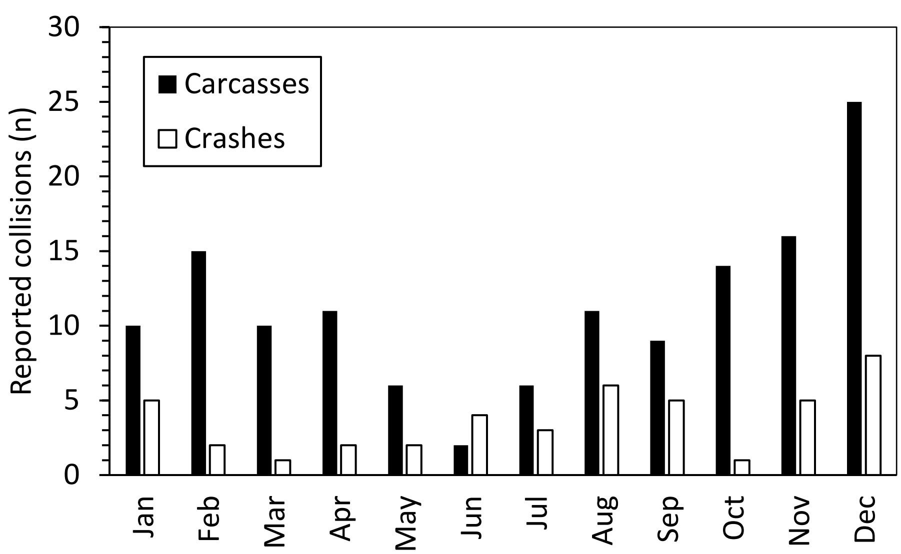

Figure 3: The number of reported large wild mammal carcasses and animal-vehicle crashes per month (2009-2018) for mile reference posts 50.8-53.0.

Most animal-vehicle crashes occurred at the end of the afternoon and in the evening (5 pm - 10 pm) and in the early morning (6 am - 8 am) (Figure 4).

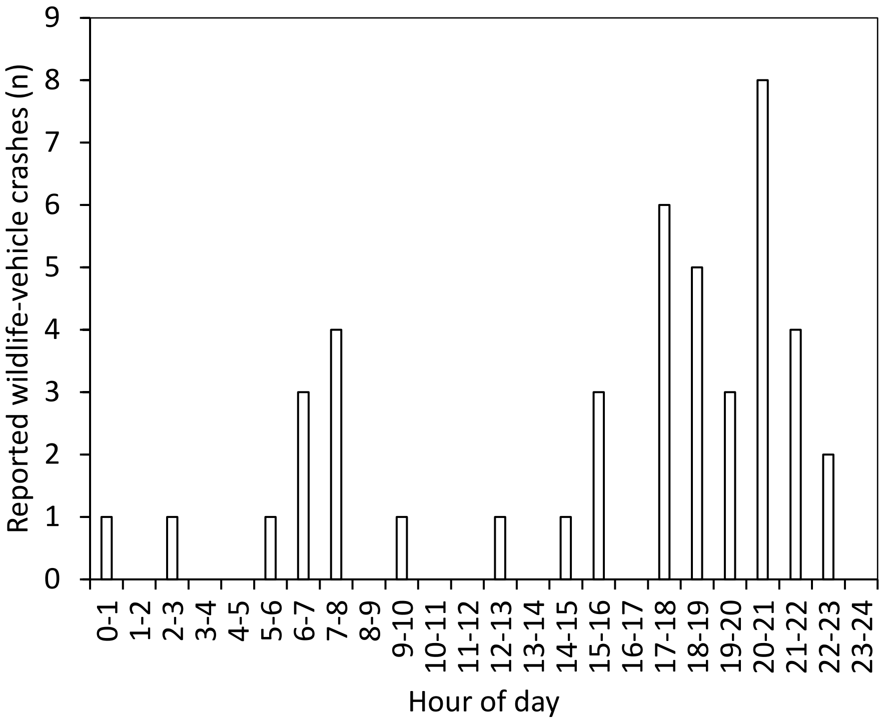

Figure 4: The number of reported animal-vehicle crashes by hour of day (2009-2018) for mile reference posts 50.8-53.0.

2.4. Discussion

The carcass reports were dominated by white-tailed deer (90.37%), followed by mule deer (8.89%), and elk (0.74%). There was no consistent increase or decrease over the most recent 10-year period in large wild mammal carcasses or animal-vehicle crashes, but the crash data were less variable from year to year than the carcass data. Along the road section concerned, the number of reported animal-vehicle crashes (n=44 in 10 years) was approximately one-third of the number of large wild mammal carcasses (n=135 in 10 years); 32.59%. This underreporting of animal-vehicle crashes compared to large wild mammal carcasses is comparable to that of other roads in other areas.

Most of the collisions occurred between August through January, though carcass observations remained high through April. Spring and early summer (May through July) had relatively few animal-vehicle collisions. Most animal-vehicle crashes occurred at the end of the afternoon and in the evening (5 pm - 10 pm) and in the early morning (6 am - 8 am). The peak in animal-vehicle crashes at the end of the afternoon through the evening and a second smaller peak in the early morning is similar to what other studies have found. These patterns may be reflecting potential seasonal fluctuations in daily deer movements between the foothills (west of the highway) and the river and associated riparian habitat (east of the highway). However, the observed seasonality in collisions may also be related to potential seasonal movements between winter and summer ranges. Other potential factors are seasonal fluctuations in traffic volume and whether rush hour traffic overlaps with dusk and dawn when deer activity on and near the road is highest (see e.g. Huijser et al., 2017). The observed pattern over the seasons, with non-tourist months having the highest numbers, suggests that primarily residents are involved with the collisions rather than primarily tourists.

3. COST-BENEFIT ANALYSES

3.1. Introduction

Costs were expressed in 2019 US$. Costs related to earlier years were converted to 2019 US$ based on the Consumer Price Index (US Department of Labor, 2019).

3.2. Methods

3.2.1. Costs Animal-Vehicle Collisions

As instructed by the Montana Department of Transportation, the following costs for different categories for human injuries and fatalities associated with an animal-vehicle crashes were based on the Montana Department of Transportation Highway Safety Improvement Program and the historic animal-vehicle crash data for the road section between mile reference posts 50.8-53.0 (MDT, 2018; Table 2). The animal-vehicle crashes along the road section of interest south of Livingston were mostly in the category "No apparent (human) injury / property damage only" with one in the category "suspected minor (human) injury" (Table 2). For the purpose of the cost-benefit analyses in this report, the average animal-vehicle crash costs associated with property damage (i.e. vehicle repair costs) and the occasional suspected human injury was set at US$ 13,200 (in 2019 US$) (0.9773 * US$ 10,764 + 0.0227 * US$ 118,104)). An additional US$ 182 (in 2019 US$) was added for carcass removal. Thus, the total costs of an animal-vehicle crash was set at US$ 13,382 (in 2019 US$) (US$ 13,200 + US$ 182). The same cost estimate was applied to each large wild mammal carcass (i.e. deer and elk).

Table 2: Crash categories for human injuries and fatalities, the costs associated with a crash, and the number and percentage of animal-vehicle crashes observed along the road section of interest (2009-2018, mile reference posts 50.8 through 53.0) (MDT, 2018, US Department of Labor, 2019).

Crash categories human injuries and fatalities	Costs 2018 US$	Costs 2019 US$	N	%
K (Fatal)	$6,010,200	$6,103,432	0	0.00
A (Suspected serious injury)	$318,400	$323,339	0	0.00
B (Suspected minor injury)	$116,300	$118,104	1	2.27
C (Possible injury)	$65,500	$66,516	0	0.00
O (No apparent injury, Property Damage Only (PDO))	$10,600	$10,764	43	97.73

3.2.2. Costs Animal Detection System

The estimated costs for an animal detection system between mile reference posts 51.3 and 52.5 were provided by the Montana Department of Transportation (MDT) and calculated based on both a 15- and 20-year life span (Table 3). The annual maintenance cost estimate ($4,330) was based on the experience with maintaining equipment at a Road Weather Information System location (RWIS) (Personal communication, Deb Wambach, Montana Department of Transportation). This maintenance cost was assumed to be similar for the animal detection system. It was also applied to the first 3 years of operation, despite the purchase of a 3-year warranty. This may cover potential maintenance that may not be covered by the warranty. The cost estimates do not include general labor costs for checking on the system and verifying it is still in working condition as this is assumed to be part of normal routine for road maintenance personnel (Personal communication, Deb Wambach, Montana Department of Transportation). The values in table 3 were corrected for a discount rate of 3%, and a “break-even” threshold was calculated. The break-even threshold reflects the dollar amount (in 2019 US$, corrected for a 3% discount rate) that needs to be “earned” through having an “effective” system to make the system and its associated costs over its life span pay for itself. The break-even threshold based on a 15-year life span was US$ 44,678 per year, whereas it was US$ 36,907 per year for a 20-year life span.

An animal detection system can potentially “earn” back its costs in several ways. However, for the purpose of the analyses in this report, an animal detection system could only earn back its costs through a reduction in animal-vehicle collisions, and a reduction in the associated costs (i.e. vehicle repair costs (“property damage only”), costs associated with “suspected minor human injuries”, and carcass removal costs (see section 3.2.1.). The animal detection system could not earn back its costs through a reduction in costs associated with other parameters such as serious human injuries or human fatalities as this was not observed along this road section during the 10-year period that data were provided for. See the discussion for the limitations of the model and the results of the cost-benefit analyses.

Table 3: Estimated costs for an animal detection system assuming a 20-year life span (in 2019 US$) along US Hwy 89 between mile reference posts 51.3 through 52.5).
Note: For the cost-benefit analyses based on a 15-year life span, the costs for the years 16 through 20 were removed, and system removal costs were moved from year 20 to year 15.

Year	Purchase	Warranty	System maintenance	Replace server	System removal	Utilities (power/cellular)	Total
0	$450,000	$10,000					$460,000
1			$4,330			$1,200	$5,530
2			$4,330			$1,200	$5,530
3			$4,330			$1,200	$5,530
4			$4,330			$1,200	$5,530
5			$4,330			$1,200	$5,530
6			$4,330	$600		$1,200	$6,130
7			$4,330			$1,200	$5,530
8			$4,330			$1,200	$5,530
9			$4,330			$1,200	$5,530
10			$4,330			$1,200	$5,530
11			$4,330			$1,200	$5,530
12			$4,330	$600		$1,200	$6,130
13			$4,330			$1,200	$5,530
14			$4,330			$1,200	$5,530
15			$4,330			$1,200	$5,530
16			$4,330			$1,200	$5,530
17			$4,330			$1,200	$5,530
18			$4,330	$600		$1,200	$6,130
19			$4,330			$1,200	$5,530
20			$4,330		$10,000	$1,200	$15,530
Total	$450,000	$10,000	$86,605	$1,800	$10,000	$24,000	$582,405

3.2.3. Cost of "No Action" vs. Cost of "Animal Detection System"

The cost of "no action" is to have animal-vehicle collisions continue to occur at a rate and severity equivalent to that over the past 10 years (2009-2018) along the road section concerned. For the cost calculation of "no action", the large wild mammal carcasses (i.e. deer and elk) were selected from the carcass removal data. For the cost calculation of "no action" for the crash data, all animal-vehicle crashes were included. Each of the selected large wild mammal carcass and each animal-vehicle crash was set at a cost of US$ 13,382 (in 2019 US$) (see section 3.2.1). The cost of "no action" was expressed in cost per mile per year (moving average for each 0.1 mile reference post based on that 0.1 mile long road section, and immediately adjacent road sections extending another 0.5 miles in each direction (i.e. eleven 0.1 mile reference posts (5+1+5)). The moving average over eleven 0.1 long road segments was required by the cost-benefit model that expressed costs per mile per year, and it also smoothens out likely spatial inaccuracies in the locations of the collisions; carcass data are often "rounded off" to the nearest 1.0 or 0.5 mile reference post.

The cost of "no action" was calculated between mile reference posts 50.8 through 53.0, for both large wild mammal carcass removal data and animal-vehicle crash data. This resulted in "pure output" for the shorter road section for which an animal detection system is considered (mile reference posts 51.3 through 52.5), as the cost calculations are based on a moving average extending 0.5 miles beyond the 0.1-mile-long road section concerned. The cost of "no action" was compared to the economic thresholds for the animal detection system that is currently considered for the road section between mile reference posts 51.3 through 52.5 (15-year life span and 20-year life span) (see section 3.2.2). The break-even threshold based on a 15-year life span was US$ 44,678 per year (or US$ 37,232 per mile per year), whereas it was US$ 36,907 per year (or US$ 30,756 per mile per year) for a 20-year life span.

3.2.4. Cost-Effectiveness; "Break-Even" Percentage

For an animal detection system to "earn back" its costs, it needs to reduce collisions with large animal species (see section 3.2.2). The costs and savings of the animal detection system were calculated for the road section for which the animal detection system is considered (between mile reference posts 51.3-52.5). The costs and savings were calculated for both carcass removal data and the animal-vehicle crash data for the same road section (mile reference posts 51.3-52.5). The costs and savings were calculated per year based on a range of potential effectiveness percentages in reducing collisions with large animal species: 25%, 50%, 75%, 90%, and 100% reduction. The break-even percentage reduction in collisions was also calculated. This is the minimum percentage reduction that needs to be achieved in order to have the animal detection system pay for itself.

For the purpose of the analyses in this report, it is the actual percentage reduction in the number of large wild mammal carcasses and animal-vehicle crashes along the road section with the animal detection system that matters. It is assumed that a potential future reduction in large wild mammal carcasses or animal-vehicle crashes is associated with the potential future presence of the animal detection system.

For the purpose of the calculations, the system was assumed to be operational 100% of the time. Note that the effectiveness of the system in reducing collisions with large animal species not only depends on its reliability in detecting these animals. The effectiveness also depends on how that message is communicated to the drivers. This includes the type of warning sign, whether it is associated with advisory or mandatory speed limit reduction, and the distance between consecutive signs in relation to its size (see Huijser et al., 2015 for additional details).

3.2.5. Cost-Effectiveness; Operational Years Required to "Break-Even"

The number of years that an animal detection system would have to be operational in order to "break-even" and earn back its costs (between mile reference posts 51.3 and 52.5) was calculated for the full range of possible effectiveness (range 0-100%). The number of years required to "break-even" was calculated for both reducing large animal carcasses and animal-vehicle crashes for both a 15- and 20-year life span of the animal detection system.

3.3. Results

3.3.1. Cost of No Action vs. Cost of Animal Detection System

The cost of "no action" is to have wildlife-vehicle collisions continue to occur at a rate and severity equivalent to that over the past 10 years (2009-2018) over the road section concerned (the jagged lines in Figure 5). For carcass removal data, the costs associated with "no action" was higher than the economic thresholds for an animal detection system between mile reference posts 51.3 through 52.5 (for both a 15- and 20-year life span of the animal detection system). For animal-vehicle crash data, the costs associated with "no action" was similar to the economic thresholds for an animal detection system between mile reference posts 51.3 through 52.5 (for both a 15- and 20-year life span of the animal detection system).

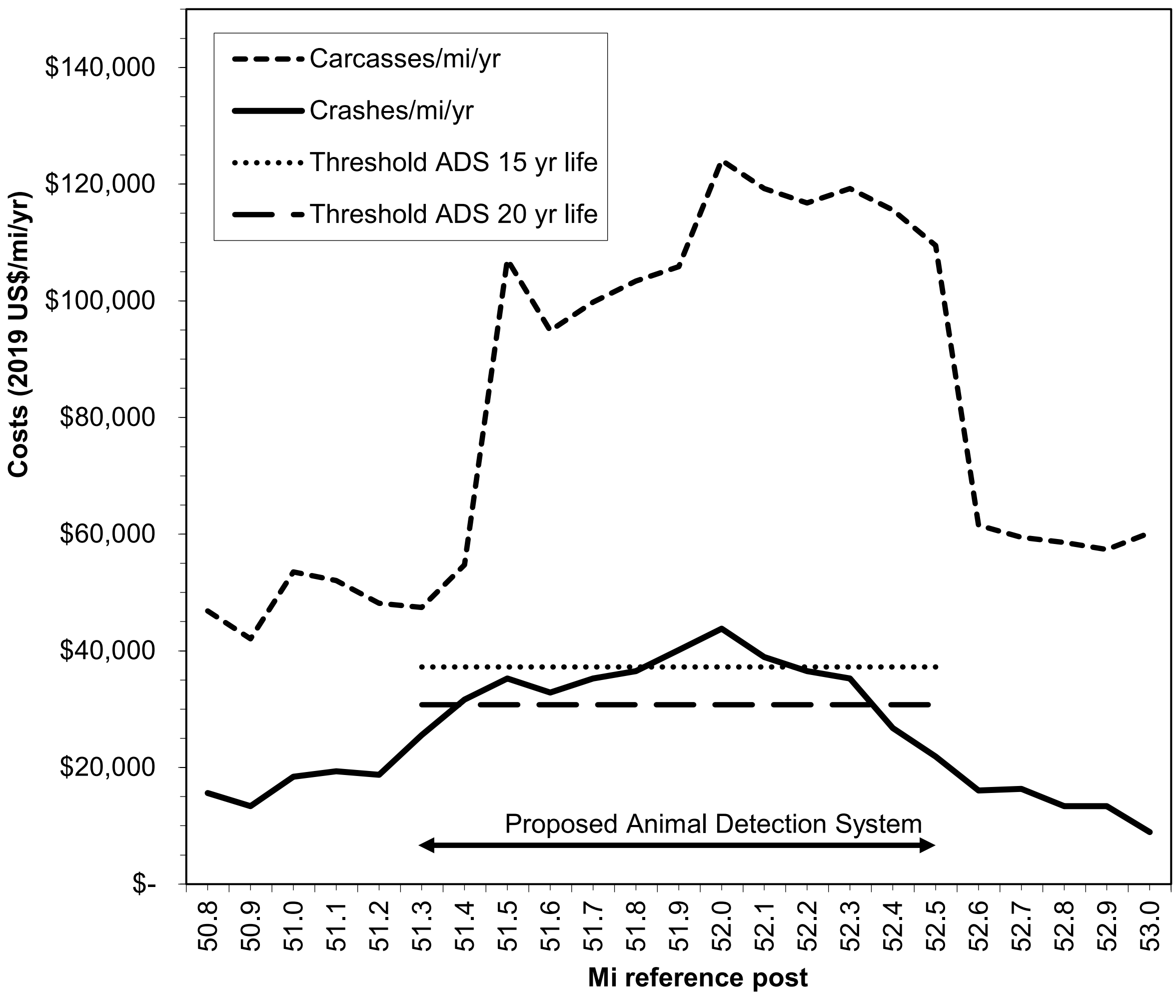

Figure 5: The cost of "no action" (carcass and animal-vehicle crash numbers and severity equivalent to that of the last 10 years) vs. the costs associated with an animal detection system (ADS) with both a 15- and 20-year projected life span.

3.3.2. Cost-Effectiveness; "Break-Even" Percentage

The break-even percentage for reducing large animal carcasses was 32.10% assuming a 15-year life span of the animal detection system (Figure 6). For a 20-year life span the break-even percentage was 26.52% (Figure 6). The break-even percentage for large animal-vehicle crashes was 92.74% assuming a 15-year life span of the animal detection system (Figure 6). For a 20-year life span the break-even percentage was 76.61% (Figure 7).

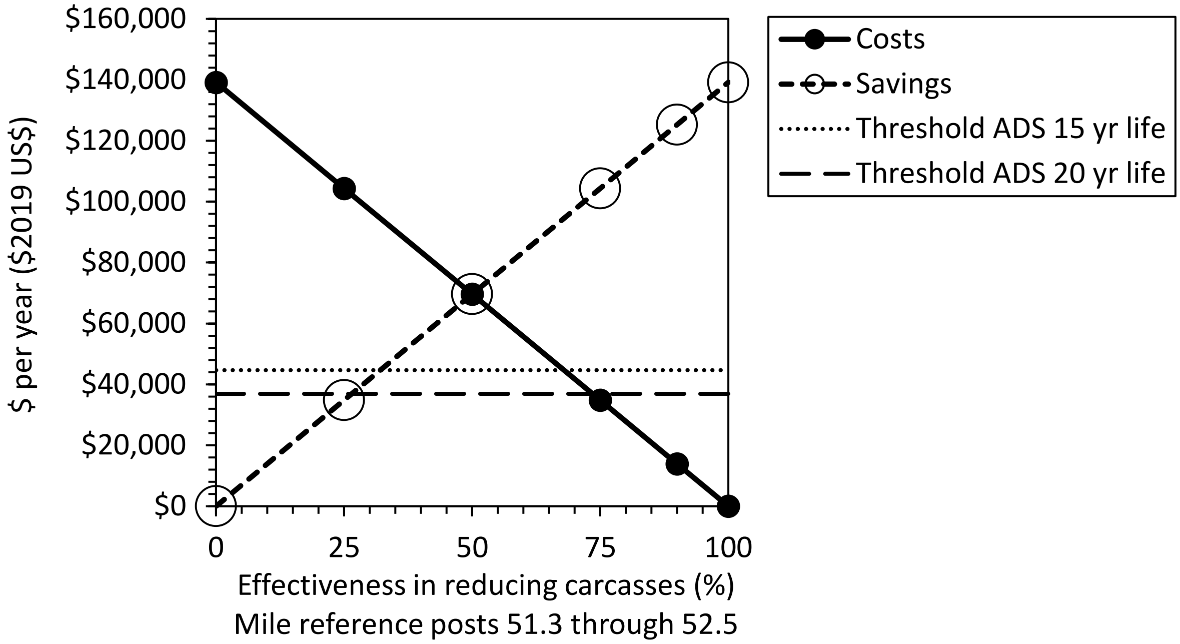

Figure 6: The costs of collisions based on large animal carcasses and the savings as a result of reducing these collisions through the presence of an animal detection system (ADS) (effectiveness range 0-100%), and the break-even thresholds to have the animal detection system pay for itself for the road section between mile reference posts 51.3 and 52.5.

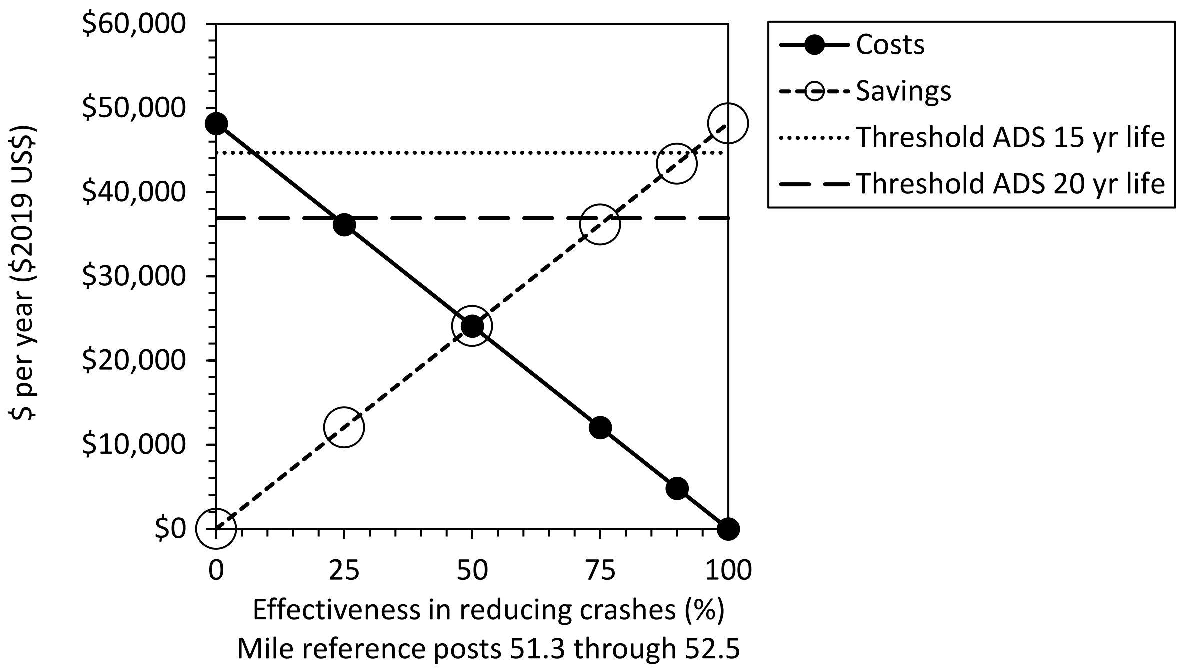

Figure 7: The costs of collisions based on animal-vehicle crashes and the savings as a result of reducing these collisions through the presence of an animal detection system (ADS) (effectiveness range 0-100%), and the break-even thresholds to have the animal detection system pay for itself for the road section between mile reference posts 51.3 and 52.5.

3.3.3. Cost-Effectiveness; Operational Years Required to "Break-Even"

The number of years that an animal detection system would have to be operational in order to "break-even" and earn back its costs through a reduction in large animal carcasses and animal-vehicle crashes decreased exponentially with higher effectiveness of the system (Figure 8 and 9). If the effectiveness of the system in reducing large animal carcasses is ≥32.10% (15-year life span of the ADS) or ≥26.52% (20-year life span of the ADS), the economic benefits of the system exceed the costs (Figure 8). The thresholds for reducing animal-vehicle crashes are ≥92.74% (15-year life span of the ADS) and ≥76.61% (20-year life span of the ADS) (Figure 9). Lower effectiveness of the system in reducing collisions means that for the system to pay for itself, the system would have to remain operational for longer than its assumed life span of 15 or 20 years.

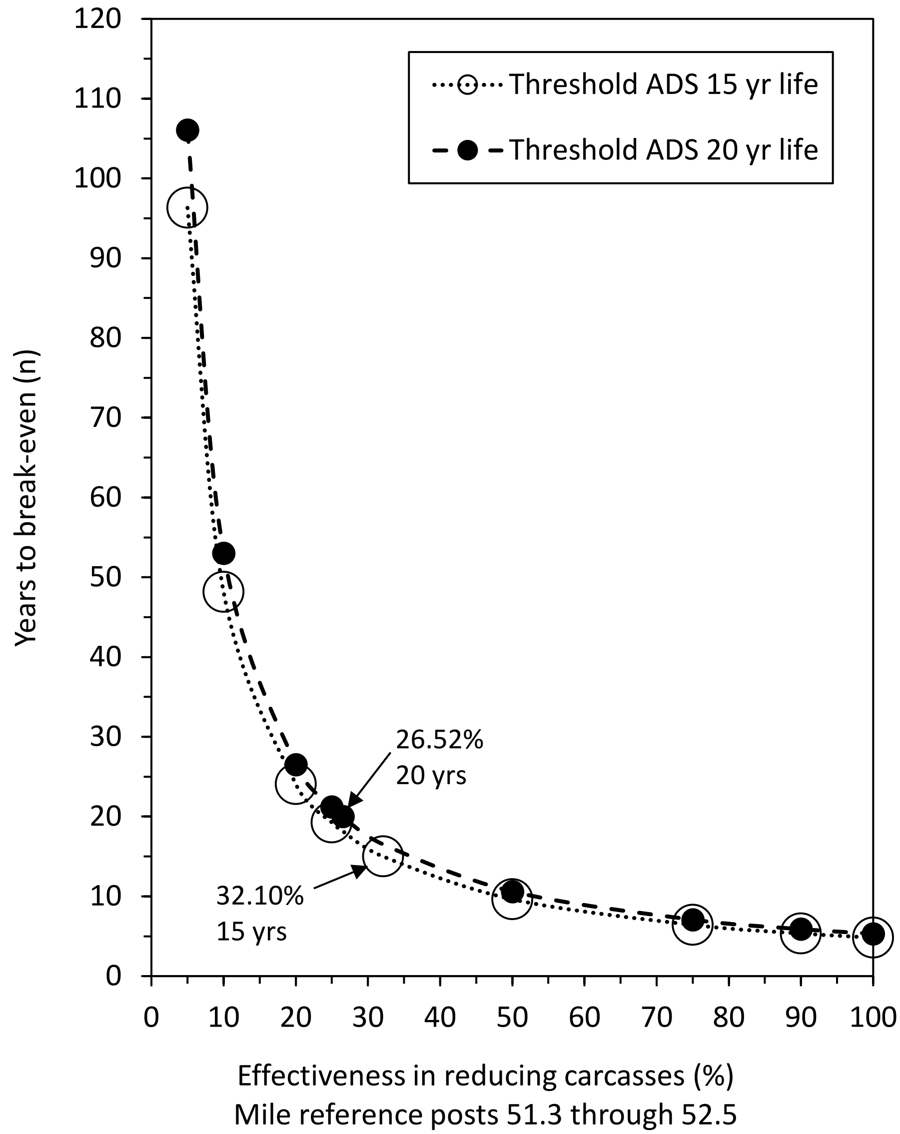

Figure 8: The number of years that an animal detection system would have to be operational in order to "break-even" dependent on its effectiveness (range 0-100%) in reducing large animal carcasses for both a 15 and 20 year life span of the animal detection system, between mile reference posts 51.3 and 52.5.

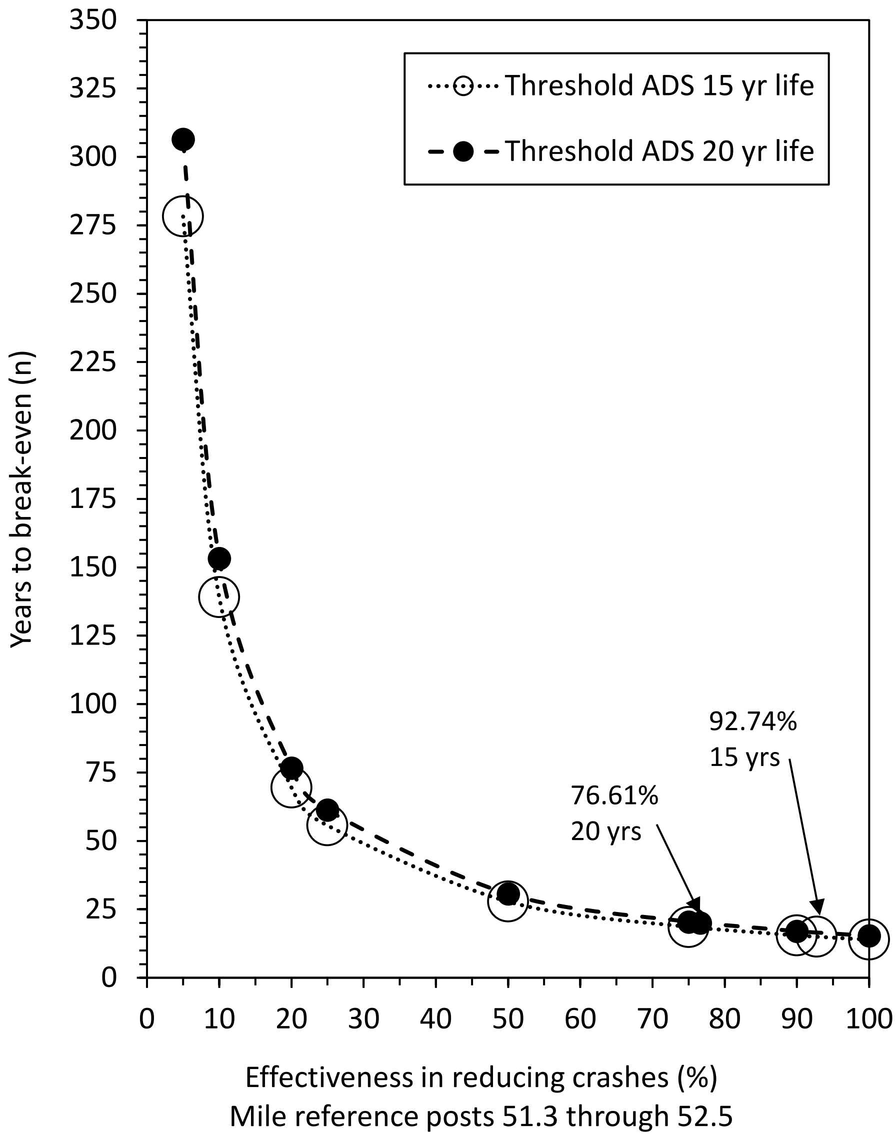

Figure 9: The number of years that an animal detection system would have to be operational in order to "break-even" dependent on its effectiveness (range 0-100%) in reducing animal-vehicle crashes for both a 15 and 20 year life span of the animal detection system, between mile reference posts 51.3 and 52.5.

3.4. Discussion

The costs associated with the average reported animal-vehicle crash (US$ 13,382) were also applied to each reported large wild mammal carcass. One could argue that the costs associated with the average reported large wild mammal carcass are likely lower than the costs for the average reported animal-vehicle crash, simply because most of the collisions that resulted in carcasses only (i.e. no crash report) were not reported to law enforcement, presumably because they did not meet the thresholds (i.e. minimum estimated vehicle repair costs of US$ 1,000 or human injuries or human fatalities) (Huijser et al., 2007). On the other hand, only including animal-vehicle crashes and ignoring large wild mammal carcass removal data, would likely result in a severe underestimation of the costs associated with animal-vehicle collisions as animal-vehicle crashes represented only 32.59% of the large wild mammal carcasses along the road section concerned. Furthermore, the number of reported large wild mammal carcasses is still a minimum number for animal-vehicle collisions. The actual number of animal-vehicle collisions is likely higher, as animals that were hit but that were only injured or that died later out of sight or outside the right-of-way, were not reported by road maintenance personnel and never made it into the carcass removal database.

For large wild mammal carcass removal data, the costs associated with "no action" was higher than the economic thresholds for an animal detection system between mile reference posts 51.3 through 52.5 (for both a 15- and 20-year life span of the animal detection system). For animal-vehicle crash data, the costs associated with "no action" was similar to the economic thresholds for an animal detection system between mile reference posts 51.3 through 52.5 (for both a 15- and 20-year life span of the animal detection system). This means that the costs associated with the implementation of an animal detection system are similar (based on animal-vehicle crash data) or lower (based on large wild mammal carcass data) than the costs of allowing large animal-vehicle collisions to continue to occur.

Based on the assumptions, input parameters, and values for these parameters, the exact percentage reduction in large wild mammal carcasses and animal-vehicle crashes that needs to be achieved in order to have the animal detection system pay for itself was calculated. This "break-even percentage" was 32.10% for large wild mammal carcasses, assuming a 15-year life span of the animal detection system. For a 20-year life span, the break-even percentage was 26.52%. For animal-vehicle crashes, the "break-even percentage" was 92.74% assuming a 15-year life span of the animal detection system, and 76.61% assuming a 20-year life span. If the system is more effective than these thresholds in reducing large mammal collisions, the economic benefits of the system are higher than the costs. If the system is less effective than these thresholds in reducing large mammal collisions, the economic benefits of the system are lower than the costs. If the system is to still "break-even" with an effectiveness that is lower than the thresholds, the system would have to remain operational for longer than its assumed life span of 15 or 20 years. Because of the emphasis on parameters related to human safety, and the model not including parameters associated with biological conservation, the cost-benefit analyses conducted, are by definition limited in scope. The cost-benefit model only includes parameters associated with vehicle repair costs ("no apparent injury / property damage only") and "suspected minor human injuries". The animal detection system could not earn back its cost through a reduction in costs associated with other human safety parameters such as serious human injuries or human fatalities (because this was not observed along this road section in the last 10 years). However, given a high enough sample size, and given enough time, the results of other studies suggest that there will eventually be severe human injuries and human fatalities associated with the animal-vehicle collisions along the road section concerned. Based on a synthesis, the probability of a deer-vehicle collision resulting in a human injury (all severity categories combined) has been estimated at 0.05 (5 out of 100 collisions) (Huijser et al., 2009). The probability of a deer-vehicle collision resulting in a human fatality has been estimated at 0.0003 (3 out of 10,000 collisions) (Huijser et al., 2009). However, the cost-benefit analyses conducted for this report are based on the actual animal-vehicle crash data for the road section concerned (mile reference posts 50.8

through 53.0), and excluded costs associated with severe human injuries and human fatalities as they did not occur there in the 10 years included in the analyses. Parameters related to biological conservation were also not included in the model. Therefore, reducing large wild mammal collisions could not generate economic benefits related to biological conservation. Nonetheless, one can argue that there are economic values associated with biological conservation. Therefore, the outcomes of the analyses are conservative; if parameters related to biological conservation would be known and included in the analyses, it would increase the costs associated with collisions with large wild mammals, and the thresholds for implementing measures aimed at reducing such collisions would be more easily met. Examples of parameters related to biological conservation are 1. A reduction in injured animals; 2. A reduction in direct animal road mortality; 3. Increased wildlife population size and wildlife population persistence, potentially including threatened or rare large mammal species; and 4. Passive use values and direct economic benefits associated with having wildlife in the landscape. Because of the emphasis on parameters related to human safety and the model not including parameters associated with biological conservation, the cost-benefit analyses conducted for this report are by definition limited in scope and the outcomes should not be used as a litmus test for implementing mitigation measures. Rather, the outcome of the cost-benefit analyses should be one of the parameters that should be considered in the decision process.

The cost-benefit analyses also assume that the implementation of the animal detection system will be successful and that it results in a reliable system that is operational 100% of the time. However, many past animal detection system projects have failed because of technological problems, management problems, or financial problems (see e.g. Huijser et al., 2006; Huijser et al., 2015). In addition, even if a system is reliable in detecting large wild mammals, it may still experience technical malfunction during certain periods. When a system is “down” it cannot reduce collisions, and therefore the potential reduction in collisions, and the associated cost savings, are reduced.

It is assumed that a potential future reduction in large wild mammal carcasses or animal-vehicle crashes after the installation of an animal detection system is associated with the presence of that animal detection system. However, potential increases or decreases in deer population size (or other large wild mammal species) can also affect these numbers and thus the observed percentages. The same is true for potential changes in traffic volume, vehicle speed, the number of lanes and the width of the highway, potential changes in roadway lighting, and the time of day people drive their vehicles. Finally, changes in the search and reporting effort for large wild mammal carcasses and animal-vehicle crashes can also affect the carcass and animal-vehicle crash numbers and thus the potential percentage reduction in collisions after system installation. To be certain if and to what degree a potential reduction in animal-vehicle collisions is indeed because of the presence of an animal detection system rather than other variables, a Before-After-Control-Impact (BACI) research design should be applied.

The author of this report recognizes that cost-benefit analyses such as the ones included in this report can never capture all parameters and all values accurately. Nonetheless, the cost-benefit analyses described in this report suggest that, based on the assumptions and input parameters, it is likely economically beneficial to implement an animal detection system along this road section. The author strongly suggests though to not base the decision on whether to implement an animal detection system on the cost-benefit analyses alone. The proposed measure, in this case an animal detection system, must be consistent with the stated objectives of the project, and an appropriate risk evaluation should be part of the decision process (see Huijser et al., 2015).

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