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Cost Justification and Examples of Cost-Benefit Analyses of Mitigation Measures Aimed at Reducing Collisions with Large Ungulates in the United States and Canada

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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- ($6,617), elk- ($17,483) and moose-vehicle collision ($30,760), 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. For example, we calculated that wildlife exclusion fencing in combination with large mammal underpasses (one every 2 km) and wildlife jump-outs generates economic benefits if the pre-mitigation collisions are greater than 3.2 deer, 1.2 elk, or 0.7 moose per km per year (all at 3% discount rate). 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. While the analyses can be expanded to include other parameters (e.g. the economic value of habitat connectivity or viable wildlife populations), 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.

Introduction

Wildlife-vehicle collisions affect human safety, property and wildlife. 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. 2007). These numbers have increased even further over the last decade (Tardif & Associates Inc. 2003, Huijser et al. 2007). In the United States, these collisions were estimated to cause 211 human fatalities, 29,000 human injuries and over one billion US dollars in property damage annually (Conover et al. 1995). In most cases the animals die immediately or shortly after the collision (Allen and McCullough 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, Huijser et al. 2007; van der Grift et al. 2008). In addition, some species also represent a monetary value that is lost once an individual animal dies (Romin and Bissonette 1996, Conover 1997).

Over 40 types of mitigation measures aimed at reducing collisions with large ungulates have been described (see reviews in Knapp et al. 2004, Huijser et al. 2007). 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. 2006). 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), and while this may seem surprising, wildlife-vehicle collisions, at least until recently, are not always included in safety analyses by transportation agencies, let alone in cost-benefit analyses (Knapp and Witte 2006).

In this paper we provide a justification for the monetary costs and benefits of a range of mitigation measures aimed at reducing collisions with the most commonly reported large ungulates in the United States and Canada: deer (white-tailed deer (*Odocoileus virginianus*) and mule deer (*O. hemionus*) combined), elk (*Cervus elaphus*), and moose (*Alces alces*) (Huijser et al. accepted). We realize that the results of the associated cost-benefit analyses are directly dependent on the parameters included in the analyses and the assumptions and estimates required to conduct the analyses. For example, our cost-benefit analyses do not include passive use costs. However, we do evaluate each mitigation measure with regard to potential safe crossing opportunities for wildlife. Connectivity across roads for wildlife is also in the interest of human safety as animals are more likely to break through a barrier (e.g. wildlife fencing) if safe crossing opportunities are not provided or if they are too few, too small, or too far apart. Even if wildlife fencing is combined with safe crossing opportunities for wildlife, animals may still end up in between the fences, caught in the transportation corridor, and these animals pose a risk to human safety. For these reasons, it is considered good practice to accompany absolute barriers with safe crossing opportunities for wildlife and escape opportunities for animals that end up in between the barriers (e.g. wildlife jump-outs). For this paper we addressed the importance of safe crossing opportunities for wildlife by reviewing the individual mitigation measures for their potential barrier effect on the movements of large ungulates and including jump-outs with wildlife fencing.

The results of the cost-benefit analyses allow for much needed direction for transportation agencies and natural resource management agencies in the implementation and further research and development of mitigation measures aimed at reducing collisions with large ungulates.

Cost Benefit Analyses

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. 2007). Based on the available data, 13 of these measures were considered effective in reducing collisions with large animals (effectiveness >0%) (see section "Effectiveness and Costs of Mitigation Measures"). In addition, we estimated the costs (in 2007 US$) of these mitigation measures per year over a 75-year period (see section "Effectiveness and Costs of Mitigation Measures"). 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 more details on methods see Huijser et al. (accepted).

Effectiveness and Costs of Mitigation Measures

We estimated the effectiveness of 13 types of mitigation measures for reducing collisions with large ungulates such as deer, elk and moose, and whether these mitigation measures still allow animals to cross the road (Table 1). Mitigation measures considered ineffective (effectiveness estimated at 0% (Huijser et al. 2007)), lacking effectiveness data, or having insufficient data were excluded from the cost-benefit analyses in this paper. If more than one estimate was available for the effectiveness of each of the 13 mitigation measures reviewed, 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. Of the 13 measures listed, only wildlife fencing is an absolute barrier for large ungulates (Table 1).

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 may only be suited for very specific circumstances.

The estimated costs for each of the mitigation measures over a 75-year period vary greatly (Table 1). The following paragraphs provide a rationale for the estimated costs of the individual mitigation measures. The costs of the mitigation measures 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).

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. 2007). The costs were 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 US$ using the U.S. Consumer Price Index (U.S. Department of Labor 2008).

Mitigation measure	Effect-iveness	Crossing opportunity?	Source	Present value costs (US$)
Seasonal wildlife warning sign	26%	Yes	Sullivan et al. (2004): 51%; Rogers (2004): 0%	$3,728
Vegetation removal	38%	Yes	Jaren et al. (1991): 56%; Lavsund and Sandegren (1991): 20%	$16,272
Fence, gap, crosswalk	40%	Yes	Lehnert and Bissonette (1997): 42%, 37%	$300,468
Population culling	50%	Yes	Review in Huijser et al. 2007	$94,809
Relocation	50%	Yes	Review in Huijser et al. 2007	$391,870
Anti-fertility treatment	50%	Yes	Review in Huijser et al. 2007	$2,183,207
Fence (incl. dig barrier)	86%	No	Reed et al. (1982) 79%; Ward (1982): 90% Woods (1990): 94-97%; Clevenger et al. (2001): 80%; Dodd et al. (2007): 87%	$187,246
Fence, underpass, jump-out	86%	Yes	Reed et al. (1982) 79%; Ward (1982): 90% Woods (1990): 94-97%; Clevenger et al. (2001): 80%; Dodd et al. (2007): 87%	$538,273
Fence, under- and overpass, jump-out	86%	Yes	Reed et al. (1982) 79%; Ward (1982): 90% Woods (1990): 94-97%; Clevenger et al. (2001): 80%; Dodd et al. (2007): 87%	$719,667
Animal detection system (ADS)	87%	Yes	Mosler-Berger and Romer (2003): 82%; Dodd and Gagnon (2008): 91%	$1,099,370
Fence, gap, ADS	87%	Yes	Mosler-Berger and Romer (2003): 82%; Dodd and Gagnon (2008): 91%	$836,113
Elevated roadway	100%	Yes	Review in Huijser et al. 2007	$92,355,498
Road tunnel	100%	Yes	Review in Huijser et al. 2007	$147,954,696

Table 1. The estimated effectiveness, present value costs (in 2007 US$, 3% discount rate) 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.

Seasonal wildlife warning sign

Seasonal wildlife warning signs were estimated at US$400 for a large sign, and US$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 US$960 per km (US$1,053 in 2007 US$). The projected life span of the signs and warning lights was set at 10 years.

Vegetation removal

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 US$500 per km per year (US$530 in 2007 US$) (Andreassen et al. 2005).

Population culling, relocation and infertility treatment

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 US$110 (US$132 in 2007 US$), US$450 (US$540 in 2007 US$), and US$1,128 (US$1,296 in 2007 US$) per deer (females only), respectively. The estimate for killing a deer was based on estimates for the use of professional sharpshooters; US$108-US$121-US$194 per deer for conservation officers, park rangers, and police officers, respectively (Doerr et al. 2001). Others estimated these costs at US$91-US$310 per deer (DeNicola et al. 2000). The estimate for relocating a deer was based on estimates by Beringer et al. (2002) (US$387 per relocated deer) and De Nicola et al. (2000) (US$431 or US$400-US$2,931 per deer). The estimate for giving a female deer an anti-fertility treatment was based on estimates by Walter et al. (2002) (US$1,128 per treated deer) (US$1,300 in 2007 US$). 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 US$9,029 and US$36,936 respectively (reduction of 68.4 deer) (in 2007 US$). 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 US$71,110 (in 2007 US$). For these mitigation measures there were no estimates available for elk and moose, and we used the same costs estimates for all three species.

Animal detection system

The purchasing cost for an animal detection system was estimated at US$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 US$75,000 per km road length (both sides of the road). The planning costs were estimated at US$50,000 and the installation costs were estimated at US$50,000 per km road length (all in 2007 US$). Maintenance and operation costs were estimated at US$14,800 per km per year (US$10,000 for problem identification and problem solving, parts (US$3,000), vegetation management (US$1,500), and remote access to the system (US$300) (all in 2007 US$). 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 US$10,000 per km (in 2007 US$).

Wildlife fencing

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: US$26, US$38, US$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 US$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 US$47 per m (US$48 in 2007 US$). For both sides of a road this translates into US$96,000 per km road length (in 2007 US$). 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 US$500 per km per year and fence removal costs were set at US$10,000 per km road length (all in 2007 US$).

Safe crossing opportunities

Safe crossing opportunities and escape opportunities were not included in the cost estimates for wildlife fencing, 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.

Jump-outs

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 US$11,000 (US$13,200 in 2007 US$) (Bissonette and Hammer 2000) and US$6,250 (2006) (US$6,425 in 2007 US$) (Personal communication Pat Basting, Montana Department of Transportation). We set the costs for a jump-out at US$9,813 (in 2007 US$) with a projected life span of 75 years.

Wildlife fencing in combination with gaps in the fence and crosswalks

Wildlife fencing in combination with gaps in the fence and crosswalks painted on the road at such gaps was studied 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 US$28,000 (US$36,075 in 2007 US$) (US$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 US$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 US$96,000 per km (see section on wildlife fencing). Fence maintenance costs were set at US$500 per km per year, and fence removal costs was set at US$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; US$49,065 per km).

Wildlife fencing in combination with gaps in the fence and animal detection systems

The cost for purchasing one section of a break-the-beam animal detection system was set at US$8,500 (Personal communication Lloyd Salsman, Sensor Technologies & Systems, December 2007). A gap requires a beam at each side of the road (US$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 US$13,500 per km (in 2007 US$). The planning costs were estimated at US$25,000 and the installation costs were estimated at US$25,000 per km road length (all in 2007 US$). Maintenance and operation costs were estimated at US$11,800 per km per year (US$10,000 for problem identification and problem solving, parts (US$1,000), vegetation management (US$500), and remote access to the system (US$300). The projected life span of the signs and warning lights was set at 10 years. System removal costs were estimated at US$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 US$96,000 per km (see earlier section on wildlife fencing). Fence maintenance costs were set at US$500 per km per year, and fence removal costs was set at US$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; US$49,065 per km).

Wildlife fencing in combination with wildlife underpasses

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 US$500,000 (materials and construction). The cost for an underpass (elliptical culvert, about 7 m wide, 4-5 m high) was based on the US$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 (US$668,200 in 2007 US$) (Personal communication Pat Basting, Montana

Department of Transportation); the CanUS$225,000-CanUS$250,000 (exchange rate 1.36 CanUS$ for 1 US$ in 1996; US$218,731-US$243,034 in 2007 US$) 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 US$Can5,400 per m (road width) (exchange rate 1.36 CanUS$ for 1 US$ in 1996; US$5,428 per m in 2007 US$) 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 US$ in 2004; US$41,136-US$68,560 per m in 2007 US$) for large underpasses (7-10 m wide) in 2004 in The Netherlands (Kruidering et al. 2005). The planning costs were estimated at US$50,000 per structure (US$25,000 per km) (in 2007 US$). Maintenance and operation costs were estimated at US$2,000 per structure per year (US$1,000 per km per year) (in 2007 US$). The projected life span of an underpass was set at 75 years. Structure removal costs were estimated at US$30,000 per structure (US$15,000) per km) (in 2007US$). 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 US$96,000 per km (see earlier section on wildlife fencing). Fence maintenance costs were set at US$500 per km per year, and fence removal costs was set at US$10,000 per km road length (in 2007 US$). 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; US$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.

Wildlife fencing in combination with wildlife underpasses and overpasses

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 US$5,000,000 in 2007 US$ (materials and construction). The cost for an overpass (about 50 m wide) was based on the CanUS$1,750,000 for an overpass (52 m wide) over the Trans Canada Highway (four lanes) in Banff National Park in 1996 (Personal communication Anthony P. Clevenger, Western Transportation Institute) (exchange rate 1.36 CanUS$ for 1 US$ in 1996; US$1,701,242 in 2007 US$); 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 US$ in 2004; US$4,387,866 in 2007 US$) (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 US$ in 2004; US$1,919,691-US$12,477,993 in 2007 US$) (Kruidering et al. 2005; Brabants Dagblad 2004). The planning costs were estimated at US$50,000 per structure (US$25,000 per km) (in 2007 US$). Maintenance and operation costs were estimated at US$2,000 per structure per year (US$1000 per km per year) (in 2007 US$). The projected life span of an overpass was set at 75 years. Structure removal costs were estimated at US$350,000 for an overpass (US$14,000 per km) and US$30,000 for an underpass (13,800 per km) (in 2007 US$). Fencing and escape ramp configuration and costs were identical to the previous paragraph.

Elevated roadway, road tunnel

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

Cost Estimates for Deer-, Elk-, and Moose-Vehicle Collisions

The total estimated costs for the average deer-, elk-, and moose-vehicle collision is summarized in Table 2. Since we calculated the costs for an average collision, the costs of collisions that result in human injuries or fatalities, in addition to property damage, are higher than this average. 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. 2007), 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 Huijser et al. accepted), the total estimated annual costs associated with ungulate-vehicle collisions is estimated at US$6,247,759,000- US$12,495,518,000. In Canada, with an estimated 45,000 large mammal-vehicle collisions, the estimated annual costs are US$281,149,155 (Tardif & Associates Inc. 2003).

Description	**Deer (US$)**	**Elk (US$)**	**Moose (US$)**
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**

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

The following sections provide a rationale for the cost estimates shown in Table 2. 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 US$. The components included in our cost estimate were vehicle repair costs, costs associated with human injuries and fatalities, 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 US$2,900 for all species combined (Personal communication Dick Luedke, State Farm Insurance). The species specific costs were US$2,850 for deer (n = ±178,500), US$4,550 for elk (n = ± 900), and US$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 US$2,622 (deer), US$4,550 (elk), and US$5,600 (moose) (all in 2007 US$).

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. 2007); 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. 2007)) and the standard costs associated with each injury category, (US$24,418 for possible human injuries, US$46,266 for evident human injuries, and US$231,332 for incapacitating or severe human injuries (U.S. Department of Transportation 1994, Huijser et al. 2007)), it results in species specific cost estimates for human injuries (Table 3).

Type of human injury	Deer (US$)	Elk (US$)	Moose (US$)
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**

Table 3. Estimated costs (in 2007 US$) per type of human injury for the average deer-, elk-, and moose-vehicle collision.

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. 2007); 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 (US$3,341,468 (U.S. Department of Transportation 1994, Huijser et al. 2007)), it results in a cost estimate for human fatalities of US$1,002 (deer), US$6,683 (elk), and US$13,366 (moose) for each collision (all in 2007 US$).

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 US$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 US$125 (deer), US$375 (elk), and US$500 (moose) for each collision (all in 2007 US$).

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 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 US$377 for deer, US$579 for moose (just Alaska) and for elk hunting (CO, ID, MT, OR, WY) were US$380 for resident hunters and US$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 US$424. Corrected to 2007 price levels, these values are US$441 for deer, US$496 for elk, and US$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 US$723, US$2,480, and US$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 US$116 for deer, US$397 for elk, and US$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 US$30.50 per deer for contractors and US$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 US$50 (deer), US$75 (elk) and US$100 (moose) (all in 2007 US$).

Threshold Values

Huijser et al. (accepted) show the results of cost-benefit analyses over a 75-year period using discount rates of 1%, 3% and 7% and identifies 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, it was calculated that wildlife exclusion fencing in combination with large mammal underpasses (one every 2 km) and wildlife jump-outs generates economic benefits if the pre-mitigation collisions are greater than 3.2 deer, 1.2 elk, or 0.7 moose per km per year (all at 3% discount rate).

Real World Example

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 (see Huijser et al. accepted). The costs associated with deer-, elk-, and moose-vehicle collisions for ten road sections in the United States and Canada varied between US$3,636 and US$46,155 per kilometer per year (Huijser et al. accepted). While these numbers may not seem high in relation to the costs per kilometer per year for many of the mitigation measures (Table 1), it is important to realize that the costs associated with collisions on the ten road sections are averaged out over relatively long road sections and that specific locations on a road section can still exceed thresholds. To illustrate this concept we conducted a more detailed cost analyses for one of these road sections (Figure 1). For example, the benefits of animal detection systems as a stand-alone mitigation measure exceed the costs on 3.9% of an 8.2 km (5.1 mi) long road section on I-90 west of Missoula, MT (Ninemile area). Similarly, this percentage is 25.5% for wildlife fencing with gaps and animal detection systems in these gaps, and jump-outs; 27.5% for wildlife fencing with under- and overpasses, and jump-outs; and 56.9% for wildlife fencing with underpasses, and jump-outs (Figure 1).

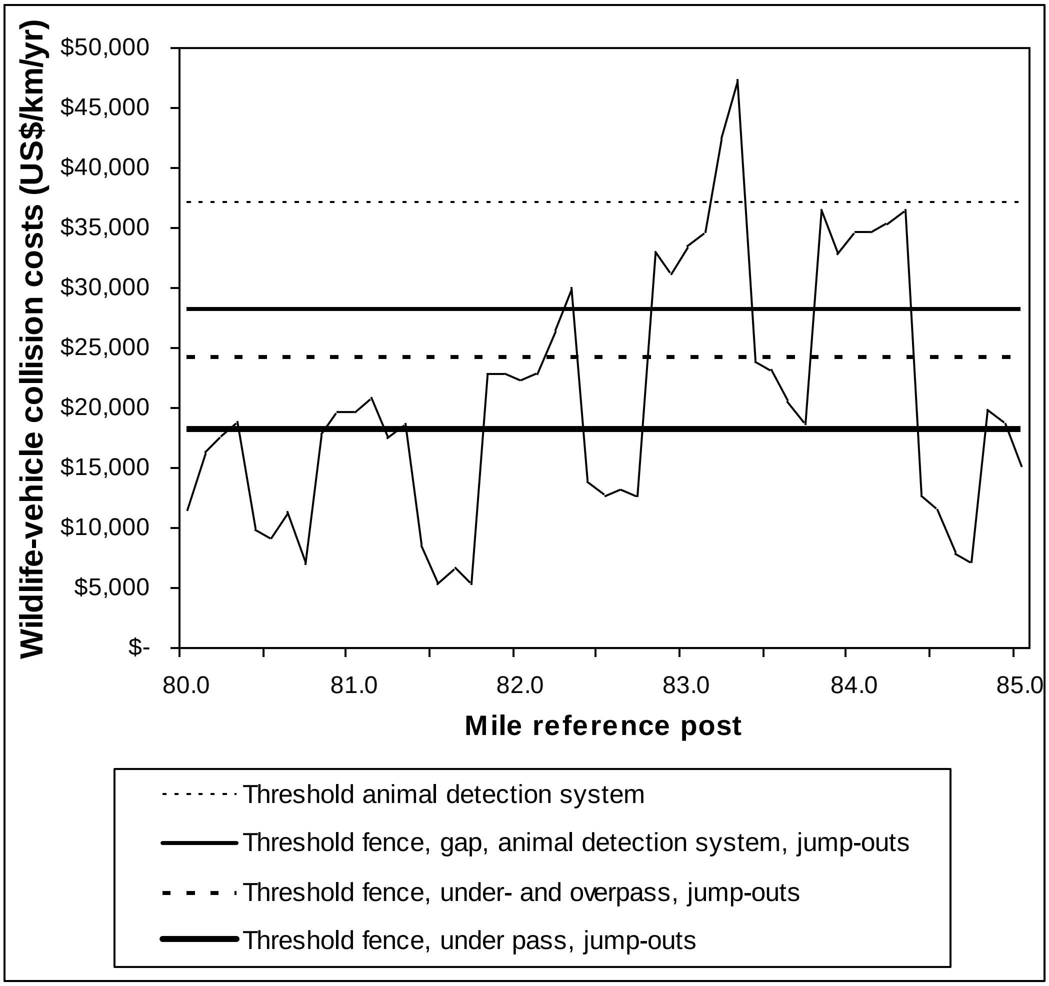

Figure 1. I-90 Ninemile area, west of Missoula, MT, USA. The costs (in 2007 US$) associated with wildlife-vehicle collisions (white-tailed deer, mule deer, and 2 black bears and 1 wolf (black bears and wolves conservatively were estimated to have equal cost as deer) along the 4-lane I-90 (mi reference posts 80.0-85.0) per year (average 1998-2008), 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.

Discussion and Conclusion

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 effective in reducing collisions with large ungulates. However, the degree of 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 (see Huijser et al. accepted). Collision and carcass data from ten road sections throughout the United States and Canada showed 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 and that the implementation of mitigation measures would be economically feasible. 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.

While it may appear attractive to implement mitigation measures that have relatively low threshold values, not all mitigation measures reduce wildlife-vehicle collisions substantially. Therefore, while mitigation measures with relatively low threshold values and with limited effectiveness may be considered for longer road sections with relatively few wildlife-vehicle collisions, mitigation measures with higher threshold values and higher effectiveness may be considered for shorter road sections that have relatively many wildlife-vehicle collisions.

Wildlife fencing as a stand-alone mitigation measure has relatively low threshold values and reduces wildlife-vehicle collisions substantially. 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). Future cost-benefit analyses may include a monetary value for having viable populations of different species, as well as other passive use values.

We believe that the cost-benefit model presented in this paper can be a valuable decision support tool for transportation agencies and natural resource management agencies when deciding on the implementation of 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 also allow for wildlife movements across the road. This connectivity is essential to the survival probability of the fragmented populations for some species in some regions.

Biographical Sketches

Marcel Huijser received his M.S. in population ecology (1992) and his Ph.D. in road ecology (2000) at Wageningen University in Wageningen, The Netherlands. He studied plant-herbivore interactions in wetlands for the Dutch Ministry of Transport, Public Works and Water Management (1992-1995), hedgehog traffic victims and mitigation strategies in an anthropogenic landscape for the Dutch Society for the Study and Conservation of Mammals (1995-1999), and multifunctional land use issues on agricultural lands for the Research Institute for Animal Husbandry at Wageningen University and Research Centre (1999-2002). Currently Marcel works on wildlife-transportation issues for the Western Transportation Institute at Montana State University (2002-present). He is a member of the Transportation Research Board (TRB) Committee on Ecology and Transportation and co-chairs the TRB Subcommittee on Animal-Vehicle Collisions.

John Duffield is an economist at the University of Montana where he has taught and conducted research for the last 35 years. He has a Ph.D. (1974) in economics from Yale and a B.A. (1968) in economics and math from Northwestern University. His field is natural resource economics, with an emphasis on nonmarket values for fish, wildlife and water resources. He has worked on a broad range of policy issues including energy modeling and forecasting (coal development on the Northern Great Plains), hydroelectric development issues (electricity versus the values of free flowing rivers) and on many issues relating to recreation management and valuation. His primary current project is estimating ecosystem values for the Grand Canyon to inform water allocation and management in the Colorado River. Much of his work has been on endangered species, including critical habitat analysis for bull trout in the Columbia and Klamath River Basins. In 1992 he coauthored a book on natural resource damage assessment and has worked on a number of significant cases including serving as the lead economist for the Alaska natives in the Exxon Valdez oil spill case. He has long been involved in policies relating to fish, wildlife and hydroelectric energy development and currently serves on the Independent Economic Advisory Board for the Northwest Power and Conservation Council, based in Portland, Oregon.

Tony Clevenger has carried out research during the last 12 years assessing the performance of mitigation measures designed to reduce habitat fragmentation on the Trans-Canada Highway (TCH) in Banff National Park, Alberta. Since 2002, he has been a research wildlife biologist for the Western Transportation Institute (WTI) at Montana State University. Tony is currently a member of the U.S. National Academy of Sciences Committee on Effects of Highways on Natural Communities and Ecosystems. Since 1986, he has published over 40 articles in peer-reviewed scientific journals and has co-authored three books including, Road Ecology: Science and Solutions (Island Press, 2003).

Rob Ament, M.Sc., Biological Sciences, is the Road Ecology Program Manager at the Western Transportation Institute at Montana State University. He has more than 25 years of experience in field ecology, natural resource management, environmental policy and organizational development. He manages nine road ecologists with over 20 active research projects throughout North America, three of which he is the principal investigator.

Pat McGowen obtained his B.S. and M.S. in Civil Engineering from Montana State University, and his Ph.D. from University of California Irvine in Transportation Systems Engineering. He has been a licensed professional civil engineer in Montana since April 2000. He is an assistant professor jointly appointed between the Western Transportation Institute (WTI) and Civil Engineering Department at Montana State University where he has worked on projects relating to rural ITS, transportation impacts to wildlife, safety and travel and tourism. Dr. McGowen is a national expert on highway-wildlife interactions. He developed the Artemis Clearinghouse, a wildlife-vehicle collision mitigation web-based clearinghouse. He has been involved in projects including the Roadside Animal Detection System Testbed, the National Wildlife Vehicle Collisions Study, and Habitat Connectivity and Rural Context Sensitive Design. Dr. McGowen is the founder and co-chair of the TRB subcommittee on Animal Vehicle Collisions (ANB20-2). Dr. McGowen, along with other colleagues at WTI was awarded the 2008 Best of ITS Award from the Intelligent Transportation Society of America for Best New Innovative Practices for Partnerships for Deploying Animal Vehicle Crash Mitigation Strategies.

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