

Wildlife-Vehicle Collision and Crossing Mitigation Measures: A Literature Review for Blaine County, Idaho

by

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A report prepared for

Board of Blaine County Commissioners
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May, 2008

1. Report No. 4W1403A		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Wildlife-Vehicle Collision and Crossing Mitigation Measures: A Literature Review for Blaine County, Idaho		5. Report Date May 2008			
		6. Performing Organization Code			
7. Author(s) M.P. Huijser & A.V. Kociolek		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. Project No. STP-2390 (157) Key No.: 09441 Agreement No. 6619			
12. Sponsoring Agency Name and Address Board of Blaine County Commissioners 206 First Avenue South, Suite 3000 Hailey, Idaho 83333		13. Type of Report and Period Covered Literature Review October 2006 – May 2008			
		14. Sponsoring Agency Code			
15. Supplementary Notes Research performed in cooperation with Board of Blaine County Commissioners and the US Department of Transportation, Federal Highway Administration. A PDF version of this report is available from WTI's website at http://www.wti.montana.edu/ .					
16. Abstract This report reviews mitigation measures aimed at reducing mule deer and elk-vehicle collisions and at maintaining or improving habitat connectivity for wildlife. This review represents the first task (task 1a and 1b) of a project that aimed to identify and prioritize road sections that may require mitigation along a 26 mi long road section of S.H. 75 in Blaine County, Idaho (between Timmerman Jct (Jct with Hwy 20) and the Trail Creek Bridge in Ketchum, Idaho). The project aimed to review potential mitigation measures (task 1a and 1b, this report), and to collect and analyze historic and current wildlife-vehicle collision (WVC) data and provide advice on potential mitigation measures, including animal detection systems (see a separate report). The mitigation measures reviewed in this report include those that are aimed at influencing driver behavior and those that are aimed at influencing animal movements, specifically for mule deer and elk. For each mitigation measure that is discussed, the report includes a general description of the measure, species that may benefit from the measure, the effectiveness of the mitigation measure in terms of reducing WVCs, examples of studies examining the effectiveness of the mitigation measure in terms of reducing WVCs, the effectiveness of the mitigation measure in terms of reducing the barrier effect of roads and traffic, potential disadvantages or undesired side effects of the measure, maintenance requirements of the mitigation measure, and the range of costs for construction, installation and/or maintenance of the mitigation measure, if available. The authors of this report consider animal detection systems and wildlife fencing (in combination with safe crossing opportunities for wildlife) to be potential primary mitigation measures that should be considered for the reduction of mule deer- and elk-vehicle collisions along S.H. 75 in Blaine County, Idaho.					
17. Key Words Blaine County, Elk, Habitat connectivity, Idaho, Mitigation measures, Mule deer, Review, State Highway 75, Wildlife-vehicle collisions, Wildlife crossing			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 117	
				22. Price	

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ACKNOWLEDGMENTS

The authors would like to thank Blaine County for initiating and supporting this project. In addition, the authors would like to thank the persons who have provided information and images for this review of mitigation measures. The authors also thank Rob Ament, Carol Diffendaffer and Neil Hetherington of the Western Transportation Institute staff for contributing to this project.

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1 INTRODUCTION

Blaine County, in cooperation with Idaho Transportation Department (ITD), published a Request For Proposal (RFP) to gather more information about the wildlife-vehicle collisions and the potential installation of an animal detection system along the 26 mile long section of State Highway 75 (SH 75) between Timmerman Jct (Jct with Highway 20) and the Trail Creek Bridge in Ketchum, Idaho (Blaine County, 2006). The ultimate purpose of the effort is to eventually contribute to a reduction in animal-vehicle collisions, especially with mule deer and elk. This translates into increased public safety, reduced wildlife mortality, and reduced economic losses (e.g. due to property damage) along the road section concerned.

More specifically, the project had the following tasks and research questions (WTI, 2006):

- Task 1a – Conduct literature review on animal detection systems
 - Task 1b – Provide a summary of design alternatives (review of other mitigation measures)
- Task 2 – Re-analyze existing road kill data
- Task 3 – Collect and help organize additional road-kill data
- Task 4 – Collect wildlife crossing data at grade and under two existing bridges
- Task 5 – Collect wildlife population data
- Task 6 – Review potential sites and advise on the installation of an animal detection system
- Task 7 – Deliver final report

This manuscript relates to tasks 1a and 1b. The remaining tasks are addressed in Huijser et al. (2008).

2 TASK 1A: REVIEW OF ANIMAL DETECTION SYSTEMS

2.1 Introduction

Animal detection systems use technology to detect large animals (e.g., deer (*Odocoileus sp.*), elk (*Cervus elaphus*) and/or moose (*Alces alces*)) as they approach the road. When an animal is detected, signs are activated that warn drivers that large animals may be on or near the road at that time.

A road-based animal detection system consists of two parts: the part that detects large animals as they approach the road, and the part that warns the drivers after detection has occurred (Figure 1). A transportation agency or natural resource management agency usually takes the initiative for site and species specific mitigation measures. Site selection is often based on accident reports and road-kill data for large animal species. The transportation agency and natural resource management agencies then decide on the appropriate approach; in this case an animal detection system. After a vendor is selected an animal detection system is designed, built and delivered by the vendor. An installation contractor then puts the system in place. Once the system is installed and working according to the agreed upon specifications, the transportation agency may operate and maintain the system. In some cases natural resource management agencies may assist with checking up on the system. Currently most systems have to be checked at the site regularly to verify that the system is indeed operating correctly. In some cases there is remote access to the detection data and system diagnostics through land-based phone lines, or cell or satellite phone. There may also be algorithms in place that screen the data continuously for unusual patterns that may indicate that there is a problem with the system or parts thereof. Once a problem with the system is detected a person may be notified through an automated system. Figure 1 shows the concept of operations for animal detection systems. Arrows indicate direction of output and processes. Solid lines indicate output and processes that exist already. Dotted lines indicate output and processes that may be developed in the future.

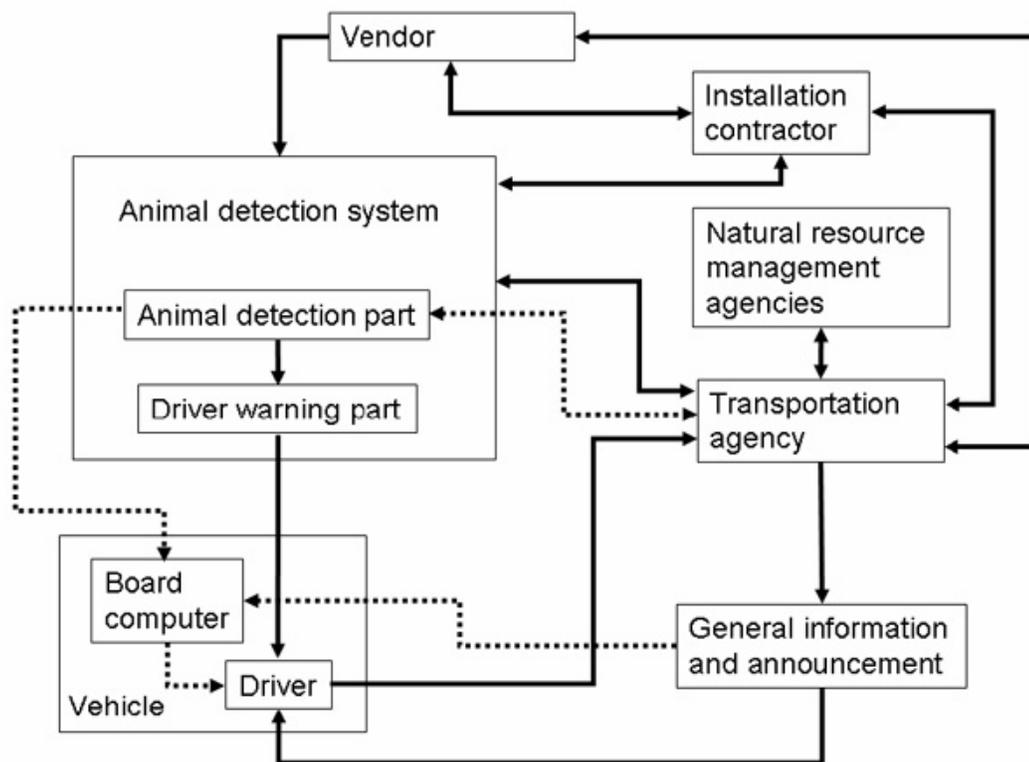


Figure 1: Concept of Operation.

The transportation agency provides information to the traveling public about the purpose and the location of the animal detection system. This information should be provided just before the drivers get to the site with the animal detection system. Road signs and highway advisory radio messages are the most obvious ways to deliver this information to the driver. In the future this information may also be delivered to an on-board computer inside the vehicle. The information would be provided as soon as the vehicle gets within a certain radius of the animal detection system. This procedure would require a two-way GPS-based communication system. When approaching the animal detection system a driver may be confronted with an activated warning signal indicating that a large animal has been detected and is present on or near the road at that time. In the future this warning signal may also be delivered to an on-board computer inside the vehicle.

There have been numerous projects that included the installation and evaluation of the effectiveness of animal detection systems (reviews in Farrell et al., 2002; Robinson et al., 2002; Huijser & McGowen, 2003). So far only a couple of these animal detection systems have been studied with regard to system reliability and system effectiveness. Examples include the area cover systems in Switzerland (Kistler, 1998; Romer & Mosler-Berger, 2003; Mosler-Berger & Romer, 2003; review in Huijser et al. 2006a) and Finland (Muurinen & Ristola, 1999; Taskula, 1999), the systems at two sites in Wyoming (Gordon et al., 2001; Gordon & Anderson, 2002; Gordon et al., 2004; van der Giessen, 2007), the area cover system in Kootenay National Park, Canada (Kinley et al., 2003), the break-the-beam system in Yellowstone National Park in Montana (Huijser et al., 2006a; b), and the area cover system near Payson in Arizona (Dodd & Gagnon, 2008). However, most systems have never been evaluated properly, and the information with regard to those systems remains anecdotal at best. Nevertheless, the information that is available shows that, depending on road and weather conditions and reduced speed limits, the warning signs can cause drivers to reduce their speed (Muurinen & Ristola 1999; Kistler 1998; Kinley et al., 2003; review in Huijser et al., 2006a; Dodd & Gagnon, 2008). Warning lights may also result in more alert drivers, which can potentially lead to a substantial reduction in stopping distance: 20.8 m at 88 km/h (68 ft at 55 mi/h) (Green, 2000; Huijser et al., 2006a). Finally, research from Switzerland has shown that animal detection systems can reduce ungulate-vehicle collisions by as much as 81-82% (Kistler, 1998; Romer & Mosler-Berger, 2003; Mosler-Berger & Romer, 2003). These results are encouraging, but there remains much to be learned about the installation, operation and maintenance, and the reliability and effectiveness of animal detection systems (Huijser, 2003; 2006).

In order to reduce the number of animal-vehicle collisions, animal detection systems need to detect animals reliably, and they also need to influence driver behavior so that drivers can avoid a collision. Most animal detection system technologies are vulnerable to ‘false negatives’ and ‘false positives’ (see review in Huijser et al., 2006). False negatives occur if an animal approaches, but the system fails to detect it. False positives occur if the system reports the presence of an animal, but there is no animal present. Numerous false positives result in a system that resembles a permanently flashing warning light that is not connected to sensors. False negatives should be avoided or kept to an absolute minimum as drivers expect an animal detection system to detect all or nearly all large animals that approach the road. False positives should also be minimal, but it is more acceptable to have a few false positives than a few false negatives. Nevertheless, it is important that animal detection systems are reliable as drivers are expected to respond to the warning signals. An ongoing project that investigates the reliability of 9 different animal detection systems from 5 different vendors has shown that at least some of these systems are able to detect large mammals very reliably (Huijser et al., 2007).

Once an animal detection system reliably detects the target species and the warning signals and signs are activated, driver response determines how effective the system ultimately is in avoiding or reducing animal-vehicle collisions. Figure 2 splits driver response into two components: increased driver alertness and lower vehicle speed.

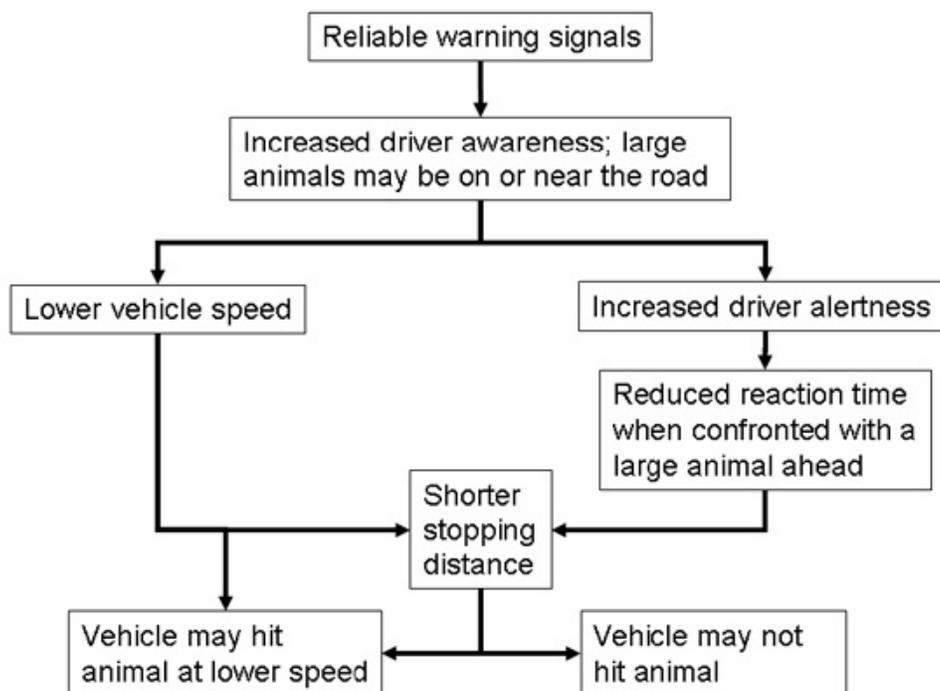


Figure 2: Warning signals and driver response.

A higher state of alertness of the driver, lower vehicle speed, or a combination of the two can result in a reduced risk of a collision with the large animal and less severe collisions. A reduced collision risk and less severe collisions mean fewer human deaths and injuries, and lower property damage. In addition, fewer large animals are killed or injured on the road without having been restricted in their movements across the landscape and the road. Furthermore, fewer large dead animals will have to be removed, transported and disposed off by road maintenance crews.

2.2 System Technologies

Animal detection systems use sensors to detect large animals as they approach the road. The technology for most animal detection systems is either based on “area cover sensors” or “break-the-beam sensors” (Huijser & McGowen, 2003). Area cover sensors detect large animals within a certain range of a sensor. Area coverage systems can be active or passive. Passive systems detect animals by only receiving signals. The two most common are passive infrared and video detection. These systems require algorithms that distinguish between e.g. moving vehicles with warm engines and moving pockets of hot air and movements of large animals. Active systems send a signal over an area and measure its reflection. The primary active area coverage system is microwave radar.

Break-the-beam sensors detect large animals when their body blocks or reduces a beam of infra-red, laser or microwave radio signals sent by a transmitter and received by a receiver. Other techniques include geophones that record vibrations in the ground as large animals

approach, and radio collared animals combined with receivers located in the right-of-way (see section 2.4).

2.3 System Effectiveness and Effectiveness Evaluation

System effectiveness, i.e. fewer and less severe animal-vehicle collisions, can be obtained through two mechanisms: increased driver alertness and reduced vehicle speed (see also Figure 2). These two mechanisms are described in the next two sections. The section after that discusses the effectiveness of animal detection systems in reducing wildlife-vehicle collisions.

2.3.1 Driver Alertness

Activated warning signs are likely to make drivers more alert. Driver reaction time to an unusual and unexpected event can be reduced from 1.5 s to 0.7 s if drivers are warned (Green, 2000). Assuming a constant vehicle speed of 88 km/h (55 mi/h) before and after the warning signals are presented to the driver, increased driver alertness could reduce the stopping distance of the vehicle by 21 m (68 ft). However, this reduction in reaction time and stopping distance has not specifically been tested with respect to the presence of large animals in rural areas. Experiments with a driving simulator (see e.g. Hammond & Wade, 2004) that simulates animal movements across the road and that measures driver behavior (e.g. reaction time, breaking, stopping distance, and speed on impact) could fill this knowledge gap.

The awareness and alertness of the driver is likely to be influenced by the type of warning signals presented. Currently there are no specific standards for these warning signals and signs, and regulations and practices differ between countries and different regions within a country. However, there is evidence that different signs are interpreted differently by drivers. For example, if drivers are presented a non-activated warning light and a standard black on yellow deer warning sign, and if other black on yellow warning text signs say “use extra caution when flashing” 92% of the respondents interpreted the sign correctly; i.e. there may still be deer on the road despite the fact that the warning signals are not activated (Katz et al., 2003). This percentage was much lower with other text signs: “animal detected when flashing” (57.6%) and “when flashing” (62.5%). Drivers may not increase their eye movements (scanning behavior) in response to activated warning signs (Hammond & Wade, 2004), but the presence of deer or a deer decoy in the right-of-way does seem to trigger a relatively strong reduction in vehicle speed when the flashing warning lights are activated (Gordon et al, 2001; Gordon & Anderson, 2002; Kinley, et al, 2003). This indicates that activated warning signals may indeed cause drivers to be more alert.

2.3.2 Vehicle Speed

Once drivers are aware that a large animal may be on or near the road in front of them, they may lower the speed of their vehicle. Previous studies have shown variable results; substantial decreases in vehicle speed (≥ 5 km/h (≥ 3.1 mi/h)) (Kistler, 1998; Muurinen & Ristola, 1999; Kinley, et al, 2003; Dodd & Gagnon, 2008), minor decreases in vehicle speed (< 5 km/h (< 3.1 mi/h)) (Kistler, 1998; Muurinen & Ristola, 1999; Gordon & Anderson, 2002; Kinley, et al., 2003; Gordon et al., 2004; Hammond & Wade, 2004) and no decrease or even

an increase in vehicle speed (Muurinen & Ristola, 1999; Hammond & Wade, 2004). The variability of the results is likely related to the type of warning signal and signs (see also Chapter 4), whether the warning signs are accompanied with advisory or mandatory speed limit reductions, road and weather conditions, whether the driver is a local resident, and perhaps also cultural differences that may cause drivers to respond differently to warning signals in different regions.

Kistler (1998) found that drivers reduced their speed substantially when presented activated warning signals that were accompanied with a mandatory reduction of the maximum speed limit (40 km/h, 24.8 mi/h); the average vehicle speed decreased from 68 km/h (42.3 mi/h) (warning lights off) to 46 km/h (28.6 mi/h) (warning lights on). Other locations that had warning signs only and no reduced maximum speed limit showed only a minor reduction in vehicle speed. Here the average vehicle decreased from 51 km/h (31.7 mi/h) (warning lights off) to 47 km/h (29.2) (warning lights on). However, vehicle speed with the lights off was relatively low already and vehicle speed with the lights on was similar to that with activated warning signals in combination with a mandatory reduction in speed limit.

During the day, Muurinen and Ristola (1999) observed a slight increase in vehicle speed as a response to the activated warning signals; an increase of 0.4-0.5 km/h (0.2-0.3 mi/h). During the night however, there was a minor reduction in vehicle speed, 1.6-2.6 km/h (1.0-1.6 mi/h); and drivers reduced their speed substantially when it rained, 14.0-15.6 km/h (8.7-9.7 mi/h). These results suggest that drivers are more likely to reduce vehicle speed and reduce it substantially when visibility and road conditions are poor.

Drivers that live in the area surrounding an animal detection system are more likely to be familiar with the purpose and reliability of an animal detection system than non-locals. If the animal detection system is reliable and if drivers receive confirmation (i.e. if the warning lights are on they see a large animal on or near the road; if the warning lights are off they do not see a large animal on or near the road), local drivers may learn to trust an animal detection system. Therefore, local drivers may be more alert, and they may reduce their speed more than non-local drivers. However, if an animal detection system is not reliable or if the drivers do not receive confirmation, local drivers may be less responsive than non-local drivers.

Kistler (1998) found that local drivers showed greater speed reduction than non locals. With mandatory speed limit reduction: locals lights off -- 68 km/h (42.3 mi/h), locals warning lights on -- 44 km/h (27.3 mi/h); non-locals warning lights off -- 70 km/h (43.5 mi/h), non-locals warning lights on -- 51 km/h (31.7 mi/h). Without mandatory speed limit reduction: locals warning lights off -- 51 km/h (31.7 mi/h), locals warning lights on -- 44 km/h (27.3 mi/h); non-locals warning lights off -- 50 km/h (31.1 mi/h), non-locals lights on -- 47 km/h (29.2 mi/h). These readings indicate that local drivers may have trusted the animal detection systems more than non-local drivers. This also suggests that driver response may be less pronounced on roads that have a relatively high proportion of non-local drivers. Finally, the results indicate that one is more likely to find a response (lower vehicle speed) to the flashing warning lights if drivers have been given the opportunity to learn to trust the system. Therefore speed readings taken immediately after system installation may show smaller speed reductions than speed readings taken three months later, for example.

Minor reductions in vehicle speeds may not seem meaningful, but the relationship between vehicle speed and the risk of fatal accidents (for humans) is exponential (Kloeden et al., 1997). This means that at high vehicle speed a small decrease in speed results in a disproportionately large decrease in the risk of the severity of a potential accident. Thus a relatively small reduction in vehicle speed can be very important. However, the relationship between vehicle speed and the risk of fatal accidents has not specifically been tested with respect to large animals in rural areas.

Since small reductions in vehicle speed are important, speed studies must have relatively large sample sizes. For example, in order to detect a substantial reduction in vehicle speed (≥ 5 km/h; ≥ 3.1 mi/h), a minimum of 115 vehicles per treatment is required (1 sided t-test, $\alpha = 0.05$, power = 0.8) (Figure 3:). This number is based on a power analyses conducted with speed data from the site along US Hwy 191 in Yellowstone National Park, MT (Huijser et al., 2006a). To detect smaller reductions in vehicle speed a much larger sample size is required. For example, in order to detect a reduction in vehicle speed of ≥ 2.5 km/h (≥ 1.6 mi/h), a minimum of 455 vehicles per treatment would be required (1 sided t-test, $\alpha = 0.05$, power = 0.8) (Figure 3:). Other sites may have different vehicle speeds and variation in speed. As a consequence other sites may require a higher or lower minimum sample size.

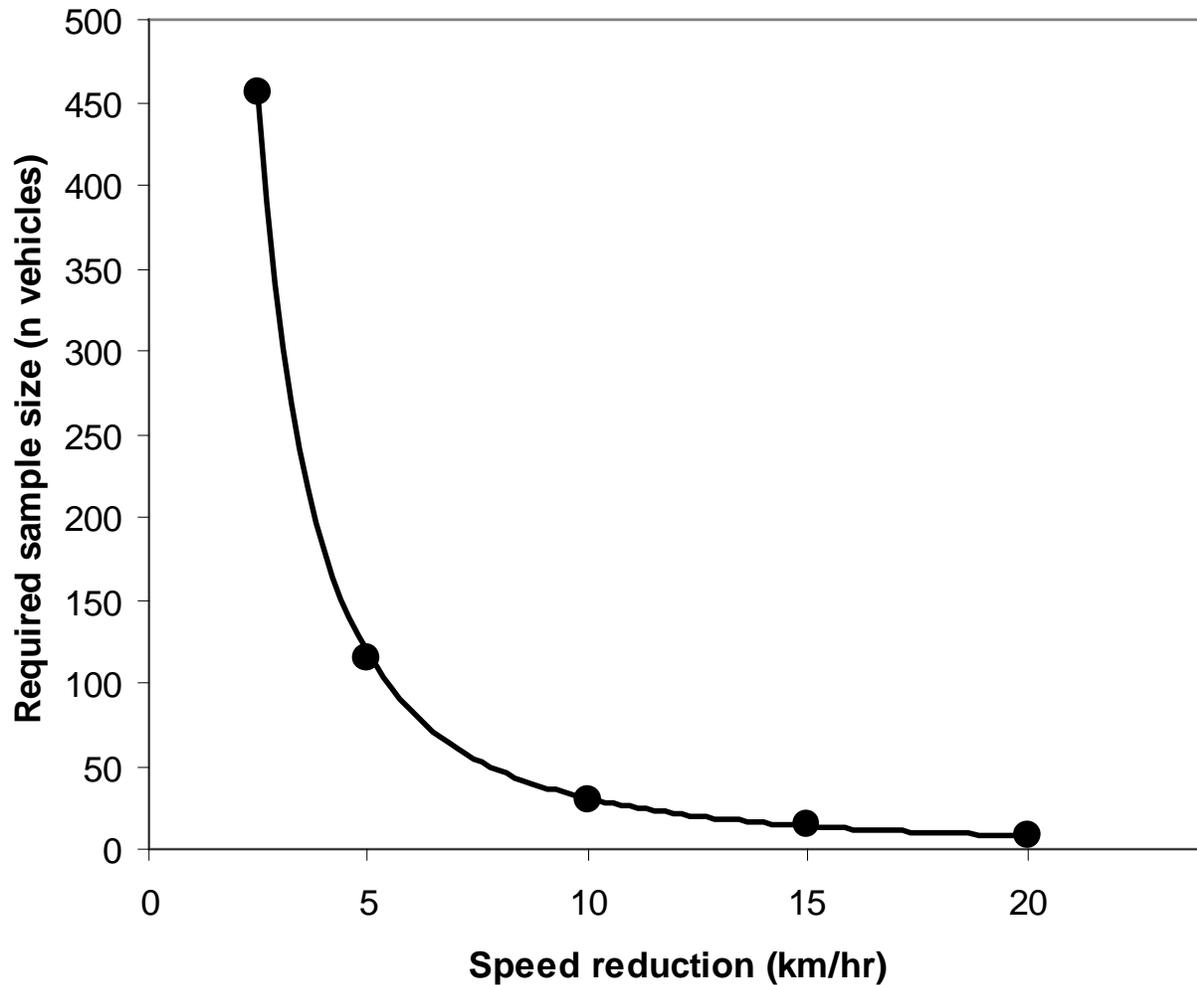


Figure 3: Sample size to detect speed reduction.

Figure 3: shows the sample size (number of vehicles) required to detect a certain reduction in vehicle speed. (1 sided t-test, $\alpha = 0.05$, power = 0.8). This power analysis is based on speed data from independently traveling passenger cars and combined trucks at the site along US Hwy 191, in Yellowstone National Park, Montana (Huijser et al., 2006a) (Figure 4): mean vehicle speed was 108.7 km/h, SD=15.2, n=52 (67.5 mi/h, SD=9.4) even though the posted speed limit is only 88 km/h (55 mi/h). There was no significant difference between the speed of passenger cars and combination trucks ($P=0.382$, 2-sided t-test), nor was there a significant difference in the speed between the two travel directions: passenger cars: $P=0.284$; combination trucks: $P= 0.944$ (2-sided t-test).



Figure 4: An animal detection system on U.S. Highway 191 in Yellowstone National Park (© Marcel Huijser).

There may be many factors to consider when designing speed studies, for example, any combination of 1. Lights on or off, 2. Vehicle type, 3. Day or night, 4. Road surface dry, wet or icy, 5. No precipitation, fog, rain or snow. Sex and age of the driver are also related to vehicle speed, but one may not be able to record these variables without stopping the vehicle or recording individual license plates. The first five factors listed above may already result in a very high number of speed readings, especially if one is interested in detecting relatively small reductions in vehicle speed.

Depending on the road conditions and traffic volume, vehicles may travel in groups (platoons) as there may be few opportunities to overtake other vehicles. When measuring the effect of flashing warning lights on vehicle speed it is important to only include the speed data from the first vehicle in a platoon as the speed of the following vehicles is likely to be influenced by that of the first vehicle.

Speed readings that time vehicles passing over a known distance can be obtained in various ways (e.g. traffic counters, radar guns and stopwatches). Traffic counters allow for automated data collection which can be very convenient, especially if large sample sizes are required. However, many traffic counters require tubes across the road and this technique cannot be

used in areas that receive snow as snowplows destroy the tubes. Radar guns and related equipment may require parked cars, radar signals, trailers, and other objects to be near the road, which may trigger drivers to reduce their speed (Robertson, 2000), regardless of whether the warning signs are activated. Timing vehicles from a distance does not affect driver behavior and can result in data that are not confounded by other factors. However, it is imperative that the error rate in starting and stopping the stopwatch is negligible compared to the total traveling time (Pignataro, 1973). In addition it is important to realize that these vehicle speeds relate to the average speed over the distance concerned; it is not a spot speed. This is not necessarily good or bad. Spot speed measurements are more likely to result in relatively high and low vehicle speed readings than speed measurements over a certain distance. However, when measuring vehicle speed in an animal crossing zone, speed measurements that relate to this zone rather than a spot in this zone may be more appropriate.

2.3.3 Animal-Vehicle Collisions

Transportation agencies, highway patrol, or other organizations or individuals usually record animal-vehicle collisions or road kill before and after an animal detection system is installed. It is important that the data are collected for several years both before and after installation (comparison in time) as well as at the site with the animal detection system and on road sections in the surrounding area (comparison in space). Comparisons in time may be confounded by fluctuating animal populations, changes in traffic volume and the time of travel, and changes in the landscape that may influence animal movement patterns to and from the road. Comparisons in space could be influenced by variability in site conditions, as well as other factors that may change or differ between the test and control sites.

A major challenge is that the road sections over which animal detection systems are installed are often relatively short, usually only a couple of hundred meters (yards) (see section 2.4). The average number of large animals that was killed per time period prior to the installation of an animal detection system on those short road sections is usually relatively low, perhaps 'only' one or two per year. In addition, the number of collisions can vary substantially from year to year at a specific location due to chance alone. Combined with the fact that most projects only collect data from one location for a few years, it is hard to show a potential statistically significant reduction in the number of animal-vehicle collisions after a system is installed and activated. Long road sections with animal detection systems at multiple locations and monitoring over many years can help overcome these issues. An alternative is that the road kill and animal-vehicle collision data are combined for different systems from different locations. Such a meta-analysis would show whether animal detection systems, regardless of the system type and manufacturer, reduce the number of animal-vehicle collisions.

Animal-vehicle collision or road kill data have to be based on a fixed search and reporting effort (monitoring) if the data are used to evaluate the effectiveness of an animal detection system. Monitoring data does not necessarily require that every collision or carcass is reported, but it does require a fixed search and reporting effort. Incidental observations or inconsistent search and reporting effort result in data that are not suitable to investigate the most important measures of system effectiveness: the number of animal-vehicle collisions or the number of road kill.

Even if monitoring data are collected, the data may not be properly documented, not published or not available for analyses. Kistler (1998), Romer and Mosler-Berger (2003), and Mosler-Berger and Romer (2003) published on the number of animal-vehicle collisions before and after seven infrared area cover detection systems were installed in Switzerland (Table 1). These systems reduced the number of animal-vehicle collisions by 82% on average (Table 1) (1-sided Wilcoxon matched-pairs signed-ranks test, $P=0.008$, $n=7$). See Kistler (1998) and paragraph 4.4.1 for details on the seven sites and systems. All seven sites showed a reduction in collisions after an animal detection system was installed, and three of the seven sites did not have a single collision after system installation (as of 6-7 years after installation). The data relate to collisions with roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*), and collisions that occurred during the day when the systems were not active were excluded from the analyses. While the sites with an animal detection system showed a strong reduction in the number of animal-vehicle collisions, the total number of animal-vehicle collisions in the wider region remained constant (Kistler, 1998). This is further evidence that the reduction in collisions is indeed related to the presence of the animal detection systems and not the result of potential reductions of the ungulate populations or major changes in traffic volume and time of travel. Furthermore, detection data stored by the systems and tracking data confirmed that ungulates still frequented the sites (Mosler-Berger & Romer, 2003).

Data from a site in Arizona (Dodd & Gagnon, 2008) showed that elk-vehicle collisions were reduced from 11.7 per year on average to 1 per year after an animal detection system was installed in a gap in an electric fence (1 year of data post installation) (91% reductions in collisions with large animals).

Table 1: Number of Collisions With Large Animals Before and After the Installation of Animal Detection Systems at Seven Locations in Switzerland.

Location	Before			After			Reduction	
	Coll. (N)	Yrs	Coll./yr	Coll. (N)	Yrs	Coll./yr	Coll./yr	%
Warth	14	7	2.00	3	10	0.30	1.70	85.00
Soolsteg	8	11	0.73	1	6	0.17	0.56	77.08
Val Maliens	7	3	2.33	6	5	1.20	1.13	48.57
Marcau	12	4	3.00	6	5	1.20	1.80	60.00
Schafrein	26	8	3.25	0	6	0.00	3.25	100.00
Duftbächli	18	8	2.25	0	6	0.00	2.25	100.00
Grünenwald	6	8	0.75	0	7	0.00	0.75	100.00
Average reduction								81.52

Anecdotal data from other sites show the following:

- The animal detection system near Sequim, WA, is believed to have led to a reduction in elk-vehicle collisions (Pers. com. Shelly Ament, Washington Department of Fish and Wildlife; Pers. com. David Rubin, Sequim Elk Habitat Committee).
- The site with the system near Clam Lake, WI (see section 2.4) has experienced 2 elk-vehicle collisions between when the system became operational (19 December 2006) and fall 2007 (Clam Lake Elk News, 2007). During this same period the previous year there were 5 elk vehicle collisions; suggesting a 60% reduction in collisions with large animals.
- About 50% fewer white-tailed deer than expected were hit at the site near Marshall, MN (see section 2.4) between when the animal detection system became operational (April 2007) and January 2008 (CBS, 2008). Before the system became operational between 40 and 80 white-tailed deer were hit on the 1 mi long road section equipped with the system (Star Tribune, 2007).

2.4 Sites with Animal Detection Systems

This section lists all animal detection systems and their study sites throughout North America as known to the authors (April 2008). In addition we included contact details for vendors (Appendix A), including of vendors that have not had their system installed along a roadside yet or that are based outside of North America. The authors identified 15 sites in North America that have or have had an animal detection system (Figure 5). In addition, there are at least 22 locations in Europe that have or have had an animal detection system (Huijser et al., 2006a). To the best of the authors' knowledge 8 of the sites in North America have a system that is currently in operation (as April 2008). A system at the 9th site is believed to have operational problems (Tijeras Canyon, New Mexico). On the remaining 6 sites the systems have been dismantled. In addition, to best of the authors' knowledge, there are 6 sites for which an animal detection system is planned (Figure 5). For additional information on the individual sites see Huijser et al. (2006a).



Figure 5: Location of animal detection systems in North America.

Table 2 describes the location, highway, system type and manufacturer for the systems at the 21 sites in North America. Table 3 describes the target species, distance covered and other characteristics of the animal detection systems at the 15 sites that have or have had an animal detection system in North America.

Table 2: Location, Highway, system type and vendor of animal detection systems.

#	Location	Highway	System type	Vendor (Appendix A)
1	Colville, 3 mi north of Chewelah WA	Hwy 395 (mi 290)	Laser break-the-beam	WSDOT Research Office
2	Nugget Cyn., betw. Kemmerer and Cokeville, WY	Hwy 30 (mi 30.5)	a. Passive infrared sensors, b. buried geophones (vibrations) and passive infrared sensors, c. microwave sensors	a. FLASH, b. Eagle Telonics, c. EIS Electronic Integrated Systems, Inc.
3	Sequim, WA	Hwy 101	Radio collared elk with receivers placed in the r-o-w	David Rubin
4	Camden State Park, SW of Marshall, MN	Hwy 23	Laser break-the-beam	Lewis Enterprises Inc.
5	Kootenay NP, N of Dolly Varden Day-Use Area	Hwy 93	Cameras, passive infrared	Rainbow group
6	N of Orland, about 10 mi NW of Angola, IN	Indiana Toll Road (I-80/90, mi 130-142)	Laser break-the-beam	ICx Radar Systems
7	Wenatchee, WA	US 97A (mi 206)	Infrared laser break-the-beam	Battelle Marine Sciences Laboratory
8	Yellowstone NP, MT	US 191 (mi 28-29)	Laser break-the-beam	ICx Radar Systems
9	Los Alamos, NM	Restricted access	Infra-red break-the-beam	Bill Goodson, Goodson & Associates
10	Thompson-town, PA	Hwy 22/322 (mi 360-361)	Area-cover microwave detectors	Oh Deer Inc.
11	Herbertville, Quebec	Hwy 169 (km 32)	Laser break-the-beam, later infrared break-the-beam	Service Camera Pro
12	W of Pinedale, WY	U.S. 191 (mi 105.09-106.45)	buried geophones (vibrations) and passive infrared sensors	Eagle Telonics
13	Clam Lake, WI	Hwy 77	Radio collared elk with receivers placed in the r-o-w	?
14	Preacher Canyon, AZ	S.R. 260	Passive infrared cameras	Electrobraided Fence
15	Tijeras Canyon, NM	2 sites, NM 333 (old route 66), paralleling I-40	Cameras (detect animal movement)	Econolite Control Products Inc.
A	Betw. Presque Isle and Caribou, or near Rangeley, MA	Hwy 1 or 4	Undecided	Undecided
B	W of Flagstaff, AZ, or S of Flagstaff	I-40 (mi 148-222) or I-17 (near mi 211)	Undecided	Undecided
C	Betw. Durango Bayfield, CO	U.S. 160 (mi 95-96)	Buried cable (detect changes electromagnetic field)	Magal Senstar
D	Elko County, ±30 mi E of Wells, NV	I-80 (around mi 95)	Undecided	Undecided
E	± 4 mi E of Fort Jones, CA	Hwy 3 (mi 36.6-37.3)	Undecided	Undecided
F	Betw. Boulder and Lyons, CO	U.S. 36	Undecided	Undecided

Table 3: Target species, distance covered and other characteristics of animal detection systems.

ID #	Location	Target species	Distance covered	Fence	Cost System	Cost Install.	Ev.	Installed	Operational
1	Colville, WA	Deer, elk	402 m	No	\$ 9,000 ¹	\$3,000	O	20 Jun '00	Removed spring '02
2	Nugget Cyn., WY	M-deer	92 m	Yes	\$200,000 ²	?	OV	1 Dec '00	8 Dec '00-21 May '01
3	Sequim, WA	Elk	4,827 m	No	\$60,000 ³ , \$13,000 ⁴	?	OC	Apr '00	Apr '00-present
4	Marshall, MN	W-t deer	1,609 m	No	\$50,000	\$7,000 ⁵	O	Jun '01	Apr '07-present
5	Kootenay NP, BC	W-t deer	1,000 m	No	?	?	OV	Jun '02	Sep '03-Oct '03
6	IN Toll Road, IN	W-t deer	9,654 m ⁶	No	\$1,300,000	?	O	Apr '02	Oct '04 - present
7	Wenatchee, WA	Deer	213 m	No	<\$40,000 ⁷	?	OC	Oct '02	Removed spring '04
8	Yellowstone NP, MT	Elk	1,609 m	No	\$349,000 ⁸	\$60,000	O	Oct/Nov '02	Nov '04 - present
9	Los Alamos, NM	Elk	30 m	No	\$500 ⁹	\$2,000	O	Nov '02	Nov '02-Feb '03
10	Thompson-town, PA	W-t deer	±804 m	No	\$90,000	\$130,000	O	May '04	Removed 31 Jan '05
11	Herbertville, Quebec	Moose	10 m	Yes	\$4,100	\$4,100	OC	Fall 2004	Spring 2005 - present
12	Pinedale, WY	M-deer/ pronghorn	2,180 m	No	\$982,510 ¹⁰	\$982,510 ¹⁰	OV C	Oct 2005	Oct 2005-present
13	Clam Lake, WI	Elk	9.654 m	No	?	?	OC	Dec '06	Dec '06 - present
14	Preacher Canyon, AZ	Elk	18 m	Yes	\$700,000	?	OV C	Feb '07	Feb '07 - present
15	Tijeras Canyon, NM	Deer	?	?	?	?	?	Summer '07	Not operational yet

W-t deer = White-tailed deer; M-deer = Mule deer; Ev. = Evaluation: info available on: O = Operation and maintenance, V = Vehicle speed, C = Animal -vehicle collisions. Present = April 2008. ¹ Excl. signage, batteries; ² Incl. operation & maintenance, research, excl. WYDOT salaries; ³ Equipment; ⁴ Herding and collaring; ⁵ Excl. salaries; ⁶ Divided over 6 sections; ⁷ Incl. research, design, installation; ⁸ Incl. research and development; ⁹ Excl. salaries and video equip; ¹⁰ Equipment and installation combined.

2.5 Additional Issues

During installation, operation and maintenance a range of problems and other issues were identified (see review in Huijser et al., 2006a). We grouped them into four categories: false positives, false negatives, maintenance, and landscape, ecology and animals (Table 4). The table shows that area-cover and break-the-beam systems seem to be particularly vulnerable to false positives and false negatives. False positives occur if the system is triggered by causes other than the presence of large animals (target species). This also emphasizes an important limitation of animal detection systems; they are only intended to detect certain large species and they do not attempt to reduce collisions with relatively small species. False negatives

occur if a large animal is present, but the system fails to detect it. For example, tall, wet or moving vegetation, precipitation (incl. snow spray from snowplows), low flying birds, cars on driveways or access roads, can all trigger area-cover detector systems and break-the-beam systems. If the driveways or side roads receive only little use, one could decide to accept a certain number of false positives. Another strategy is to accept a certain number of “gaps” in the detection system at the location of the driveways or side roads. Another problem occurs when animals pass the sensors and then loiter in the right-of-way or on the road. Most animal detection systems do not detect the animals once they have passed the sensors. This results in false negatives as the warning signs are typically switched off within a couple of minutes. Other false negatives can occur if the sensors are placed close to the road and if the animal approaches the road very quickly. If the warning signs are placed at relatively great intervals drivers may not pass a warning sign before they are confronted with a large animal. This potential problem could be addressed by installing warning signs at short intervals. Another option is to install animal detection systems at short road sections in combination with a fence that funnels the animals through the narrow crossing area.

Radio collar systems such as the one in Sequim, WA (see section 2.4) can also produce false negatives. It is unlikely that all the individuals in a certain area can be equipped with radio collars. As a consequence, the animals without a radio collar are only detected if radio-collared animals accompany them. Therefore the system only works well for highly gregarious and not for solitary species. The system also works much better for a resident population than for migrants from far away locations that may only cross the road once or twice per year. The radio-collar system also requires re-collaring effort. The batteries of the radio collars usually run out after several years and then they must be replaced. In addition, individuals may die as a result of hunting, injuries or old age. Experts usually minimize the stress for the animals during capturing and handling, but the animals are exposed to a certain amount of stress during capturing and handling, and as a result of carrying a radio collar.

All systems have or can have a wide variety of maintenance issues. In addition, most systems require a period during which major technical problems are identified and hopefully solved. Ironically, the presence of posts and equipment in the right-of-way may also be a problem on its own. Animal detection systems and animal warning systems may help reduce the number of animal-vehicle collisions, but they are also a potential safety hazard to vehicles that run off the road. This could lead to liability claims. Finally, as more animal detection and animal warning systems are installed, signage will have to be standardized.

Another limitation of most systems is the inability to determine the direction the animal is moving in. This leads to a warning when an animal is leaving the side of the road and this could be considered a false detection. On the other hand, animals may decide to turn around and approach the road again which results in shorter warning time for drivers. This could be an argument for detecting all animals that are on or near the road, regardless of whether they are approaching or leaving.

Table 4: Summary of Issues, Problems and Experience with Operations.

Issues Problems and Experiences	Area cover systems	Break-the-beam systems	Geo-phone system	Radio-collar system
False positives				
High, moving or wet vegetation	√	√		
Flying birds, nesting birds, rabbits	√	√		
Wind, rain, water, fog, snow spray, falling leaves	√	√	√	
Snow and ice accumulation on sensors or ground	(√)	√		
Microwave radio signal reflection off guard rail		√		
Sun, heat, unstable sensors	√	√	√	
Insufficient ventilation in box (fog on lens)	(√)	√		
Frost, low temperatures	√	√		
Lightning	(√)	√	√	(√)
Long distance between transmitter and receiver		√		
Traffic on road	√	√	(√)	
Traffic on driveways or side road	(√)	√		
Passing trains			√	
Signals from other transmitters		√		√
False negatives				
Curves, slopes not covered by sensors	(√)	√		
Loitering animals in right-of-way not detected	(√)	√	(√)	
None of the individuals that cross have collars				√
Not feasible for non-gregarious species / migrants				√
Insufficient warning time	(√)	(√)	(√)	
Some systems are only active during the night	√	√		
Maintenance				
Maintenance costs (e.g. mowing, power, fences)	(√)	√	(√)	(√)
Shade/snow on solar panels	(√)	√	(√)	(√)
Vandalism and theft of e.g. solar panels	(√)	√	(√)	(√)
Safety (cars of road)	(√)	√	(√)	(√)
Broken sensors, warning lights or other material	√	√	(√)	√
Period required to solve technical difficulties	√	√	√	√
Signs (standardization, liability)	√	√	√	√
No remote access to data (poor cell phone coverage)	(√)	√	√	(√)
Landscape, ecology, animals				
Landscape aesthetics	(√)	√	(√)	(√)
Animals crossing areas may change overtime	(√)	√	(√)	(√)
Animals may wander between fences (if present)	√	(√)	(√)	(√)
Small animals are not detected	√	√	√	√
Continuous effort to capture animals				√
Stress for the animals involved				√
Not in habitat linkage zones (light disturbance)		√ ¹		

√ = problem has been reported or issue applies, (√) = problem has not been reported, but it could occur. ¹
= For Swedish system that illuminates the road and right-of-ways once an animal is detected.

2.6 Discussion and Conclusion

This review of animal detection systems shows that a wide variety of animal detection systems have been installed across North America, and also in Europe (see review in Huijser et al., 2006a). Many of the systems encountered technical problems or experienced false positives, false negative or maintenance issues. This was to be expected since most animal detection and animal warning systems are new applications of relatively new technology. In addition, the systems are typically exposed to rain, snow, heat and frost. A few systems seem to have resolved most of the problems and operate well. Examples of successful systems that appear either reliable or effective are the Swiss system (installed at many sites in Europe and at a test facility of the Western Transportation Institute in central MT), the Finnish system, the geophone system originally installed in Nugget Canyon, WY, the radio collar system near Sequim, WA and near Clam Lake, WI, the laser break-the-beam system along US Hwy 191 in Yellowstone National Park, the laser break-the-beam system near Marshall, MN, and the camera system in Preacher Canyon, AZ (review in Huijser et al., 2006a; this report). Each system type has its own (potential) strengths and weaknesses, and one has to review them carefully before installing a system in a particular location.

It is important that animal detection systems produce very few false positives and false negatives. False positives may cause drivers to eventually ignore activated signs, and false negatives present drivers with a hazardous situation. Driver response through reduced vehicle speed or increased alertness determines how effective animal detection systems really are. Previous studies have shown that drivers do not always substantially reduce their speed in response to activated warning signs (Muurinen & Ristola, 1999; Gordon & Anderson, 2002). Drivers may only reduce their speed when road and weather conditions are bad or when the warning signs are accompanied with a maximum speed limit sign (Muurinen & Ristola, 1999; Kistler, 1998). However, failure to substantially reduce vehicle speed under all circumstances does not necessarily make animal detection systems ineffective. Minor reductions in vehicle speed are important too since a small decrease in vehicle speed is associated with a disproportionately large decrease in the risk of a fatal accident (Kloeden et al., 1997). In addition, activated warning signs are likely to make drivers more alert. Driver reaction time to an unusual and unexpected event can be reduced from 1.5 s to 0.7 s if drivers are warned (Green, 2000).

Assuming a vehicle speed of 88 km/h (55 mi/h), increased driver alertness can reduce the stopping distance of the vehicle by 21 m (68 ft) (see Chapter 3). Only two studies have addressed the ultimate parameter of system effectiveness. Different studies or data sources indicate animal detection systems may reduce the number of animal-vehicle collisions by 50%, 60%, 82%, or 91% (this report). This is an encouraging result, but further evaluation of different systems under different circumstances is required before the conclusion of these studies can be generalized.

In conclusion, animal detection and animal warning systems have the potential to be a reliable and effective mitigation tool. However, animal detection and animal warning systems are not the perfect solution for every location. They are one tool in the transportation professional's arsenal and should be implemented only in situations where they are more desirable than other mitigation techniques, most notably wildlife fencing in combination with under- and overpasses (see also task 1b). In addition, further research and development is needed before animal detection and animal warning systems can be applied on a wide scale.

3 TASK 1B: OTHER MITIGATION MEASURES

3.1 Introduction

This section provides an overview of mitigation measures to reduce collisions with large animals. This section focuses on mitigation measures other than animal detection systems which were discussed in Chapter 2. While other reports have reviewed close to 40 different types of mitigation measures (e.g. Knapp et al. 2004, Huijser et al. 2007b, c; Huijser & Paul, 2008), the review in this report is restricted to the following:

- Mitigation methods aimed at influencing driver behavior
 - Vehicle speed reduction
 - Wildlife warning signs (standard, non-standard, seasonal)
- Mitigation methods aimed at influencing animal movements
 - Vegetation management in right-of-way
 - Road design features
 - Reflectors or mirrors
 - Wildlife fencing
 - Boulders in right-of-way
 - Wildlife fencing in combination with safe crossing opportunities (gaps in fence with warning standard signs, gaps in fence with animal detection systems, wildlife under- and overpasses) and escape mechanisms (jump-outs)

For each mitigation measure, this report lists:

- A general description of the measure, including species the measure may affect;
- The effectiveness in terms of reducing WVCs;
- Examples of studies examining the effectiveness of the mitigation measure in terms of reducing WVCs;
- The effectiveness in terms of reducing the barrier effect of roads and traffic;
- Potential disadvantages or undesired side effects of the measure;
- Maintenance requirements of the mitigation measure; and
- The range of costs for construction, installation and/or maintenance of the mitigation measure, if available.

This review is mostly based on Huijser & Paul (2008).

3.2 Reduce Vehicle Speed

For areas with high WVC frequency, reducing vehicle speed is occasionally suggested as a mitigation strategy. Before discussing the methods and implications of this strategy, it is important to understand the different types of speeds associated with the design and operation of a highway:

- The **design speed** is “a selected speed used to determine the various geometric design features of the roadway” (AASHTO 2004). Certain minimum design standards are used for different design speeds. A higher design speed typically means higher minimums for curve radius, lane widths, shoulder widths, clear zone widths, and other design parameters. Higher design speeds also mean lower maximums for the number of access points (e.g., intersections, driveways, or interchanges) per mile.
- After a road is built, a spot speed study is done. **Operating speed** is determined as “the speed at which drivers are observed operating their vehicles during free-flow conditions. In the United States, the 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature” (AASHTO 2004). Speed studies are typically done before speed limit signs are installed, or speed limit signs are covered during the study. The theory assumes that drivers are the best judge of a safe driving speed of a roadway and 85 percent of the people will travel at reasonable speeds.
- The enforceable **posted speed limit** is the maximum legal speed at which a vehicle is allowed to travel. These are typically set near the operating (85th percentile) speed.
- When a portion of the roadway has characteristics where the design speed is less than that of the rest of the road, an **advisory speed** can be posted. Advisory speeds are lower than the posted speed limit and are not enforceable other than by using basic “reasonable and prudent” laws.

Under ideal circumstances, the design speed, operating speed, and posted speed should be very similar for a given roadway. Here we discuss three ways to reduce operating vehicle speed: 1) reduce the posted speed, 2) reduce the design speed through traffic calming or redesign, and 3) post an advisory speed.

3.2.1 Posted Speed Limit

General Description

The ability to reduce the posted speed depends on who owns the roadway (state, county, city), as well as the legislation and guidelines governing those agencies. Once approval for the reduced speed is obtained, this mitigation is implemented by replacing the existing speed limit signs. Direct benefits in terms of reduced WVCs are unknown, though reduced vehicle speed and increased driver alertness may reduce WVCs. At relatively high speeds (e.g., ≥ 80 km/h), a speed reduction of even a few kilometers per hour can be beneficial as it leads to a disproportionate decrease in the risk of a severe collision. Kloeden et al. (2001) estimated that even a 5 km/h reduction in speed from 80 km/h on undivided roads could lower casualty crashes by 31-32 percent. In addition, lower vehicle speeds lead to shorter stopping distances, which may not only reduce the severity of a crash, but may also help avoid a collision altogether.

Species: Reducing speed does not target WVCs for specific species.

Percent effectiveness in reducing WVCs

The effect of reducing vehicle speed on WVCs is unclear. However, for all crashes, reducing vehicle speeds generally reduces the frequency of severe crashes involving human injury or fatality (National Research Council 1998). Though data are limited, road mortality may only substantially decrease with relatively low posted speed limits (e.g. ≤ 45 mi/h (≤ 72 km/h) (Gunther et al. 1998).

Examples of studies:

- One location where posted vehicle speeds were reduced to mitigate WVCs is on the Yellowhead Highway in Jasper National Park, Alberta. This roadway is a rural two-lane highway, with 3.7 m (12 ft) lane widths, and 3 m (10 ft) shoulders (Bertwistle 1999). Passing sight distance exists for most of its length. Passing sight distance is “determined on the basis of the length needed to complete normal passing maneuvers in which the passing driver can determine that there are no potentially conflicting vehicles ahead before beginning the maneuver” (AASHTO 2004). Prior to the mitigation, the speed limit for the roadway was 90 km/h. Traffic in 1998 was 1.2 million vehicles per year with a high percentage of trucks, buses and recreational vehicles. The area includes grizzly bear, white-tailed deer, mule deer, bighorn sheep, and elk. In 1991, the speed limit was reduced from 90 km/h to 70 km/h on three sections of the road that were 2.5 km, 4 km, and 9 km in length. Bertwistle (1999) reported that, on average, 5,475 speeding tickets are issued each year (although he was not specific as to whether these were in the 70 km/h zones or on the highway as a whole). Even with the speed limits and enforcement, a speed study in 1995 at two of the speed reduction locations showed that less than 20 percent of the vehicles obeyed the 70 km/h speed limit. Bertwistle (1999) reported that bighorn sheep collisions actually increased in the reduced speed zones and decreased in the control areas where the limit remained 90 km/h. Elk collisions were monitored at one reduced-speed location and both the control and the reduced-speed zones had increases in elk-vehicle collisions. The data presented by Bertwistle (1999) appear to be inconclusive.
- A report by Biota Research and Consulting, Inc. (2003), summarized WVCs in the Jackson, Wyoming, area. On a 1.4 km stretch of highway the authors suggested highway lighting as a solution, because even with the posted speed limit reduced to 35 mi/h (56 km/h), drivers continued to strike and kill deer. The report does not state whether there was a decrease in WVCs as a result of the posted speed limit reduction.
- In Yellowstone National Park, a 55 mi/h (88 km/h) road with higher annual traffic levels had comparatively more road kill than lower speed (≤ 45 mi/h; ≤ 72 km/h) and lower volume roads (Gunther et al. 1998). Based on the length of roads, the road sections with a posted speed limit of 55 mi/h (88 km/h) had 5.4 times more road killed animals than expected and the road sections with a posted speed limit of ≤ 45 mi/h (≤ 72 km/h) had 33.2 percent fewer road killed animals than expected (Gunther et al. 1998).
- On State Route 29 and U.S. Hwy 41 in southern Florida, the night speed limit has been lowered from 60 mi/h (97 km/h) to 45 mi/h (72 km/h) to reduce collisions with the Florida panther (*Puma concolor coryi*) (Figure 6). However, actual vehicle speeds are around 70-75 mi/h (113-121 km/h) during the day and 60-65 mi/h (97-105 km/h) during the night (Deborah Jansen, Big Cypress National Preserve, personal comment).



Figure 6: Reduced nighttime speed limit to protect the Florida panther along State Route 29 in southern Florida (© Marcel Huijser).

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all species. Reducing vehicle speeds does not necessarily address potential road and traffic avoidance behavior displayed by certain individuals or species. Nonetheless, signs do not physically restrict animal movements.

Potential disadvantages or undesired side effects

Extreme caution should be taken in reducing the posted speed limit substantially below the operating speed. Such a reduction can set up a situation where motorists are encouraged to break the law and it may lead to increased speed dispersion (the variability of vehicle speeds) and associated safety risks. Speed dispersion can also lead to a transition from a normal distribution of vehicle speeds to a bimodal distribution: one group of vehicles traveling at about the posted speed limit and another traveling at about the operating speed. It has been shown that speed dispersion increases crash rates even if average speeds decrease. Solomon (1964) and Cerrelli (1981) found that vehicles traveling close to the average speed had the lowest crash involvement rates, while rates increased for both faster and slower vehicles. Garber and Gadiraju (1988) found a similar U-shaped relationship, where the further the posted speed was from the design speed, the higher the crash rate for the roadway. Speed dispersion is a particularly serious issue on two-lane rural roads (where WVCs occur most

often), because it increases the number of vehicles passing in unsafe situations. Another disadvantage of lower posted speeds is an increase in travel time.

Maintenance requirements

Signs may require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

Costs include:

- The cost of a speed limit sign (24 x 30 inches; 61x76 cm) (about US\$55, USA Traffic Signs 2008);
- The cost of vehicle speed enforcement.

3.2.2 Design Speed and Traffic Calming

General Description

Reducing the design speed of a road may be more effective in reducing operating vehicle speed than reducing the posted speed limit. A lower design speed typically relates to sharper horizontal and vertical curves, narrow lane widths, narrow or no shoulders, and narrow clear zones (i.e., obstructions such as trees closer to the roadway). In addition to the basic highway geometrics, there are numerous traffic calming methods used to slow vehicles down. These are typically used in residential neighborhoods or on a highway approaching a town, and rarely on major highways in rural areas where most WVCs occur. Traffic calming treatments include speed bumps/humps, traffic circles, curb extensions, sidewalk extensions, raised medians and rumble strips. Reduced vehicle speed and increased driver alertness may reduce road kill for all road crossing wildlife species.

Species: Reducing speed does not target WVCs for specific species.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

Direct benefits in terms of reduced WVCs are inconclusive.

Examples of studies:

- In Yellowstone National Park, roads that were designed and reconstructed for higher speeds resulted in increased road kill. Although it was not implemented, extensive modeling on the potential impacts of design speed reductions led to recommendations for not upgrading design speed of roadways during planned reconstruction (Gunther et al. 1998).
- Four “slow points” were installed on a road in Tasmania that had experienced a dramatic increase in collisions with eastern quolls (*Dasyurus viverrinus*) and Tasmanian devils (*Sarcophilus laniarius*) after the road section in a national park was widened and sealed and modal speed increased by 20 km/h (Jones 2000). In addition, after the initial widening the population size of the two species declined substantially and the eastern

quoll population became extinct. The "slow points" consisted of concrete barriers with a "Give Way" sign that constricted traffic to a single lane in the center of the road in or close to locations that had a concentration of road kill (Jones 2000). The tight curves and the merging of traffic forced vehicles to slow down. After the installation of the "slow points", the median vehicle speed in the center of the road section dropped by about 20 km/h (17-35 percent reduction), while vehicle speed at the outer two "slow points" close to the park boundary and wildlife zone boundary was only reduced by 1-7 percent. In addition, road mortality became more sporadic; the eastern quoll population was reestablished and two years after installing the "slow points," reached 50 percent of its previous size before the road was widened and sealed 2 years after the installation of the 'slow points' (Jones 2000). Furthermore there was some indication the Tasmanian devil population was recovering as well.

- Figure 7 shows an example of where speed bumps are used to reduce vehicle speed for cassowaries (*Casuarius casuarius*), a large bird species in Queensland, Australia. The top sign originally displayed a warning for a speed bump, but was vandalized with a black marker to depict a dead cassowary.



Figure 7: Speed bumps (lower right in picture) are used to reduce WVCs in Queensland, Australia (© Marcel Huijser). Please disregard graffiti on signs that made the speed bump look like a dead cassowary.

- In southern Florida, mitigation measures were installed including: 1) rumble strip patches in combination with 2) a black-on-yellow warning sign that reads "PANTHER CROSSING NEXT [X] MI" that has 3) a permanently activated flashing amber light installed on top of the warning sign (Figure 8). These mitigation measures were designed to reduce collisions with the Florida panther by increasing driver alertness and reducing vehicle speed.



Figure 8: Patches of rumble strips accompany a panther warning sign along State Route 29 in southern Florida (© Marcel Huijser).

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Signs do not restrict animal movements.

Potential disadvantages or undesired side effects

- While roads with lower design speeds may encourage lower vehicle speeds, the narrower clear zones associated with such designs have been associated with higher levels of WVCs and other types of collisions.
- Utilizing less-than-desirable geometric features (sharper horizontal curves, reduced lane widths, narrow or no shoulders, and more narrow clear zones) may reduce the overall safety of the roadway. The reduction in safety may be greater if these features violate driver expectancy.

- Depending on the road, its function, and traffic volume, traffic calming may lead to greater congestion and driver frustration.
- Traffic calming options are not viable for through traffic and most high speed state highways.

Maintenance requirements

Some traffic calming designs may result in snow removal difficulties and maintenance issues.

Installation and maintenance costs

No costs were identified in the literature review. Redesigning roads for lower speeds is likely relatively expensive unless they are done as part of a reconstruction project, but the authors were unable to locate documented costs.

3.2.3 Post Advisory Speed Limit

General Description

When a portion of a roadway has characteristics that result in a design speed that is lower than adjacent road sections, advisory speed limits may be useful. Advisory speeds are not enforceable, except by basic reasonable and prudent laws. Posted advisory speed limits have been used (or have the potential to be used) in conjunction with other mitigation measures, such as animal detection systems, in-vehicle technologies, and wildlife warning signs (e.g., Figures 9 and 10). Reduced vehicle speed and increased driver alertness may reduce road kill for all road crossing wildlife species.

Species: Reducing speed does not target WVCs for specific species.



Figure 9: Advisory speed limits accompany a deer warning sign near ‘t Harde, The Netherlands (© Marcel Huijser). Note: The LED part of the warning sign is linked to an animal detection system, but the advisory speed limit reduction sign is always visible in daylight, regardless of the presence and detection of large animals.



Figure 10: The same sign as shown in Figure 9 when triggered at night (© Marcel Huijser).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

Evidence for whether advisory speed limits are effective at reducing WVCs remains sparse.

Examples of studies:

- In Saudi Arabia, enhanced camel (*Camelus dromedarius*) warning signs with reduced advisory speed limits resulted in relatively small, but statistically significant reductions of vehicle speed (3-7 km/h), whereas standard camel warning signs did not. Enhanced signs were also larger than the standard warning signs, had diamond reflective material, had a yellow camel on a black background, and/or were accompanied by text message “camel-crossing” signs (Al-Ghamdi and AlGadhi 2004).
- In Montana, wildlife advisory messages posted on permanent and portable Dynamic Message Signs reduced vehicle speeds. The greatest effect occurred during dark conditions, when the number of WVCs is higher (Hardy et al. 2006).
- In The Netherlands, advisory speed limit signs accompany gaps in exclusionary wildlife fencing (Figures 9 and 10). See also section 3.9 Wildlife Fencing With Gaps, and Figures 34 and 35.

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Signs do not restrict animal movements.

Potential disadvantages or undesired side effects

Advisory speed limits are not enforceable.

Maintenance requirements

Signs must be installed in specific locations, and may require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

The cost of an advisory speed limit sign is about US\$70 (USA Traffic signs 2008).

3.3 Wildlife Warning Signs

Roadway wildlife warning signs are perhaps the most commonly applied WVC mitigation measure (Forman et al. 2003, Sullivan & Messmer 2003). The signs alert drivers to the potential presence of wildlife on or near the road, and urge them to be more alert, to reduce the speed of their vehicle, or a combination of both (see also section 2.1 and Figure 2). These signs attempt to prevent a collision, or to reduce the severity of a collision through lower vehicle speeds at impact.

Since the effectiveness of warning signs depends on driver response, it is critical that warning signs are reliable (i.e., the driver is warned when there is a relatively high chance of WVCs on specific locations). The warning signs discussed below (standard warning signs,

large or enhanced warning signs, seasonal wildlife warning signs) should be placed in road sections that exceed a certain minimum risk of WVCs. Note that animal detection systems were discussed in Chapter 2 already.

3.3.1 Standard

General Description

The standard deer warning sign in the United States is a diamond-shaped panel with a black deer symbol on a yellow background. These signs are intended to inform drivers that the upcoming road section has a history of a higher-than-average number of deer-vehicle collisions. Sometimes signs also indicate the length of applicable road section (Figure 11).



Figure 11: Standard deer warning sign on Highway 83 in Montana includes the length of the road section that the warning sign applies to (© Marcel Huijser).

Species: Standard signs can be used for specific species for areas with a higher-than-average number of species-specific wildlife-vehicle collisions. However, standard signs do not necessarily address potential road avoidance behavior of certain individuals or species.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 0%

The available data suggest that standard deer warning signs are ineffective in reducing WVCs, in general, and deer-vehicle collisions, in particular. Most authors doubt the effectiveness of standard warning signs (Williams 1964, cited in Pojar et al. 1975, Putman 1997, Sullivan & Messmer 2003, Putman et al. 2004), but only two studies were found that investigated their effectiveness, confirming those doubts (Rogers 2004, Meyer 2006).

Examples of studies:

- Meyer (2006) investigated the effectiveness of standard deer warning signs in Kansas by comparing the accident data before and after sign installation. After taking all available

accident data before sign installation and other road and landscape parameters into consideration, there was no evidence that the presence of the deer warning signs had reduced deer-vehicle collisions (Meyer 2006).

- In Saudi Arabia, the installation of standard camel-crossing signs did not result in reduced vehicle speed. Standard warning signs were triangular, with all sides measuring 110 cm, had a white interior with black camel silhouette and red border, and did not have diamond-shaped reflective material (Al-Ghamdi and AlGadhi 2004).
- The installation of deer warning signs did not reduce the number of deer-vehicle collisions in Michigan (Rogers 2004).
- In a driving simulator study, a standard deer warning sign resulted in an average vehicle speed of 123.2 km/h (76.6 mi/h), just over the posted speed limit of 120.7 km/h (75 mi/h) (Stanley et al. 2006). This result showed that standard deer warning signs failed to reduce the average vehicle speed to the posted speed limit.

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Signs do not restrict animal movements.

Potential disadvantages or undesired side effects

As a general rule, unnecessary signs should be removed as they may distract drivers and require maintenance. However, one may choose not to remove standard warning signs if WVCs have been substantially reduced. One reason for this is potential liability for the transportation agency in case of a WVC (Arizona Court of Appeals 2004).

Maintenance Requirements

Signs must be installed in specific locations, and may require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

One study (Pojar et al. 1975) estimated costs at US\$94 per sign (not adjusted for inflation). USA Traffic Signs (2008) reports the following costs: US\$45 (61 cm x 61 cm; 24 in x 24 in), US\$68 (76 cm x 76 cm; 30 in x 30 in), US\$100 (91 cm x 91 cm; 36 in x 36 in).

3.3.2 Non-Standard

General Description

Large or enhanced animal warning signs may take many forms. They can be larger than the standard wildlife warning signs, include graphic images of a vehicle hitting wildlife, and may have permanently activated flashing amber warning lights, light emitting diodes (LEDs), red or orange flags attached to the signs, or messages displayed on Variable Message Signs (VMS) (Figures 12-19). Such signs are designed to attract the attention of the driver and to relay a stronger message than standard wildlife warning signs. However, uniformity across the country is desirable so that drivers learn and understand what different signs represent.

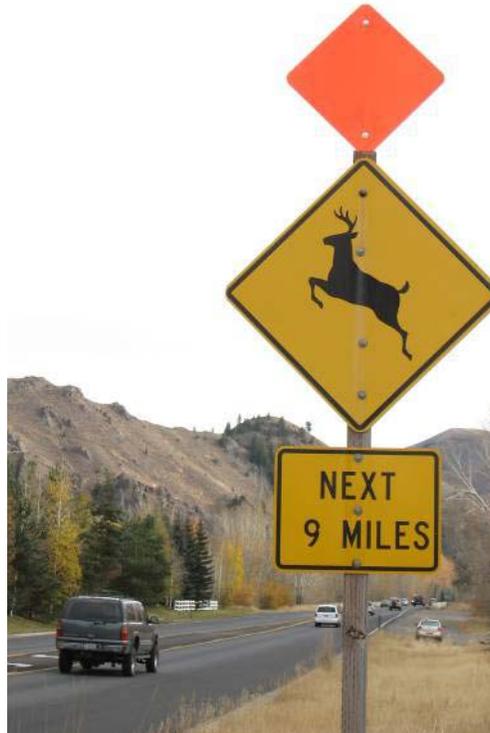


Figure 12: Enhanced standard deer warning sign on State Highway 75 in Idaho (© Marcel Huijser).

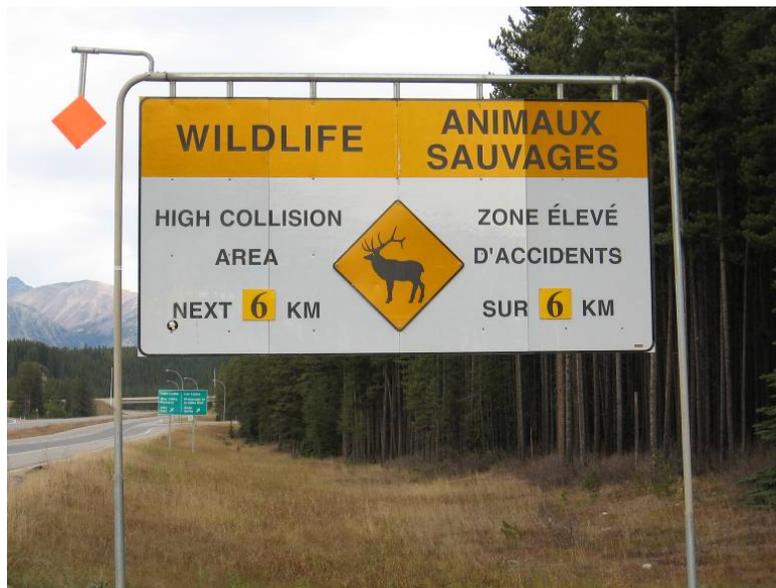


Figure 13: Non-standard elk warning sign on the TransCanada highway, Alberta (© Marcel Huijser).



Figure 14: A VMS updates motorists on moose casualties near Hoback Junction in Wyoming (©Angela Kociolek).



Figure 15: Large enhanced warning sign for bighorn sheep along State Highway 75 in Idaho (© Marcel Huijser).



Figure 16: Large warning sign for wildlife along Hwy 93 south of Radium Hot Springs in British Columbia (© Marcel Huijser).



Figure 17: Large warning sign for bighorn sheep along Hwy 93 south of Radium Hot Springs in British Columbia (©Marcel Huijser).



Figure 18: Warning sign for deer along Hwy 93 in Kootenay National Park in British Columbia (© Marcel Huijser).



Figure 19: Warning sign for elk along Hwy 93 in Kootenay National Park in British Columbia (© Marcel Huijser).

Species: Non-standard signs can be used for specific species in target areas with a higher-than-average number of species-specific WVCs. However, non-standard signs do not necessarily address potential road avoidance behavior displayed by certain individuals or species.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

Observed reduction in vehicle speed suggests that large or enhanced wildlife warning signs may be somewhat effective, but the limited available data on WVCs indicate that the speed reduction through such signs may not really be effective in reducing WVCs (Pojar et al. 1975).

Examples of studies:

- Hammond and Wade (2004) conducted an experiment in a driving simulator and exposed drivers to standard deer warning signs and to enhanced deer warning signs, which were standard warning signs with a flashing light on top. The average vehicle speed with standard deer warning signs was 99.6 km/h. The enhanced sign with the light turned off resulted in similar speeds of 99.5 km/h, but the enhanced sign with the light turned on resulted in a significantly lower vehicle speed of 95.9 km/h, a reduction of 3.7 km/h (Hammond & Wade 2004).
- Hardy et al. (2006) found that wildlife advisory messages on permanent and portable Dynamic Message Signs reduced vehicle speeds and corresponding safe-stopping sight distances by 1–9 percent (1.8–21.9 m), with the greatest effect occurring during dark conditions.
- Lighted animated deer crossing signs reduced vehicle speed by 4.8 km/h compared to the same signs when they were turned off (Pojar et al. 1975). The presence of deer carcasses as a “supplement” to the signs resulted in a much greater reduction in vehicle speed: 12.6 km/h (lights turned off) and 10.0 km/h (lights turned on) (Pojar et al. 1975). Despite the successful speed reduction of the lighted animated signs, they did not result in a reduction of deer-vehicle collisions (Pojar et al. 1975).
- Stanley et al. (2006) conducted experiments with a driving simulator and found that enhanced wildlife warning signs resulted in lower vehicle speeds and earlier braking when drivers were confronted with a deer in the simulated environment.
- Enhanced camel warning signs in Saudi Arabia resulted in a significant reduction of vehicle speed whereas standard camel warning signs did not (Al-Ghamdi & AlGadhi 2004). The standard warning signs were triangular where all sides were 110 cm, with a red border and white interior with black camel silhouette, and did not have diamond reflective material. The enhanced signs were larger than the standard warning signs, had diamond reflective material, had a yellow camel on a black background, and/or were accompanied by the text message “camel-crossing” and a reduced advisory speed limit. The enhanced signs reduced vehicle speed by 3 to 7 km/h (Al-Ghamdi & AlGadhi 2004).

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. Signs do not restrict animal movements.

Potential disadvantages or undesired side effects

By their very nature, non-standard warning signs diminish the uniformity of warning signs generally. Standard warning signs are desirable so that drivers learn and understand what different signs represent (known as “driver expectancy”). While non-standard signs may draw attention, a potential downside is that it takes drivers longer to interpret the sign, simply because it is non-standard.

Maintenance Requirements

Signs must be installed in specific locations, and may require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

One cost estimate (Pojar et al. 1975) reported in the literature was US\$2,000 per sign (not adjusted for inflation). A portable Digital Message System is estimated to cost at least US\$15,000 and permanent DMS designs are much more expensive.

3.3.3 Seasonal

General Description

Seasonal wildlife warning signs are designed to deliver time-specific messages to drivers. They are displayed at certain times of the year when animals cross the road most frequently, such as during a seasonal migration (Figures 20-22). Seasonal signs can be used for specific species for areas with a higher-than-average number of species-specific WVCs.



Figure 20: Seasonal warning signs for bison in Yellowstone National Park (WTI file photo).



Figure 21: A permanent deer warning sign in Idaho has hinges, allowing for its seasonal use (© Marcel Huijser).



Figure 22: Seasonal deer migration sign in Utah (© Marcel Huijser).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 26%

Seasonal wildlife warning signs may result in a 26 percent reduction in deer-vehicle collisions. However, these types of signs are only applicable in situations where deer (or other large animals) display road crossing behavior that is concentrated in space and time.

Examples of studies:

- Sullivan et al. (2004) erected temporary warning signs with reflective flags and permanently flashing amber lights in locations that were known to be used by mule deer (*Odocoileus hemionus*) during their seasonal migration. The number of deer-vehicle collisions was reduced by 51 percent (from a range of 41.5 to 58.6 percent for individual test areas) compared to control areas. The signs reduced the percentage of speeders from 19 percent to 8 percent during their first season of operation, but the effect was less pronounced in the second season, perhaps due to driver habituation (Sullivan et al. 2004).
- Rogers (2004) investigated the effect of enhanced deer warning signs (black on yellow sign showing a deer and a car symbol, combined with a black on orange sign stating “HIGH CRASH AREA”) on the number of deer-vehicle collisions. The signs were deployed between October and January (the peak time for deer-vehicle collisions) for three consecutive years. Rogers (2004) found no effect of the seasonal signs on the number of deer-vehicle collisions.

Effectiveness in reducing the barrier effect of roads and traffic

Reduced vehicle speed and increased driver alertness may increase the number of successful road crossing events for all road crossing wildlife species. However, it does not necessarily address potential road avoidance behavior displayed by certain individuals or species. In addition, the location and time of road crossings by threatened and endangered species may not be the same as those for the most frequently hit species, such as deer.

Potential disadvantages or undesired side effects

This mitigation measure is site-, species-, and population-specific, with limited use otherwise. The signs reportedly are subject to vandalism and theft (Sullivan et al. 2004).

Maintenance Requirements

As seasonal signs are temporary, maintenance is required to install and remove them. They may also require maintenance from vehicle- or weather-related damage and vandalism.

Installation and maintenance costs

Sullivan et al. reported a cost of US\$270 per km (US\$435 per mile).

3.4 Vegetation Management in the Right-of-Way

3.4.1 Vegetation Removal

General Description

Visibility may be improved by reducing roadside vegetation that may obscure wildlife approaching the road. White-tailed deer-vehicle collisions are associated with wooded areas and edge habitat, and are negatively correlated with the distance between roadway and forest cover (Puglisi et al. 1974, Gleason and Jenks 1993, Finder et al. 1999). Removing roadside vegetation, especially shrubs and trees, may allow motorists to see wildlife approaching the road, thereby avoiding collisions. However, in forested areas the clearance of shrubs and trees in the right-of-way may also result in the creation of edge habitat.

Species: Vegetation removal may have the most impact on foraging animals such as ungulates. Increased visibility for drivers may reduce road kill for all road crossing species. Those species that avoid open areas may be negatively affected through an increase of the barrier effect of the widened road corridor.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 38%

There is evidence that vegetation removal is somewhat effective in reducing WVCs. The effects, however, may be temporary and more study is needed.

Examples of studies:

- In a study of DVC mortalities in east central South Dakota, Gleason and Jenks (1993) found that deer were killed more often than expected in areas adjacent to shelterbelts with canopy vegetation.
- Puglisi et al. (1974) found that DVC occurrences were less common where wooded areas were more than 23 m (25 yards) away from a highway in Pennsylvania.
- Clearing vegetation from roadsides resulted in a 20 percent reduction in moose-vehicle collisions in Sweden (Lavsund & Sandegren 1991).
- In Sweden, predictive models showed moose-vehicle collisions were more common on roads that cross through clear-cuts and young forests (Seiler 2005). Collisions may be reduced by 15 percent where the distance between forest cover and the road is greater than 100 m (Seiler 2005).

- While it is recognized that the results may not translate to a highway setting, the clearing of vegetation across a 20 to 30 m swath on each side of a Norwegian railway reduced moose-train collisions by 56 percent (+/-16 percent; Jaren et al. 1991).
- In Norway, a study evaluating the effect of scent-marking, intercept feeding and forest clearing demonstrated that forest clearing resulted in a 49 percent reduction in moose-vehicle collisions (Andreassen et al. 2005).
- Thomas (1995) stated that vegetation clearing is one of the most commonly applied measures to reduce moose-vehicle collisions, and recommended it be used to address moose-vehicle collisions in Alaska.
- Increasing distance between the roadway and forest cover has been shown to be negatively correlated to DVCs in Illinois; recommendations from that study included removing vegetation to provide an open width of the road corridor of at least 40 m in areas where DVCs are particularly high (Finder et al. 1999).
- In addition to affecting visibility, roadside vegetation management may be directed to reducing the attractiveness of roadside forage to animals. While vegetation management to increase visibility and reduce the draw of animals to the right-of-way may be complementary goals in some cases, Putman et al. (2004) summarize the potentially conflicting outcomes of reducing vegetation along roadways:

“The management of roadside vegetation - and specifically, the clearance of woodland or scrub from a margin at the road edge - may have benefits both in increasing driver awareness of deer at the roadside, and increasing visibility of oncoming traffic to the deer themselves. In addition, removal of such vegetation and the cover that it provides may also reduce the probability of deer approaching so close to the road edge in the first place. The method and timing of removal of such vegetation may however be critical. While the removal of vegetation within transportation corridors may help improve driver and animal visibility, simple cutting of encroaching shrub and tree growth may at the same time increase the subsequent attractiveness of these cut-over areas as foraging sites by deer. Such measures might thus actually result in an increase in the number of deer utilizing the roadside - ultimately increasing the risk of accident.”

Effectiveness in reducing the barrier effect of roads and traffic

Shrub and tree clearing may increase the barrier effect of the transportation corridor for species that avoid open areas and, as a result, such clearing practices can be harmful in otherwise forested areas.

- One study found that the width of the right-of-way affected crossing of the Trans Canada highway by wolverines (Austin 1998). Wolverines were more likely to cross the highway in areas with cover closer to the road than in areas with longer distances between cover.

Potential disadvantages or undesired side effects

Removal of brush or trees may result in fresh growth of attractive forage (e.g. grasses) that draws grazing animals to the right-of-way (Groot Bruinderink & Hazebroek 1996), potentially counteracting the safety gains of better visibility with increased probability of wildlife encounters.

Maintenance requirements

Vegetation removal requires a long-term maintenance commitment.

Installation and maintenance costs

Vegetation removal requires a long-term maintenance commitment and may involve expenses to acquire right-of-way in order to manage vegetation as desired. Jaren et al. (1991) calculated that if collisions are reduced by at least 50 percent as a result of removing vegetation, then vegetation removal would be economically beneficial if applied in areas where more than 0.3 per km moose-train collisions occur. Andreassen et al. (2005) estimated forest clearing for 18 km at US\$500 per km, showing that the number of moose saved using this technique could result in a profit of US\$1,080. Andreassen et al. (2005) stated that forest clearing may be more economical than scent-marking and supplemental feeding, pointing out that the initial cutting is the main expense.

3.4.2 Minimize Nutritional Value or Influence Species Composition of Right-of-Way Vegetation

General Description

Roadside vegetation can attract wildlife to roads and increase their vulnerability to WVCs (Case 1978, Cain et al. 2003) (Figures 23 and 24). The practice of planting trees near roadways for landscaping reasons can attract ungulates to the right-of-way and increase the risk of WVCs (Putman 1997). Several sources recommend managing vegetation in the right-of-way so that it does not serve as an attractant to wildlife (e.g., by planting unpalatable species, reducing forage quality, or applying noxious chemicals) (Groot Bruinderink & Hazebroek 1996, Putman 1997, Hyman & Vary 1999 as cited in Evink 2002, Wells et al 1999, Rea 2003, Riley & Sudharsan 2006), while others focus on improving roadside habitat for wildlife (Varland & Schaefer 1998).



Figure 23: Bighorn sheep foraging along roadside on U.S. 93 near Darby, Montana (© Marcel Huijser).



Figure 24: Deer foraging along roadside in the Salmon River Valley, Idaho (© Marcel Huijser).

Species: Minimizing nutritional value or influencing species composition of right-of-way vegetation generally targets herbivores, especially ungulates.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

Techniques employing forage repellents, unpalatable species and roadside brush removal have been used with limited effectiveness on reducing WVCs or are not cost-efficient when broadly applied (Rea 2003). The need to properly study the safety impact of vegetation management along roadways remains (Knapp 2005).

Examples of studies:

- A detailed literature review on roadside vegetation management, plant response to tissue removal, and ungulate foraging behavior yielded recommendations for more carefully designed cutting regimes as a countermeasure for reducing moose-vehicle collisions (Rea 2003).
- Willows cut in mid-July were found to be high in digestible energy and protein compared to plants cut at other times of the year and uncut controls, suggesting that summer brush cutting regimes may inadvertently be attracting moose with nutritious re-growth (Rea & Gillingham 2001, Rea 2003). Cutting in early June results in browse with significantly less nutritional value for the first two years after cutting compared to plants cut later in the growing season and uncut controls (Rea & Gillingham 2001, Rea 2003). Rea (2003) recommended cutting roadside brush in early spring soon after leaves develop to keep nutritional value and palatability to a minimum but recognized operational challenges and limitations (i.e., ground too wet for tractor use, different ungulate species-specific responses to same management regime, etc.) and cautions that this countermeasure may not be suitable for all management areas.
- No studies were found that specifically analyze the WVC safety impacts of roadside management policies or plantings (Knapp 2005), however, a 1999 report by the Arizona Department of Transportation describes a future five-year monitoring plan to address the effectiveness of a number of mitigation measures (including those related to vegetation/habitat changes) on reducing WVCs (Brown et al. 1999).

Effectiveness in reducing the barrier effect of roads and traffic

Reducing habitat quality may increase the barrier effect of roads and traffic for certain species (Forman & Alexander 1998).

Potential disadvantages or undesired side-effects

Minimizing the nutritional value of vegetation in right-of-ways may affect native vegetation along the roadside, but this is not necessarily the case.

Maintenance requirements

High levels of maintenance may be required for management techniques such as roadside brush cutting, planting of undesirable species, and applying herbicides. There are operational

challenges and limitations to roadside brush cutting regimes (e.g., ground moisture early in season, species-specific responses to same management regime, etc.) (Rea 2003).

Installation and maintenance costs

No costs were identified in the literature review.

3.5 Road Design Features

General Description

Consideration of some basic WVC mitigation principles in designing various elements of a highway could minimize the potential for WVCs. The following items should be considered when designing roadways that have a high likelihood for WVCs, such as two-lane, rural/suburban, low/medium volume highways that pass through wildlife habitat:

- Side slopes: Steep side slopes can hide approaching animals from the driver's view. The AASHTO (2004) Green Book recommends slopes of one foot vertical to four feet horizontal or flatter. It further recommends that slope transitions should be gently rounded. This slope is clearly visible (whether cut or fill) by the driver. Designers should use steeper fill slopes with caution, as drivers may not be able to see deer approaching the roadway until the animal leaps over the guardrail. If a steeper side-slope is used, consider a landing on the top for animals to be visible to drivers (and visa versa) before jumping over the guardrail.
- At locations where the roadway crosses drainages, known migration corridors, or known animal habitat, the designer should take extra caution to make animals visible to drivers. At these locations avoid curves, steep side slopes and narrow clear zones.
- At locations where culverts or bridges are installed, consider making the culverts and bridges wide enough to include opportunities for animals to cross under the road. This consideration relates especially to terrestrial animals that may require a bank on either side of a stream or river to cross under the road.
- When designing drainage, consider the impact on wildlife movement and attraction. Avoid creating pooled water in the right of way which can create attractive vegetation. Some wildlife will avoid crossing rip-rap. If rip-rap funnels animals to an undesirable crossing location, consider filling gaps in the rip-rap with sand and gravel (which may make it more conducive for animals to cross) or extend the rip-rap to a more suitable crossing location.
- When considering seeding mixes for the roadside, consider unpalatable species. Also consider plants that do not grow so tall as to visually obscure animals approaching the roadway.
- Concrete median barriers can cause problems for wildlife. When crossing the roadway, wildlife may pause at the barrier, or turn around, increasing their time in the roadway. A summary of the literature by Clevenger and Kociolek (2006) found that "the general hypothesis is that concrete Jersey barriers may increase the risk of direct vehicle mortality [of wildlife]." Mitigations include gaps in the barrier at strategic hot spot locations, cutouts at the bottom for small animals, or using cable barrier designs instead.

- Aside from the basic principles listed here, the designer should estimate the potential magnitude of the WVC problem when designing a road. If there are areas along the route that have a high potential for WVCs, the designer should consider including some of the mitigations mentioned in this report (e.g., wildlife fencing).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

Effectiveness in reducing the barrier effect of roads and traffic

Unknown, but some of the road designs are likely to increase the barrier effect of the road (e.g. steep slopes, concrete barriers).

Potential disadvantages or undesired side effects

Some of the mitigation measures can increase the barrier effect of the road corridor (e.g. steep slopes and concrete barriers)

Maintenance requirements

Standard maintenance schedules would apply mitigation measures that are derived from standard to road design features.

Installation and maintenance costs

Variable, depending on material, installation and maintenance.

3.6 Reflectors and Mirrors

General Description

Deer mirrors and reflectors (Figure 25) are roadside installments intended to act as visual wildlife repellents. Mirrors directly reflect vehicle headlights off the roadway and into the surrounding right-of-way (Danielson & Hubbard 1998). Reflectors beam colored reflected light from headlights into roadside habitat (Swareflex, D. Swarovski & Co., Wattens, Austria, <http://www.swareflex.com/> (accessed 26 January 2007)) or onto the roadway itself (Strieter-Lite, Strieter Corp., Rock Island, Illinois, <http://www.strieter-lite.com/> (D'Angelo et al. 2006)).



Figure 25: Deer reflector along Hwy 93 in British Columbia (© Marcel Huijser).

Species: Reflectors and mirrors are mostly designed to deter deer from the road and right-of-way.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 0%

Most studies testing the effectiveness of mirrors and/or reflectors on reducing WVCs found that they had: 1) no effect (Waring et al. 1991, Ford & Villa 1993, Reeve & Anderson 1993, Cottrell 2003, Rogers 2004), 2) mixed results (Pafko & Kovach 1996, Barlow 1997), or 3) inconclusive results (Gulen et al. 2000). Differences in experimental design and in the variety of models tested confound the comparison of results (D'Angelo et al. 2004). However, Schafer and Penland (1985) did find a significant reduction (88 percent) in WVCs using Swareflex reflectors in Washington State. Pafko and Kovach (1996) found in Minnesota that reflectors reduced the incidence of rural WVCs by 50-97 percent, but suburban metropolitan WVCs increased.

Examples of studies:

- In Wyoming, 39 percent of Swareflex reflectors showed deterioration after three years (Reeve and Anderson 1993).
- The Strieter-Lite company suggests there is scientific proof that their reflectors reduce DVCs by 78-90 percent (Grenier 2002, unpublished) and that reflective luminance, or brightness, is not a major factor because wild animals have acute night vision (Sielecki 2001). Sivic and Sielecki (2001) conducted a spectrometric evaluation of Swareflex and Strieter-Lite wildlife warning reflectors and noted operational implications of low-light reflection intensities.

- Utah DOT discontinued use of reflectors due to an increase in deer kills and difficulty in keeping reflectors clean; high installation and maintenance/cleaning costs were also factors (Page 2006).

Effectiveness in reducing the barrier effect of roads and traffic

Wildlife mirrors and reflectors are designed to deter animals when traffic is present. Therefore, wildlife mirrors and reflectors are likely to increase the barrier effect of the transportation corridor, but this effect may be lessened or absent when no vehicles are present. Examples of studies:

- Studies testing the influence of reflectors on animal behavior found little or no evidence of avoidance (Zacks 1985, Waring et al. 1991, D'Angelo et al. 2006). Ramp and Croft (2002), however, found Swareflex reflectors produced a weak fleeing response in kangaroos. Ujvari et al. (1998) found that deer initially responded to reflectors with alarm and flight but then became habituated to the light reflection.
- D'Angelo et al. (2006) studied Strieter-Lite wildlife warning reflectors in four colors (red, white, blue-green and amber) and found them to be ineffective at altering white-tailed deer behavior so that DVCs might be prevented. Interestingly, data indicated that deer moved toward vehicles in the presence of some of the reflectors. D'Angelo et al. (2006) recommended that future development of deer-deterrent devices for WVC mitigation be based on empirical knowledge of deer senses and behavior.

Potential disadvantages or undesired side effects

Deer have been documented to move toward vehicles in the presence of reflectors (D'Angelo et al. 2006). Reflectors require suitable placement, alignment maintenance and regular cleaning (Sielecki 2004); however, in a roadside application it is challenging to keep reflectors clean at all times (Sielecki 2001, Page 2006). Reflectors have been stolen and vandalized (Sielecki 2004).

Maintenance requirements

Reflectors have installation guidelines, and they must be regularly aligned and cleaned.

Installation and maintenance costs

A manufacturer advertises the total cost of installation with reflectors, posts, equipment, and labor to be US\$4,000-US\$6,000 per km. The average life of reflectors is 12.5 years, so costs amount to US\$169 to US\$199 per km per year. Maintenance costs are estimated at US\$300 per km per year (Strieter-Lite, Strieter Corp., Rock Island, Illinois, <http://www.strieter-lite.com/>).

In British Columbia, reflectors cost approximately US\$10,000 per km to install along both sides of a highway, and maintenance costs range in the order of US\$500 to US\$1,000 per km annually (Sielecki 2004).

3.7 Wildlife Fencing without Gaps

General Description

Fencing is one of the most commonly applied measures to physically separate wildlife from motorists (e.g., Romin & Bissonette 1996) (Figures 26-28). Wildlife fences in North America

typically consist of 2.0-2.4 m (6.5-8 ft) high wire mesh fence material. Several types of fence material are used, but page-wire or cyclone fence material is most common. Wooden or metal fence posts are typically used; the latter are particularly important when fencing over rock substrates. To keep other species from climbing over fences (e.g., cougars, bears), fences can be taller, mesh size can be smaller, and overhangs can be incorporated into the design (Jones and Longhurst 1958, Gloyne and Clevenger 2001) (Figure 29).



Figure 26: Wildlife fence along Interstate 90 near Bozeman, Montana (© Marcel Huijser).



Figure 27: Wildlife fencing along the TransCanada Highway (© Marcel Huijser).



Figure 28: A 3.4 m high chain link fence along SR 29 in southern Florida designed to prevent Florida panthers from entering the roadway and to guide them toward underpasses (© Marcel Huijser).



Figure 29: A 3.4 m high chain link fence along SR 29 in southern Florida was equipped with three strands of outriggered barbed wire to prevent Florida panthers from climbing the fence (© Marcel Huijser).

Species: Wildlife fencing can be used to reduce wildlife-vehicle collisions for a range of target species. Modifications may be required, depending on size and climbing abilities of target species. Wildlife fencing is often intended for large mammals, especially those that cannot easily climb or otherwise cross wildlife fencing. However, fencing, screens, concrete walls or other barriers have also been applied for smaller species, including reptiles, amphibians and medium-sized mammals.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 87%

When installed and maintained correctly, wildlife fencing can form a nearly impermeable barrier to large mammals, eliminating or substantially reducing the number of wildlife-vehicle collisions. Most studies report an 80-95 percent reduction in wildlife-vehicle collisions. Since fencing creates an almost absolute barrier to wildlife movements, fencing should typically be combined with safe wildlife crossing opportunities (e.g., wildlife underpasses and wildlife overpasses). Since some animals still breach fences and walk around fence ends, escape opportunities and fence end treatments are also considered good practice.

Examples of studies:

- Woods (1990) reported a 94-97 percent reduction in ungulate-vehicle collisions along a fenced section of the Trans-Canada Highway in Alberta, Canada. Along the same road,

Clevenger et al. (2001b) showed that fences were effective in reducing vehicle collisions with ungulates by 80 percent. Clevenger et al (2001b) also found that WVCs were closer to fence ends than expected; however access points (gaps in the fence) were not hotspots for WVCs.

- In Pennsylvania, Feldhamer et al. (1986) concluded that a 2.7 m (8.9 ft) high fence was more effective than the 2.2 m (7.2 ft) high fence, but that deer permeated both types of fences, and overall DVCs were not reduced. They suggested that fencing may be effective if properly maintained to fix holes that people cut into it, and repair gaps that develop under the fence. They also suggested that the size of the openings in the woven wire mesh be decreased.
- In Sweden, fencing reduced moose-vehicle collisions by 80 percent (Lavsund & Sandegren 1991).
- In British Columbia, exclusion fencing (2.4 m high) was 97-99 percent effective at reducing accidents with large wildlife (Sielecki 1999).
- Reed et al. (1982) reported an average reduction of 78.5 percent for DVCs in Colorado as a result of the installation of wildlife fencing.
- Ward (1982) reported a reduction of greater than 90 percent for mule deer in Wyoming.
- Boarman and Sazaki (1996) found that new or properly maintained fences significantly reduced mortality for several wildlife species, including the desert tortoise. They found 93 percent fewer tortoise carcasses and 88 percent fewer vertebrate carcasses along a fenced section compared to an unfenced section of highway.
- The effectiveness of electric fencing (ElectroBraid™) in keeping deer off runways at airports was studied by Seamans and VerCauteren (2006), and their results could be applicable to preventing deer from accessing highways. The authors found that fencing as low as 1.3 m (4.3 ft) was sufficient to exclude deer, unless deer were pressured across it. Fences were highly effective (90 percent) when turned on and maintained.
- In a theoretical study investigating how full fencing (no wildlife crossings) with the intent of keeping wildlife off of roadways and reducing wildlife mortality might affect the long-term viability of animal populations, Jaeger and Fahrig (2004) modeled population responses to a range of scenarios. Their models showed that when no fencing was in place, traffic mortality had a stronger effect on population viability than the effect of animals avoiding the road. The authors concluded that fencing could improve viability in populations with high road mortality. They discouraged the use of fencing (without crossing structures) when the population size was stable.

Effectiveness in reducing the barrier effect of roads and traffic

With wildlife fencing, animal movements across the road are blocked or nearly completely blocked. This increases the barrier effect of the road, disrupting daily, seasonal and dispersal movements, and potentially reducing the population survival probability of the species concerned. Species that cannot easily penetrate, climb or otherwise cross wildlife fencing are confronted with an increased barrier effect of the transportation corridor, unless sufficient safe crossing opportunities are provided.

Potential disadvantages or undesired side effects

Wildlife fences, when installed correctly, form a nearly impermeable barrier to large mammals. While this can nearly eliminate collisions with large mammals or at least reduce the number of collisions substantially, wildlife fences result in several undesirable side effects. For example:

- Animal movements across the road are strongly reduced or completely blocked, which strongly increases the barrier effect of the road. Daily, seasonal and dispersal movements are all strongly reduced or eliminated. For some species, and in certain situations, this may severely reduce the population survival probability of the species concerned. The species affected may include some that are not a safety threat or that may not have a population in the immediate vicinity of the transportation corridor. Therefore, absolute barriers, such as wildlife fencing, when applied over long distances, should typically be accompanied with safe crossing opportunities for a wide array of species.
- Animals are more likely to break through the wildlife fencing if safe crossing opportunities are not provided or if there are too few, or if they are too small, or too far apart. 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 between the fences around fence ends by digging under the fence (coyotes have been known to slip beneath the fence along the Trans-Canada Highway in Banff National Park), through gaps in the fence, or they may be able to climb the fence. Therefore, absolute barriers such as wildlife fencing should typically be accompanied with escape opportunities for animals that end up between the fences.
- Animals can and do cross the road where fences end. In some cases it can result in a concentration of WVCs at fence ends (Clevenger et al. 2001b, Norris Dodd, Arizona Game and Fish Department, personal communication). Therefore, consideration should be given to measures that mitigate a potential concentration of WVCs at fence ends.
- Wildlife fencing can have a negative impact on landscape aesthetics; many people perceive tall wildlife fences as ugly. The Utah DOT has painted wire mesh fencing dark brown which camouflages the wire mesh to some extent. A chain link fence for Key deer on Big Pine Key in southern Florida (Figure 30) and a similar fence for the American crocodile and people along U.S. Hwy 1 between Florida City and Key Largo (Figure 31) have been coated with black plastic to reduce the impact of the fence on landscape aesthetics. However, camouflaging fencing because of landscape aesthetics may conflict with increasing risks for wildlife (see next bullet).



Figure 30: A 2.44 m (8 ft) high chain link fence along U.S. Hwy 1 on Big Pine Key, Florida, has been coated with plastic to make the fence blend in with its surroundings (© Marcel Huijser).



Figure 31: A 1.83 m (6 ft) high chain link fence along U.S. Hwy 1 between Florida City and Key Largo, Florida, has been coated with plastic to make the fence blend in with its surroundings (© Marcel Huijser).

- Wildlife fencing may pose a direct or indirect mortality risk for certain species. Large mammals may get tangled up in the fence, or fences may injure them, potentially resulting in a slow death. In addition, wildlife fences may also be exploited by predators when pursuing prey. After the addition of two lanes on the Trans-Canada Highway and installation of fencing that cut off escape terrain for bighorn sheep, coyotes, wolves and possibly cougars learned to stampede sheep into the fence (Cliff White, Parks Canada, personal communication). About 40 bighorn sheep were killed this way in the first two years after fencing until a mitigation measure was put in place that made the fence more visible to the bighorn sheep (Cliff White, Parks Canada, personal communication). In addition, wolves, bears and other predators have also occasionally been seen running prey species into wildlife fences (Leeson 1996). Finally, birds may collide with fences and die (Baines & Summers 1997, Dobson 2001). Thus, camouflaging fencing because of landscape aesthetics may conflict with increasing risks for wildlife.
- Access roads to the main road require a disruption of the wildlife fencing, resulting in an opening that has to be mitigated in order to avoid animals getting caught inside the fences along the transportation corridor.
- Access for people (e.g., for hiking, biking, or fishing) may be blocked by wildlife fencing.

Wildlife underpasses and overpasses are tunnels and vegetated bridges designed to allow wildlife to cross the road. In addition, wildlife jump-outs are usually integrated with wildlife fencing. These features allow animals that do manage to cross the fence to escape from the fenced road and right-of-way.

Maintenance requirements

If properly installed, fence material (wire and posts) should last 20 years or more without replacement (Grande et al. 2000; Terry McGuire, Parks Canada, personal communication). Regular fence maintenance is critical in order to keep it functioning properly. Earth slumping on hill slopes, inadequate installation techniques resulting in gaps between ground and fence bottom, and breaches of the fence by the public (e.g., access for fishing, hunting, or snowmobiling) allow animals to gain entry to the right-of-way. Fence maintenance is a major concern because priorities and budgets change over time. Fence maintenance is often neglected shortly after construction; meanwhile fence damage and gaps are a recurrent problem.

Installation and maintenance costs

- Wildlife fencing (2.4 m, or 8 ft high) in Banff National Park, Alberta, cost Can\$30 per m (Can\$9 per ft) for one side of the highway during the phase 3A Trans-Canada Highway expansion in 1997 (Terry McGuire, Parks Canada, personal communication). For the entire 18 km section of highway, fencing both sides cost roughly Can\$1 million. ElectroBraid™ fencing used in the study by Seamans and VerCauteren (2006) consisted of five rope strands at 25 cm (9.7 in) and cost US\$9 per m (US\$2.7 per ft) (Seamans & VerCauteren 2006). 1.2 m high (4-ft), 5-Braid™ ElectroBraid™ Deer Exclusion Fence is advertised at US\$4300 per km (US\$7,000 per mile) while 1.5 m (5 ft) high, 5-Braid™ ElectroBraid™ Moose Exclusion Fence is advertised at US\$4750 per km (US\$7,500 per mile) (ElectroBraid 2006).

- Sielecki (1999) compared the benefits to costs of fencing over different time spans (20-30 years) and given different levels of potential damage prevented. He concluded that benefits of the wildlife fencing outweighed potential costs in 12 of 16 cases. Fencing in his study ranged from Can\$40,000-80,000 per km.
- The cost of wildlife fencing along U.S. Highway 93 on the Flathead Reservation in Montana varied depending on the road section concerned: US\$26, US\$38, US\$41 per m (US\$7.9, US\$11.6, US\$12.5 per ft) (Pat Basting, Montana Department of Transportation, personal communication). A finer mesh fence was dug into the soil and attached to the wildlife fence for some fence sections at a cost of US\$12 per m (US\$6.7 per ft) (Pat Basting, Montana Department of Transportation, personal communication).
- Fencing could be impractical in dense vegetation areas, where there is little or no public roadside right-of-way.

3.8 Boulders in the Right-of-Way

General Description

Large boulders have been placed in the right-of-way, outside of the clear zone, as an alternative to wildlife fencing. Large boulders are thought to make it hard for animals, especially ungulates, to walk across an area.

Species: Boulders in the right-of-way is intended for ungulate species and/or other animals that cannot cross large boulders.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

The large boulders are believed to be an effective alternative to wildlife fencing if all the gaps are eliminated. In contrast to wildlife fences, large boulders are natural and, depending on the landscape, can address the landscape aesthetics concern associated with wildlife fences.

Examples of studies:

- Boulders have been used for this purpose along State Route 260 in Arizona (Terry Brennan, U.S. Forest Service, personal communication; Norris Dodd, Arizona Game and Fish Department, personal communication) (Figures 32 and 33). The boulder barrier was not extended through areas with steep slopes, since it was thought that wildlife would not move through these steep areas. However, animals have traveled through these areas. The barrier is thought to be effective with exception of the gaps in the steep areas (Norris Dodd, Arizona Game and Fish Department, personal communication).



Figure 32: Large boulders placed in the right-of-way as a barrier to elk and deer along State Route 260 in Arizona (© Marcel Huijser).



Figure 33: Large boulders placed in the right-of-way as a barrier to elk and deer with a view of State Route 260 (under construction) in Arizona (© Marcel Huijser).

Effectiveness in reducing the barrier effect of roads and traffic

If boulders are indeed an absolute barrier to ungulates and/or other species groups, animal movements across the road are strongly reduced or completely blocked. This increases the barrier effect of the road. Daily, seasonal and dispersal movements may be strongly reduced or eliminated, and depending on the species and local situation, may reduce the population survival probability of the species concerned. Large species (e.g., ungulates) that cannot cross boulders are likely to be confronted with an increased barrier effect of the transportation corridor, unless sufficient safe crossing opportunities are provided for.

Potential disadvantages or undesired side effects

- If boulders are indeed an absolute barrier to ungulates and/or other species groups, safe passage may have to be provided for wildlife at selected locations.
- The barrier effect effects of large boulders would have to be carefully evaluated for other species.

Maintenance requirements

Debris may need to be removed from boulder fields.

Installation and maintenance costs

Costs for the Arizona case study were less than US\$197 per m (less than US\$60 per linear foot) (Norris Dodd, Arizona Game and Fish Department, personal communication).

3.9 Wildlife Fencing with Gaps

General Description

Absolute barriers such as wildlife fences increase the barrier effects of a road, disrupting daily, seasonal and dispersal movements, and potentially reducing the population survival probability of the species concerned. The species affected may include species that are not a safety threat or that may not even have a population in the immediate vicinity of the transportation corridor. Therefore absolute barriers, such as wildlife fencing, should typically be accompanied with safe crossing or escape opportunities for wildlife.

Gaps in fences on opposite sides of the road allow animals to cross the road. In most cases such gaps are accompanied with wildlife warning signs, crosswalks for wildlife, wildlife warning signs in combination with mandatory or advisory speed limit reductions, or animal detection systems. These can inform the drivers that a large animal may be on or near the road at that time. Once a driver is aware that a large animal may be on or near the road ahead, the driver may lower the speed of the vehicle or may become more alert or both.

Species: Wildlife fencing can be used to reduce WVCs for a range of target species. Modifications may be required, depending on the size of the target species. Wildlife fencing is often intended for large mammals, especially those that cannot easily climb or otherwise cross wildlife fencing. Small- or medium-sized animals are not detected by animal detection systems. Species that avoid open areas or unnatural substrate (e.g., pavement) may not benefit from an at-grade crossing opportunity.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: with warning signs and crosswalk—40 percent; with animal detection systems—82 percent.

- Wildlife fences may reduce road mortality by 80-99 percent, but may increase the barrier effect of the road. Gaps in the wildlife fence allow animals to cross the road, but mortality can occur since they cross at grade, thereby reducing the effectiveness of the wildlife fence. Data are not available on the road kill that occurs at a gap with or without warning signs, but a gap in a wildlife fence that is combined with wildlife warning signs and a crosswalk reduced the effectiveness of the wildlife fence from 80-99 percent to 42.3 percent (four-lane highway) and 36.8 percent (two-lane highway) (Lehnert & Bissonette 1997). Animal detection systems have been used at gaps in wildlife fences, but there are not data on the effectiveness of this measure in combination with a gap in a fence. As a stand-alone mitigation measure, however, animal detection systems may reduce collisions with ungulates by 82 percent on average (review in Huijser et al. 2006).

Examples of studies:

- A system of wildlife fences and gaps was installed to reduce vehicle collisions with mule deer (*Odocoileus hemionus*) along a two-lane and divided four-lane highway in northeastern Utah (Lehnert & Bissonette 1997). The gap had warning signs for motorists and a crosswalk was painted on the road surface as an additional sign for motorists. Road mortality was reduced by 42.3 percent (four-lane highway) and 36.8 percent (two-lane highway) compared to the expected road mortality. However, statistical significance of this reduction could not be demonstrated.
- Along State Route 260 near Payson, Arizona, a gap in an electric fence has been combined with an animal detection system (Dodd & Gagnon 2008). Preliminary results indicated that activated warning lights reduced vehicle speeds by about 20 percent and that elk-vehicle collisions may have been reduced by about 92 percent (Dodd & Gagnon 2008).
- The Netherlands has installed animal detection systems at gaps in wildlife fencing at two locations ('t Harde and Ugchelen) (Huijser et al. 2006a) (Figures 34 and 45).
- Similar to wildlife fences, median barriers can be an absolute or partial barrier to certain species (Clevenger & Kociolek 2006). In some cases gaps have been created in the median barrier to allow animals to cross the road. However, the effectiveness of these gaps has largely been untested (Clevenger & Kociolek 2006).



Figure 34: Gap in a wildlife fence accompanied by wildlife warning signs and advisory speed limit reduction, the Netherlands (© Marcel Huijser).



Figure 35: Gap in a wildlife fence combined with an animal detection system, wildlife warning signs and advisory speed limit reduction, the Netherlands (© Marcel Huijser).

Effectiveness in reducing the barrier effect of roads and traffic

Large mammal species that cannot easily climb or otherwise cross wildlife fencing are likely to be confronted with an increased barrier effect of the transportation corridor because their movements across the road are restricted to certain locations. However, the percentage of successful crossings may increase, as the gaps allow for at-grade road crossing in restricted areas.

Potential disadvantages or undesired side effects

At gaps in fences, animals cross the road at grade, exposing the drivers and wildlife to potential collisions. This may reduce the effectiveness of the wildlife fence, but to what extent depends on the type of warning signals that are presented to drivers at the fence gap. No data have been located about the risk of gaps that have static warning signs, but the available data for wildlife warning signs in combination with crosswalks suggest that the effectiveness of wildlife fencing may be reduced from about 87 percent to about 40 percent. The available data for animal detection systems suggest that a gap with an animal detection system may reduce the effectiveness of the wildlife fencing from 87 percent (on average) to 82 percent. In addition, once through a gap, animals may wander along the road or in the right-of-way, becoming trapped between the wildlife fences, exposing the drivers and wildlife to other potential collisions. Measures that allow animals to escape from the road and right-of-way should typically be implemented (see further information later in this section).

Maintenance requirements

Regular fence maintenance is critical in order to keep it functioning properly. Earth slumping on hill slopes, inadequate installation techniques resulting in gaps between ground and fence bottom, and breaches of the fence by the public (e.g., for fishing, hunting, or snowmobiling) allow animals to gain entry to the right-of-way. Fence maintenance is a major concern because priorities and budgets change over time. Fence maintenance is often neglected shortly after construction; meanwhile fence damage and gaps are a recurrent problem. Reliability of the sensors used in animal detection systems have shown problems, although some of the manufacturers have overcome these problems (Huijser et al. 2006a; Huijser et al 2007a).

Installation and maintenance costs

- The costs of crosswalks across a two-lane road and a four-lane road (excluding wildlife fencing and escape from right-of-way measures) were reported at US\$15,000 and US\$28,000, respectively (Lehnert & Bissonette 1997).
- The estimated cost of animal detection systems at a gap in the fence is US\$50,000 (including installation and fence) (Huijser et al. 2006a).

3.10 Wildlife Fencing with End Treatments

Wildlife fencing eventually stops somewhere. To prevent animals from walking around fence ends onto the right-of-way between the fences or onto the road, some form of end treatment may be required. Angled fencing away from the road may reduce the problem, but additional mitigation measures such as constructed boulder fields or animal detection systems may be required.

3.10.1 Mitigation for Fence Ends: Boulders Between Fence and Roadway

General Description

To discourage ungulate species from entering the fenced sections of the Trans-Canada Highway in Alberta, rock impediments or boulder fields were placed at the ends of the fence between the roadway and the fence, as shown in Figure 36 (Clevenger et al. 2002a). Boulders, roughly the size of bowling balls, were laid out uniformly to create a boulder field. The boulders are thought to discourage animals, especially ungulates, from walking across them.



Figure 36: The boulder field at the fence end at Dead Man's Flats along the Trans-Canada Highway east of Canmore, Alberta (© Bruce Leeson).

Alternatively, the fence end can angle towards the road and concrete barriers can prevent vehicles from crashing into the fence posts (Figure 37).



Figure 37. Fence end brought close to the road with a concrete barrier for safety along Hwy 93S in Banff National Park, just west of Castle Jct (© Marcel Huijser, WTI-MSU).

Species: Boulders in the right-of-way are intended for ungulate species and/or other animals that do not easily cross large boulders.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

Clevenger et al. (2002a) found that the combination of the boulder field and wildlife fencing were effective in reducing WVCs. The boulders were believed to be an effective deterrent in keeping ungulates from wandering between the fences (Clevenger et al. 2002a).

Examples of studies:

- In Banff National Park, Canada, DVCs on a particular road segment were reduced after the installation of fencing in combination with a boulder field. The boulders were credited as an effective deterrent in keeping ungulates from walking around the fence onto the right-of-way (Clevenger et al. 2002a). The boulder field begins at the fence end, sits on the margin of the paved edge of the highway, and is approximately 15 m wide and 20-25 m long (16.4 x 21.9-27.3 yard). Placing a guardrail between the road and boulder field provided for highway safety compliance in Alberta (and probably most states).
- The boulder field at Dead Man's Flats wildlife underpass along the Trans-Canada Highway east of Canmore, Alberta, is 100 m (328 ft) long with the width varying from about 8 to 20 m, (26 to 66 ft), depending on how close the fence is positioned to the roadway, with the boulders extending right from the pavement edge to the fence (Bruce Leeson, personal communication). In addition, a 19 m (62 ft) wide strip of boulders was

placed in the median. The boulders are subangular, quarried rock, ranging in size from 20 to 60 cm (7.8 to 23.6 in) (about 75 percent are larger than 30 cm (11.8 in). The boulder apron, at a depth of about 40-50 cm (15.7-19.7 in), is installed on geofabric on sub-excavated smoothed ground. The boulders project about 20-30 cm (7.8-11.8 in) above the local ground surface (Bruce Leeson, personal communication).

Effectiveness in reducing the barrier effect of roads and traffic

With wildlife fencing, animal movements across the road are blocked or nearly completely blocked. This increases the barrier effect of the road, disrupting daily, seasonal and dispersal movements, and potentially reducing the population survival probability of the species concerned. Large species (e.g., grizzly bear, gray wolf) that cannot easily climb or otherwise cross wildlife fencing are likely to be confronted with an increased barrier effect of the transportation corridor, unless sufficient safe crossing opportunities are provided.

Potential disadvantages or undesired side effects

In areas of regular snowfall, the boulder fields become covered with snow, which allows ungulates to travel across them. There may be some motorist safety issues for some states by having an obstruction (and hazard) within the clear zone. In Alberta these safety issues were addressed by placing a guardrail at the road edge.

Maintenance requirements

Debris may need to be removed from boulder fields.

Installation and maintenance costs

The material and labor for the installation of boulders at the fence end at Dead Man's Flats wildlife underpass along the Trans-Canada Highway east of Canmore, Alberta, was estimated to cost Can\$65,000 (installed in 2005, cost estimate for 2007) (Bruce Leeson, personal communication).

3.10.2 Mitigation for Fence Ends: Animal Detection Systems

General Description

Animals may cross the road where fences end, which can in some cases result in a concentration of WVCs. Installing animal detection systems (see Chapter 2) at fence ends may reduce WVCs at these points.

Species: Animal detection systems detect large animals (i.e., deer and larger), while small- to medium-sized mammal species such as Canada lynx and gray wolf may rarely or never be detected.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

The benefits of using animal-vehicle detection systems at fence ends are unknown, but as a stand-alone mitigation measure, animal detection systems can reduce collisions with large ungulates by 82 percent (review in Huijser et al. 2006a). The application of animal detection systems at fence ends can be expected to result in a similar reduction in WVCs, but data on effectiveness are relatively scarce and may vary.

Examples of studies:

- In Arizona, an experiment is currently being conducted with animal detection systems at fence ends to mitigate a concentration of deer- and elk-vehicle collisions (Dodd & Gagnon 2008).

Effectiveness in reducing the barrier effect of roads and traffic

Species that cannot easily climb or otherwise cross wildlife fencing are confronted with an increased barrier effect by the transportation corridor because their movements across the road are restricted to certain locations. However, the percentage of successful crossings may increase. Only larger-sized species (i.e., deer and larger) may benefit from the presence of an animal detection system. Animal detection systems do not restrict animal movements.

Potential disadvantages or undesired side effects

No undesirable effects were identified in the literature review.

Maintenance requirements

Fences and animal detection systems may require maintenance (see relevant sections above).

Installation and maintenance costs

No costs were identified in the literature review.

3.11 Wildlife Fencing with Escape Opportunities

Animals may end up between fences or other barriers placed along the transportation corridor posing a safety risk and exposing the species concerned to road mortality. Therefore, absolute barriers, such as wildlife fencing, should typically be accompanied with escape opportunities for animals that have ended up between the fences (Reed et al. 1974a; Ludwig & Bremicker 1983; Feldhamer et al. 1986; Bissonette & Hammer 2000).

3.11.1 Jump-outs or Escape Ramps

General Description

Jump-outs or “escape ramps” are sloping mounds of soil placed against a backing material on the right-of-way side of the fence (Figure 38 and 39). The highway fence is tied in to the edges of the jump-out. Jump-outs are designed to allow animals caught between the fences to jump out of the right-of-way. At the same time, jump-outs should not allow animals to jump into the right-of-way area. Little is known about the appropriate height for jump-outs. The appropriate height of jump-outs is likely dependent on the main species of interest and the terrain (e.g., up-slope or down-slope), but they are typically 1.6-2.2 m (5-7 ft) in height.



Figure 38: A jump-out along a 2.4 m (8 ft) high fence along U.S. Highway 93 in Montana (© Marcel Huijser).



Figure 39: A jump-out along a 2.4 m (8 ft) high fence along U.S. Highway 93 in Montana (© Marcel Huijser).

To prevent injury to the animals that jump out, the landing spot at the bottom of the jump-out should consist of loose soil or other soft material (Bruce Leeson, personal communication). Where bears are present the walls must be smooth to prevent them from climbing into the right-of-way (Bruce Leeson, personal communication) (Figure 40). Furthermore, it is thought to be best for jump-outs to be positioned in a set-back in the fence, in an area protected with tree cover, where animals may calm down and have time to decide whether to jump off the jump-out (Bruce Leeson, personal communication). A short fence on the jump-out itself, perpendicular to the road and the right-of-way fence, may also help guide animals to the jump-outs. For additional guidelines see Bissonette and Hammer (2000).



Figure 40: A jump-out along a 2.4 m (8 ft) high fence with smooth metal to prevent bears from climbing into the right-of-way along the Trans-Canada Highway, Lake Louise area, Banff National Park, Canada (© Marcel Huijser).

Species: The vertical drop off on the backside of escape ramps is designed to preclude deer and other large mammals from gaining access to the right-of-way from the non-highway side of the fence. Deer and elk are the most common users of jump-outs along the Trans-Canada Highway in Banff National Park, but moose and bighorn sheep have also used these structures (Bruce Leeson, personal communication).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 29%

Based on Bissonette and Hammer (2000), jump-outs were effective in allowing deer to escape the right-of-way and in reducing DVCs. Using jump-outs or “escape ramps” along

two fenced road sections reduced collisions by 28.6 percent on average (Bissonette & Hammer 2000). Jump-outs were eight to eleven times more effective than one-way gates (Bissonette and Hammer 2000).

Examples of studies:

- Bissonette and Hammer (2000) studied the effectiveness of earthen escape ramps (jump-outs) and one-way gates along a fenced section of U.S. Highway 91 and U.S. Highway 40 in northern Utah. The 2.4 m (8 ft) fence was not 100 percent effective, due to human vandalism and gaps under the fence, so additional measures were necessary to help get deer off the highway. The authors noted peaks in DVCs in spring and fall, and noted that DVCs declined after installation of the jump-outs. Jump-outs were eight to eleven times more effective than one-way gates. The authors calculated that if the ramps offset even 2 percent of deer mortality, they would be considered cost-effective within one to two years. They recommended jump-outs instead of one-way gates, and concluded that (with fencing) these are effective mitigation measures for removing deer from highway rights-of-way and minimizing accidents with motorists.
- Clevenger et al. (2002a) documented use of jump-outs by deer, elk and coyote on the Trans-Canada Highway.

Effectiveness in reducing the barrier effect of roads and traffic

While jump-outs are not intended as a crossing structure, they do allow animals that are trapped between the fences in the right-of-way to escape. Thus they reduce the trapping and potential road mortality of the individuals involved.

Potential disadvantages or undesired side effects

If the jump-outs are not high enough, animals may jump up and end up in the right-of-way between the fences. On the other hand, if jump-outs are too high, animals will not use them to escape from the transportation corridor. Furthermore, jump-outs need to be well away from the travel lanes and clear zone to avoid the danger of cars that have run off the road crashing into them.

Maintenance requirements

Debris may need to be removed from on or under jump-outs.

Installation and maintenance costs

Reported costs for one jump-out range from US\$11,000 (Bissonette & Hammer 2000) to US\$6,250 (Pat Basting, Montana Department of Transportation, personal communication).

3.11.2 One-way Gates

General Description

One-way gates allow animals to enter from the road side and go through the fence, providing a possible opportunity for escape from the transportation corridor.

Species: Gates (Figures 41 and 42) have been built for different sized species, ranging from moose, elk, and deer to the Eurasian badger (Ludwig & Bremicker 1983, Bissonette & Hammer 2000, Kruidering et al. 2005).



Figure 41: One-way elk gate in British Columbia, (© Marcel Huijser).



Figure 42: One-way Eurasian Badger gate, the Netherlands (© Marcel Huijser).

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

In general, one-way gates are no longer recommended as wildlife can learn how to use them to get into the right-of-way (Clevenger et al 2002b), sometimes aided by hikers, fishermen, equestrians and bikers who propped and tied the gates open (Bruce Leeson, personal communication). Jump-outs appear more effective than one-way gates in allowing ungulates to escape from the right-of-way (Bissonette & Hammer 2000).

Examples of studies:

- One-way gates were believed to be relatively effective for deer (Reed et al. 1974a); however, in a later study, only 17 percent of deer that approached one-way gates actually used them (Lehnert 1996).
- In Banff National Park, Canada, an elk herd not only learned how to go through the gate the “wrong way” but they also destroyed the gate within a week after they learned how to enter the gate from the “wrong side” (Bruce Leeson, personal communication). In the same area, coyotes learned to crawl through the tines to feed on mice that became more abundant in the right-of-way now that it was no longer grazed by ungulates (Bruce Leeson, personal communication).
- At another location, at least one elk has been observed “taking a gate out” as the gate was too small for its body size (Monique DiGiorgio, Southern Rockies Ecosystem Project, personal communication), and at least one moose has been observed getting its antlers stuck and damaging its velvet (Rick Sinnott, Alaska Fish and Game, personal communication).

Effectiveness in reducing the barrier effect of roads and traffic

While one-way gates are not intended as a crossing structure, they do allow some animals that are trapped between the fences in the right-of-way to escape. Thus they reduce the trapping and potential road mortality of the individuals involved. However, jump-outs appear to be used more readily by animals than one-way gates, and one-way gates have been observed to be a safety hazard for some wildlife species. They are no longer recommended.

Potential disadvantages or undesired side-effects

There are undocumented reports that animals tried to reverse course by backing up once they had entered elk gates, after which they got stuck and wounded themselves, and later died.

Maintenance requirements

Gates may be impaired or destroyed by wildlife, requiring repair or replacement. Gates may need to be monitored to ensure they remain closed and not propped open by human users.

Installation and maintenance costs

Estimated costs were reported at US\$8,000 per one way gate (Bissonette & Hammer 2000).

3.12 Wildlife Fencing Intersecting with Access Roads

Access roads that intersect with the main road disrupt wildlife fencing, resulting in a gap where animals can walk around a fence end and enter the right-of-way.

3.12.1 Gaps Caused by Access Roads: Gates

General Description

Gates (Figure 43) can be opened when leaving or accessing the main road. This approach is an inconvenience to drivers, as they have to stop and get in and out of their vehicle. Gates are normally only installed at access roads that have very low traffic volume.



Figure 43: Gate on a low volume access road along U.S. Highway 93 in Montana (© Marcel Huijser).

Species: Gates at access roads are intended to be a barrier for species that cannot cross a wildlife fence or gate.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: unknown

For species that cannot cross a wildlife fence or gate, direct road mortality is likely to decrease compared to having an opening through which animals can readily access the road and right-of-way. The use of gates results in no further reduction in collisions compared to an undisrupted wildlife fence (presuming the gates are closed by users).

Examples of studies:

- Access road gates are used for the U.S. Highway 93 reconstruction project in Montana to retain the integrity of wildlife fencing.

Effectiveness in reducing the barrier effect of roads and traffic

Unknown, however, the barrier effect of the transportation corridor is likely to increase.

Potential disadvantages or undesired side effects

Gates are an inconvenience to drivers, and they may potentially increase WVCs if they are left open.

Maintenance requirements

Gates may be impaired or destroyed by wildlife, requiring repair or replacement. Gates may need to be monitored to ensure they remain closed and not propped open by human users.

Installation and maintenance costs

Costs for single- and double-panel gates along U.S. Highway 93 on the Flathead Indian Reservation in Montana were US\$300-360 and US\$350-US\$550, respectively (Pat Basting, Montana Department of Transportation, personal communication).

3.12.2 Wildlife Guards

General Description

Cattle or wildlife guards are designed to discourage wildlife, especially ungulates, from walking through a gap in the fence (Figure 44 and 45).



Figure 44: Wildlife guard along U.S. Highway 93 on the Flathead Indian Reservation, Montana (© Marcel Huijser).



Figure 45: Wildlife guard along U.S. Highway 1 for Key deer on Big Pine Key, Florida (© Marcel Huijser).

Species: Wildlife guards are designed for animals that do not easily cross cattle guards, especially ungulates. Wildlife guards may not be as effective for other species, such as bears.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs:

Cattle or wildlife guards offer no additional benefits in reducing WVCs compared to undisturbed wildlife fencing. Depending on the type of cattle or wildlife guard, the guard may be ineffective at discouraging certain species, or it may be only partly effective (e.g., 75-99 percent for Florida Key deer), depending on the type of wildlife guard (Peterson et al. 2003). Intrusions result in wildlife ending up on the road or between the fences along the right-of-way, posing a threat to traffic safety and putting the animal's life in danger.

Examples of studies:

- Standard cattle guards may be easily passable by Florida Key deer and mule deer (Reed et al. 1974b), dangerous to pedestrians and cyclists (Peterson et al. 2003), and special designs may be needed (for example, those developed for the Florida Key deer (Peterson et al. 2003)) (Figure 49).
- In some cases, such as along a side road of the TransCanada Highway in Banff National Park, Canada, a wildlife guard has also been put under electric current to discourage bears from walking across it.
- An electrified mat across an access road has been used to discourage ungulates from using a gap in a fence at an access road to approach a larger road with higher traffic

volume and vehicle speeds (David Bryson, Electrobraid Fence Ltd, personal communication).

Effectiveness in reducing the barrier effect of roads and traffic

Unknown, however, if the wildlife guards work as intended, it is a serious barrier to the target species. As such, the measure is not intended to reduce the barrier effect of the road and associated fencing.

Potential disadvantages or undesired side effects

Depending on the design, cattle or wildlife guards may be dangerous to pedestrians and cyclists and unpleasant to drivers.

As mentioned above, depending on the design and target species, some cattle or wildlife guards may be fully or partially passable to certain wildlife species.

Maintenance requirements

Silt, debris, and snow must be cleared from beneath the wildlife guard, possibly requiring regular maintenance.

Installation and maintenance costs

The reported cost of a specially designed wildlife guard was US\$30,000 (Pat Basting, Montana Department of Transportation, personal communication).

3.13 Wildlife Underpasses and Overpasses

General Description

Wildlife underpasses and overpasses are used extensively by a wide array of species to get from one side of the road to the other side (Falk et al. 1978, Ludwig & Bremicker 1983, Feldhammer et al. 1986, Clevenger et al. 2002b) (Figures 46-51). The performance of these structures in reducing WVCs and creating crossing opportunities is linked to associated wildlife fencing that keeps animals off the road and funnels them toward the wildlife overpasses and underpasses (Clevenger et al. 2002b). In some cases wildlife fencing is only installed over relatively short distances funneling wildlife toward a crossing structure (e.g. Dodd et al. 2003). The use of wildlife fencing was found to increase the use of underpasses by elk (*Cervus elaphus*) and to substantially increase the permeability of a road (Dodd et al. 2007). In other cases wildlife underpasses and overpasses have no or very limited wildlife fencing, making them the primary measure to reduce WVCs on short road sections.

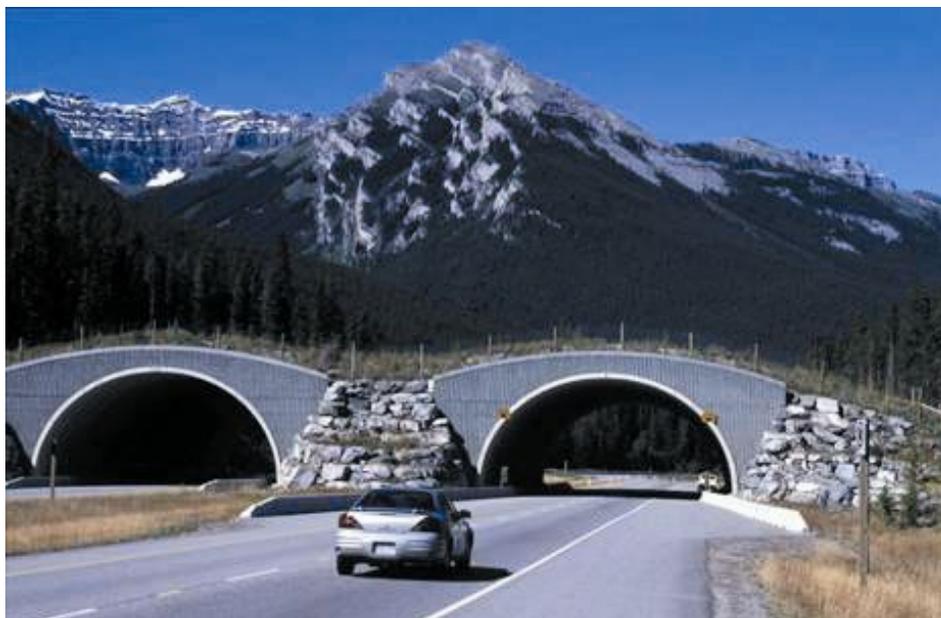


Figure 46: Wildlife overpass along the Trans-Canada Highway in Banff National Park, Alberta (© Marcel Huijser).



Figure 47: Red Earth Overpass on the Trans-Canada Highway (© Tony Clevenger).

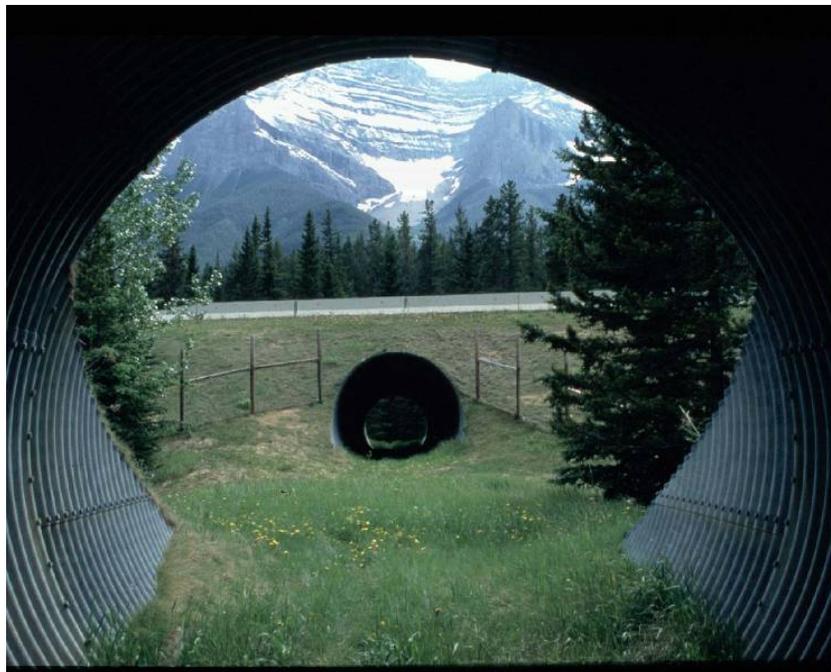


Figure 48: A large wildlife crossing culvert along the Trans-Canada Highway in Banff National Park, Alberta (© Tony Clevenger).



Figure 49. Bighorn sheep using an underpass along the Trans-Canada Highway near Canmore, Alberta (© Tony Clevenger).



Figure 50: Wildlife underpass along U.S. Highway 93 on the Flathead Indian Reservation, Montana (© Marcel Huijser).



Figure 51: Underpass in southern Florida that allows for ecosystem processes (hydrology) as well as wildlife use, including the Florida Panther (© Marcel Huijser).

The use of wildlife underpasses and overpasses depends on many parameters, including their location in the landscape, their dimensions, the habitat surrounding the structures, human co-use, and the time since installation (learning curve for the animals) (Clevenger et al. 2002b). These factors also depend on the species concerned (Clevenger et al. 2002b).

Species: A wide variety of species has been shown to use wildlife underpasses and overpasses (Falk et al. 1978, Ludwig and Bremicker 1983, Feldhammer et al. 1986, Clevenger et al. 2002a). The location, type, and dimensions of wildlife crossing structures must be carefully planned with regard to the species and surrounding landscape. For example, grizzly bears, deer and elk tend to use wildlife overpasses to a greater extent than wildlife underpasses, while black bears and mountain lions use underpasses more frequently than overpasses (Clevenger et al. 2002b). In addition, different species use different habitats, influencing their movements and where they want to cross the road.

Guidelines for different wildlife taxa in Europe and North America can be found in Iuell (2003), Foster and Humphrey (1995), Clevenger and Waltho (2000), Clevenger and Waltho (2005), and Kruidering et al. (2005). If large species are involved that are sensitive to human disturbance, or if multiple habitats have to be provided for on an overpass, wildlife overpass structures are generally recommended to be at least 50-70 m (164-230 ft) wide. Further rationale for this width is provided by Pfister et al. (2002) who showed that the increase in use of wildlife overpasses increases linearly until a width of about 50 m (164 ft) at which point the increase in wildlife use starts to taper off.

Effectiveness in reducing WVCs

Percent effectiveness in reducing WVCs: 87%

Wildlife overpasses and underpasses increase the effectiveness of wildlife fencing, or other barriers alongside the road, in reducing WVCs. If no safe crossing structures are provided, animals are more likely to break through the wildlife fencing (or other barrier) and thereby reduce the effectiveness of the wildlife fencing. Wildlife fencing in combination with underpasses or overpasses can reduce ungulate-vehicle collisions by 80 percent or more (Sielecki 1999, Clevenger et al. 2001).

Examples of studies:

- In North America, wildlife tunnels and overpasses are far less common than in Europe, affording fewer opportunities for experience and study. Only six of the latter are found in North America, and only two, in Banff, have been studied with regard to their effectiveness in reducing road mortality and allowing for safe crossing opportunities.
- Numerous species have been documented to regularly use 26 wildlife underpasses and two overpasses on the TransCanada Highway in Banff National Park. Almost 101,000 wildlife crossings have been recorded between 1996 and 2007 with almost 12,000 crossings at the overpasses. Species documented using underpasses include black bear, bobcat, cougar, coyote, deer, elk, fox, goat, grizzly bear, moose, bighorn sheep, and wolf. Species documented using overpasses include black bear, bobcat, cougar, coyote, deer, elk, fox, grizzly bear, moose, bighorn sheep, and wolf (Adam Ford, WTI, personal communication) (Figure 52). While Canada lynx and wolverine have also been observed using underpasses and while Canada lynx has been observed using an overpass, the

number of observations are too low to conclude that these species will readily use crossing structures.



Figure 52: Wildlife use of wildlife overpasses on the TransCanada Highway in Banff National Park. Clockwise from upper left: moose, grizzly bear, gray wolf, and elk (© Tony Clevenger).

- In Banff National Park, Canada, grizzly bears, deer and elk tend to use overpasses to a greater extent than underpasses, while black bears and mountain lions tend to use underpasses more than overpasses (Clevenger et al. 2002a).
- Twenty-four underpasses along a 64 km (39.7 mi) long section of Interstate 75 in southern Florida were installed to allow for water flow and movement of animals, including the Florida panther (Foster and Humprey 1995).

- In Montana, wildlife underpasses and one wildlife overpass along U.S. Hwy 93 on the Flathead Indian Reservation, and one wildlife overpass across State Hwy 83 near Salmon Lake are planned, under construction or completed.

Effectiveness in reducing the barrier effect of roads and traffic

A wide variety of mammal species have been observed using wildlife underpasses and overpasses, apparently in relatively large numbers. As such, these crossing structures appear to substantially reduce the barrier effect of a wildlife fence. Much depends, though, on the location, concentration and dimensions of the crossing structures.

Potential disadvantages or undesired side effects

No apparent disadvantages or unintended side effects. However, if overpasses are not designed properly, the species for which they were intended may use them less than desirable or not at all.

- Little is known about the effect of wildlife fencing, with or without associated safe crossing opportunities, on individuals or species that do not live in the immediate vicinity of the road, fence and crossing structures. Species that show seasonal migration or individuals that disperse over long distances may not have the time to become familiar with the location of safe crossing opportunities, and, if they do encounter them, they may choose not use them.

Maintenance requirements

Maintenance is likely to be similar to other types of bridges and underpasses. However, soil and moisture may require specific attention with wildlife overpasses.

Installation and maintenance costs

- Costs vary widely depending on dimensions of the structures. Some estimated costs for different underpass structures are: box culverts (3.0 m high x 2.5 m wide (9.8 ft x 8.2 ft)) = Can\$2,800 per m length (Can\$854 per ft); elliptical culverts (4 m high x 7 m wide (13 ft x 23 ft)) = Can\$5,400 per m length (Can\$1,646 per ft); open span bridge underpass (5 m high x 13 m wide (16 ft x 43 ft)) = Can\$55,000 per m length (Terry McGuire, Parks Canada, unpublished data).
- In The Netherlands, large underpasses (7-10 m wide (23-33 ft)) are estimated to cost €30,000 - €50,000 per m (Kruidering et al. 2005).
- Tunneling and overpass structures can cost approximately Can\$33,650 per m (Can\$10,259 per ft) for a 50 m (164 ft) wide overpass to Can\$119,300 for a 27 m (88 ft) wide and 200 m (656 ft) long tunnel (Terry McGuire, Parks Canada, unpublished data). Actual overpasses were estimated at Can\$1,750,000 (Anthony P. Clevenger, WTI, personal communication).
- A proposed overpass across Montana Highway 83 near Salmon Lake (two-lane road) is estimated to cost between US\$1.5 million and US\$2.4 million (Pat Basting, Montana Department of Transportation, personal communication).
- The costs for seven wildlife overpasses in The Netherlands ranged between €1,400,000 and €5,600,000 (Kruidering et al. 2005).

4 COSTS AND BENEFITS OF MITIGATION MEASURES

There are substantial costs associated with WVCs. Recent research (Huijser et al., 2007c) estimated the average cost for each deer, elk, and moose collision at US\$8,015, US\$17,475 and US\$28,600 respectively. The estimates include costs associated with vehicle repair, human injuries, human fatalities, towing, accident attendance and investigation, hunting and recreational value of the animal concerned, and carcass removal and disposal. The costs associated with other species may be different. For example, bighorn sheep are a major tourist attraction in Radium Hot Springs and, when hunted, some hunters pay large sums to be able to kill bighorn sheep. Thus the costs associated with bighorn sheep–vehicle collisions may be substantially higher than e.g. for a deer.

Table 5 summarizes the costs of the mitigation measures identified in this report and their effectiveness in reducing WVCs, specifically DVCs. The costs are presented (where possible) as cost per km of road length per year. The same method was used for quantifying the potential benefits as a result of reducing DVCs. For this analysis, researchers used a hypothetical 1 km (0.62 mi) road section of a two-lane road (one lane in each direction) that had five DVCs per year. The cost associated with one DVC was estimated at US\$8,015 (previous paragraph). Finally, the balance (dollar amount saved per km road length per year) was calculated (benefits – costs). It is important to note that the costs for these mitigation measures are primarily the responsibility of transportation agencies, while the benefits are mostly for insurance companies. Thus, a positive balance between benefits and costs for a given mitigation measure generally indicates that the mitigation measure concerned could be a wise investment for society as a whole, but the costs and benefits are paid for or received by different groups in society.

It should be noted that the costs and benefits in Table 5 are based on the literature reviewed in Huijser et al. (2007b). The costs do not necessarily include all costs, such as maintenance, financing, and impact of construction on traffic. Furthermore, costs and benefits can vary widely for different sites and situations (e.g., geographic locations, effectiveness, frequency of WVCs, surrounding terrain).

In some cases the costs could not be translated to costs per km per year, and no further cost-benefit calculations were conducted for these mitigation measures. However, this does not necessarily mean that these mitigation measures are not effective in reducing DVCs or that they are not a wise investment. Instead, it may only indicate that further research or analysis would be necessary to quantify the potential benefits.

The calculations presented here do not include inflation indexes and discounting was not applied. Table 5 provides the best guess about costs, effectiveness, and benefits, based on the information currently available. Nonetheless, the calculations provide an initial insight into the balance between the costs and benefits of different mitigation measures and how this balances compares between measures.

The remainder of this section discusses the values in Table 5 for each mitigation measure for which sufficient data were available.

Table 5: Summary cost/benefit of mitigation measures

Mitigation measure	Costs (US\$/km/yr)	% WVC reduction	Benefits (US\$/km/yr)	Balance (US\$/km/yr)
Reduce vehicle speed	?	?	?	?
Standard wildlife warning signs	\$12	0%	\$0	-\$12
Non-standard wildlife warning signs	\$249	?	?	?
Seasonal wildlife warning signs	\$27	26%	\$10,420	\$10,393
Animal detection systems (ADS)	\$31,300	82%	\$32,862	\$1,562
Vegetation removal	\$500	38%	\$15,229	\$14,729
Nutritional value	?	?	?	?
Road Design Features	?	?	?	?
Reflectors or mirrors	\$495	0%	\$0	-\$495
Fence (incl. dig barrier)	\$3,760	87%	\$34,865	\$31,105
Boulders in right-of-way	\$2,461	?	?	?
Fence with gap and warning signs	\$4,303	0%	\$0	-\$4,303
Fence with gap and crosswalk	\$5,041	40%	\$16,030	\$10,989
Fence with gap and ADS	\$10,036	82%	\$32,862	\$22,826
Fence with underpasses	\$5,754	87%	\$34,865	\$29,111
Fence with overpasses	\$26,378	87%	\$34,865	\$8,487
Fence with underpasses and overpasses	\$7,403	87%	\$34,865	\$27,462

KEY: The Table assumes one km with five DVCs per year. ?=unknown or uncertain.

The costs and the potential reductions in WVCs resulting from a reduction in traffic speed are unknown. However, unless actual vehicle speeds are reduced to about 45 mi/h (70 km/h) a substantial reduction of WVCs is unlikely. Therefore this mitigation measure was not included in the analysis.

Standard wildlife warning signs are relatively inexpensive: US\$94 per sign. The costs per km per year (two signs per km, one sign for each travel direction, assumed life span of 10 years, no maintenance) are US\$12, but since standard wildlife warning signs are considered ineffective in reducing WVCs (i.e., US\$0 benefit), the final cost for this mitigation measure remains at US\$12 per km per year. The effectiveness of non-standard wildlife warning signs is largely unknown, causing them to be excluded from the analysis. Seasonal wildlife warning signs (two signs per km, one sign for each travel direction, and an assumed life span of 10 years, no maintenance) may result in a 26 percent reduction of DVCs, and could end up saving US\$10,393 per km per year. Bear in mind, however, that these types of signs are only applicable in situations where deer (or other large animals) display road crossing behavior that is concentrated in space and time. Animal detection systems (life span 10 years, costs include maintenance) cost more, but may still result in a positive balance of US\$1,562 per km per year because of their ability to reduce WVCs by 82 percent. Note that the estimate on the effectiveness of animal detection systems may change as more data become available; they should still be considered experimental.

There is insufficient data available with regard to influencing the nutritional value of the vegetation in the right-of-way. Vegetation removal, however, demonstrates more potential and may result in a positive balance of US\$14,729 per km per year. Road design features are

very variable in nature and costs, and very little is known with regard to their effectiveness in WVC reduction.

Assuming that deer reflectors and mirrors (life span 12.5 years, costs includes maintenance) are indeed not effective in reducing DVCs, they have a negative balance of US\$495 per km per year.

There are insufficient data available to conduct a cost-benefit analysis for using large boulders in the right-of-way as a barrier for ungulates. However, the cost estimate on using boulders was provided by Norris Dodd (Arizona Game and Fish Department, personal communication).

Wildlife fences (life span 20 years or more, not including maintenance) can reduce collisions with ungulates by at least 80 percent and have a positive balance of US\$34,712 per km per year. The costs for long bridges and long tunnels (at least several hundreds of meters long) were set at US\$781,250 and US\$1.5 million per km per year, respectively (80-year life span). Both long bridges and tunnels result in a strongly negative balance.

To accommodate for animal movements from one side of a road to the other, wildlife fences are often combined with measures that allow animals to cross the road at grade, or to cross under or over the road through crossing structures. This section focuses on crossing opportunities for large animals only (deer size and up). The cost benefit analysis assumed one crossing opportunity per 2 km (1.24 mi) (0.5 crossing opportunity/km). In addition, gaps were set at a width of 100 m (109.3 yard), and the number of escape ramps between gaps was set at 2.5 per roadside per km (one every 317 m (346.6 yard) between gaps). In addition, the animals could “escape” through the gaps. The number of escape ramps between crossing structures was set at 3.5 per roadside per km (two immediately next to a crossing structure (50 m on either side from center), and 5 in between at 317 m (346.6 yard) intervals between the crossing structures). The escape ramps on either side of a crossing structure are required because of the contiguous 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. The length of the fence was not reduced because of gaps or crossing structures because of possible additional fencing at gaps and overpasses, and the contiguous nature of fencing for underpasses. In addition, for at-grade crossings, it was assumed that all deer movements that would have taken place in the unmitigated road section (and that resulted in five DVCs per km per year) would be funneled through these gaps, and that the number of DVCs is not reduced as the result of a potential reduction in the number of deer crossings because of the presence of the wildlife fence.

The life span of the material associated with crosswalks (see Lehnert & Bissonette, 1997) was set at 10 years, while the life span for wildlife crossing structures was set at 80 years. The cost for the mitigation measure that includes a combination of wildlife fencing with underpasses and overpasses was based on 0.5 crossing structures per km, all of them underpasses except for 1 overpass every 25 km (15.5 mi). The cost for an underpass (a wide culvert, ± 7 m wide, ± 5 m high) was set at US\$200,000, while the cost for an overpass (50 m wide) was set at US\$3.5 million. The cost for an escape ramp was set at US\$8,500 (life span

80 years). Wildlife fences with gaps that are mitigated by warning signals (US\$12/km/yr, 10-year life span) or a crosswalk (US\$750/km/yr, 10-year life span) have a negative balance while wildlife fences in combination with animal detection systems, wildlife underpasses, wildlife overpasses, or a combination of wildlife underpasses and overpasses all have a positive balance.

Many of the mitigation measures showed a positive balance. Some of the mitigation measures (long tunnels, long bridges, and anti-fertility treatment) showed a strongly negative balance. Because of their strongly negative balance, these mitigation measures are, in general, not recommended to reduce WVCs, at least not from a strictly monetary perspective. However, if alternatives are not suitable given the local conditions, or if other factors besides WVC reduction play a role, these measures may be considered after all. All other mitigation measures for which the cost-benefit analyses could be conducted had a positive or only a slightly negative balance. However, it is also important to evaluate mitigation measures on the portion of the problem that may not have been solved. None of the mitigation measures are 100 percent effective in reducing collisions, and if a substantial number of collisions and associated costs remain, a mitigation measure may not be attractive, despite a potential positive balance.

Figure 53 shows the individual mitigation measures (excluding long tunnels, long bridges, and ant-fertility treatment) in relation to their balance and the costs associated with the DVCs that have remained. Based on the results, the authors of this report identified wildlife fencing, with or without wildlife underpasses or a combination of wildlife underpasses and overpasses, and animal detection systems with wildlife fencing, as the most cost-effective mitigation measures (measures identified by solid oval). These mitigation measures have a strongly positive balance with relatively few remaining DVCs and associated costs. Animal detection systems without wildlife fences or wildlife fences with a high density of wildlife overpasses (measure identified by dashed oval) are also cost-effective. However, their positive balance is less strong than for wildlife fencing with or without wildlife underpasses; wildlife overpasses; a combination of wildlife underpasses and overpasses; and animal detection systems with wildlife fencing. It is important to note though that these mitigation measures offer different levels of habitat connectivity and that this non-monetary value was not included in the analyses. Furthermore, the balance between costs and benefits of all the mitigation measures may change as new or better estimates become available or as prices change over time. Nonetheless, based on the assumptions and estimates, the mitigation measures listed above are among the most attractive, at least from a monetary perspective.

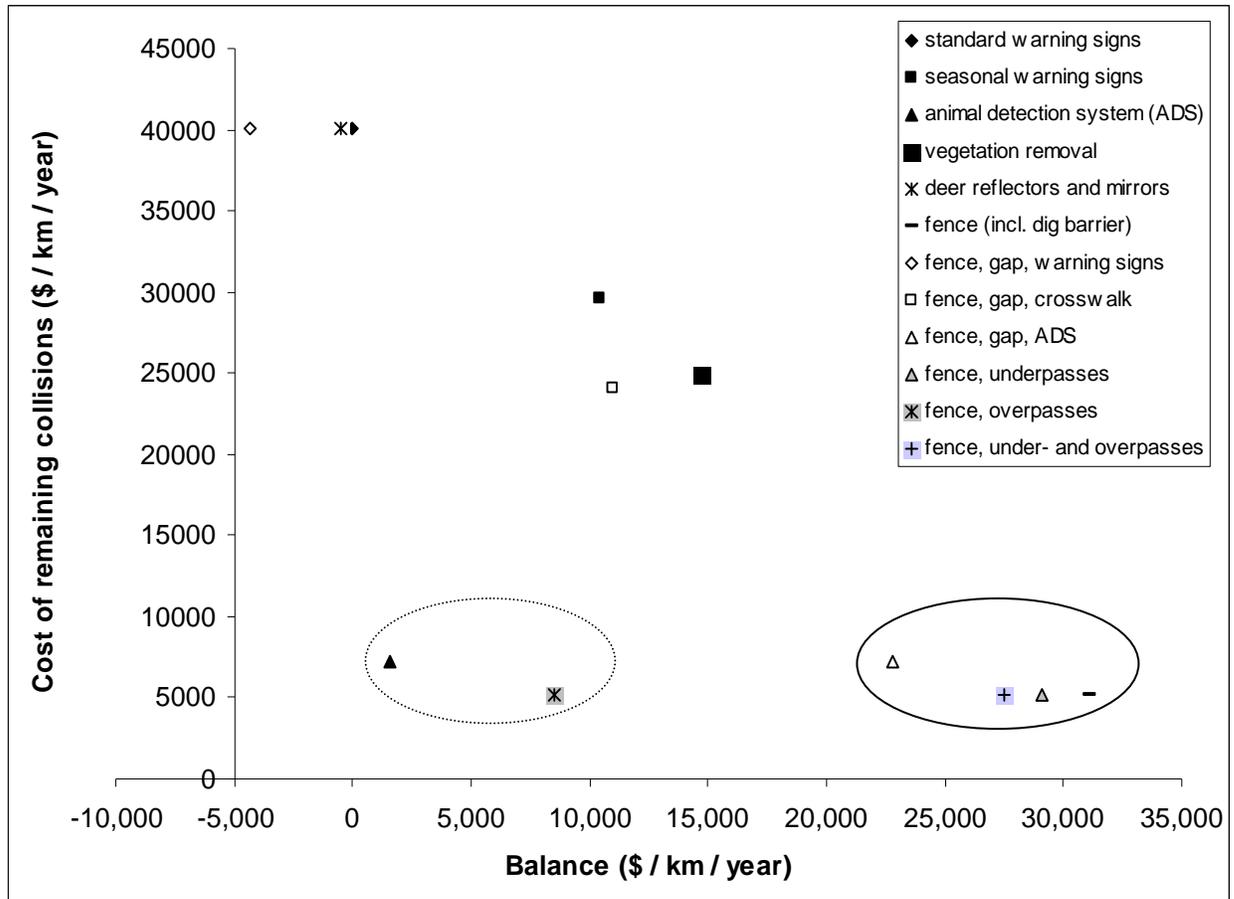


Figure 53: Balance and remaining costs for the different mitigation measures (further explanation in text).

5 SPECIES-SPECIFIC PERFORMANCE OF WILDLIFE FENCING AND SAFE CROSSING OPPORTUNITIES

5.1 Species-Specific Performance

Table 6 rates the performance of different types of safe crossing opportunities in combination with wildlife fencing for a range of species with regard to collision reduction and safe crossing opportunities. Wildlife fencing (on the left in the table) serves as a reference.

Information on bighorn sheep, mountain goats, wolverine, bobcat, and Canada lynx with regard to their use of wildlife underpasses and overpasses is limited, hence the question marks (= unknown) in Table 6. However, bighorn sheep, mountain goats, and Canada lynx have been observed using underpasses, and the Canada lynx has been observed using overpasses (Singer & Doherty, 1985, Hewitt et al., 1998, Clevenger et al., 2002b, Tigasa et al., 2002, Plumb et al., 2003, Anthony P. Clevenger, WTI, personal communication). Bighorn sheep are expected to use overpasses (Epps et al., 2005, McKinney & Smith, 2007), but the authors of this report are unaware of actual data that show bighorn sheep have used overpasses. Coyotes do not appear to have a clear preference for overpasses or underpasses and seem to readily use a variety of crossing structure types (Anthony P. Clevenger, WTI, personal communication). Wolverines, which are extremely rare in the area, have used a creek bridge underpass and a 4 x 7 m elliptical culvert along the Trans-Canada Highway in Banff National Park, Alberta, (Anthony P. Clevenger, WTI, personal communication).

Table 6: The suitability of different mitigation measures for reducing collisions and providing safe crossing opportunities for different species and species groups.

Species	Fence (incl. dig barrier)		Fence with gap and ADS		Fence with underpasses		Fence with overpasses		Fence with underpasses and overpasses	
	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings	Collisions	Crossings
White-tailed deer	O	N	O	O	O	U	O	O	O	O
Mule deer	O	N	O	O	O	U	O	O	O	O
Elk	O	N	O	O	O	U	O	O	O	O
Moose	O	N	O	O	O	U	O	O	O	O
Bighorn sheep	O	N	O	O	O	U	O	?	O	U
Mountain goat	O	N	O	O	O	U	O	?	O	U
Black bear	U	N	O	O	U	O	U	U	U	O
Grizzly bear	O	N	O	U	O	U	O	O	O	O
Wolverine	O	N	U	O	O	U	O	?	O	U
Mountain lion	U	N	U	O	U	O	U	U	U	O
Canada lynx	U	N	U	O	U	?	U	?	U	?
Bobcat	U	N	U	O	U	O	O	?	O	O
Gray wolf	O	N	U	O	O	U	O	O	O	O
Coyote	U	N	U	O	U	O	O	O	O	O
Points	23	0	22	27	23	17	25	16	25	23
Points combined	23		49		40		41		48	

O= Optimal, U = Usable, possibly with adaptations, N = Not suitable, ? = Unknown.
Points: O = 2 points, U = 1 point, N = 0 points.

5.2 Animal Detection Systems vs. Wildlife Crossing Structures

The pros and cons of animal detection systems versus wildlife crossing structures (such as underpasses and overpasses) in combination with wildlife fencing are summarized below (adapted from Huijser et al. 2006a). Note that this section is based on having a reliable (Huijser et al. 2006a, 2007a, Dodd & Gagnon, 2008) and effective (review in Huijser et al. 2006a, Dodd & Gagnon 2008) animal detection system. Because data on the reliability and effectiveness is still limited, animal detection systems should still be considered experimental and the estimates on their reliability and effectiveness may change substantially as more data become available.

Pros for Animal Detection Systems

- Animal detection systems have the potential to provide wildlife with safe crossing opportunities anywhere along the mitigated roadway, but wildlife crossing structures are usually limited in number and they are rarely wider than about 50 m (54.6 yard).
- Animal detection systems are less restrictive to wildlife movement than fencing or crossing structures. They allow animals to continue to use existing paths to the road or to change them over time.
- Animal detection systems can be installed without major road construction or traffic control for long periods.
- Animal detection systems are likely to be less expensive than wildlife crossing structures, especially once they are mass produced.

Cons for Animal Detection Systems

- Although the available data on the effectiveness of animal detection systems with regard to collision reduction are encouraging, animal detection systems currently are not as “tried and proven” as wildlife crossing structures.
- Currently, animal detection systems only detect large animals (e.g., deer, elk, or moose). Relatively small animals are not detected, and drivers are not warned about their presence on or near the road.
- Wildlife crossing structures can provide cover (e.g., vegetation, living trees, tree stumps) and natural substrate (e.g., sand, water) allowing better continuity of habitat.
- Some types of animal detection systems are only active in the dark and animals that cross during the daylight may not be protected.
- Animal detection systems usually require the presence of poles and equipment in the right of way, sometimes even in the clear zone, presenting a safety hazard of their own.
- Animal detection systems may substantially reduce the number of WVCs, but since they allow large animals to cross the road at grade, they will never completely eliminate WVCs.
- Animal detection systems can be aesthetically displeasing.
- Wildlife crossing structures are likely to have greater longevity and lower maintenance and monitoring costs.

The choice between animal detection systems (with or without wildlife fencing or wildlife crossing structures in combination with wildlife fencing) currently depends on whether the success of the project is defined as: 1) accomplishing a certain minimum result in terms of WVC reduction and/or safe crossing opportunities for wildlife, or 2) conducting research that helps to further evaluate the effectiveness of different mitigation measures. The choice also depends on the problem at hand (WVCs and/or lack of safe crossing opportunities for wildlife) and the species or species groups concerned, as well as the local situation, including road, right-of-way, and landscape characteristics. For additional considerations see Huijser et al. (2006a).

6 CONCLUSION

Although there have been many mitigation measures suggested to reduce WVCs, only a few of the measures reviewed in this report have the potential to substantially reduce WVCs. Only wildlife fencing and animal detection systems have proven to be able to reduce WVCs with large mammals substantially (>80%). It is important to note, however, that animal detection systems should still be considered experimental, whereas the estimated effectiveness of wildlife fencing in combination with wildlife underpasses and overpasses is more robust. Large boulders in the right-of-way as an alternative to wildlife fencing appear to have potential as a barrier to ungulates and may be an alternative to wildlife fencing. However, this measure should still be considered experimental. The effectiveness of other mitigation measures in reducing WVCs is relatively low (<50%), impractical, or unknown.

Wildlife fencing and the use of large boulders in the right-of-way increase the barrier effect of the road. These measures should typically only be used if safe crossing opportunities for wildlife are also provided. Such crossing opportunities could consist of at-grade crossings at a gap in the barrier, with or without additional warning signals for drivers (e.g. animal detection systems), or wildlife underpasses and overpasses.

For the species evaluated, a combination of different types of crossing opportunities appears better than providing a single type of crossing opportunity. The authors of this report believe animal detection systems with or without wildlife fencing, and wildlife fencing in combination with wildlife underpasses and overpasses, are potential primary mitigation measures to be considered for the reduction of WVCs along SH 75 between Timmerman Junction and Ketchum, ID. However, animal detection systems should still be considered experimental, whereas the performance estimates for wildlife fencing and underpasses and overpasses are much more robust. The authors of this report also consider experiments with large boulders in the right-of-way to be mitigation measures that have potential for reducing WVCs along SH 75. However, this mitigation measure should also be considered experimental rather than a proven mitigation measure. Finally, the authors of this report consider public information and education good practice, but recognize that such efforts may not reduce wildlife-vehicle collisions substantially. However, public information and education does increase awareness of wildlife-vehicle collisions and help build support for potential mitigation measures.

7 REFERENCES

- Al-Ghamdi, A.S. & S.A. AlGadhi. 2004. Warning signs as countermeasures to camel-vehicle collisions in Saudi Arabia. *Accident Analysis and Prevention* 36: 749-760.
- Allen, R.E. and D.R. McCullough. 1976. Deer-car accidents in southern Michigan. *Journal of Wildlife Management* 40: 317-325.
- American Association of State Highway Transportation Officials (AASHTO). 2004. *A Policy on Geometric Design of Highways and Streets (Green Book)* 5th edition. ISBN 1-56051-263-6. AASHTO, Washington D.C.
- Andreassen, H.P., H. Gundersen & 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.
- Arizona Court of Appeals. 2004. Booth v. State of Arizona. 2 CA-CV 2003-0097. Court of Appeals, State of Arizona, Division Two. Opinion Filed: 30 January 2004. Available from the Internet, accessed 29 November 2006. URL: <http://www.apltwo.ct.state.az.us/Decisions/CV20030097Opinion.pdf>
- Austin, M. 1998. Wolverine winter travel routes and response to transportation corridors in Kicking Horse Pass between Yoho and Banff National Parks. Thesis, University of Calgary, Alberta, Canada.
- Baines, D. & R. W. Summers. 1997. Assessment of bird collisions with deer fences in Scottish Forests. *Journal of Applied Ecology* 34 (4): 941-948.
- Barlow, C. 1997. Performance evaluation of wildlife reflectors in British Columbia. In: Clevenger, A.P. & K. Wells (eds.). *Proceedings of the second roads, rails and the environment workshop*: 60-64. Parks Canada, Banff National Park, Alberta & Columbia Mountains Institute of Applied Ecology, Revelstoke, Canada.
- Bertwistle, J. 1999. The effects of reduced speed zones on reducing bighorn sheep and elk collisions with vehicles on the Yellowhead Highway in Jasper National Park. In: Evink, G.L., P. Garrett & D. Zeigler (eds.). *Proceedings of the third international conference on wildlife ecology and transportation*: 89-97. Missoula, Montana. FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida.
- Biota Research and Consulting, Inc. 2003. Jackson Hole roadway and wildlife crossing study, Teton County, Wyoming. Final report for Jackson Hole Wildlife Foundation, Jackson, Wyoming.

- Bissonette, J.A. & M. Hammer. 2000. Effectiveness of earthen ramps in reducing big game highway mortality in Utah: Final Report. Utah Cooperative Fish and Wildlife Research Unit Report Series 2000 (1): 1-29.
- Blaine County. 2006. RFP – Blaine County State Highway 75 wildlife data collection and mitigation research project. 18 May 2006, Blaine County, ID, USA.
- Boarman, W.I. & M. Sasaki. 1996. Highway mortality in desert tortoises and small vertebrates: success of barrier fences and culverts. In: Evink, G.L., P. Garrett, D. Zeigler & Berry (eds.). Proceedings of the transportation-related wildlife mortality seminar: trends in addressing transportation-related wildlife mortality. FL-ER-58-96. Florida Department of Transportation, Tallahassee, Florida.
- Brown, D.L., J. Laird, W.D. Summers & A. Hamilton. 1999. Methods used by the Arizona Department of Transportation to reduce wildlife mortality and improve highway safety. In: Evink, G.L., P. Garret & D. Zeigler (eds.). Proceedings of the third international conference on wildlife ecology and transportation: 175-178. Missoula, Montana. FL-ER-73-99. Florida Department of Transportation, Tallahassee, Florida.
- Cain, A.T., V.R. Tuovila, D.G. Hewitt & M.E. Tewes. 2003. Effects of a highway and mitigation projects on bobcats in southern Texas. *Biological Conservation* 114 (2): 189-197.
- Case, R.M. 1978. Interstate highway road-killed animals: a data source for biologists. *Wildlife Society Bulletin* 6: 8-13.
- CBS. 2008. New Ideas To Stop Car-Deer Crashes. 10 January 2008. Available from the internet: <http://www.cbsnews.com/stories/2008/01/10/eveningnews/main3698120.shtml>
- Cerrelli, E. 1981. Safety consequences of raising the national speed limit from 55 mph to 60 mph. National Highway Traffic Safety Administration, U.S. Department of Transportation.
- Clam Lake Elk News. 2007. Clam Lake Elk News, July through September 2007, 7 (3). Available from the internet: <http://www.dnr.state.wi.us/org/land/wildlife/elk/q3.pdf>
- Clevenger, A. P., B. Chruszcz & K. Gunson. 2001b. Drainage culverts as habitat linkages and factors affecting passage by mammals. *Journal of Applied Ecology* 38: 1340-1349.
- Clevenger, A.P., B. Chruszcz, K. Gunson, K. & M. Brumfit. 2002a. Highway mitigation monitoring: Three Sisters Parkway interchange. Final report, August 1999 - July 2002. Prepared for Alberta Sustainable Resource Development, Canmore, Alberta, Canada.
- Clevenger, A.P., B. Chruszcz, K. Gunson & J. Wierzchowski. 2002b. Roads and wildlife in the Canadian Rocky Mountain Parks: movements, mortality and mitigation. Final report to Parks Canada. Banff, Alberta, Canada.

- Clevenger, A.P. & A.V. Kociolek. 2006. Highway median impacts on wildlife movement and mortality. State of the practice survey and gap analysis. Final report. Research Report Number F/CA/MI-2006/09. Western Transportation Institute-Montana State University, Bozeman, Montana.
- Clevenger, A.P. & N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. *Conservation Biology* 14: 47–56.
- Clevenger, A.P. & N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation* 121: 453-464.
- Cottrell, B. H. 2003. Technical assistance report: evaluation of deer warning reflectors in Virginia. VTRC 03-TAR6. Virginia Transportation Research Council in cooperation with U.S. Department of Transportation and Federal Highway Administration, Charlottesville, Virginia.
- D'Angelo, G.J., R.J. Warren, K.V. Miller & G.R. Gallagher. 2004. Literature review: evaluation of strategies designed to reduce deer vehicle collisions. Prepared for Georgia Department of Transportation, Georgia.
- D'Angelo, G. J., J.G. D'Angelo, G.R. Gallagher, D.A. Osborn, K.V. Miller & R.J. Warren. 2006. Evaluation of wildlife warning reflectors for altering white-tailed deer behavior along roadways. *Wildlife Society Bulletin* 34 (4): 1175-1183.
- Danielson, B.J. & M.W. Hubbard. 1998. A literature review for assessing the status of current methods of reducing deer vehicle collisions. Report for The Task Force on Animal Vehicle Collisions, The Iowa Department of Transportation, and The Iowa Department of Natural Resources, Iowa.
- Dobson, J.D. 2001. Marking fences to reduce bird collisions in woodlands. *Scottish Forestry* 55 (3): 168-169.
- Dodd, N.L., J.W. Gagnon & R.E. Schweinsburg. 2003. Evaluation of measures to minimize wildlife-vehicle collisions and maintain wildlife permeability across highways in Arizona. In: Irwin, C.L., P. Garrett & K.P. McDermott (eds.). *Proceedings of the 2003 international conference on ecology and transportation: Making Connections*: 353-354. Lake Placid, New York. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina.
- Dodd, N.L., J.W. Gagnon, S. Boe, A. Manzo, & R.E. Schweinsburg. 2007. Evaluation of measures to minimize wildlife-vehicle collisions and maintain wildlife permeability across highways State Route 260, Arizona, Final report. Arizona Game and Fish Department Research Branch, Phoenix, Arizona.

Dodd, N. & 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.

ElectroBraid. 2006. Wildlife Exclusion with ElectroBraid™. Available from the internet, accessed 28 November 2006. URL: <http://www.electrobraid.com/wildlife/wildlife.html>

Epps, C.W., P.J. Palsbøll, J.D. Wehausen, G.K. Roderick, R.R. Ramey II & D.R. McCullough. 2005. Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. *Ecology Letters* 8: 1029-1038.

Evink, G.L. 2002. NCHRP Synthesis 305: Interaction between roadways and wildlife ecology: a synthesis of highway practice. Transportation Research Board. National Academies, Washington, D.C., USA.

Falk, N.W, H.B. Graves & E.D. Bellis. 1978. Highway right-of-way fences as deer deterrents. *Journal of Wildlife Management* 42: 646-650.

Farrell, J.E., L.R. Irby & P.T. McGowen. 2002. Strategies for ungulate-vehicle collision mitigation. *Intermountain Journal of Sciences* 8 (1): 1-18.

Feldhamer, G.A., J.E. Gates, D.M. Harman, A.J. Loranger & K.R. Dixon. 1986. Effects of Interstate highway fencing on white-tailed deer (*Odocoileus virginianus*) activity. *Journal of Wildlife Management* 50 (3): 497-503.

Finder, R.A., J.L. Roseberry & A. Woolf. 1999. Site and landscape conditions at white-tailed deer vehicle collision locations in Illinois. *Landscape and Urban Planning* 44: 77-85.

Ford, S.G. & S.L. Villa. 1993. Reflector use and the effect they have on the number of mule deer killed on California highways: Final Report. Report FHWA-CA-PD94-01. California Department of Transportation, Sacramento, California.

Forman, R.T.T. & L.E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29: 207-31.

Forman, R.T.T., D. Sperling, J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahrig, R. France, C.R. Goldman, K. Heanue, J.A. Jones, F.J. Swanson, T. Turrentine & T.C. Winter. 2003. *Road ecology: science and solutions*. Island Press, Washington D.C.

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

Garber, N. & R. Gadiraju. 1988. Speed dispersion and its influence on accidents. AAA Foundation for Traffic Safety, USA.

Gleason, J.S. & J.A. Jenks. 1993. Factors influencing deer vehicle mortality in east central South Dakota. *The Prairie Naturalist* 25 (4): 281-289.

- Gloyne, C.C. & A.P. Clevenger. 2001. Cougar (*Puma concolor*) use of wildlife crossing structures on the Trans-Canada highway in Banff National Park, Alberta. *Wildlife Biology* 7 (2): 117-124.
- Gordon, K.M. & S.H. Anderson. 2002. Motorist response to a deer-sensing warning system in western Wyoming. Pages 549-558 in: *Proceedings of the International Conference on Ecology and Transportation*, 24-28 September 2001, Keystone, CO, USA.
- Gordon, K., S.H. Anderson, B. Gribble, M. Johnson. 2001. Evaluation of the FLASH (Flashing Light Animal Sensing Host) system in Nugget Canyon, Wyoming. Wyoming Cooperative Fish and Wildlife Research Unit. University of Wyoming, Laramie, WY, USA.
- Gordon, K.M., M.C. McKinstry & S.H. Anderson. 2004. Motorist response to a deer sensing warning system. *Wildlife Society Bulletin* 32: 565-573.
- Grande, J., L.S. Katz & G. Slifer. 2000. Deer fence fact sheet: high-tensile woven wire fences for reducing wildlife damage. Rutgers Cooperative Extension, New Jersey Agricultural Experiment Station, Rutgers University, New Jersey.
- Green, M. 2000. How long does it take to stop? Methodological analysis of driver perception-brake times. *Transportation Human Factors* 2 (3): 195-216.
- Grenier, R.H. 2002. A study of the effectiveness of Strieter-Lite wild animal warning reflector systems. Available from the Internet, accessed 18 November 2006. URL: http://www.strieter-lite.com/images/scientific_report.pdf
- Groot Bruinderink, G.W.T.A & E. Hazebroek. 1996. Ungulate traffic collisions in Europe. *Conservation Biology* 10 (4): 1059-1067.
- Gulen, S., G. McCabe & S.E. Wolfe. 2000. Evaluation of wildlife reflectors in reducing vehicle-deer collisions on Indiana Interstate 80/90. SPR-3 (076). Indiana Department of Transportation, Divisions of Research and Toll Roads, Indiana.
- Gunther, K., M. Biel, & H. Robinson. 1998. Factors influencing the frequency of road killed wildlife in Yellowstone National Park. In: Evink, G.L., P. Garrett, D. Zeigler & J. Berry (eds.). *Proceedings of the international conference on wildlife ecology and transportation*: 32-42. Fort Myers, Florida. FL-ER-69-98. Florida Department of Transportation, Tallahassee, Florida.
- Hammond, C. & M.G. Wade. 2004. Deer avoidance: the assessment of real world enhanced deer signage in a virtual environment. Final Report. Minnesota Department of Transportation. St. Paul, Minnesota. Available from the Internet, accessed 30 November 2004. URL: <http://www.lrrb.gen.mn.us/pdf/200413.pdf>
- Hardy, A.R., S. Lee & A.F. Al-Kaisy. 2006. Effectiveness of animal advisory messages as a speed reduction tool: A case study in Montana. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1973, pp. 64-72.

- Hewitt, D.G., A. Cain, V. Tuovila, D.B. Shindle & M.E. Tewes. 1998. Impacts of an expanded highway on ocelots and bobcats in southern Texas and their preferences for highway crossings. In: Evink, G.L., P. Garrett, D. Zeigler & J. Berry (eds.). Proceedings of the international conference on wildlife ecology and transportation: 126-134. Fort Myers, Florida. FL-ER-69-98. Florida Department of Transportation, Tallahassee, Florida.
- Huijser, M.P. 2003. Animal detection systems: research questions, methods and potential applications: 9 p. Proceedings of Infra Eco Network Europe (IENE) conference. Habitat Fragmentation due to Transport Infrastructure & Presentation of the COST 341 action, 13 - 15 November 2003, Brussels, Belgium. CD-ROMs with the proceedings can be ordered from the internet. URL: <http://www.iene.info/> Accessed 27 September 2004.
- Huijser, M.P. & P.T. McGowen. 2003. Overview of animal detection and animal warning systems in North America and Europe. Pages 368-382 in: C.L. Irwin, P. Garrett, and K.P. McDermott (eds.). 2003 Proceedings of the International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC, USA. Also available from the internet. URL: <http://www.itre.ncsu.edu/cte/icoet/03proceedings.html>
- Huijser, M.P., P.T. McGowen, W. Camel, A. Hardy, P. Wright, A.P. Clevenger, L. Salsman & 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, MT, USA. Available from the internet: http://www.oregon.gov/ODOT/TD/TP_RES/ResearchReports.shtml
- Huijser, M.P., W. Camel & A. Hardy. 2006b. The reliability of the animal detection system along US Hwy 191 in Yellowstone National Park, Montana, USA. Pages: 509-523 in: C.L. Irwin, P. Garrett and K.P. McDermott (eds.). Proceedings of the 2005 International Conference on Ecology and Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC, USA. Available from the internet: URL: http://www.icoet.net/ICOET_2005/05proceedings_directory.asp
- Huijser, M.P., T.D. Holland & M. Blank. 2007a. The Comparison of Animal Detection Systems in a Test-Bed: A Quantitative Comparison of System Reliability and Experiences with Operation and Maintenance. Interim Report. 4W0049 interim report, Western Transportation Institute – Montana State University, Bozeman, Montana, USA. Available from the internet: www.coe.montana.edu/wti/wwwshare/4W0049%20Interim%20Report/
- Huijser, M.P., A. Kociolek, P. McGowen, A. Hardy, A.P. Clevenger & R. Ament. 2007b. Wildlife-Vehicle Collision and Crossing Mitigation Measures and Associated Costs and Benefits: a Toolbox for the Montana Department of Transportation. FHWA/MT-07-002/8117-34, Montana Department of Transportation, Helena, Montana. Available from the Internet: http://www.mdt.mt.gov/research/projects/env/wildlife_crossing_mitigation.shtml

- Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith & R. Ament. 2007c. Wildlife-vehicle collision reduction study. Report to Congress. U.S. Department of Transportation, Federal Highway Administration, Washington D.C., USA. Available from the internet:
www.wti.montana.edu/RoadEcology/documents/Wildlife_Vehicle_Collision_Reduction.pdf
- Huijser, M.P. & K.J.S. Paul. 2008. Wildlife-vehicle collision and crossing mitigation measures: a literature review for Parks Canada, Kootenay National Park. Report 4W1929 A, Western Transportation Institute – Montana State University, Bozeman, Montana, USA USA.
- Huijser, M.P. & A.V. Kociolek, L. Oechsli & D. Galarus. 2008. Wildlife Data Collection and Potential Highway Mitigation Along State Highway 75, Blaine County, Idaho. Report 4W1403B, Western Transportation Institute – Montana State University, Bozeman, MT, USA.
- Hyman, W.A. & D. Vary. 1999. NCHRP Synthesis 272: Best management practices for environmental issues related to highway and street maintenance. Transportation Research Board, National Research Council, Washington, D.C., USA.
- Iuell, B., G.J. Bekker, R. Cuperus, J. Dufek, G. Fry, C. Hicks, V. Hlavác, V. Keller, C. Rosell, T. Sangwine, N. Tørsløv, & B. le Maire Wandall,. 2003. COST 341. Habitat Fragmentation due to Transportation Infrastructure. Wildlife and traffic: a European handbook for identifying conflicts and designing solutions. KNNV Publishers, Utrecht, The Netherlands.
- Jaeger, J.A.G. & 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 & B. Wiseth. 1991. Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. *Alces* 27: 93–99.
- Jones, M.E. 2000. Road upgrade, road mortality and remedial measures: impacts on a population of eastern quolls and Tasmanian devils. *Wildlife Research* 27: 289-296.
- Jones, M.B. & W.M. Longhurst. 1958. Overhanging deer fences. *Journal of Wildlife Management* 22 (3): 325-326.
- Katz, B.J., G.K. Rousseau, & D.L. Warren. 2003. Comprehension of warning and regulatory signs for speed. Proceedings 73rd Institute of Transportation Engineers (ITE) Annual Meeting and Exhibit, August 24-27, 2003, Seattle, WA, USA.
- Kinley, T.A., N.J. Newhouse & H.N. Page. 2003. Evaluation of the wildlife protection system deployed on Highway 93 in Kootenay National Park