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Erratum: The maps of Fig 1 and Fig. 2 have been switched in the version published on the web. Table 3 was not printed correctly ion the version online. Thee version in this PDF is printed correctly.

OVERVIEW OF ANIMAL DETECTION AND ANIMAL WARNING SYSTEMS IN NORTH AMERICA AND EUROPE

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ABSTRACT

The purpose of animal detection and animal warning systems is to prevent or reduce the number of animal-vehicle collisions. These systems are specifically aimed at large animals (e.g. ungulates) that can cause human death, injury and property damage. Animal detection systems detect large animals before they enter the road and then warn drivers that a large animal is on or near the road at that time. Animal warning systems detect vehicles and then warn the animals through a variety of audio and visual signals. This paper lists all animal detection and animal warning systems known to the authors in September 2003. We identified 27 locations where systems are or have been in place in North America and Europe. In addition, we identified 20 sites for which an animal detection or animal warning systems are planned. We described the main characteristics of the systems and reviewed them with respect to operation and maintenance. We conclude that animal detection and animal warning systems have the potential to be an effective mitigation tool. However, further research and development is needed before they can be applied on a wide scale.

Keywords: animal-vehicle collisions, dynamic warning signs, intelligent transportation systems (ITS), operation and maintenance, road safety, technology

INTRODUCTION

Animal-vehicle collisions affect human safety, property and wildlife. In the United States more than 90% of animal-vehicle collisions involve deer (Hughes et al. 1996), and the total number of deer-vehicle collisions was estimated at more than one million per year (Conover et al. 1995). These collisions were estimated to cause 211 human fatalities, 29,000 human injuries and over one billion dollars in property damage a year (Conover et al. 1995). Similar numbers are available from Europe (excluding Russia) where the annual number of collisions with ungulates was estimated at 507,000. These collisions were estimated to cause 300 human fatalities, 30,000 human injuries and over one billion dollars in material damage per year (Groot Bruinderink & Hazebroek 1996). These numbers are likely to have increased even further over the last decade (Hughes et al. 1996; Romin & Bissonette 1996; Anonymous 2003a). In most cases the animals die immediately or shortly after the collision (Allen & McGullough 1976). In some cases it is not just the individual animals that suffer. Some species are also affected on the population level and may even be faced with a serious reduction in population survival probability (e.g., van der Zee et al. 1992; Huijser & Bergers 2000; Proctor 2003). In addition, in some species a monetary value is lost once an animal dies (Romin & Bissonette 1996; Conover 1997).

Historically animal-vehicle collisions have been addressed by putting up signs that warn drivers for potential animal crossings. In other cases wildlife warning reflectors or wildlife fences have been installed to keep animals away from the road (e.g. Clevenger et al. 2001). However, conventional warning signs appear to have only limited effect because drivers are likely to habituate to them (Pojar et al. 1975), wildlife warning reflectors may not be effective (Reeve & Anderson 1993; Ujvári et al. 1998), and wildlife fences isolate populations. In some selected areas wildlife fencing has been combined with a series of wildlife crossing structures (e.g. Foster & Humphrey 1995; Clevenger et al. 2002). In most cases however, such crossing structures are limited in number and width, mostly because of their relatively high costs. In this paper we review a relatively new alternative to wildlife crossing structures; animal detection and animal warning systems that are located in the right-of-way. Vehicle based animal detection systems (e.g. Bendix 2002; Cadillac 2003) are not included in this paper. Animal detection systems detect large animals 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. Animal warning systems operate on a slightly different principle as they detect vehicles, not the animals. When a vehicle is detected the animals are alerted through a range of audio and visual signals from stations placed in the right-of-way. This paper lists all animal detection and animal warning systems in the world known to the authors as of September 2003. In addition, we describe the main characteristics of the systems and we review them with respect to operation and maintenance.

METHODS

Information on the existence of animal detection and animal warning systems in the right-of-way is not well documented at this time. Our list of animal detection and animal warning systems is based on previous overviews (Farrell et al. 2002; Robinson et al. 2002), research reports, searches on the internet, newspaper articles, press releases, and interviews with researchers, system manufacturers and integrators, and employees from transportation agencies. Our overview distinguishes between locations that have an operational system, an installed system that is not operational yet, a dismantled system, and locations for which a system is planned (situation September 2003).

We classified the systems into two main categories; area-cover systems and break-the-beam systems. We also identified three unique systems. We described each system with respect to the following parameters: 1. location, 2. target species, 3. technology, 4. system vendor, 5. system installer, 6. road length covered by the sensors, 7. presence or absence of adjacent fencing, 8. system costs, 9. installation costs, 10, whether or not data are available on operation and maintenance, driver behavior, and number of animal-vehicle collisions, 11. month and year of installation, and 12. period of operation. Finally we discuss additional issues that may affect the operation and maintenance of the systems.

RESULTS

System numbers and general location

We identified 27 locations with an animal detection or animal warning system. Nine of these sites are located in North America; eight sites with an animal detection system, and one site with an animal warning system (fig. 1). As far as we know only four of these sites have a system that is currently in operation (situation September 2003). On three sites a system has been installed, but the systems are not operational yet. On the remaining two sites the systems have been dismantled. In Europe we identified 18 locations with animal detection systems (fig. 2). As far as we know 17 of them have a system that is currently in operation. The system on the remaining site has been dismantled. In addition to the 27 sites mentioned above, we have identified 5 sites in North America and 15 sites in Europe for which an animal detection system has been planned.

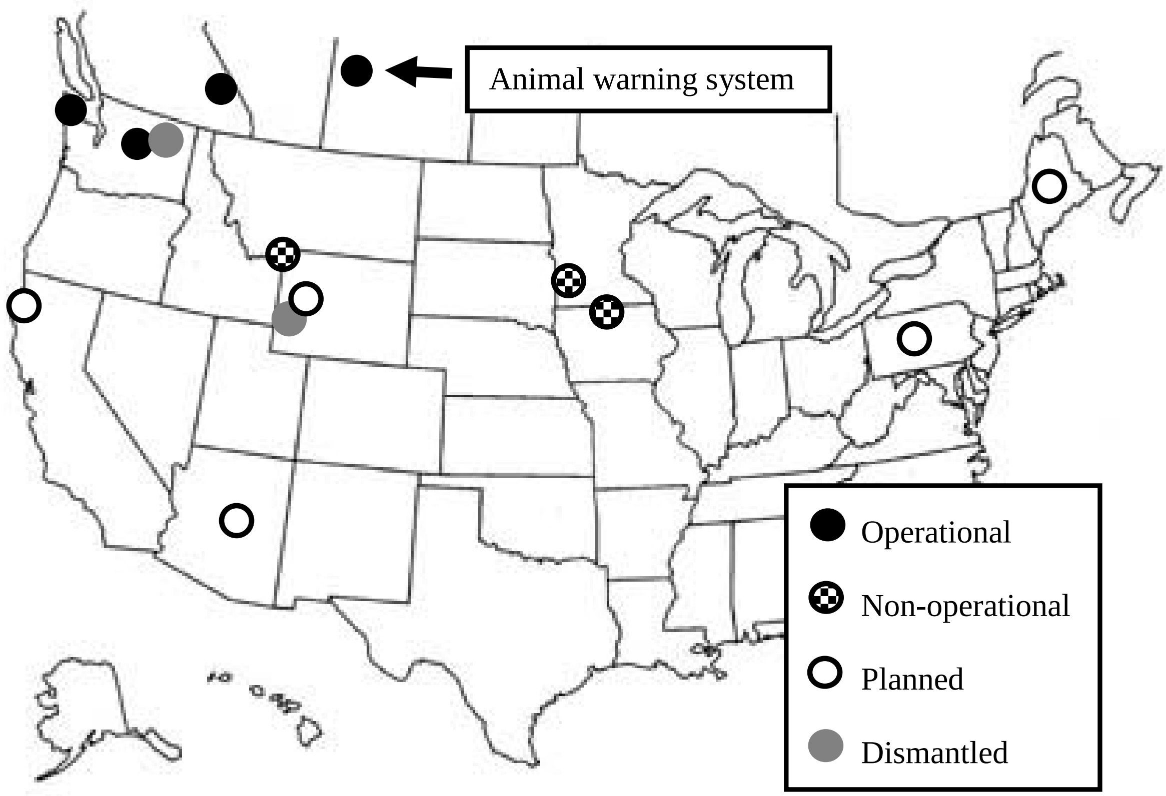

Fig. 1. The location of animal detection and animal warning systems in North America.

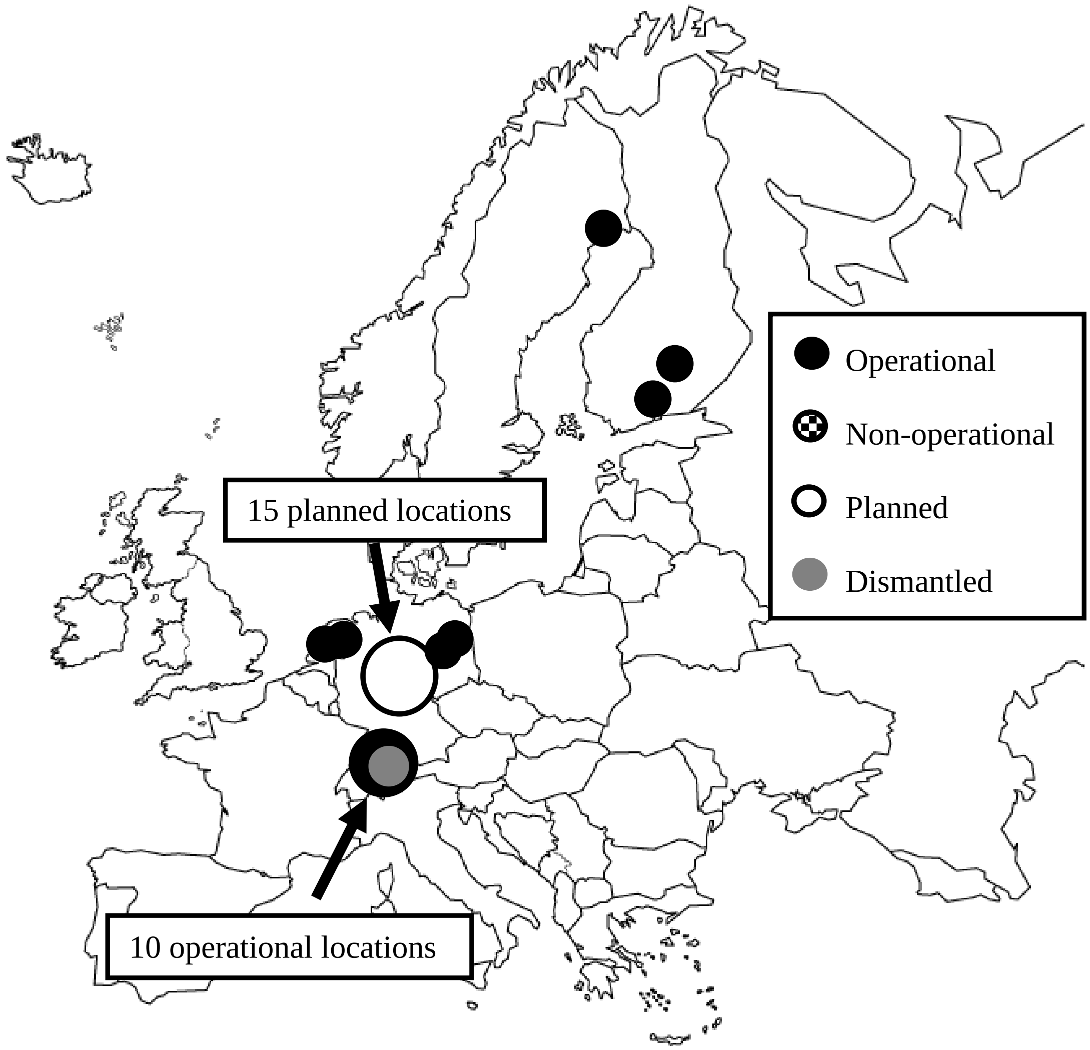

Fig. 2. The location of animal detection systems in Europe.

Existing Systems

The main characteristics of existing systems are listed in table 1. More details on the area-cover systems (section a. through e.), break-the-beam-systems (section f. through m.), and three unique systems (section d., n. and o.) are described below.

a. Seven locations, Switzerland
Kistler (1998) and Tschudin (1998) reported on a study that covered seven locations in Switzerland. The systems were supplied by Calonder Energy AG in Dietikon, Switzerland. Each system consisted of a series of passive infrared sensors. The sites, their installation date, the width of the crossing area and number of sensors installed, are listed in table 2. The passive sensors were designed to detect ungulates such as roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*) within a 30-100 m radius.

Table 1. Main characteristics of area-cover systems (a-e), break-the-beam-systems (f-m), and three unique systems (d, n and o). Evaluation: information available on: O = Operation and maintenance, V = Vehicle speed, C = Animal –vehicle collisions. CH = Switzerland, D = Germany, NL = The Netherlands, S = Sweden. Present = September 2003.

ID #	Location	Target species	Distance covered	Fence	Cost system	Cost Install.	Eval-uation	Installed	Operational
a	7 loc., Switzerland	Roe deer, red deer	50-200 m	No	$11,500	?	OVC	‘93-‘96	‘93/’96-present[1]
b	Box, Uusimaa, Finland	Moose	220 m	Yes	$60,000	$40,000	OV	Sep ‘96	Dec ’96-present
c	Mikkeli, Finland	Moose	90 m	Yes	$40,000	$30,000	O	‘99	‘99-present
d	Nugget Cany., WY, USA	Mainly mule deer	92 m	Yes	$200,000[2]	?	OV	1 Dec ‘00	8 Dec ’00-21 May ‘01
e	Kootenay NP, BC, Canada	White-tailed deer	1,000 m	No	?	?	O	Jun ‘02	Sep ’03-present
f	4 loc. CH; 2 loc. D	Roe deer, red deer	?		±$20,000[3]		?	‘98-‘01/ ‘02?	?
g	2 loc. NL	Roe deer, red deer, wild boar	200-250 m	Yes	±$50,000[4]		O	‘99	in operation
h	Rosvik, S	Moose	100 m	Yes	±30,000[5]	?	O	‘99	’00-present
i	Colville, WA, USA	Deer, elk	402 m	No	$ 9,000[6]	$3,000	O	20 Jun ‘00	Taken down spring ‘02
j	Marshall, MN, USA	White-tailed deer	1,609 m	No	$50,000	$7,000[7]	O	Jun ‘01	Turned off Nov ‘01
k	Wenatchee, WA, USA	Deer	213 m	No	<$40,000[8]	?	O	Oct ‘02	Oct ‘02-present
l	Yellowstone NP, MT, USA	Elk	1,609 m	No	$350,000[9]	$60,000	O	Oct/ Nov ‘02	Not operational
m	South Bend, IN, USA	White-tailed deer	9,654 m[10]	No	?	?	O	Apr ‘02	Not operational
n	Sequim, WA, USA	Elk	4,827 m	No	$60,000[11], $13,000[12]	?	O	Apr ‘00	Apr ‘00-present
o	Harris, SK, Canada	Mostly Mule deer	5,000 m	No	$36,000[13]	?	O	Apr ‘02	Apr ’02-present

[1] All in operation except Marcau site (road work Aug ‘97)
[2] Incl. operat. & maint., research, excl. WYDOT salaries
[3] In Switzerland
[4] Incl. installation and fence
[5] Excl. ± $70,000 for electricity
[6] Excl. signage, batteries
[7] Excl. salaries
[8] Incl. research, design, installation
[9] Including research and development
[10] Divided over 6 sections (1 mile each)
[11] For equipment
[12] For herding and collaring
[13] Excl. in kind contributions

Table 2. Main characteristics of the seven systems located in Switzerland (Kistler 1998).

Location	Installed	Distance covered (m)	Sensors (n)
Warth	February 1993	150	7
Soolsteg	November 1996	80-90	6
Val Maliens	May 1993	150	5-8
Marcau	May 1993	50-60	2
Schafrein	December 1995	80	5-6
Duftbächli	December 1995	30-50	4
Grünenwald	December 1995	190-200	4-6

The sensors were installed in a 20-30 m wide zone on both sides of the road. Once an animal was detected LED signs with a deer symbol were activated to alert the drivers. Once activated, the signs stayed on for 45 s. Five of the sites also had an LED sign with an enforceable maximum speed limit (40 km/h). The seven systems were only activated during the night. A time clock and light sensor switched the systems on and off automatically. The rationale was that human activities during the daytime would cause a high number of false detections. In addition, the sensors were relatively sensitive to differences in temperature, which occurs frequently during the day. There were no fences or other barriers specifically erected for wildlife on either side of the crossing areas. However, most locations had support walls, steel nets and guardrails just before and after the crossing areas, which helped funnel the wildlife through the crossing area (Kistler 1998). Depending on the site, local game wardens or road maintenance personnel checked the system every 3-5 days, once a week, or once every two weeks. Warm engines of passing vehicles, and falling branches, especially with strong winds, caused false detections. Broken sensors, loss of power due to snow covered solar panels, and broken lamps in the warning signs caused additional problems.

b. Box, Finland

This system consists of microwave radar sensors that were designed to detect moose (*Alces alces*) in a 220 m wide gap in a several km's long moose proof fence along Hwy 7, near Box, between Helsinki and Porvoo, about 20 km south-west from Porvoo, Uusimaa, Finland (Taskula 1997; Muurinen & Ristola 1999; Pers. com. Kari Taskula, Sabik). Sabik Ltd, Finland, supplied and installed the system. Five poles were placed on each side of the road 5-20 m from the pavement. Each pole had two sensors that faced away from the road. The sensors were designed to detected large animal movements up to 50 m distance within a 60° horizontal angle. When a large animal was detected, LED message signs with a moose symbol were turned on. The signs warned drivers about the presence of large animals on or near the road remaining lit for two to three minutes after being triggered by an animal. The message signs were located 150-200 m before the crossing area. Detection of a large animal also activated a video camera and recorder. The camera turned and zoomed toward the detection area. The images were used to verify the presence of large animals and to evaluate the reliability of the system. The system records start and end time of every detection event of all detectors, the status of the signs (on or off), and invalid detections. The data are stored in a file that is downloaded on a daily basis from a remote location through a modem and a user interface program. It is also possible to open the modem connection through the user interface program and to monitor the system real time. The system was installed in September 1996, but tests and modifications to the system took another three months. To distinguish moose from other moving objects such as rain or rain spray, the system was programmed to only detect objects moving towards the sensors at a speed greater than 0.8 m/s. The sensors were placed 3 m above the ground and their vertical angle was modified to reduce false detections caused by small animals such as rabbits and birds. Furthermore the signal had to be contiguous for at least 0.5 s. Rain and variations in air pressure also caused false detections. This was mitigated by attaching metal eaves to the detectors and by filtering out rain noise at the interface. In addition, 16 passive infrared detectors and one rain detector were integrated into the system to help filter out false detections (Taskula 1999). The microwave detectors were automatically switched off if multiple consecutive detections were reported after rain was detected. The system operated on infrared detectors only under those conditions. After the system became fully operational in mid-December 1996, some false detections continued to occur (Taskula 1999; Pers. com. Kari Taskula, Sabik). In spring when the snow melted and the water warmed on the pavement, spray from passing vehicles triggered the system. After improvements were made in 1997-1998 most of the problems disappeared, and false detections became rare. However, but there are still a few false detections in spring.

c. Mikkeli, Finland
This system is similar to the one described above. It is located along Hwy 5, between Lahti and Mikkeli, about 25 km south-west from Mikkeli, Finland (Pers. com. Kari Taskula, Sabik). The detector poles were located 5 m from the pavement. If an agreement had been reached with a local landowner, the detectors would have been placed 15-20 m from the roadside. This would have eliminated false detections caused by rain spray from passing vehicles. Gaps in the fence at side roads and the relatively short width of the crossing area increase the chance that moose wander off along the road in the right-of-way, instead of crossing the road at a straight angle. However, only one such event has ever been documented (situation September 2003).

d. Nugget Canyon, Wyoming, USA
The Flashing Light Animal Sensing Host (FLASH) was designed to detect mule deer (*Odocoileus hemionus*) and consisted of a series of infrared sensors placed at 17-19 m intervals on both sides of Hwy 30 (mile post 30.5, Nugget Canyon, between Kemmerer and Cokeville, Wyoming (Gordon et al. 2001; Gordon & Anderson 2002; Pers. com. Stanley Anderson, Wyoming Cooperative Fish and Wildlife Research Unit). The FLASH system was designed by Victoria Gooch. Mid-American Manufacturing Technology Center (MAMTC) and the Wyoming Department of Transportation (WYDOT) installed the system. There were five sensors on each site of the road and they spanned a 92 m gap in an 11,263 m long fence. The sensors were designed to detect the body heat of large animals. Once they did, flashing warning lights above a permanently visible warning sign were activated to alert drivers. The signs were placed about 300 m before the crossing

area. The text read “attention, deer on road when flashing”. In addition, a unique geophone unit, paired with infrared scopes, was installed on the south side of the road. An additional pair of infrared scopes was installed on the north side of the road in the second year (but no geophone unit), and microwave sensors were installed south of the road. Finally a video-camera system was installed to monitor deer moving through the crossing area. The geophone unit was designed to detect ground vibrations caused by ungulates walking through the crossing area and also served as a control for the FLASH system. The infrared scopes were part of the geophone system and had to be triggered at the same time as the geophone sensors to result in a valid detection. This was needed to eliminate false detections due to vibrations from passing trains on a nearby railroad and vehicles (Gordon et al. 2001). The microwave sensors formed a separate system, but they did not cover the entire area and this system was susceptible to false detections as a result of passing trucks, vegetation moving in the wind and birds. Repositioning of the radar heads resulted in complete area coverage, but false detections continued and the system was seldom used. The systems were tested and modified during the 1998-1999 season. The passive infrared sensors of the FLASH system continued to suffer from reduced sensitivity due to sun exposure throughout the 1999-2000 season and were replaced by active infrared sensors in November 2000. The FLASH system became operational on 4 December 2000 (Gordon & Anderson 2002). The FLASH system worked reliably until January 2001 after which many false detections started to occur; more than 50% of the detections were false (Gordon et al. 2001; Gordon & Anderson 2002). This was due to frost on the sensors, birds feeding on carrion in the crossing area, and snow thrown by passing snowplows. Additional problems occurred in early April 2001 as a defective transmitter started to cause false detections in response to passing trucks. However, no evidence was found that the FLASH system failed to detect deer moving through the crossing area. Nevertheless, the FLASH system was found to be too unreliable for deployment. The geophone system was never found to record false detections and seemed to be reliable (Gordon et al. 2001; Gordon & Anderson 2002; Pers. com. Matthew Johnson, Wyoming Department of Transportation). It was suggested that the geophone system could be further developed in the future. However, at one point lightning did cause malfunctioning in the geophone system.

e. Kootenay, British Columbia, Canada

In June 2002 an animal detection system was installed along Hwy 93, in Kootenay National Park in British Columbia, Canada, about 60 km north of Radium, immediately north of the Dolly Varden Day-Use Area (Kinley et al. 2003; Pers. com. Nancy Newhouse Sylvan Consulting; Pers. com Hillary Page, Sage Consulting). The system was designed to detect large animals, specifically white-tailed deer (*Odocoileus virginianus*). ICBC, QWIP Technologies, OCTEC Ltd., Intranstech and FLIR Systems Inc. all provided support for research and development. Parks Canada helped install the system. Two infrared cameras that detect heat and additional equipment were installed in the right of way. The software uses a combination of motion, speed and size to determine whether the warning system should indeed be triggered. The system, especially the cooling system of the cameras, experienced technical difficulties during the first year (June through October 2002). A modified system with different infrared cameras was installed in May 2003 (Pers. com. Hillary Page, Sage Consulting). The road length covered by the system was cut in half (from 2000 m to 1000 m) because of the different cameras. The system has standard black on yellow deer warning signs with amber flashing lights on top to warn drivers. The system became operational in September 2003 (Pers. com. Nancy Newhouse, Sylvan Consulting). The system is currently only active from dusk to dawn. The system may eventually be operational 24 hrs a day.

f. Four sites in Switzerland; two sites in Germany

In addition to the 7 sites described under section a., four other animal detection systems have been installed in Switzerland after Kistler's study was published (Kistler 2002): St. Annawald (1998), In den Böschen (1999), Grauholz (1999), Herenacher (2001) (Kistler 2002). The systems came from the same manufacturer (Calonder Energy AG), but the technology seemed to differ from the seven sites described under section a.; the new systems work on a break-the-beam principle (Kistler 2002). Some systems operate on laser beams, while other operate on infrared beams. An additional two sites have been installed in Germany between Kassel and Herleshausen in Hessen (Bundesstrasse B400, Alberberg, Eschweg) and Sachsen-Anhalt (Anonymous 2002a; Pers. com. Christa Mosler, Infodienst Wildbiologie & Oekologie, Swiss Wildlife Information Service).

g. Two sites in The Netherlands

There were two systems installed in The Netherlands: one near ‘t Harde (N309) and one near Ugchelen (N304) (Pers. com. Herman van Zandbrink, Provincie Gelderland; van den Hoorn 2000). The system manufacturer was Calonder Energy AG, the same as discussed under sections a. and f. The two systems in The Netherlands were designed to detect wild boar (*Sus scrofa*), roe deer and red deer. They are solar powered and operate on a focused infrared beam that is positioned at ±50 cm above the ground. The crossing areas are about 200-250 m wide and have about 500 m long fences before and after the crossing area on both sides of the road. Once an animal is detected LED warning signs with a red deer in combination with an advisory 50 km/h speed limit sign are activated. The systems are only switched on during the night. The animals tend to stay away from the road during the daylight hours (Pers. com. Herman van Zandbrink, Provincie Gelderland). The sensor boxes have to be well anchored on a concrete foundation to remain stable (Pers. com. Herman van Zandbrink, Provincie Gelderland). Ventilation of the boxes is also an issue as rain or snow may cause the lens to fog up. The distance between the sensors (200-250 m) may be a little too far; smaller distances may reduce the number of false detections. Fallen trees and tall grasses can also produce false detections, as the sensors were only ±50 cm above the ground. From time to time the batteries lost too much of their power. Lightning struck one of the sensors, which caused a series of false detections. In addition, vehicles that ran off the road damaged equipment on two occasions; a sensor post and a signal pole. Another problem occurred when small birds used the sensor box as a nesting site (Pers. obs. Marcel Huijser), but mesh wire in front of the holes can solve this problem.

h. Rosvik, Sweden

In 1999 an animal detection system was installed along highway E4 near Rosvik in northern Sweden (between Piteå and Luleå) (Pers. com. Andreas Seiler, Grimsö Wildlife Research Station, Department of Conservation Biology, Swedish University of

Agricultural Sciences; Kjell Ståhl, Road Administration, Luleå). The system was designed by PIK AB, Karlskrona, Sweden, and it was installed by the manufacturer and the Road Administration. The system operates on a break-the-beam principle with infrared light. The system was installed in a 100 m wide opening in a fence and it was designed to detect moose. When an animal is detected lights are turned on that illuminate the highway at the crossing area. This should allow drivers to see the animal better. In addition, red warning lamps in the right-of-way are activated. A standard moose crossing sign with the text "wildlife passage" is located just before the crossing area. The electricity supply was a major problem, but that issue was solved in winter 2001/2002.

i. Colville, Washington, USA

On 20 June 2000 an animal detection system was installed on Hwy 395 (mile post 290), north of Spokane, south of Colville, three miles north of Chewelah, Washington (Shipley 2001; Robinsen et al. 2002; Pers. com. J. Schafer, WSDOT Research Office; Brian Walsh, WSDOT, Traffic Safety and Operations). The system consisted of two lasers, one placed on each side of the road, two standard deer warning signs, two smaller rectangular signs that read "When Flashing", and two solar powered red flashing beacons. The system was designed by an electrical engineer (subcontracted) and manufactured in-house at the WSDOT Research Office. The system was installed by the vendor and WSDOT. When the laser beam was broken the lights were switched on. The lasers operated on batteries with a one-week lifespan while the red strobes were solar powered. Obtaining a clear line-of-sight in the right-of-way was a problem. In addition, the sighting of the lasers proved difficult, partly because of the distance between the sensors. Sunlight heating up of the plastic boxes holding the laser equipment may have caused problems with the sighting of the laser (Shipley 2001; Robinsen et al. 2002; Pers. com. Brian Walsh, WSDOT, Traffic Safety and Operations). False detections caused the batteries to drain quicker than anticipated. Finally the system has experienced theft of solar-power units. The system was taken down spring 2002.

j. Marshall, Minnesota, USA

Around June 2001 an animal detection system was installed along a 1,609 m long section of Hwy 23 at Camden State Park southwest of Marshall, Minnesota (MNDOT 2001a). The system consisted of a series of laser transmitters and receivers, and was integrated by Lewis Enterprises Inc., Saint Louis Park, MN. The vendor and MNDOT installed the system. The distance between the stations is approximately 200 m (Pers. com. Erik Lewis, Lewis Enterprises Inc.). The system had two laser beams between all stations. The lowest beam was about 65 cm from the ground, and the second beam was about 30 cm above the first (Pers. com. Robert Weinholzer, Minnesota Department of Transportation; MNDOT 2001b). The system was only triggered when both beams were broken at the same time. This reduced false detections as a result of e.g. flying birds, but not as a result of heavy fog. When both laser beams in the same segment were broken amber flashing beacons were activated that continued to flash for about one minute. The warning lights were situated on standard deer warning signs. In addition, there were advisory signs that notified drivers that they were entering a test area and that deer or other animals may be present when lights are flashing. Testing was suspended during the winter months due to high maintenance costs (MNDOT 2001b). The batteries had to be replaced more often than anticipated and the grass-herb vegetation between the sensors had to be mown regularly as the tall grass caused many false detections (Pers. com. Robert Weinholzer, Minnesota Department of Transportation; MNDOT 2001b)). The Minnesota Department of Transportation plans to hardwire the system in 2004. Solar panels were considered, but maintenance, vandalism and theft were considered too much of a risk. Vegetation management in the right-of-way could be reduced if weed mats or gravel strips would be situated between the sensors (Pers. com. Erik Lewis, Lewis Enterprises Inc.).

k. Wenatchee, Washington, USA

In October 2002, an animal detection system was installed along US 97A (mile post 206), near Wenatchee, Washington. When laser beams are broken along a 213 m long road section, yellow flashing beacons on 5 by 6 foot black on yellow warning signs with a deer profile are activated (WSDOT 2003a; b). The system was designed and integrated by Parks Griebble and Battelle Laboratories. Other signs that said, “when flashing”, accompanied the deer signs. When the system was triggered the lights flashed for 60 s. False detections were a problem between October 2002 and January 2003. No deer were killed between October 2002 and January 2003. The system seems to operate well (Pers. com. Jennene Ring, WSDOT North Central Region Traffic Engineer). However, deer also crossed frequently just outside of the area covered by the system. In addition, deer may loiter in the right-of-way. If these deer stay there longer than one minute the signals are turned off, and drivers are no longer warned of their presence.

l. Yellowstone NP, Montana, USA

In October and November 2002 an animal detection system was installed along a 1,609 m long road section of Hwy 191 (mileposts 28-29) in Yellowstone National Park south of Big Sky, Montana (WTI 2002a; b). The system was designed and integrated by Sensor Technologies & Systems, Scottsdale, Arizona. Michiana Contracting, Plymouth, Indiana and Eagle Rock Timber, Idaho Falls, Idaho installed the system. Each transmitter sends a uniquely coded, continuous microwave RF signal to its intended receiver (STS 2002). The transmitters and receivers are mounted about 120 cm above the ground (designed to detect elk (*Cervus elaphus*)). If this signal is blocked, the receiver sends a UHF radio signal to the master station. The master station then sends the beacon-on command to the three nearest beacons. Each beacon is situated above a standard elk warning sign and signs that say, “when flashing” “next 1 mile”. The flashing beacons alert on-coming traffic that there may be a large animal on or near the road. After the designated timeout period (3 minutes), the master station transmits the beacon-off command to the beacon stations. If the signal is blocked continuously, the beacons will stop flashing after 12 minutes. The system records every break-of-the-beam, how long it lasted, date, time, and section number (there are six sections on the east side of the road and nine sections on the west side of the road). It was anticipated that these data could be accessed from a remote location through a cell phone modem. However, cell phone coverage proved to be insufficient for reliable data transmission. Each station is powered by a stand-alone solar electric power system. Each station configuration has a different power system designed to meet the load requirements of that station. The solar power systems were designed to operate without down time due to darkness and snow cover, but shady spots and snow did cause a power problem at one post. An additional battery was installed to increase storage capacity. However, it is unknown whether this is sufficient to solve the problem. The system has not been operational yet (situation September 2003) due to problems with the communication system at low temperatures. The system produced a large number of false detections and the vendor is in the process of replacing the communication system (situation September 2003). Snow spray from snowplows also triggered the system. In addition, a car that ran off the road damaged one of the sensors, but the car is unlikely to have received major damage from the equipment. An elk sign disappeared. Furthermore, personnel from Yellowstone National Park and local residents have expressed their concern with the dimension of the posts and equipment, and the solar panels in particular. The size of equipment is thought to have a negative effect on the landscape quality, and reflection of the sun on the solar panels is a nuisance. The system is anticipated to become operational by 1 October 2003.

m. Indiana Toll Road, Indiana, USA

In April 2002 an animal detection system was installed along the Indiana Toll Road (I-80/90, around mile posts 130-140) near South Bend, Indiana. (Pers. com. Sedat Gulen, Research Division, Indiana Department of Transportation). The system was designed and integrated by Sensor Technologies & Systems, Scottsdale, Arizona. Michiana Contracting, Plymouth, Indiana, installed the system. The total length covered by the system is 9,654 m, but the system was split up in 6 sections of 1,609 m (1 mile) each (Anonymous 2003b; Pers. com. Sedat Gulen, Research Division, Indiana Department of Transportation). A 1 mile long control section follows each 1 mile section with sensors. There are two blocks (each with 3 sections and their controls), which are 4-5 miles apart. This system is the same as described for the site in Yellowstone National Park (see section l.). The system is not operational yet due to problems with the radio system (see also section l.). The system is anticipated to become operational in the fall of 2003.

n. Sequim, Washington, USA

This system was installed along a 4,827 m long section of Hwy 101, near Sequim, on the Olympic Peninsula, Washington. In 1999 about 10% of the elk herd was radio collared (Williams, 1999; New York Times 2001; Carey 2002; Pers. com. Shelly Ament, Washington Department of Fish and Wildlife). An effort was made to radio collar lead cows, but this was not always possible. Receivers placed along the road scan for the frequencies of the individual radio collars 24 h per day. When the radio-collared individuals come within about 400 m from the road, the receivers that pick up the signal activate the flashing beacons that are linked to that receiver. There are four receivers in total. Typically only one receiver picks up the signal at the same time, but if the radio-collared individual is about halfway between two receivers, the signal may be picked up by both receivers. Two receivers are linked to only one flashing beacon (at both ends of the road section). The two other receivers are each linked to two flashing beacons, one for each travel direction. Standard black on yellow elk crossing signs that say “elk x-ing” accompany the flashing beacons. The system was designed and integrated by Shelly Ament and Dave Ruben, mostly with off the shelf equipment. WSDOT and the Washington Department of Fish and Wildlife installed the system. To block false detections, a device that counted the pulses of the radio signal had to be added. This device filtered out signals from other, non-elk, radio transmitters. The system became operational in fall 2000. The batteries of the radios have a three-year life span, but most of them last much longer. A second capture session took place in March 2003. There were 8 elk (7 cows, 1 bull) with a radio collar in September 2003. The system seems to work well, even after a change in habitat use caused the elk to cross the road more frequently than they used too. Maintenance was limited to replacing the battery pack of a receiver and some minor repairs to a receiver. Some signs were vandalized (paint), but the signs were cleaned relatively easily afterwards.

o. Harris, Saskatchewan, Canada
In April 2002 a 5 km long section of Hwy 7 (km control section 7-04, km 0-6), near Harris, Saskatchewan, Canada, was equipped with a system that detects vehicles (Anonymous 2001; SHT 2002). Once vehicles are detected, units in the roadside are activated that alert deer through a variety of noise and light signals (IRD 2002; Pers. com. Jim Wirachowsky and Rob Bushman, International Road Dynamics). The system was designed and installed by International Road Dynamics (IRD, Saskatoon, Saskatchewan Canada). The units in the roadside are about 230 m apart and consist of a small cabinet with electronics, sensors for vehicle detection, and an animal warning device (Pers. com. Bushman, International Road Dynamics). The units are powered by solar panels and batteries. When no vehicles are present the system is not active. The communication system and power supply have been improved since the system was installed (Pers. com. Rob Bushman, International Road Dynamics). In addition, MP3 players were added which allow for a great variety of sounds to be recorded and played. The system will be tested for two years. The effectiveness will be evaluated by a committee that include the vendor (IRD), SGI, Saskatchewan Highways and Transportation, Saskatchewan Environment, Saskatchewan Wildlife Federation, Royal Canadian Mounted Police, Canadian Automobile Association, Saskatoon and Area Safety Council and the West Central Municipal Government Committee (Anonymous, 2002b).

Planned systems

In addition to the animal detection and animal warning systems that have been installed (section a. through o.), we identified 20 additional locations for which an animal detection or animal warning system is planned (section p. through t., see below).

p. Thompsontown, Pennsylvania, USA
An animal detection system will be installed in October 2003 along a ±804 m long section of Hwy 22/322 (between mile posts 360-361), just east of Thompsontown, Pennsylvania, approximately 35 miles northwest of Harrisburg (Edwards and Kelcey 2003; Pers. com. Pat Wright and Marcel Huijser, Western Transportation Institute - MSU). It is a four-lane highway with two lanes in each direction and a grass median. The system was designed and integrated by Oh Deer, Inc., Mason City, Iowa. The cost of the system is $90,000. PENNDOT and the vendor will install the system, which is designed to detect white-tailed deer in an area, as opposed to a “break-the-beam-system”. The microwave detectors cover the entire right-of-way and should filter out moving vehicles, swaying branches, rain and snow. The 17 posts (each with 2 sensor units) will be placed

at approximately 91 m intervals along the side of the road, and they will operate on solar power. Hardwiring was calculated at more than $50,000 whereas the cost for solar panels was estimated at $7,500 (Edwards and Kelcey 2003). Standard deer crossing signs (black on yellow) will be combined with yellow flashing lights and additional signs that say "when flashing", "next ½ M". Signs that say "animal detection test section ahead" and "end test section" will be installed before and after the sensors.

q. McDonald creek area, California, USA

The California Department of Transportation (CALTRANS), District 1, has identified a 965 m long road section along Hwy 101 where elk cross the road frequently. The road section lies between mileposts 114.18 and 115.52, in Humboldt State Park, McDonald Creek area, near Eureka. This area has had a concentration of collisions, resulting in dozens of human injuries, and many dead elk (Pers. com. Susan Taylor, North Region Environmental Management Branch, California Department of Transportation). At this time there is a flashing warning light in place to alert drivers, but the flashing is continuous, independent of the presence of the elk. Since drivers tend to ignore permanent warning signs, CALTRANS is interested in installing an animal detection system. However, funding is not anticipated until summer 2004.

r. Preacher Canyon, Arizona, USA

State Route 260 from Payson to the Mogollon Rim in Arizona, northeast of Phoenix, Arizona, is being widened (Dodd et al. 2003; Pers. com. Norris Dodd and Jeff Gagnon, Arizona Game and Fish Department). This road section is known for its high number of collisions with elk. To reduce the collisions and to make the road more permeable to wildlife, a total of 17 bridges and underpasses will be built. The first section, Preacher Canyon, has been completed already. There are two wildlife underpasses located in this section near Little Green Valley. In addition, wildlife fencing (500 m road length), jump-outs and one-way gates have been provided for. Although the underpasses are used intensively, many elk and white-tailed deer walk along the fence and cross the road at the end of the fence (Dodd et al. 2003). This has been demonstrated through infrared video images. In addition, the Arizona Game and Fish Department has tracked elk movements and highway crossings through GPS telemetry and assessed the wildlife-vehicle collision rate for nearly two years. This monitoring will be conducted an additional two years after fencing. Furthermore, the Arizona Game and Fish Department has proposed to install animal detection systems at two fence ends in the Preacher Canyon area, on both sides of the road. One section is 1-1.2 km in road length, and the other measures about 1.5 km (Pers. com. Norris Dodd, Arizona Game and Fish Department). Funding is not expected until spring 2004.

s. Pinedale, Wyoming, USA

A 3,218 m long road section of Hwy 191, west of Pinedale, Wyoming has a concentration of animal-vehicle collisions with pronghorn (*Antilocapra americana*) (Pers. com. Matthew Johnson, Wyoming Department of Transportation). The Wyoming Department of Transportation has proposed to install an animal detection system along this section. Funding is not anticipated until fall 2003.

t. Maine, USA

Ungulate-vehicle collisions are a major safety concern in Maine. There are two locations that are potential candidates for the installation of animal detection systems: Hwy 1 between Presque Isle and Caribou, and an 804 m long road section on Hwy 4 near Rangeley (Pers. com. Robert van-Riper, Maine Department of Transportation). Both locations have a history of ungulate-vehicle collisions with moose as well as white-tailed deer. Funding is not anticipated until fall 2003.

u. 15 sites, Germany

15 sites are currently in the planning phase in Germany (Pers. com. Giacomo Calonder, Calonder Energy, Switzerland). No further details are available at this time.

Additional issues

During operation and maintenance a range of problems and other issues were identified (see section a. through o.). We grouped them into four categories: false positives, false negatives, maintenance, and landscape, ecology and animals (Table 3). 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. Most of the causes of false positives and false negatives have already been discussed (see section a. through o.), but some have not been explicitly mentioned yet. For example, cars on driveways or side roads can also 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 (section n.) 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 species. The system also works much better for a resident population than for

Table 3. Summary of the issues, problems and experiences with operation and maintenance of the animal detection and animal warning systems. √ = problem has been reported or issue applies, (√) = problem has not been reported, but it could occur. [1] = For Swedish system that illuminates the road at the crossing area and that has red warning lights in the right-of-way.

Issues, problems and experiences	Passive detector systems	Break-the-beam systems	Geo-phone system	Radio-collar system	Deer warning system
False positives					
Moving or growing vegetation	√	√			
Flying birds, nesting birds, rabbits	√	√			
Wind, rain, water, fog, snow spray (snowplows)	√	√			
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 equipment	√	√	(√)	√	(√)
Period required to solve technical difficulties	√	√	√	√	√
Signs (standardization, liability)	√	√	√	√	√
No remote access to data (no cell phone coverage)	(√)	√	√	(√)	(√)
Landscape, ecology, animals					
Landscape aesthetics	(√)	√	(√)	(√)	(√)
Animals crossing areas may change overtime	(√)	√	(√)	(√)	(√)
Animals may wander between fences (if present)	√	(√)	(√)	(√)	(√)
Small animals (non-target species) are not detected	√	√	√	√	
Animals may adapt and are no longer deterred					√
Not suitable for high traffic volumes					√
Continuous effort to capture animals				√	
Stress for the animals involved				√	
Not in habitat linkage zones (sound, light)		√[1]			√

migrants from far away locations that may only cross the road once or twice per year. The radio-collar system 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.

The animal warning system is special in the sense that it depends on alerting animals when a vehicle approaches. Many animal species have been shown to adapt to disturbance if this is not accompanied by an immediate and real threat. Therefore, the audio and visual signals produced by the stations in the right-of-way may not scare the animals away from the road once they have been exposed to it for a certain time. However, the animals do not necessarily have to flee away from the right-of-way to reduce the number of collisions. If the animals learn to associate the audio and visual signals with approaching vehicles, they may be less likely to enter the road at that time. If animal warning systems are effective one should probably avoid installing them in areas that have been identified as habitat linkage zones because they promote wildlife movement, especially for dispersing individuals. These individuals may not have been exposed to the audio and visual signals before, and animal warning systems may cause a habitat linkage zone to be less effective. Additionally, these systems are not well suited for high traffic flows since the animal warnings would be running continuously in such locations.

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 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.

DISCUSSION AND CONCLUSION

This overview shows that a wide variety of animal detection and animal warning systems have been installed across North America and Europe. 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 are the Swiss system (section a., f. and g.), the Finnish system (section b. and c.) and, although still in an experimental stage, the geophone system (section d.) and the radio collar system (section n.). However, 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). When we assume a vehicle speed of 88 km/h (55 MPH), increased driver alertness can reduce the stopping distance of the vehicle by 21 m (68 ft). Only one study has addressed the ultimate parameter of system effectiveness. Kistler (1998) has shown that the passive infrared detection systems in Switzerland (section a.) were able to reduce the number of animal-vehicle collisions by 82%. This is an encouraging result, but further evaluation of different systems under different circumstances is required before we can generalize Kistler's conclusion.

We conclude that animal detection and animal warning systems have the potential to be an 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. In addition, further research and development is needed before animal detection and animal warning systems can be applied on a wide scale.

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