Cost-benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in North America; a decision support tool

by

Marcel P. Huijser[1],

John W. Duffield[2],

Anthony P. Clevenger[1],

Robert J. Ament[1], and

Pat T. McGowen[1]

[1] Western Transportation Institute at Montana State University (WTI-MSU), PO Box 174250, Bozeman MT 59717-4250, USA.

[2] The University of Montana, Department of Mathematical Sciences (MMAI01), Mathematics Building, Missoula, MT 59812-0864, USA.

A report prepared for the

Wilburforce Foundation
3601 Fremont Avenue North, Suite 304
Seattle, WA 98103-8753

WTI-MSU Technical Report REP-08-01

October 9, 2008

1. Report No. WTI-MSU Technical Report REP-08-01	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Cost-benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in North America; a decision support tool	**5. Report Date** October 2008 **6. Performing Organization Code**	
7. Author(s) M.P. Huijser, J.W. Duffield, A.P. Clevenger, R.J. Ament & P.T. McGowen	**8. Performing Organization Report No.**	
9. Performing Organization Name and Address Western Transportation Institute (WTI-MSU) College of Engineering Montana State University PO Box 174250 Bozeman, MT 59717-4250	**10. Work Unit No.** **11. Contract or Grant No.**	
12. Sponsoring Agency Name and Address Wilburforce Foundation 3601 Fremont Ave N #304 Seattle, WA 98103-8753	**13. Type of Report and Period Covered** Research Report January 2008 - October 2008 **14. Sponsoring Agency Code**	

15. Supplementary Notes

Research performed in cooperation with Wilburforce Foundation. A PDF version of this report is available from WTI's website at http://www.wti.montana.edu/.

16. Abstract

Wildlife-vehicle collisions, especially with deer (*Odocoileus* spp.), elk (*Cervus elaphus*) and moose (*Alces alces*) are numerous and have shown an increasing trend over the last several decades in the United States and Canada. We calculated the costs associated with the average deer-, elk- and moose-vehicle collision, including vehicle repair costs, human injuries and fatalities, towing, accident attendance and investigation, monetary value to hunters of the animal killed in the collision, and cost of disposal of the animal carcass. In addition, we reviewed the effectiveness and costs of 13 mitigation measures considered effective in reducing collisions with large ungulates. We conducted cost-benefit analyses over a 75-year period using discount rates of 1%, 3% and 7% to identify the threshold values (in 2007 $) above which individual mitigation measures start generating benefits in excess of costs. These threshold values were translated into the number of deer-, elk-, or moose-vehicle collisions that need to occur per kilometer per year for a mitigation measure to start generating economic benefits in excess of costs. In addition, we calculated the costs associated with large ungulate-vehicle collisions on ten road sections throughout the United States and Canada and compared these to the threshold values. Finally, we conducted a more detailed cost analyses for one of these road sections to illustrate that even though the average costs for large ungulate-vehicle collisions per kilometer per year may not meet the thresholds of many of the mitigation measures, specific locations on a road section can still exceed thresholds. We believe the cost-benefit model presented in this paper can be a valuable decision support tool for determining mitigation measures to reduce ungulate-vehicle collisions.

17. Key Words Animal-vehicle collisions, Cost-benefit analysis, Deer, Economic, Effectiveness, Elk, Human injuries and fatalities, Mitigation measures, Moose, Ungulate, Vehicle repair cost, Wildlife-vehicle collision	**18. Distribution Statement** Unrestricted. This document is available through WTI-MSU.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 48	**22. Price**

DISCLAIMER

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Wilburforce Foundation or Montana State University.

Alternative accessible formats of this document will be provided upon request. Persons with disabilities who need an alternative accessible format of this information, or who require some other reasonable accommodation to participate, should contact Kate Heidkamp, Assistant Director for Communications and Information Systems, Western Transportation Institute, Montana State University, PO Box 174250, Bozeman, MT 59717-4250, telephone number 406-994-7018, e-mail: KateL@coe.montana.edu

ACKNOWLEDGEMENTS

This effort was funded, in part, by the Wilburforce Foundation. The authors would like to thank the Wilburforce Foundation for their support. In addition, the authors also thank Pat Basting, Jon Fleming, Bert Johnson, Dick Luedke, Terry McGuire, Chris Neher, Lloyd Salsman, and Bethanie Walder for their help, comments and suggestions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Wildlife-vehicle collisions, especially with deer (*Odocoileus* spp.), elk (*Cervus elaphus*) and moose (*Alces alces*) are numerous and have shown an increasing trend over the last several decades in the United States and Canada. We calculated the costs associated with the average deer-, elk- and moose-vehicle collision, including vehicle repair costs, human injuries and fatalities, towing, accident attendance and investigation, monetary value to hunters of the animal killed in the collision, and cost of disposal of the animal carcass. The estimated costs for the average collision with a deer, an elk, or a moose are $6,617, $17,483, and $30,760 respectively. In addition, we reviewed the effectiveness and costs of 13 mitigation measures considered effective in reducing collisions with large ungulates. The mitigation measures that were estimated to reduce collisions by 80% or more were 1. wildlife fencing; 2. wildlife fencing in combination with wildlife underpasses and wildlife jump-outs; 3. wildlife fencing in combination with wildlife underpasses and overpasses, and wildlife jump-outs; 4. animal detection systems; 5. wildlife fencing in combination with animal detection systems installed at gaps in the fence; 6. elevated roadway; and 7. road tunnels.

We conducted cost-benefit analyses for all 13 mitigation measures over a 75-year period using discount rates of 1%, 3% and 7% to identify the threshold values (in 2007 $) above which individual mitigation measures start generating benefits in excess of costs. These threshold values were translated into the number of deer-, elk-, or moose-vehicle collisions that need to occur per kilometer per year for a mitigation measure to start generating economic benefits in excess of costs. For example, with a discount rate of 3%, wildlife fencing in combination with wildlife underpasses and overpasses, and wildlife jump-outs needs to save $24,230 per km per year, through a reduction in collisions, in order to generate benefits in excess of costs. This threshold value translates into 4.26 deer-, 1.61 elk-, and 0.92 moose-vehicle collisions per km per year. When road mortality numbers are higher, wildlife fencing in combination with wildlife underpasses and overpasses, and wildlife jump-outs generate benefits in excess of costs.

Furthermore, we calculated the costs associated with large ungulate-vehicle collisions on ten road sections throughout the United States and Canada and compared these to the threshold values. Finally, we conducted a more detailed cost analyses for one of these road sections to illustrate that even though the average costs for large ungulate-vehicle collisions per kilometer per year may not meet the thresholds of many of the mitigation measures, specific locations on a road section can still exceed thresholds. We believe the cost-benefit model presented in this paper can be a valuable decision support tool for determining mitigation measures to reduce ungulate-vehicle collisions.

1. INTRODUCTION

Wildlife-vehicle collisions affect human safety, property and wildlife (Figure 1 and 2). In the United States the total number of large mammal-vehicle collisions has been estimated at one to two million in the United States and at 45,000 in Canada annually, (Conover et al. 1995, Tardif & Associates Inc. 2003, Huijser et al. 2007a). These collisions were estimated to cause 211 human fatalities, 29,000 human injuries and over one billion dollars in property damage annually (Conover et al. 1995). Similar figures are available from Europe, where the annual number of collisions with ungulates was estimated at 507,000, causing 300 human fatalities, 30,000 human injuries and over one billion dollars in material damage (Groot Bruinderink and Hazebroek 1996). In the United States and Canada these numbers have increased even further over the last decade (Tardif & Associates Inc. 2003, Huijser et al. 2007a). In most cases the animals die immediately or shortly after the collision (Allen and McGullough 1976). In some cases it is not just the individual animals that suffer. Road mortality may also affect some species on the population level (e.g. van der Zee et al. 1992, Huijser and Bergers 2000), and some species may even be faced with a serious reduction in population survival probability as a result of road mortality, habitat fragmentation and other negative effects associated with roads and traffic (Proctor 2003). In addition, some species also represent a monetary value that is lost once an individual animal dies (Romin and Bissonette 1996, Conover 1997).

Figure 1. Vehicle damage as a result of a collision with a white-tailed deer (© Marcel Huijser).

Figure 2. An a elk killed as a result with a collision with a vehicle (© Marcel Huijser).

Over 40 types of mitigation measures aimed at reducing animal-vehicle collisions have been implemented or described (see reviews in Hedlund et al. 2004, Knapp et al. 2004, Huijser et al. 2007a). Examples include warning signs that alert drivers of potential animal crossings, wildlife warning reflectors or mirrors (e.g. Reeve and Anderson 1993, Ujvári et al. 1998), wildlife fences (Clevenger et al. 2001), and animal detection systems (Huijser et al. 2006a). However, the effectiveness and costs of these mitigation measures vary greatly. When the effectiveness is evaluated in relation to the costs for the mitigation measure, important insight is obtained regarding which mitigation measures may be preferred, at least from a monetary perspective. Nonetheless, very few cost-benefit analyses exist (but see e.g. Reed et al. 1982).

In this paper we compare the monetary costs and benefits of a range of mitigation measures aimed at reducing collisions with large ungulates. In the United States, the vast majority of all reported wildlife-vehicle collisions involve deer (*Odocoileus* spp.). In addition, the vast majority of all animal-vehicle collisions that result in human injury (86.9%) or human fatality (77%) involve deer as well (Conn et al. 2004, Williams and Wells 2005). The numbers vary between regions; in California deer amount to 54.4% of the reported animal-vehicle collisions, in Maine 81.2% (Huijser et al. 2007a). In certain areas, e.g. Maine, collisions with moose (*Alces alces*) are relatively numerous (15.1%) (Huijser et al. 2007a). Of all the claims submitted to a major auto insurance company in the United States (national market share about 17.5%) in 2006-2007 for vehicle repair as a result of a collision with deer, elk, or moose, 99.2% related to deer, 0.5% to elk and 0.3% to moose (n_{total} is approximately 180,000) (Personal communication Dick Luedke, State Farm Insurance). In British Columbia, Canada, 85.6% of all reported animals killed by traffic were deer (78.6%) or moose (7.0%) (Sielecki 2004). In the Ottawa-Carleton area, Canada, 93.1% of all reported animal-vehicle collisions involved deer (92.2%) or moose (0.9%) (Tardif & Associates Inc. 2003). For this paper we conducted separate analyses for the costs and benefits of mitigation measures aimed at reducing collisions with deer (white-tailed deer (*O. virginianus*) and mule deer (*O. hemionus*) combined), elk (*Cervus elaphus*), and moose.

The results of the economic analyses apply to North America since the values used in the analyses are based on data from the United States and Canada. Furthermore, we realize that the results of the analyses are directly dependent on the parameters included in the analyses and the assumptions and estimates required to conduct the analyses. Nonetheless, the results of the cost-benefit analyses allow for much needed direction in the implementation and further research and development of mitigation measures aimed at reducing collisions with large ungulates.

2. METHODS

2.1. Cost-benefit analyses

We estimated the effectiveness of 13 types of mitigation measures for reducing collisions with large ungulates such as deer, elk and moose (Table 1). In addition, we estimated the costs (in 2007 $) of these mitigation measures per year over a 75-year period (Appendix A, Table 1). The costs included design, construction or implementation, maintenance, and removal efforts. The 75-year period is equal to the longest lifespan of the mitigation measures reviewed (i.e. underpasses and overpasses). In the 75th year no new investments were projected (only maintenance and removal costs) for the following mitigation measures: wildlife fence alone; wildlife fence, gap and crosswalk; wildlife fence, underpasses and jump-outs; wildlife fence, under- and overpasses; wildlife fence and animal detection systems; elevated roadway; and road tunnel (see Figures 3 through 6 for illustrations).

Table 1: The estimated effectiveness, present value costs (in 2007 $, 3% discount rate), and costs per percent reduction of mitigation measures aimed at reducing collisions with large ungulates over a 75 year time period. The measures are ordered based on their estimated effectiveness.

Mitigation measure	Effect-iveness	Source	Present value costs	Costs per percent reduction
Seasonal wildlife warning sign	26%	Sullivan et al. (2004): 51%; Rogers (2004): 0%	$3,728	$143
Vegetation removal	38%	Jaren et al. (1991): 56%; Lavsund and Sandegren (1991): 20%	$16,272	$428
Fence, gap, crosswalk	40%	Lehnert and Bissonette (1997): 42%, 37%	$300,468	$7,512
Population culling	50%	Review in Huijser et al. 2007a	$94,809	$1,896
Relocation	50%	Review in Huijser et al. 2007a	$391,870	$7,837
Anti-fertility treatment	50%	Review in Huijser et al. 2007a	$2,183,207	$43,664
Fence (incl. dig barrier)	86%	Reed et al. (1982) 79%; Ward (1982): 90% Woods (1990): 94-97%; Clevenger et al. (2001): 80%; Dodd et al. (2007): 87%	$187,246	$2,177
Fence, underpass	86%	Reed et al. (1982) 79%; Ward (1982): 90% Woods (1990): 94-97%; Clevenger et al. (2001): 80%; Dodd et al. (2007): 87%	$538,273	$6,259
Fence, under- and overpass	86%	Reed et al. (1982) 79%; Ward (1982): 90% Woods (1990): 94-97%; Clevenger et al. (2001): 80%; Dodd et al. (2007): 87%	$719,667	$8,368
Animal detection system (ADS)	87%	Mosler-Berger and Romer (2003): 82%; Dodd and Gagnon (2008): 91%	$1,099,370	$12,636
Fence, gap, ADS	87%	Mosler-Berger and Romer (2003): 82%; Dodd and Gagnon (2008): 91%	$836,113	$9,610
Elevated roadway	100%	Review in Huijser et al. 2007a	$92,355,498	$923,555
Road tunnel	100%	Review in Huijser et al. 2007a	$147,954,696	$1,479,547

Figure 3. A wildlife fence (2.4 m (8 ft) high) designed to keep large ungulates from entering the road corridor (© Marcel Huijser).

Figure 4. An underpass (7 m (23 ft) wide, 4 m (13 ft) high), designed for large mammals (© Marcel Huijser).

Figure 5. A wildlife overpass (52 m (171 ft) wide), designed for large mammals (© Marcel Huijser).

Figure 6. An animal detection system, designed to detect large mammals as the approach the road, and associated warning signs for drivers (© Marcel Huijser).

We also estimated the benefits generated by the 13 mitigation measures. The benefits are a combination of the effectiveness of the mitigation measures in reducing collisions with large ungulates and the costs associated with the average collision. The cost of a collision with a large ungulate typically increases with the size and weight of the species. For this analysis we estimated the costs for the average collision with a deer, an elk, or a moose (Appendix B, Table 2). Some mitigation measures take considerable planning and installation time. Therefore we did not project any benefits in the first year of the cost-benefit analyses. This delay in the start of the benefits applied to all mitigation measures, except seasonal signs, vegetation removal, population culling, relocation, and anti-fertility treatment.

Table 2: Summary of estimated costs (in 2007 $) for the average deer-, elk, and moose-vehicle collision.

Description	Deer	Elk	Moose
Vehicle repair costs per collision	$2,622	$4,550	$5,600
Human injuries per collision	$2,702	$5,403	$10,807
Human fatalities per collision	$1,002	$6,683	$13,366
Towing, accident attendance and investigation	$125	$375	$500
Hunting value animal per collision	$116	$397	$387
Carcass removal and disposal per collision	$50	$75	$100
Total	$6,617	$17,483	$30,760

For our cost-benefit analyses, all costs and benefits are in real terms (i.e. constant 2007 $). Accordingly, since we excluded inflation effects in our benefit and cost streams over time, we also used real (as opposed to nominal) discount rates. Presenting the analysis in nominal terms with inflation included in future values and an inflation component in the discount term would be mathematically equivalent. In order to correctly compare benefits and costs elements which are distributed asymmetrically over time, we computed present discounted values and amortized these into equivalent annual terms. The typical pattern for the mitigation measures we examined is that costs are largely construction oriented in the present (e.g. an investment in a fence with an underpass in the first year of a 75-year period) while benefits are distributed more uniformly over the life of the project (i.e. a certain reduction in collisions and associated costs each year). In this situation, the cost-benefit analysis is sensitive to the discount rate chosen.

Following the guidance provided in the U.S. Office of Management and Budget Circular A-94 (U.S. OMB 1992) and other federal guidelines (U.S. Environmental Protection Agency 2000) we conducted the analyses for real discount rates of 7%, 3% and 1%. The 7% rate is required by OMB for federal benefit-cost analyses and is based on a shadow price of capital theory;

specifically (at least in 1992) 7% is OMB's estimate of the real after-tax return on investment in the private sector (essentially the opportunity cost of instead investing in public projects). A more widely accepted discount parameter for at least intra-generational accounting is choosing a social discount rate based on the rate at which individuals translate consumption through time with reasonable certainty (e.g. a consumption rate of interest theory). For this, historical returns on safe assets such as U.S. Treasury securities are used (post-tax and corrected for inflation), with empirical estimates for rates in the 1% to 3% range (U.S. Environmental Protection Agency 2000). For inter-generational discounting (for which a project with a lifespan of 75 years would obviously qualify) other theories based in part on ethical considerations which explicitly trade-off the well-being of current and future generations come into play, and rates of 0.5% to 3% are plausible. As an example from the economics literature, a recent survey of several thousand economists on the issue of an appropriate discount rate for the problem of global warming indicated a wide-range of opinions on the appropriate rate, rates declining over the time-period of the analysis from about 4% to 0% for the very long term, and a long-term average rate of 1.75% in real terms (Weitzman 2001).

After estimating the costs for each mitigation measure, and after correcting for the discount rate, we calculated how much benefit (in 2007 $) each mitigation measure needs to generate over a 75-year period in order to breakeven and have the benefits exceed the costs (threshold values). Equation 1 shows our methods for estimating costs:

$$A_j = \left[\sum_{t=1}^{n} \frac{c_{tj}}{(1+d)^n}\right]\left[\frac{(1+d)^n \cdot d}{(1+d)^n - 1}\right]$$

The first term is simply the present value of costs over the period t equals 1 to n with discount rate d and annual costs (c_{tj}) in year t for mitigation measure j. The second term is an amortization factor; the product of the two terms equals A_j, which is the amortized real annual cost over period n for technology j. Annual benefits are given by equation 2:

$$B_j = r_j k \sum_{i=1}^{m} \alpha_i c_i + \sum_{i=1}^{m} v_{ij}$$

Annual benefits are the sum of the reduction in direct collision costs for species i (equals 1 to m) and any nonuse or passive use values v_{ij} for these species. With respect to direct collision costs, r_j is the reduction in wildlife-vehicle collisions from technology j (r is a ratio) and k is the initial pre-mitigation level of wildlife-vehicle collisions per kilometer per year for the road section of interest. The term rk accordingly is the reduction in the number of wildlife-vehicle collisions. The average species-weighted average cost per collision is the summation of the share of collisions due to species i times species specific collision costs c_i. The product of the reduction in collisions and the average cost per collision gives the benefits associated with a given mitigation measure. Passive use costs were not included in our empirical application, but they are referenced here for completeness. Passive or nonuse values are generally based on existence or bequest motives (Krutilla 1967) and include values in addition to those that arise directly due to the collision. In this context, passive values could include the value individuals (even those who perhaps never drive the road section of interest) place on knowing that wildlife pain and suffering is reduced by a given mitigation measure, or on knowing that the viability or health of a given species or ecosystem is being protected or improved by a mitigation measure that offers connectivity or safe wildlife passage across the road-way corridor. For example, collisions with vehicles have been a substantial cause of mortality for endangered or threatened large predators such as the Florida panther (*Felis concolor coryi*) and the red wolf (*Canis rufus*) (Huijser et al. 2007a). Extensive economics literature has estimated the passive use values for such species (for example, Duffield and Neher (1996) provided estimates of benefits associated with wolf recovery in Yellowstone National Park). In our case, and in the absence of comprehensive passive use values, we suggest that mitigation measures that do not provide connectivity (e.g. fencing by itself) are not comparable to mitigation measures that do (e.g. fence in combination with underpasses) as highlighted in our discussion section.

Setting annual benefits for technology *j* equal to annual costs and solving for *k* yields the breakeven level of pre-mitigation collisions, which we designate k^{-}_{j}, above which annual benefits will exceed costs (e.g. net benefits are positive), as shown in equation 3:

$$\overline{k_j} = \frac{A_j}{(r_j \cdot \Sigma \alpha_i \cdot c_i) + \Sigma v_{ij}}$$

As one would expect, the number of collisions required is directly proportional to the mitigation measure cost *A* (the higher the costs, the more collisions needed to justify) and inversely proportional to the reduction in collisions achieved by the technology and the direct costs and passive use costs associated with collisions for the species mix at the road segment of interest. For the simplified case of a single species and no passive use values, the breakeven value is simply (equation 4):

$$k_j = \frac{A_j}{r_j \cdot c_i}$$

Note that the right hand term is simply the product of the annual cost per unit of reduction (for example, this could be expressed as the annual cost per one percent of reduction) times the inverse of collision costs. Accordingly, it is useful in comparing costs to identify this unit cost by mitigation measure. The next two sections provide a summary of the effectiveness and costs of the mitigation measures, and the costs associated with deer-, elk-, and moose-vehicle collisions.

2.2. Effectiveness and costs of mitigation measures

We reviewed approximately 40 different types of mitigation measures or combinations of mitigation measures that aim to reduce collisions with large animals (deer and larger) (for full review see Huijser et al. 2007a). Based on the available data, 13 of these measures were considered effective in reducing collisions with large animals (Table 1). If more than one estimate for the effectiveness of a mitigation measure was available, the mean was calculated. Since the effectiveness of some of the mitigation measures is highly variable or based on only one study, additional studies may lead to an adjustment of these values at a later time. Mitigation measures considered ineffective, lacking effectiveness data, or having insufficient data were excluded from the cost-benefit analyses in this paper.

Each mitigation measure's suitability depends on the species concerned, the specific objectives of a project, and local circumstances. This paper does not discuss the advantages and disadvantages of each mitigation measure, but it is important to be aware that some mitigation measures should only be considered under very specific circumstances. For example, population culling, the relocation of individuals or infertility treatment of individuals may be considered if other mitigation measures cannot be implemented due to the local situation. However, such measures may only be practical and effective for relatively small and closed populations (Seagle and Close 1996, Rudolph et al. 2000). Furthermore, such measures are typically applied to deer rather than other species. See Huijser et al. (2007a) for a discussion on other considerations.

The estimated costs for each of the mitigation measures over a 75-year period vary greatly, as did the costs per percent reduction in collisions (Table 1). Appendix A provides a rationale for the estimated costs of the individual mitigation measures.

2.3. Cost estimates for deer, elk, and moose-vehicle collisions

The justification for the cost estimates for deer-, elk-, and moose-vehicle collisions is in Appendix A. The total estimated costs for each deer-, elk-, and moose-vehicle collision is summarized in Table 2. The majority of the costs are associated with human injuries and fatalities (deer: 56.0%; elk: 69.1%; moose: 78.6%) rather than vehicle repair costs (deer: 39.6%; elk: 26.0%; moose: 18.2%). Based on a total estimate of one to two million collisions with large mammals per year in the United States (Huijser et al. 2007a), and the estimate that 99.2% of all reported wildlife-vehicle collisions related to deer, 0.5% to elk and 0.3% to moose (see introduction), the total estimated annual costs associated with ungulate-vehicle collisions is estimated at $6,247,759,000- 12,495,518,000. In Canada, with an estimated 45,000 large mammal-vehicle collisions, the estimated annual costs are $281,149,155 (Tardif & Associates Inc. 2003).

3. RESULTS

3.1. Illustration output cost-benefit model

Figure 7 shows the threshold values (in 2007 $) for a specific mitigation measure; fencing with underpasses. For this specific mitigation measure, there is an initial construction cost in the first year of $416,191, with annual maintenance of $1,500 per year and fence removal and replacement in year 25 and 50 of $107,500 and removal less salvage in year 75 of $26,500 (all costs in 2007 $ per kilometer). The present value (3% discount rate) of this mitigation measure is $538,273 and annual amortized value per kilometer is $18,123. The annual amortized values at 7% and 1% are $32,457 and $12,437 respectively. These annual costs at the three discount rates are shown as horizontal lines (Figure 7). As one would expect, the higher the time value of money (the higher the discount rate) the greater the annual costs. The costs associated with pre-mitigation collisions with deer, elk, and moose are zero if no collisions occur. However, when collisions do occur, the costs increase with the number of collisions, and the rate of increase (slope of the line) is dependent on the species and the average costs associated with a collision (see Table 2) (Figure7). The lines representing the costs associated with pre-mitigation collisions with deer, elk, and moose cross the horizontal lines representing the annual amortized values at the breakeven points. For 3% discount rate, the breakeven point for deer, elk, and moose is 3.18, 1.21, and 0.69 collisions per kilometer per year respectively (Figure 7). If more collisions occur, then fencing with underpasses starts generating economic benefits in excess of costs.

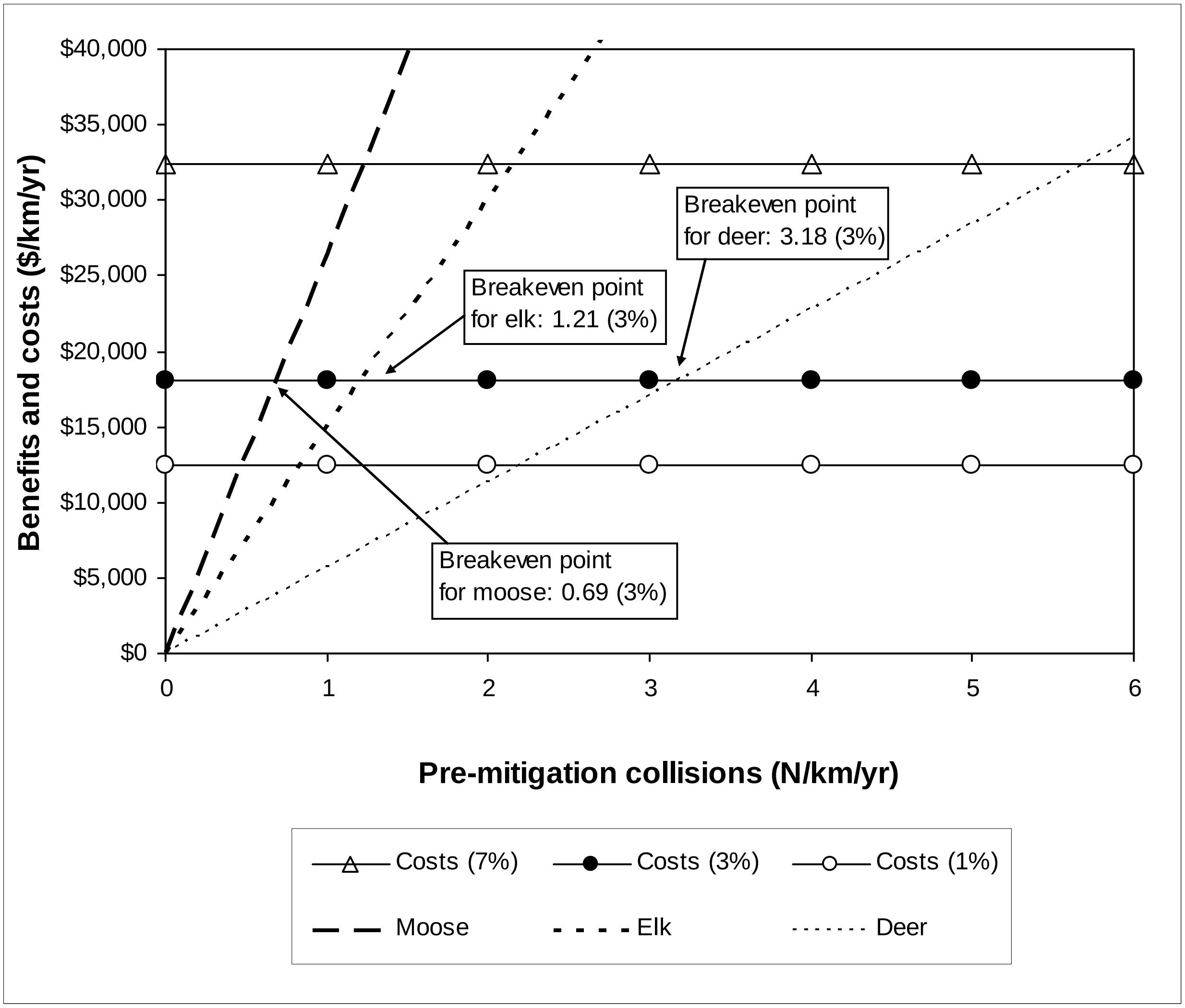

Figure 7. The number of deer-, elk-, and moose-vehicle collisions per kilometer per year (dotted lines) needed to reach the threshold values (7%, 3%, and 1% discount rate) (in real 2007 $) (solid lines) for fencing with underpasses.

Another way to look at the same data is in terms of the actual “product” or output of the mitigation measures, which is the number of collisions avoided per kilometer per year (Figure 8). From this perspective, the average benefits per collision avoided are constant (horizontal lines in Figure 8) and depend on the species: deer $6,617, elk $17,483, and moose $30,760 per kilometer per year. Average costs per collision avoided, however, decline with the number of collisions avoided, illustrating the spreading of fixed costs which underlies the economics of these mitigation measures. The breakeven point for deer, elk, and moose at 2.74, 1.04, and 0.59 collisions avoided per kilometer per year respectively (Figure 8). Note that this value, divided by the reduction achieved by the specific fencing with underpasses mitigation measure of 0.86 or 86%, yields the breakeven point in terms of pre-mitigation collisions (Figure 7)).

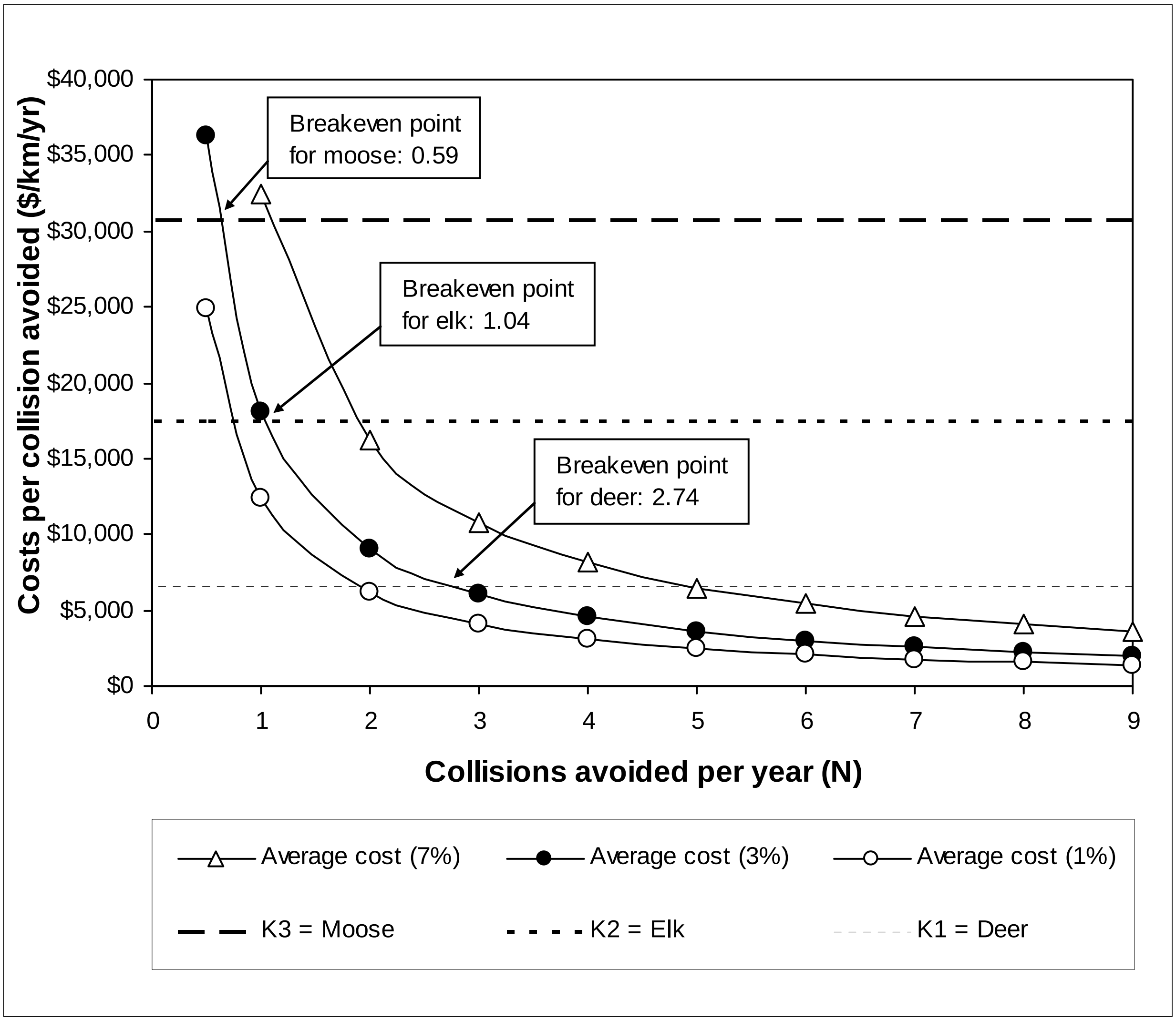

Figure 8. The average costs per collision avoided per year for deer, elk, and moose for the mitigation measure fencing with underpasses (solid lines) (at 7%, 3% and 1% discount rate) and the costs associated with the average deer-, elk-, or moose-vehicle collision (dotted lines) (all in real 2007$).

3.2. Threshold values for the mitigation measures

The minimum amount (in 2007 $) that a mitigation measure needs to generate in order to reach the breakeven point increases with the discount rate (Table 3 and 4). However, this value is not dependent on the discount rate for mitigation measures that require the same investment every year (i.e. for vegetation removal and anti-fertility treatment) (Table 3). These dollar value thresholds were translated into breakeven points for deer-, elk-, and moose-vehicle collisions per kilometer per year (Table 3 and 4). If a road section has costs or wildlife-vehicle collision numbers that exceed these threshold values, then the benefits of that mitigation measure exceed the costs over a 75-year long time period (measured in 2007 $).

Table 3: Threshold values for individual mitigation measures that are estimated to reduce collisions with large ungulates by ≤50%.

Threshold values	Discount rate	Seasonal sign	Vegetation removal	Fence, gap, signs, crosswalk, jump-outs	Population culling	Relocation	Anti-fertility treatment
$/km/yr	1%	$114	$530	$8,153	$3,040	$12,652	$71,110
$/km/yr	3%	$121	$530	$10,116	$3,099	$12,764	$71,110
$/km/yr	7%	$140	$530	$14,972	$3,215	$13,164	$71,110
deer/km/yr	1%	0.07	0.21	3.08	0.92	3.82	21.49
deer/km/yr	3%	0.07	0.21	3.82	0.94	3.86	21.49
deer/km/yr	7%	0.08	0.21	5.66	0.97	3.98	21.49
elk/km/yr	1%	0.03	0.08	1.17	0.35	1.45	8.13
elk/km/yr	3%	0.03	0.08	1.45	0.35	1.46	8.13
elk/km/yr	7%	0.03	0.08	2.14	0.37	1.51	8.13
moose/km/yr	1%	0.01	0.05	0.66	0.20	0.82	4.62
moose/km/yr	3%	0.02	0.05	0.82	0.20	0.83	4.62
moose/km/yr	7%	0.02	0.05	1.22	0.21	0.86	4.62

Table 4: Threshold values for individual mitigation measures that are estimated to reduce collisions with large ungulates by ≥80%.

Threshold values	Discount rate	Fence	Fence, under pass, jump-outs	Fence, under- and overpass, jump-outs	ADS	Fence, gap, ADS, jump-outs	Elevated roadway	Road tunnel
$/km/yr	1%	$5,223	$12,437	$15,975	$35,279	$25,634	$2,233,094	$3,328,567
$/km/yr	3%	$6,304	$18,123	$24,230	$37,014	$28,150	$3,109,422	$4,981,333
$/km/yr	7%	$8,931	$32,457	$45,142	$41,526	$34,437	$5,369,961	$9,246,617
deer/km/yr	1%	0.92	2.19	2.81	6.13	4.45	337.48	503.03
deer/km/yr	3%	1.11	3.18	4.26	6.43	4.89	469.91	752.81
deer/km/yr	7%	1.57	5.70	7.93	7.21	5.98	811.54	1397.40
elk/km/yr	1%	0.35	0.83	1.06	2.32	1.69	127.73	190.39
elk/km/yr	3%	0.42	1.21	1.61	2.43	1.85	177.85	284.92
elk/km/yr	7%	0.59	2.16	3.00	2.73	2.26	307.15	528.89
moose/km/yr	1%	0.20	0.47	0.60	1.32	0.96	72.60	108.21
moose/km/yr	3%	0.24	0.69	0.92	1.38	1.05	101.09	161.94
moose/km/yr	7%	0.34	1.23	1.71	1.55	1.29	174.58	300.61

3.3. Real world examples

The costs associated with deer-, elk-, and moose-vehicle collisions for ten road sections in the United States and Canada varied between $3,636 and $46,155 per kilometer per year (Table 5). These average costs are higher than the threshold values for some of the mitigation measures (see Table 3 and 4), indicating that the benefits of implementing such mitigation measures over the full length of the road sections concerned exceed the costs. When comparing the costs per kilometer per year to the threshold values in Table 3 and 4, please note that these threshold values are based on a divided 4-lane road, and that 2-lane roads have lower threshold values for some of the mitigation measures (e.g. those that include under- or overpasses). A more detailed cost analyses for one of the road sections in Table 5, MT Hwy 83, showed that, even though the average costs per kilometer per year may not meet the thresholds of many of the mitigation measures, certain locations on a road section can still exceed these thresholds (Figure 9). For example, the benefits of animal detection systems as a stand alone mitigation measure exceed the costs on 4.2% of the 76.9 km (47.8 mi) long road section. Similarly, this percentage is 9.4% for wildlife fencing with gaps and animal detection systems in these gaps, and jump-outs; 16.3% for wildlife fencing with under- and overpasses, and jump-outs; and 26.8% for wildlife fencing with underpasses, and jump-outs (Figure 9).

Table 5: The cost of deer-, elk-, and moose-vehicle collisions for selected road sections in the USA and Canada (all in 2007 $). R=research project, HM= highway maintenance reports, AR=highway accident reports, PWI=park warden incident reports, MSR= meat salvage reports.

Road section	Road length (km)	Data collection and year	Collisions/km/yr (costs in 2007 $)	Total cost/ km/yr	Source
SR260 (Christopher Creek section), Payson, AZ, USA	7.2	R, HM,AR (2002-2003)	2.64 elk ($46,155)	$46,155	Dodd et al. 2007
I-90 (309.0-330.9) (4-l), Bozeman Pass, MT, USA	35.2	R,HM (2003)	3.38 deer ($22,365) 0.21 elk ($3,671) 0.06 moose ($1,845)	$7,881	Hardy et al. 2006
I-80/90 (50.0-70.0), Indiana Toll Road (4-l), IN, USA	32.2	HM (2005)	2.89 deer ($19,123)	$19,123	Pers. com. Sedat Gulen, Indiana DOT
Alaska Hwy 1 (58.0-79.0) (2-l), AK, USA	33.8	AR, MSR (2006)	0.56 moose ($17,226)	$17,226	Pers. com. Rick Ernst, Kenai Nat. Wildl. Ref.
I-95 (near Medway) (4-l), ME, USA	32.2	AR (2005)	0.06 deer ($397) 0.53 moose (16,303)	$16,700	Pers. com. Duane Brunell, Maine DOT
Hwy 1, Banff Nat.P. Park (Phase 3b) (2-l), AB, CAN	28.1	AR,R, PWI (2005)	0.60 deer ($3,970) 0.32 elk ($5,595) 0.07 moose ($2,153)	$11,718	Pers. com. Shelagh Wrazej, Parks Canada
Route 169 (1.0-61.0) (2-l), QC, CAN	61.0	HM, AR (2003)	0.33 moose ($10,151)	$10,151	Pers. com. Yves Leblanc, Tecsult Inc
I-90 (55.0-70.0) (4-l), Snoqualmie Pass, WA, USA	24.1	HM (2005)	0.70 deer ($4,632) 0.25 elk ($4,371)	$9,003	Pers. com Victoria Fursman, Washington DOT
MT Hwy 83 (2-l), MT, USA	76.9	HM (1998-2003)	1.19 deer ($7,287) 0.01 elk ($176)	$7,463	Huijser et al. 2006b
Highway 93 S (2-l), Kootenay Nat.P., BC, CAN	34.2	AR, PWI (2005)	0.41 deer ($2,713) 0.03 moose ($923)	$3,636	Pers. com. Shelagh Wrazej, Parks Canada

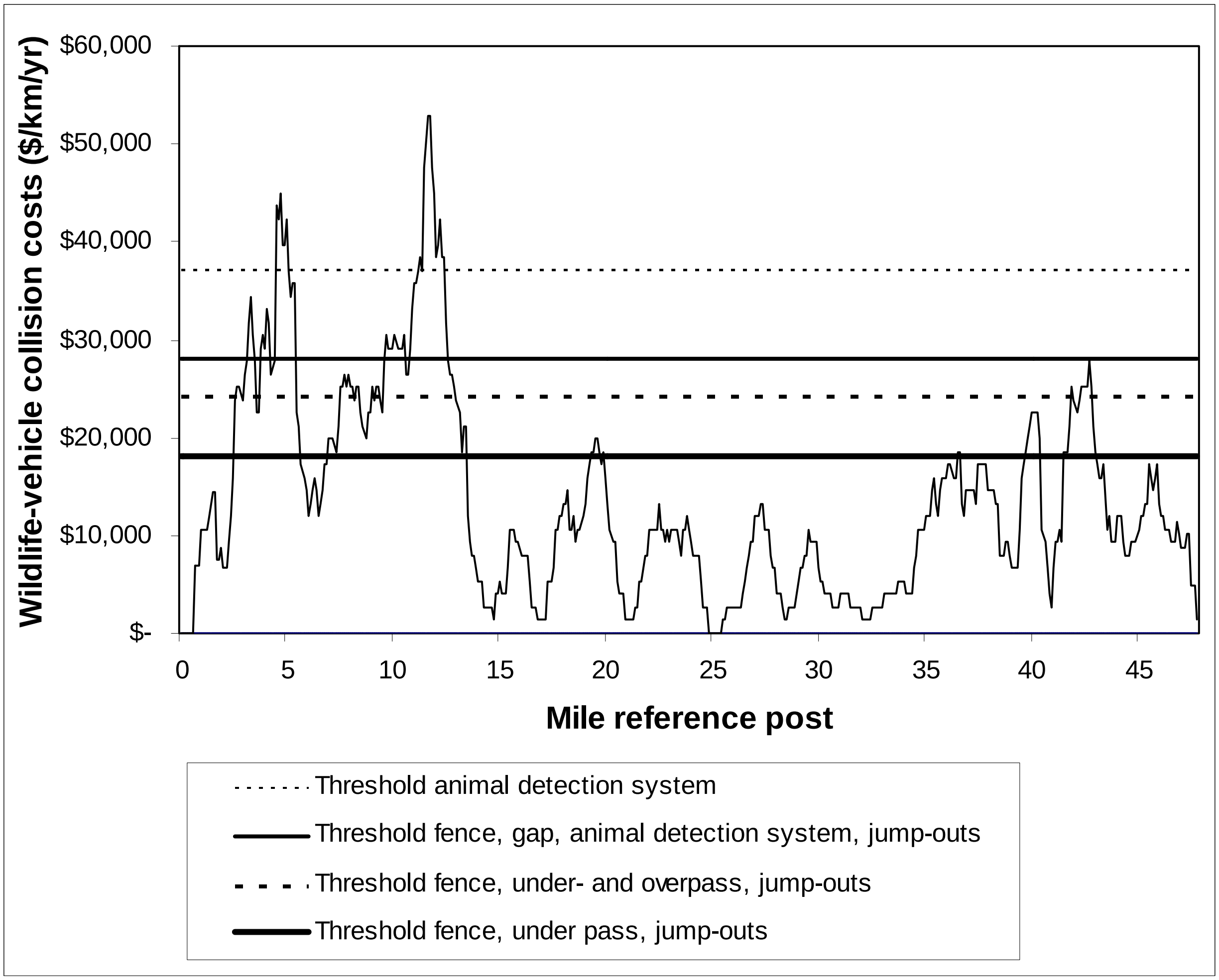

Figure 9. The costs (in 2007 $) associated with wildlife-vehicle collisions (deer and elk) along the 2-lane MT Hwy 83 (mi reference posts 0.0-47.8) per year (average 1998–2003), and the threshold values (at 3% discount rate) that need to be met in order to have the benefits of individual mitigation measures exceed the costs over a 75 year long time period. Note that the costs at each 0.1 mi concerned and five adjacent 0.1 mi units were summed (0.6 mi = 1 km) to estimate the costs per kilometer.

4. DISCUSSION

The costs associated with deer-, elk-, and moose-vehicle collisions are substantial. The majority of the costs are associated with human injuries and fatalities (deer 56.0%; elk 69.1%; moose: 78.6%) rather than vehicle repair costs (deer: 39.6%; elk: 26.0%; moose: 18.2%). Of the approximately 40 different types of mitigation measures reviewed, only 13 were considered to reduce collisions with large ungulates. However, effectiveness and the costs of these 13 mitigation measures vary greatly and, as a consequence, there are substantial differences in the threshold values between the individual mitigation measures above which the benefits of a mitigation measure exceed the costs. Collision and carcass data from ten road sections throughout the United States and Canada show that some road sections easily meet the threshold values for some of the mitigation measures. This means that the benefits of implementing such mitigation measures over the full length of the road sections concerned exceed the costs. However, when calculating the average costs of wildlife-vehicle collisions over relatively long road sections, potential concentrations of wildlife-vehicle collisions are ignored. Therefore it is important that more detailed analyses are carried out at a finer spatial scale (e.g. at 0.1-1.0 km or 0.1-1.0 mi resolution) to identify road sections where the benefits of mitigation measures may exceed the costs. Previous cost-benefit analyses estimated that wildlife fencing and wildlife fencing in combination with underpasses required 7.5 and 11.3 deer-vehicle collisions per kilometer per year respectively at a discount rate of 6% (Reed et al. 1982). These thresholds are higher than in our study, primarily because costs associated with human injuries and fatalities were not included by Reed.

While it may appear attractive to implement mitigation measures that have relatively low threshold values, not all mitigation measures reduce wildlife-vehicle collisions substantially. Some of the mitigation measures that have relatively low costs also have relatively low effectiveness in reducing wildlife-vehicle collisions. We suggest to first investigate the implementation of mitigation measures that are estimated to reduce collisions with large ungulates by at least 80%.

Wildlife fencing as a stand alone mitigation measure falls within this category and has relatively low threshold values. However, we strongly advise against increasing the barrier effect of roads and traffic without providing for safe crossing opportunities at appropriate intervals (see e.g. Bissonette and Adair 2008, Huijser et al. 2008). The reason wildlife fencing has relatively low thresholds is that connectivity for wildlife (a passive use cost) was not included in our cost-benefit analyses. However, depending on the species and local population structure, connectivity across the landscape, including roads, can be critical for the long term population viability of the species concerned, and perhaps especially for species that may not be frequently hit by cars and that have low population density in the area (e.g. Jaeger and Fahrig 2004).

Wildlife fencing in combination with underpasses, or a combination of under- and overpasses, and jump-outs, have thresholds low enough to be met at many road sections that have a concentration of collisions with large ungulates. While the costs for an individual wildlife overpasses is typically many times that for a wildlife underpass (estimated at 10 times higher costs, see Appendix A), wildlife overpasses only increase the threshold values by 28.4, 33.7% or 39.1% (at 1%, 3%, or 7% discount rate respectively) when used sparingly (in this case once every 24 km) in large scale mitigation projects.

Animal detection systems as a stand alone mitigation measure, and wildlife fencing combined with both jump-outs and animal detection systems installed at gaps, have higher thresholds than wildlife fencing in combination with under- and overpasses, but they still are low enough to be met at many road sections that have a concentration of collisions with large ungulates. Nonetheless, while the data on the effectiveness of animal detection systems are encouraging, the estimate of the effectiveness of this mitigation measure are not nearly as robust as that for wildlife fencing in combination with under- and overpasses. Therefore animal detection systems should still be considered experimental (see Huijser et al. (2006a) for a discussion on the relative strengths and weaknesses of animal detection systems and wildlife fencing in combination with under- and overpasses).

Elevated roadways and road tunnels have very high threshold values, suggesting that these measures are unlikely to be implemented based on an economic analysis of deer-, elk-, or moose-vehicle collisions alone. Elevated roadways or road tunnels appear to be primarily put in place because of landscape characteristics (e.g. the presence of a mountain or a canyon), ecosystem processes (e.g. rivers), and perhaps concerns for specific threatened or endangered species. This also illustrates another limitation of our cost-benefit analyses; it is primarily focused on the costs and benefits of collisions with large ungulates and the impacts on human safety. If other parameters are included, they may change the threshold values substantially.

The threshold values for the individual mitigation measures are based on the mitigation of relatively long road sections (e.g. at least several kilometers or miles). This is especially important for the mitigation measures that include safe crossing opportunities. In this context, it is also critical to consider the home range of the species concerned to prevent individual animals from simply walking to the beginning or end of a mitigated road section to cross at grade, potentially reducing the effectiveness of the mitigation measure (see e.g. Huijser et al. 2008).

The costs associated with collisions with large ungulates are a current estimate and may be subject to change when additional studies are conducted. The same is true for the costs (e.g. price of concrete, steel) and effectiveness of the individual mitigation measures. In addition, there may be biases in our estimates for the costs of collisions with large ungulates. For example, the cost estimates for deer-, elk-, and moose-vehicle collisions only relate to the collisions reported to the insurance industry or to law enforcement agencies, and one could argue that unreported collisions are likely to be less costly than reported collisions. Therefore we may have overestimated the average costs of a collision with a deer, elk, or moose. On the other hand, insurance industry reports and police accident reports may underestimate ungulate-vehicle collisions by about 50% (only 46.3% of the drivers who experienced a deer-vehicle collision reported the accident to the police and only 52.1% reported the collision to an insurance company (Riley and Marcoux 2006)). Drivers may not report collisions to law enforcement agencies or the insurance industry if they did not think it was necessary, if there were no human injuries or little to no vehicle damage, if they were concerned about increased insurance rates, and/or if they thought they did not have the proper coverage (Riley and Marcoux 2006). In Virginia, only 14% of the deer-vehicle collisions reported to the insurance industry were reported to law enforcement agencies (Donaldson and Lafon 2008). On MT Hwy 83, an employee of the Montana Department of Transportation estimated that about 80% of all (deer) carcasses are actually removed and reported through carcass reports (Huijser et al. 2006b) (Personal communication Bert Johnson, Montana Department of Transportation). Based on skid marks of car tires and debris he also estimated that 30% of the deer that are hit are not reported because the carcass has been removed by others or because the animal has run away from the road with unknown injuries (Huijser et al. 2006b). In Canada, a review estimated between 20-30%, and perhaps as much as 50% underreporting by the insurance industry (Tardif & Associates Inc. 2003). Furthermore, in most states and provinces in the United States and Canada, no accident report is filled out by law enforcement agencies if the estimated vehicle damage is less than $1,000 (Huijser et al. 2007b). The most conservative approach would be to only include collisions that were reported to the insurance industry or law enforcement agencies, and screen the data for potential duplicates. However, based on the studies cited above, it is clear that such an approach may lead to a serious underestimation of the actual costs of collisions with large ungulates, and one may choose to include carcass reports, recognizing that while this may overestimate the average costs associated with a deer-, elk- or moose-vehicle collisions, it may still underestimate the actual number of ungulate-vehicle collisions by about 50%.

5. CONCLUSION

We believe that the cost-benefit model presented in this paper can be a valuable decision support tool when determining mitigation measures to reduce ungulate-vehicle collisions. The tool allows for the selection of the appropriate road sections as well as the type of mitigation measure. The results suggest that there must be many road sections in the United States and Canada where the benefits of mitigation measures exceed the costs and where the mitigation measures would help society save money and improve road safety for humans and wildlife. Mitigation measures that include safe crossing opportunities for wildlife may not only substantially reduce road mortality, but would also facilitate wildlife movement across the landscape. This paper can help focus the discussion on the economics of wildlife-vehicle collisions and the benefits and costs of a range of potential mitigation measures for specific road sections.

6. REFERENCES

Allen, R. E., and D. R. McCullough. 1976. Deer-car accidents in southern Michigan. Journal of Wildlife Management 40:317-325.

Andreassen, H. P., H. Gundersen, and T. Storaas. 2005. The effect of scent-marking, forest clearing, and supplemental feeding on moose-train collisions. Journal of Wildlife Management 69(3):1125-1132.

Beringer, J., L. P. Hansen, J. A. Demand, J. Sartwell, M. Wallendorf, and R. Mange. 2002. Efficacy of translocation to control urban deer in Missouri: costs, efficiency, and outcome. Wildlife Society Bulletin 30(3):767-774.

Bissonette, J. A., and W. Adair. 2008. Restoring habitat permeability to roaded landscapes with isometrically-scaled wildlife crossings. Biological Conservation 141(2):482-488.

Bissonette, J. A., and M. Hammer. 2000. Effectiveness of earthen ramps in reducing big game highway mortality in Utah. Final Report. USGS Utah cooperative Fish and Wildlife Research Unit, Utah State University, Logan, Utah, USA.

Bissonette, J. A., C. A. Kassar, and L. J. Cook. 2008. Assessment of costs associated with deer–vehicle collisions: human death and injury, vehicle damage, and deer loss. Human–Wildlife Conflicts 2(1):17–27.

Brabants Daglad. 2004. Ecoduct over de A2. [online] URL: http://www.brabant.nl/Verplaatsen/Verkeersveiligheid/Ecoduct%20over%20de%20A2.aspx.

Clayton Resources Ltd. & Glen Smith Wildlife Consultants. 1989. Wildlife fencing and control on the Okanagan connector highway: a benefit cost analysis. Clayton Resources Ltd., Victoria, British Columbia, Canada.

Clevenger, A. P., B. Chruszcz, and K. Gunson. 2001. Highway mitigation fencing reduces wildlife-vehicle collisions. Wildlife Society Bulletin 29:646-653.

Clevenger, A. P., B. Chruszcz, K. Gunson, and J. Wierzchowski. 2002. Roads and wildlife in the Canadian Rocky Mountain Parks: movements, mortality and mitigation. Final report to Parks Canada. Banff, Alberta, Canada.

Conn, J. M., J. L. Annest, and A. Dellinger. 2004. Nonfatal motor-vehicle animal crash-related injuries-United States, 2001–2002. Journal of Safety Research 35:571– 574.

Conover, M. R. 1997. Monetary and intangible valuation of deer in the United States. Wildlife Society Bulletin 25:298-305.

Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildlife Society Bulletin 23:407-414.

Crête, M., and C. Daigle. 1999. Management of indigenous North American deer at the end of the 20th century in relation to large predators and primary productivity. Acta Veterinaria Hungarica 47: 1-16.

DeNicola, A. J., K. C. VerCauteren, P. D. Curtis, and S. E. Hygnstrom. 2000. Managing white-tailed deer in suburban environments: a technical guide. Cornell Cooperative Extension, The Wildlife Society–Wildlife Damage Management Working Group, and the Northeast Wildlife Damage Research and Outreach Cooperative, Ithaca, New York, USA.

Dodd, N., and J. Gagnon. 2008. Preacher Canyon Wildlife Fence and Crosswalk Enhancement Project State Route 260, Arizona. First year progress report. Project JPA 04-088. Arizona Game and Fish Department, Research Branch, Arizona, USA.

Dodd, N. L., J. W. Gagnon, S. Boe, A. Manzo, and R. E. Schweinsburg. 2007. Evaluation of measures to minimize wildlife-vehicle collisions and maintain permeability across highways: Arizona Route 260. Final Report 540. FHWA-AZ-07-540. Arizona Department of Transportation, Phoenix, Arizona, USA.

Doerr, M. L., J. B. McAninch, and E. P. Wiggers. 2001. Comparison of four methods to reduce white-tailed deer abundance in an urban community. Wildlife Society Bulletin 29(4):1105-1113.

Donaldson, B. M., and N. W. Lafon. 2008. Testing an Integrated PDA-GPS System to Collect Standardized Animal Carcass Removal Data. FHWA/VTRC 08-CR10. Virginia Transportation Research Council, Charlottesville, Virginia, USA.

Duffield, J. W., and C. J. Neher. 1996. Economics of wolf recovery in Yellowstone National Park. Transactions 61st North American Wildlife and Natural Resources Conference 61:285-292.

Foster, M. L., and S. R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23(1): 95-100.

Garrett, L. C., and G. A. Conway. 1999. Characteristics of moose-vehicle collisions in Anchorage, Alaska, 1991–1995. Journal of Safety Research 30: 219–223.

Government of Newfoundland and Labrador. 1997. Results of review of moose-vehicle collisions. News release 11 July 1997. [online] URL: http://www.gov.nf.ca/releases/1997/forest/0711n02.htm.

Groot Bruinderink, G. W. T. A., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. Conservation Biology 10:1059-1067.

Grund, M. D., J. B. McAninch, and E. P. Wiggers. 2002. Seasonal movements and habitat use of female white-tailed deer associated with an urban park. Journal of Wildlife Management 66(1):123-130.

Hardy, A. R., J. Fuller, S. Lee, L. Stanley, and A. Al-Kaisy. 2006. Bozeman pass wildlife channelization ITS project. Final report to Montana Department of Transportation. Western Transportation Institute – Montana State University, Bozeman, Montana, USA.

Hedlund, J. H., P. D. Curtis, G. Curtis, and A. F. Williams. 2004. Methods to reduce traffic crashes involving deer: What works and what does not. Traffic Injury Prevention 5:122–131.

Huijser, M. P., and P. J. M. Bergers. 2000. The effect of roads and traffic on hedgehog (*Erinaceus europaeus*) populations. Biological Conservation 95:111-116.

Huijser, M. P., P. T. McGowen, W. Camel, A. Hardy, P. Wright, A. P. Clevenger, L. Salsman, and T. Wilson. 2006a. Animal Vehicle Crash Mitigation Using Advanced Technology. Phase I: Review, Design and Implementation. SPR 3(076). FHWA-OR-TPF-07-01, Western Transportation Institute – Montana State University, Bozeman, Montana, USA.

Huijser, M. P., K. E. Gunson, and C. Abrams. 2006b. Animal-vehicle collisions and habitat connectivity along US Highway 83 in the Seeley-Swan Valley: a reconnaissance. Report no. FHWA/MT-06-002/8177. Western Transportation Institute – Montana State University, Bozeman, Montana, USA.

Huijser, M. P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A. P. Clevenger, D. Smith, and R. Ament. 2007a. Wildlife-vehicle collision reduction study. Report to Congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA.

Huijser, M. P., J. Fuller, M. E. Wagner, A. Hardy, and A. P. Clevenger. 2007b. Animal-vehicle collision data collection. A synthesis of highway practice. NCHRP Synthesis 370. Project 20-05/Topic 37-12. Transportation Research Board of the National Academies, Washington DC, USA.

Huijser, M. P., K. J. S. Paul, L. Oechsli, R. Ament, A. P. Clevenger, and A. Ford. 2008. Wildlife-vehicle collision and crossing mitigation plan for Hwy 93S in Kootenay and Banff National Park and the roads in and around Radium Hot Springs. Report 4W1929 B, Western Transportation Institute – Montana State University, Bozeman, Montana, USA.

Jaeger, J. A. G., and L. Fahrig. 2004. Effects of road fencing on population persistence. Conservation Biology 18(6):1651-1657.

Jaren, V., R. Andersen, M. Ulleberg, P. H. Pedersen, and B. Wiseth. 1991. Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. Alces 27:93-99.

Joyce, T. L., and S. P. Mahoney. 2001. Spatial and temporal distributions of moose vehicle collisions in Newfoundland. Wildlife Society Bulletin 29(1):281-291.

Kirkpatrick, J. F., and A. T. Rutberg. 2001. Fertility control in animals. Pages 183–198 in D.J. Salem and A.N. Rowan, editors. The state of the animals 2001. Humane Society Press, Washington, D.C., USA.

Kilpatrick, H. J., and S. M. Spohr. 2000. Movements of female white-tailed deer in a suburban landscape: A management perspective. Wildlife Society Bulletin 28(4):1038-1045.

Kilpatrick, H. J., S. M. Spohr, and K. K. Lima. 2001. Effects of population reduction on home ranges of female white-tailed deer at high densities. Canadian Journal of Zoology 79(6):949-954.

Knapp, K., X. Yi, T. Oakasa, W. Thimm, E. Hudson, and C. Rathmann. 2004. Deer-vehicle crash countermeasure toolbox: a decision and choice resource. Final report. Report Number DVCIC – 02. Midwest Regional University Transportation Center, Deer-Vehicle Crash Information Clearinghouse, University of Wisconsin-Madison, Madison, Wisconsin, USA.

Kruidering, A. M., G. Veenbaas, R. Kleijberg, G. Koot, Y. Rosloot, and E. van Jaarsveld. 2005. Leidraad faunavoorzieningen bij wegen. Rijkswaterstaat, Dienst Weg-en Waterbouwkunde, Delft, The Netherlands.

Krutilla, J. V. 1967. Conservation reconsidered. American Economic Review 57:777-786.

Lavsund, S., and F. Sandegren. 1991. Moose-vehicle relations in Sweden: a review. Alces 27:118-126.

Lehnert, M. E., and J. A. Bissonette. 1997. Effectiveness of highway crosswalk structures at reducing deer vehicle collisions. Wildlife Society Bulletin 25(4): 809-818.

Mosler-Berger, C., and J. Romer. 2003. Wildwarnsystem CALSTROM. Wildbiologie 3:1-12.

Porter, W. F., and H. B. Underwood. 1999. Of elephants and blind men: deer management in the US National Parks. Ecological Applications 9(1):3-9.

Proctor, M. F. 2003. Genetic analysis of movement, dispersal and population fragmentation of grizzly bears in southwestern Canada. Dissertation. The University of Calgary, Calgary, Alberta, Canada.

Reed, D. F., T. D. I. Beck, and T. N. Woodward. 1982. Methods of reducing deer-vehicle accidents: benefit-cost analysis. Wildlife Society Bulletin 10:349-354.

Reeve, A. F., and S. H. Anderson. 1993. Ineffectiveness of Swareflex reflectors at reducing deer-vehicle collisions. Wildlife Society Bulletin 21:127-132.

Rattey, T. E., and N. E. Turner. 1991. Vehicle-moose accidents in Newfoundland. The Journal of Bone and Joint Surgery 73(10):1487-1491.

Riley, S. J. and A. Marcoux. 2006. Deer-vehicle collisions: an understanding of accident characteristics and drivers' attitudes, awareness and involvement. Research report RC-1475. Department of Fisheries and Wildlife, Michigan State University East Lansing, Michigan, USA.

Rogers, E. 2004. An ecological landscape study of deer vehicle collisions in Kent County, Michigan. Report by White Water Associates Inc. Prepared for Kent County Road Commission, Grand Rapids, Michigan, USA.

Romin, L. A., and J. A. Bissonette. 1996. Deer-vehicle collisions: status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin 24:276-283.

Rudolph, B. A., W. F. Porter, and H. B. Underwood. 2000. Evaluating immunocontraception for managing suburban white-tailed deer in Irondequoit, New York. Journal of Wildlife Management 64(2):463-473.

Schwabe, K. A., P. W. Schuhmann, M. J. Tonkovich, and E. Wu. 2002. An analysis of deer-vehicle collisions: the case of Ohio. Pages: 91-103 in: L. Clark, editor. Human conflicts with wildlife: economic considerations. National Wildlife Research Center, Fort Collins, Colorado, USA.

Seagle, S. W., and J. D. Close. 1996. Modeling white-tailed deer (*Odocoileus virginianus*) population control by contraception. Biological Conservation 76(1):87-91.

SEMCOG. 2007. Michigan Deer Crash Coalition. [online] URL: http://www.semcog.org/MDCC.aspx

Sielecki, L. E. 2004. WARS 1983-2002. Wildlife accident reporting and mitigation in British Columbia: special annual report. Ministry of Transportation, Engineering Branch, Environmental Management Section, Victoria, British Columbia, Canada.

Sullivan, T. L., A. E. Williams, T. A. Messmer, L. A. Hellinga, and S. Y. Kyrychenko. 2004. Effectiveness of temporary warning signs in reducing deer vehicle collisions during mule deer migrations. Wildlife Society Bulletin 32(3):907-915.

Tardif, L. -P. & Associates Inc. 2003. Collisions involving motor vehicles and large animals in Canada. Final report. L-P Tardif & Associates Inc., Nepean, Ontario, Canada.

Thomas, E. 1995. Moose-vehicle accidents on Alaska's rural highways. State of Alaska, Department of Transportation and Public Facilities, Central Region, Design and Construction Division, Alaska, USA.

Ujvári, M., H. J. Baagøe, and A. B. Madsen. 1998. Effectiveness of wildlife warning reflectors in reducing deer-vehicle collisions: a behavioural study. Journal of Wildlife Management 62:1094-1099.

USA Traffic Signs. 2007. Warning for deer crossing sign. USA Traffic Signs, Binghamton, New York, USA. [online] URL: http://www.usa-traffic-signs.com/.

U.S. Department of Labor. 2008. Consumer Price Index. Bureau of Labor Statistics, Washington, D.C., USA. [online] URL: ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt.

U.S. Environmental Protection Agency. 2000. Guidelines for Economic Analysis. EPA 240-R-00-003. [online] URL: http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html.

U.S. Fish and Wildlife Service. 1998. Net economic values for bass, trout, and walleye fishing, deer, elk, and moose hunting, and wildlife watching. [online] URL: http://wsfrprograms.fws.gov/Subpages/NationalSurvey/National_Survey.htm.

U.S. Fish and Wildlife Service. 2002. 50 state reports, 2001 national survey of fishing, hunting and wildlife-associated recreation. [online] URL: http://wsfrprograms.fws.gov/Subpages/NationalSurvey/National_Survey.htm.

U.S. Fish and Wildlife Service. 2003. Net economic values for wildlife-related recreation in 2001: Addendum to the 2001 national survey of fishing, hunting, and wildlife-associated recreation. [online] URL: http://wsfrprograms.fws.gov/Subpages/NationalSurvey/National_Survey.htm.

U.S. Office of Management and Budget. 1992. Circular A-94. Guidelines and discount rates for benefit-cost analysis of federal programs. [online] URL: http://www.whitehouse.gov/OMB/circulars/a094/aO94.html.

Walter, W. D., P. J. Perkins, A. T. Rutberg, and H. J. Kilpatrick. 2002. Evaluation of immunocontraception in a free-ranging suburban white-tailed deer herd. Wildlife Society Bulletin 30(1):186-192.

Ward, A. L. 1982. Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. Transportation Research Record 859:8-13.

Ward, K. M., and J. W. Duffield. 1992. Natural resource damages: law and economics. John Wiley & Sons, Inc., New York, USA.

Weitzman, M. L. 2001. Gamma discounting. American Economic Review 91(1):260-271.

Williams, A. F., and J. K. Wells. 2005. Characteristics of vehicle-animal crashes in which vehicle occupants are killed. Traffic Injury Prevention 6:56-59.

Woods, J. G. 1990. Effectiveness of fences and underpasses on the Trans-Canada highway and their impact on ungulate populations. Report to Banff National Park Warden Service, Banff, Alberta, Canada.

Zee, F. F. van der, J. Wiertz, C. J .F. ter Braak, R. C. van Apeldoorn, and J. Vink. 1992. Landscape change as a possible cause of the badger *Meles meles* L. decline in The Netherlands. Biological Conservation 61:17-22.

7. APPENDIX A: COST ESTIMATES FOR MITIGATION MEASURES

We estimated the cost of the mitigation measures listed in Table 1 based on a review of the literature and interviews with researchers, manufacturers, and transportation agency personnel (for more detailed review see Huijser et al. 2007a). The costs were calculated for a motorway (2 lanes in each direction) and standardized as costs per kilometer road length. Unless indicated otherwise, all cost estimates were expressed as US$ as reported in the cited work. For our analyses we converted all costs to 2007 $ using the U.S. Consumer Price Index (U.S. Department of Labor 2008).

Seasonal wildlife warning signs were estimated at $400 for a large sign, and $80 for two flashing lights (Sullivan et al. 2004). For these analyses we assumed that one sign and associated flashing lights is installed per km per travel direction. This brings the total costs to $960 per km ($1,053 in 2007 $). The projected life span of the signs and warning lights was set at 10 years.

The purchasing cost for an animal detection system was estimated at $65,000 per 1,609 m (1 mi) road length (both sides of the road) (Personal communication Lloyd Salsman, Sensor Technologies & Systems, December 2007). However, since roads often have curves and driveways or objects in the right-of-way, the distance between sensors may be shorter than the maximum range of their signal, potentially leading to cost increases. For these analyses we assumed the purchasing costs, including signs and power source or supply, were estimated at $75,000 per km road length (both sides of the road). The planning costs were estimated at $50,000 and the installation costs were estimated at $50,000 per km road length (all in 2007 $). Maintenance and operation costs were estimated at $14,800 per km per year ($10,000 for problem identification and problem solving, parts ($3,000), vegetation management ($1,500), and remote access to the system ($300) (all in 2007 $). The projected life span of the signs and warning lights was set at 10 years. System removal costs at the end of the life of the system were estimated at $10,000 per km (in 2007 $).

Vegetation removal alongside the road, consist of the removal of shrubs and trees to increase visibility for drivers and to reduce the attractiveness for certain species, e.g. moose. The costs were estimated at $500 per km per year ($530 in 2007 $) (Andreassen et al. 2005).

The cost estimates for population culling, relocation and infertility treatment are typically expressed as cost per animal. For the purpose of our cost-benefit analyses we had to translate these costs to costs per km road length. For our analyses we set the treatment area in a zone parallel to, and on both sides, of a road. The width of the zone for each side of the road was based on the diameter of the home range (75 ha) of white-tailed deer in a suburban environment, 978 m (home range size estimated at 43-50-86-144 ha by Kilpatrick and Spohr (2000), Beringer et al. (2002), and Grund et al. (2002)). For both sides of the road this results in a treatment area of 195.4 ha per km road length. Population densities of (suburban) white-tailed deer that are considered a problem have been estimated at 50-88-91 individuals per km^2 (Porter and

Underwood 1999, Kilpatrick et al. 2001). Assuming a population density of 70 individuals per km^2, there are 136.8 deer present in 195.4 ha. The cost for culling, relocation, and anti-fertility treatment was set at $110 ($132 in 2007 $), $450 ($540 in 2007 $), and $1,128 ($1,296 in 2007 $) per deer (females only), respectively. The estimate for killing a deer was based on estimates for the use of professional sharpshooters; $108-$121-$194 per deer for conservation officers, park rangers, and police officers, respectively (Doerr et al. 2001). Others estimated these costs at $91-$310 per deer (DeNicola et al. 2000). The estimate for relocating a deer was based on estimates by Beringer et al. (2002) ($387 per relocated deer) and De Nicola et al. (2000) ($431 or $400-$2,931 per deer). The estimate for giving a female deer an anti-fertility treatment was based on estimates by Walter et al. (2002) ($1,128 per treated deer) ($1,300 in 2007 $). Assuming that a population can only be reduced by 50% before the culling, relocation, or anti-fertility treatment efforts become much more labor intensive, the one time culling and relocation of 68.4 deer costs $9,029 and $36,936 (reduction of 68.4 deer) (in 2007 $). Suburban white-tailed deer populations can double their population size every 2-5 years, depending on the circumstances (DeNicola et al. 2000). Assuming a closed population (no immigration from adjacent areas) and a doubling of population size every 3 years, the culling and relocation effort would have to be repeated every 3 years. For the anti-fertility treatment, it was assumed that 80% of the females (80% of 68.4 female deer is 54.7 female deer, assuming an equal sex ratio), would have to be treated annually to stabilize or reduce the population density (DeNicola et al. 2000, Rudolph et al. 2000). This results in an annual cost for anti-fertility treatment of $71,110 (in 2007 $). Note that if the population is open to immigration from adjacent areas that the effectiveness for the culling, relocation, and anti-fertility treatment efforts will be much reduced or potentially eliminated. For these mitigation measures there were no estimates available for elk and moose. While the costs of these mitigation measures may be much higher per individual elk and moose, and while these mitigation measures may be less suitable or practical for elk or moose, we used the same costs estimates as for deer.

The costs for 2.4 m (8 ft) high wildlife fencing along US Highway 93 on the Flathead Reservation in Montana varied depending on the road section concerned: $26, $38, $41 per m in 2006 (material and installation combined) (Personal communication Pat Basting, Montana Department of Transportation). A finer mesh fence was dug into the soil and attached to the wildlife fence for some fence sections at an additional cost of $12 per m (Personal communication Pat Basting, Montana Department of Transportation). For the cost-benefit analyses the cost of wildlife fencing, including a dig barrier, was set at $47 per m ($48 in 2007 $). For both sides of a road this translates into $96,000 per km road length (in 2007 $). The projected life span of a wildlife fence was set at 25 years. Fences require maintenance, for example as a result of fallen trees, vehicles that have run off the road and into the fence, and animals that may have succeeded digging under the fence (Clevenger et al. 2002). Maintenance costs were set at $500 per km per year and fence removal costs were set at $10,000 per km road length (all in 2007 $).

Animals are more likely to break through the wildlife fencing if safe crossing opportunities are not provided or if they are too few, too small, or too far apart. Certain species may also require safe crossing opportunities to maintain viable populations in an area (e.g. Jaeger and Fahrig 2004). Even if safe crossing opportunities have been provided for, animals may still end up in between the fences, caught in the transportation corridor, and these animals may pose a safety risk and expose the species concerned to road mortality after all. Animals may end up in between the fences around fence ends, by digging under the fence, through gaps in the fence, or they may be able to climb the fence. Therefore it is considered good practice to accompany absolute barriers, such as wildlife fencing, with safe crossing opportunities and escape opportunities for animals that end up in between the fences. Safe crossing opportunities and escape opportunities were not included in the cost estimates for wildlife fencing (see previous paragraph), but they are included in the mitigation measures discussed in the next paragraphs. The safe crossing opportunities and escape opportunities focus on serving large animals (deer size and larger). For our cost benefit analyses we set the number of safe crossing opportunities at one per 2 km (0.5 crossing opportunity per km) (0.3 per mi). This number is based on the actual number of crossing structures found at three long road sections (two lanes in each travel direction) that have wildlife fencing and crossing structures for large animals: 24 crossing structures over 64 km (0.38 structures per km) (Foster and Humphrey 1995); 24 crossing structures over 45 km (0.53 structures per km) (Clevenger et al. 2002); and (17 crossing structures over 31 km (0.56 structures per km) (Dodd et al. 2007). Note that this number is not based on what may be required to maintain viable wildlife populations in a landscape bisected by roads.

For our cost-benefit analyses we used jump-outs or escape ramps as escape opportunities for large animals. The reported costs for one jump-out are $11,000 ($13,200 in 2007 $) (Bissonette and Hammer 2000) and $6,250 (2006) ($6,425 in 2007 $) (Personal communication Pat Basting, Montana Department of Transportation). We set the costs for a jump-out at $9,813 (in 2007 $) with a projected life span of 75 years.

Wildlife fencing in combination with gaps in the fence and crosswalks painted on the road at such gaps was studies by Lehnert and Bissonette (1997). The cost for a wildlife crosswalk across a four lane road (excluding wildlife fencing and escape from right-of-way measures) was $28,000 ($36,075 in 2007 $) ($18,037 per km) (Lehnert and Bissonette 1997). The projected life span of a crosswalk was set at 10 years. The costs for warning signs (76 cm x 76 cm), one for each travel direction, were set at $62 per sign with a projected life span of seven years (USA Traffic Signs 2007). For this analyses we included 2 signs per gap (one for each travel direction), resulting in one sign per km. The width of the gap in the fence was set at 100 m (328 ft). However, the length of the fence was not reduced because of the gap as the fence may be angled towards the road to help direct animal movements. The cost for wildlife fencing was set at $96,000 per km (see earlier section on wildlife fencing). Fence maintenance costs were set at $500 per km per year, and fence removal costs was set at $10,000 per km road length. In addition to the gap in the fence a jump-out was provided every 317 m (1,040 ft) (5 per 2 km per roadside; 5 per km; $49,065 per km).

The cost for purchasing one section of a break-the-beam animal detection system was set at $8,500 (Personal communication Lloyd Salsman, Sensor Technologies & Systems, December 2007). A gap requires a beam at each side of the road ($17,000), but the costs for the second beam may be lower as there is only one control station required. The purchasing costs, including signs and power source or supply, were set at $13,500 per km (in 2007 $). The planning costs were estimated at $25,000 and the installation costs were estimated at $25,000 per km road length (all in 2007 $). Maintenance and operation costs were estimated at $11,800 per km per year ($10,000 for problem identification and problem solving, parts ($1,000), vegetation management ($500), and remote access to the system ($300). The projected life span of the signs and warning lights was set at 10 years. System removal costs were estimated at $5,000 per km. The width of the gap in the fence with the animal detection system was set at 100 m (328 ft). However, the length of the fence was not reduced because of the gap as the fence may be angled towards the road to help direct animal movements. The cost for wildlife fencing was set at $96,000 per km (see earlier section on wildlife fencing). Fence maintenance costs were set at $500 per km per year, and fence removal costs was set at $10,000 per km road length. In addition to the gap in the fence a jump-out was provided every 317 m (1,040 ft) (5 per 2 km per roadside; 5 per km; $49,065 per km).

For the purposes of our cost-benefit analyses for wildlife fencing in combination with wildlife underpasses, we provided a wildlife underpass every 2 km (1.2 mi). The cost for an underpass was set at $500,000 (materials and construction). The cost for an underpass (elliptical culvert, about 7 m wide, 4-5 m high) was based on the $650,000 paid for three large wildlife underpasses (about 7 m wide, 5 m high) under US Hwy 93 (two lanes) on the Flathead Reservation in Montana in 2006 ($668,200 in 2007 $) (Personal communication Pat Basting, Montana Department of Transportation); the Can$225,000-Can$250,000 (exchange rate 1.36 Can$ for 1 $ in 1996; $218,731-$243,034 in 2007 $) for an underpass (7 m wide, 4 m wide) under the Trans Canada Highway (four lanes) in Banff National Park in 1996 (Personal communication Anthony P. Clevenger, Western Transportation Institute); the $Can5,400 per m (road width) (exchange rate 1.36 Can$ for 1 $ in 1996; $5,428 per m in 2007 $) for elliptical culverts (7 m wide, 4 m high) under the Trans Canada Highway in 1996 (Personal communication Terry McGuire, Parks Canada, unpublished data); and the €30,000-€50,000 per m (road width) (exchange rate 0.80 € for 1 $ in 2004; $41,136-$68,560 per m in 2007 $) for large underpasses (7-10 m wide) in 2004 in The Netherlands (Kruidering et al. 2005). The planning costs were estimated at $50,000 per structure ($25,000 per km) (in 2007 $). Maintenance and operation costs were estimated at $2,000 per structure per year ($1,000 per km per year) (in 2007 $). The projected life span of an underpass was set at 75 years. Structure removal costs were estimated at $30,000 per structure ($15,000) per km) (in 2007$). The length of the fence was not reduced because of the gap as a result of the crossing structure, as the fence is angled towards the road and ties in with the crossing structure. The cost for wildlife fencing was set at $96,000 per km (see earlier section on wildlife fencing). Fence maintenance costs were set at $500 per km per year, and fence removal costs was set at $10,000 per km road length (in 2007 $). The number of escape ramps between crossing structures was set at 7 per roadside per 2 km (2 immediately next to a crossing structure (50 m on either side from the center of the structure), and an additional five escape ramps with 317 m (1,040 ft) intervals (7 per km; $68,691 per km). The escape ramps on either side of a crossing structure are required because of the continuous nature of the wildlife fencing and the assumption that animals will want to cross the road most often at the location of the crossing structures, as that should be one of the most important criteria for the placement of these crossing structures.

For the purposes of our cost-benefit analyses for wildlife fencing in combination with wildlife underpasses and overpasses, we provided a wildlife underpass every 2 km, but every 12th underpass (once every 24 km) was replaced with an overpass. This resulted in 0.46 underpasses and 0.04 overpasses per km (0.29 and 0.02 per mi). The frequency for wildlife overpasses is based on the actual number of overpasses on a long road section (two lanes in each travel direction) that has wildlife fencing and crossing structures for large animals: 2 overpasses over 45 km (1 every 22.5 km) (Clevenger et al. 2002). For the costs of an underpass, see the previous paragraph. The cost for an overpass was set at $5,000,000 in 2007 $ (materials and construction). The cost for an overpass (about 50 m wide) was based on the Can$1,750,000 for an overpass (52 m wide) over the Trans Canada Highway (four lanes) in Banff National Park in 1996 (Personal communication Anthony P. Clevenger, Western Transportation Institute) (exchange rate 1.36 Can$ for 1 $ in 1996; $1,701,242 in 2007 $); the €3,200,000 for an overpass (48 m wide) across the four lane motorway A28 (Leusderheide) in The Netherlands in 2004 (exchange rate 0.80 € for 1 $ in 2004; $4,387,866 in 2007 $) (Kruidering et al. 2005). However, depending on the length (road width) and width of an overpass (15-50 m), and depending on the nature of the terrain, the costs for eight wildlife overpasses in The Netherlands ranged between €1,400.000 and €9,100,000 (exchange rate 0.80 € for 1 $ in 2004; $1,919,691-$12,477,993 in 2007 $) (Kruidering et al. 2005; Brabants Dagblad 2004). The planning costs were estimated at $50,000 per structure ($25,000 per km) (in 2007 $). Maintenance and operation costs were estimated at $2,000 per structure per year ($1000 per km per year) (in 2007 $). The projected life span of an overpass was set at 75 years. Structure removal costs were estimated at $350,000 for an overpass ($14,000 per km) and $30,000 for an underpass (13,800 per km) (in 2007 $). Fencing and escape ramp configuration and costs were identical to the previous paragraph.

The costs for an elevated roadway and road tunnel were set at $60,000,000 and $115,000,000 per km respectively (in 2007 $). These estimates are based on a 200 m long elevated road way that cost Can$12,500,000 (1.06 Can$ for 1 $ in 2007; $11,792,453 in 2007 $) and a 200 m long road tunnel that was constructed for Can$24,000,000 (1.06 Can$ for 1 $ in 2007; $22,641,509 in 2007 $) in 2007 (Personal communication Anthony P. Clevenger, Western Transportation Institute – Montana State University). The planning costs were estimated at $1,000,000 per km (in 2007 $). Maintenance and operation costs were estimated at $1,000,000 per km per year (in 2007 $). The projected life span of an elevated roadway and road tunnel was set at 75 years. Structure removal costs were estimated at $6,000,000 (elevated roadway) and $11,500,000 (road tunnel) per km.

8. APPENDIX B: COST ESTIMATES FOR DEER-, ELK-, AND MOOSE-VEHICLE COLLISIONS

We estimated the cost of the average collision with a deer, elk, or moose (Table 2) based on a review of the literature. Unless indicated otherwise, all cost estimates were expressed as US$ as reported in the cited work. For our analyses we converted all costs to 2007 $ using the U.S. Consumer Price Index (U.S. Department of Labor 2008). The components included in our cost estimate were vehicle repair costs, costs associated with human injuries and fatalities (see also e.g. Bissonette et al. 2008), towing, accident attendance and investigation, the monetary value to hunters of the animal that was killed in the collision, and the cost of disposal of the animal carcass. Passive use costs were not included in our cost estimate.

Vehicle repair costs

In Nova Scotia, the percentage of collisions involving white-tailed deer which resulted in property damage was estimated at 90.2% – 3,524 collisions with property damage out of 3,905 collisions (Tardif & Associates Inc. 2003). In Utah this percentage was estimated at 94% (Romin and Bissonette 1996). There were no similar data available for elk and moose. For these analyses the percentage of collisions resulting in property damage was assumed to be 92% for collisions with deer and 100% for collisions with elk or moose. Current data from a major auto insurance company in the United States showed that in 2006-2007 the average vehicle repair costs were about $2,900 for all species combined (Personal communication Dick Luedke, State Farm Insurance). The species specific costs were $2,850 for deer (n = ±178,500), $4,550 for elk (n = ± 900), and $5,600 (moose; n = ±550) in 2006-2007 (Personal communication Dick Luedke, State Farm Insurance). Combined with the percentage of chance that a collision results in property damage, the average vehicle repair costs per collision were estimated at $2,622 (deer), $4,550 (elk), and $5,600 (moose) (all in 2007 $).

Human injures

The percentage of white-tailed deer-vehicle collisions resulting in human injuries was estimated at 2.8% in Michigan (12 injuries from 60,875 collisions) (SEMCOG 2007), 3.8% in the US Midwest (4,724 injuries from 125,608 collisions) (Knapp et al. 2004); 4% in Ohio (review in Schwabe et al. 2002), 4% (review in Conover et al. 1995), 7.7% in Ohio (10,983 injuries from 143,016 collisions) (Schwabe et al. 2002); and 9.7% in Nova Scotia (378 injuries from 3,905 collisions) (Tardif & Associates Inc. 2003). Similar data could not be retrieved for elk. The percentage of moose-vehicle collisions resulting in human injuries was estimated at 18% in Newfoundland and Labrador (Government of Newfoundland and Labrador 1997); 21.8% in Newfoundland (363 injuries from 1,662 collisions) (Tardif & Associates Inc. 2003); 20% in rural Alaska (Thomas 1995); 23% in Maine (Huijser et al. 2007a); and, 23% in Anchorage, Alaska (158 injuries from 519 collisions) (Garrett and Conway 1999). The ratio of moose-vehicle collisions to human injuries was estimated at 1:0.201 in Newfoundland (Rattey and Turner 1991) and 1:0.304 in Anchorage, Alaska (Garrett and Conway 1999). The ratios are higher than the percentages because more than one person may be present in a car, and multiple people may be injured as a result of one collision. Based on the data presented above, it was assumed that an animal-vehicle collision resulted in an average of 0.05 human injuries for deer, 0.10 for elk, and 0.20 for moose. When these proportions are combined with the relative frequency for each of the three injury categories distinguished in the General Estimates System for animal-vehicle collisions, (51.4% for possible human injuries, 38.4% for evident human injuries, and 10.3 % for incapacitating or severe human injuries (Huijser et al. 2007a)) and the standard costs associated with each injury category, ($24,418 for possible human injuries, $46,266 for evident human injuries, and $231,332 for incapacitating or severe human injuries (Huijser et al. 2007a)), it results in species specific cost estimates for human injuries (Table 6). The average costs of human injuries per collision are $2,702 for deer, $5,403 for elk, and $10,807 for moose (all in 2007 $).

Table 6: Estimated costs (in 2007 $) per type of human injury for the average deer-, elk-, and moose-vehicle collision.

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

Human fatalities

The percentage of white-tailed deer-vehicle collisions resulting in human fatalities was estimated at 0.009% in Ohio (14 collisions with human fatalities from 143,016 collisions) (Schwabe et al. 2002); 0.020% (12 fatalities from 60,875 collisions) (SEMCOG 2007); 0.029% in North America (review in Schwabe et al. 2002); 0.03% in the US Midwest (33 collisions with human fatalities from 125,608 collisions) (Knapp et al. 2004); and 0.05% in Nova Scotia (2 collisions with human fatalities from 3,905 collisions) (Tardif & Associates Inc. 2003). Similar data could not be retrieved for elk. The percentage of moose-vehicle collisions resulting in human fatalities was estimated at 0% in Anchorage, Alaska (0 fatalities from 519 collisions) (Garrett and Conway 1999); 0.26% in Newfoundland (14 fatalities from 5,422 collisions) (Joyce and Mahoney 2001), 0.36% in Newfoundland (6 collisions with human fatalities from 1662 collisions) (Tardif & Associates Inc. 2003), 0.45% in Newfoundland (3 fatalities from 661 collisions) (Rattey and Turner 1991); 0.43% in Maine (Huijser et al. 2007a); and 0.50% in rural Alaska (Thomas 1995). Based on the data presented above, it was assumed that an animal-vehicle collision resulted in an average of 0.0003 (deer), 0.0020 (elk), and 0.0040 (moose) human fatalities. When these proportions are combined with the costs associated with a human fatality ($3,341,468 (Huijser et al. 2007a)), it results in a cost estimate for human fatalities of $1,002 (deer), $6,683 (elk), and $13,366 (moose) for each collision (all in 2007 $).

Towing, accident attendance and investigation

Not all wildlife-vehicle collisions require the towing of a vehicle, and attendance or investigation by medical personnel, fire department personnel, or police. When they do, the cost for these efforts was estimated to vary between Can$100 and Can$550 (Clayton Resources Ltd. & Glen Smith Wildlife Consultants 1989). Note that the cost for the actual medical assistance is included in the cost estimates for human injuries calculated earlier. Based on the data presented above, it was assumed that the cost of towing, and accident attendance or investigation is $500, but these services are only required or provided in 25% (deer), 75% (elk) and 100% (moose) of the collisions. These assumptions result in an average cost for towing, accident attendance and investigation of $125 (deer), $375 (elk), and $500 (moose) for each collision (all in 2007 $).

Monetary value of animals

The monetary value of animals can include benefits associated with hunting or viewing the animal or with the passive use values for the existence of the given animal. Passive use values are likely to be location and population specific, and the literature on wildlife viewing values is not extensive. Therefore we only included hunting-related values in our analyses. These values are measured by what the hunter would be willing to pay over and above the costs of the hunt, for example to access a hunting area. For the U.S. and Canada access for hunting on most private and public lands is free. However, what the maximum amount the hunter would be willing to pay for access if necessary is a measure of the net benefit or hunter "willingness-to-pay" for the hunt (Ward and Duffield 1992).

These net benefits are also referred to as “consumer surplus”. For the application to collisions, the foregone expected value related to hunting would be the hunting value per animal times the probability that it would have been harvested. The hunting value per animal can be derived from the hunter willingness to pay for a season of hunting divided by the success rate per hunt. There is an extensive literature on net economic values for hunting, usually based on travel cost or contingent valuation methods (for example, see Ward and Duffield 1992), but most of these are location (e.g. hunt district or perhaps state) specific. The most comprehensive hunting value estimates have been developed by the U.S. Fish and Wildlife Service in their periodic national fishing and hunting surveys. The most recent values available for hunter willingness to pay for a season of hunting are for 2001 (U.S. Fish and Wildlife Service 2003), and in 2001 dollars averaged $377 for deer, $579 for moose (just Alaska) and for elk hunting (CO, ID, MT, OR, WY) were $380 for resident hunters and $556 for nonresident hunters or a weighted average (based on the number of resident and nonresident big game hunters for these states (U.S. Fish and Wildlife Service 2002)) of $424. Corrected to 2007 price levels, these values are $441 for deer, $496 for elk, and $678 for moose. Success rates for these species are not reported in each survey year, but were estimated by U.S. Fish and Wildlife Service (1998) for 1996 at 0.61 for deer, 0.20 for elk, and 0.14 for moose. This implies the value of a successful hunting season for these species, respectively, as $723, $2,480, and $4,843. Crête and Daigle (1999) provide estimates of 1995-1996 hunting harvest as a share of pre-harvest populations for these species in North America as 0.16 for deer (whitetail and mule deer combined) and elk, and 0.08 for moose. Given this probability that a given animal will be harvested by a hunter, the implied foregone hunting value associated with the average collision is $116 for deer, $397 for elk, and $387 for moose (Table 2).

Removal and disposal costs of deer carcasses

In Canada, the clean-up, removal and disposal costs for animal carcasses were estimated at Can$100 for deer and Can$350 for moose (Sielecki 2004). In Pennsylvania, the average for deer carcass removal and disposal in a certified facility was $30.50 per deer for contractors and $52.46 per deer for the Pennsylvania Department of Transportation in 2003-2004 (Personal communication Jon Fleming, Pennsylvania Department of Transportation). Based on the data presented above, it was assumed that the removal and disposal costs of animal carcasses were $50 (deer), $75 (elk) and $100 (moose) (all in 2007 $).