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A Quantitative Comparison of the Reliability of Animal Detection Systems and Recommended Requirements for System Reliability

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Abstract

Animal–vehicle collisions affect human safety, property, and wildlife, and the number of animal–vehicle collisions has been increasing in many regions across North America. For this project we investigated the reliability of nine different types of animal detection systems from five different manufacturers with regard to system reliability. These systems have the potential to improve human safety while not blocking or confining animal movements across the road. However, reliable warning signs are essential as the effectiveness of these systems depends on driver response. To investigate the reliability of the systems we constructed a controlled access test facility near Lewistown, Montana. The systems were installed to detect horses and llamas that roamed in an enclosure. The llamas and horses served as a model for wild ungulates. Data loggers recorded the date and time of each detection for each system. Animal movements were also recorded by six infrared cameras with a date and time stamp. By analyzing the images and the detection data, researchers were able to investigate the reliability for each system. The percentage of false positives (i.e., a detection is reported by a system but there is no large animal present in the detection zone) was relatively low for all systems (≤1%). The percentage of false negatives (i.e., an animal is present in the detection zone but a system failed to detect it) was highly variable (0–31%). The percentage of intrusions (i.e., animal intrusions in the detection area) that were detected varied between 73 and 100 percent. The results suggest that some animal detection systems are quite reliable in detecting large mammals with few false positives and false negatives, whereas other systems have relatively many false negatives. We also surveyed three stakeholder groups—employees of transportation agencies, employees of natural resource management agencies, and the traveling public—with regard to their expectations on the reliability of animal detection systems. Based on the results from the survey, the researchers recommend the following performance requirements for the reliability of animal detection systems: 1) Animal detection systems should detect at least 91 percent of all large animals that approach the road; and 2) Animal detection systems should have fewer than 10 percent of all detections be false. The recommended reliability requirements of animal detection systems were compared to the results of the reliability tests. Five of the nine systems tested met the recommended requirements. The results of this study provide transportation and other agencies with the data to decide on minimum reliability requirements for animal detection systems. Furthermore, the data show that some of the systems tested are quite reliable and may be considered for implementation along a roadside where they can be investigated for their effectiveness in reducing collisions with large wild mammals. However, experiences with installation, operation and maintenance showed that the robustness of animal detection systems may have to be improved before the systems can be deployed on a large scale.

Introduction

Animal–vehicle collisions affect human safety, property, and wildlife, and the number of animal–vehicle collisions has been increasing in many regions across North America (Huijser et al. 2007). Here we investigate a relatively new mitigation measure aimed at reducing animal–vehicle collisions while allowing animals to continue to move across the landscape. We evaluated the reliability of a range of different animal detection technologies from different manufacturers.

Animal detection systems detect large animals (e.g., deer (*Odocoileus* spp.), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*) and moose (*Alces alces*)) as they approach the road (see reviews in Huijser et al. 2006, 2009a). When an animal is detected, signs are activated, warning drivers that large animals may be on or near the road at that time. Previous studies have shown variable effects of activated warning signs on vehicle speed: substantial decreases in vehicle speed (≥5 km/h (≥3.1 mi/h)) (Kistler 1998; Muurinen and Ristola 1999; Kinley et al. 2003; Dodd and Gagnon 2008); minor decreases in vehicle speed (<5 km/h (<3.1 mi/h)) (Kistler 1998; Muurinen and Ristola 1999;

Gordon and Anderson 2002; Kinley, et al. 2003; Gordon, et al. 2004; Hammond and Wade 2004; Huijser et al. 2009a); and no decrease or even an increase in vehicle speed (Muurinen and Ristola 1999; Hammond and Wade 2004). This variability of the results is likely related to various conditions (see review in Huijser et al. 2009a):

- The type of warning signal and signs.
- Whether the warning signs are accompanied with advisory or mandatory speed limit reductions.
- Road and weather conditions.
- Whether the drivers actually see an animal.
- Whether the driver is a local resident.
- Perhaps the road length of the zone with the animal detection system and the road length that the warning signs apply to (the more location specific the better).
- Perhaps also cultural differences that may cause drivers to respond differently to warning signals in different regions.

Activated warning signs may also result in more alert drivers, which can lead to a substantial reduction in stopping distance: 20.7 m (68 ft) at 88 km/h (55 mi/h) (review in Huijser et al. 2009a). Finally, research from Switzerland has shown that animal detection systems can reduce ungulate–vehicle collisions by as much as 82 percent (Mosler-Berger & Romer 2003). Preliminary data from Arizona showed a reduction of 91 percent (Dodd and Gagnon 2008).

Before animal detection systems can be effective, they must be able to detect large animals reliably. Therefore it is important to know how reliable animal detection systems are when detecting large animals and to establish minimum norms for system reliability. Until now, measuring and comparing the reliability of different animal detection systems has been problematic due to the following factors:

- Most systems have not been properly studied, or the results have not been published.
- Different studies have evaluated systems with regard to different parameters.
- Different studies used different methods.
- Different systems have been evaluated under varying conditions (e.g., varying road and climate conditions).

For this study we investigated the reliability of different types of animal detection systems from different vendors at the same site and under similar circumstances. A test facility (Roadside Animal Detection System (RADS) test-bed) was constructed near Lewistown, Montana. Nine different animal detection systems from five different manufacturers were installed to detect horses and llamas that roamed in an enclosure. Data loggers recorded the date and time of each detection for each system. The animal movements were also recorded by six infrared cameras with a date and time stamp. By analyzing the images and the detection data, researchers were able to evaluate the system for a variety of reliability parameters. In addition, we recommend minimum standards for system reliability.

Methods

Test-bed location

The RADS test-bed is part of the TRANSCEND cold region rural transportation research facility and is located along a former runway at the Lewistown Airport in central Montana (Figure 1). The test-bed location experiences a wide range of temperatures, and precipitation ranges include mist, heavy rain, and snow; the topography is flat, and the rocky soil does not sustain much vegetation that may obstruct the signals transmitted or received by the sensors. The test-bed consists of an animal enclosure, nine different animal detection systems, and six infrared cameras with continuous recording capabilities (Figure 2). The distance covered by the systems (except for System 9) was 91 m (300 ft) (from the left to the right side of the enclosure).

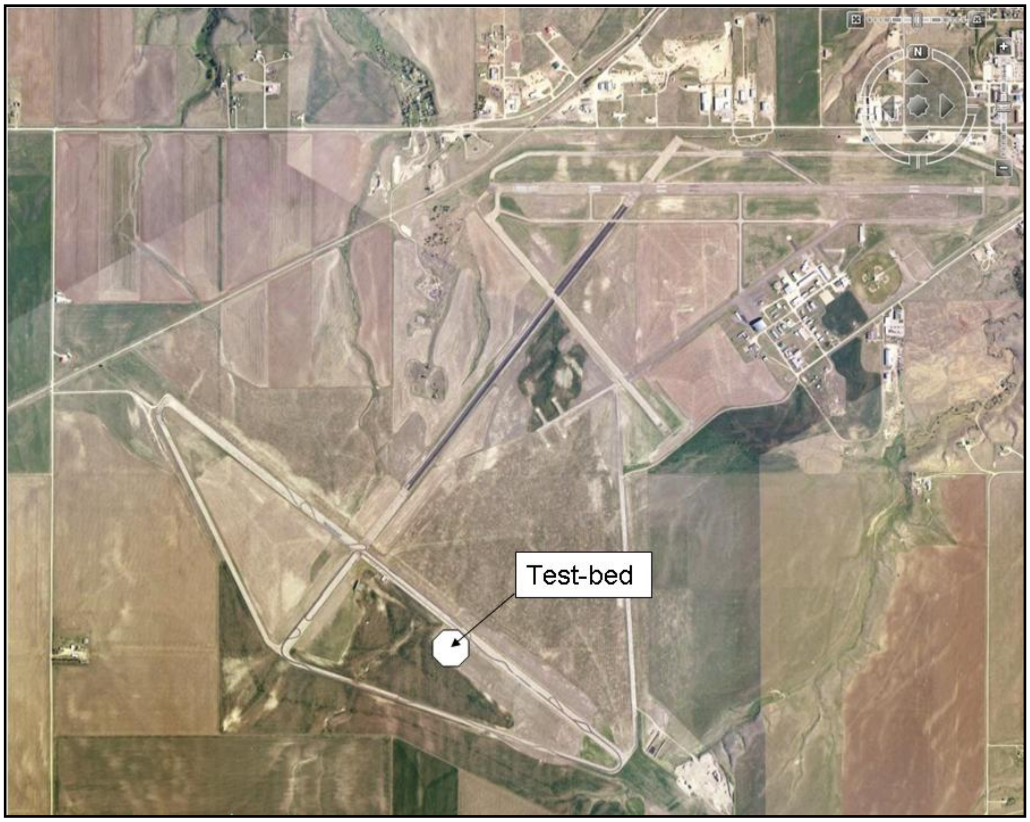

Figure1. The location of the test-bed along a former runway at the Lewistown Airport in central Montana. The current municipal airport is located on the upper right of the photo.

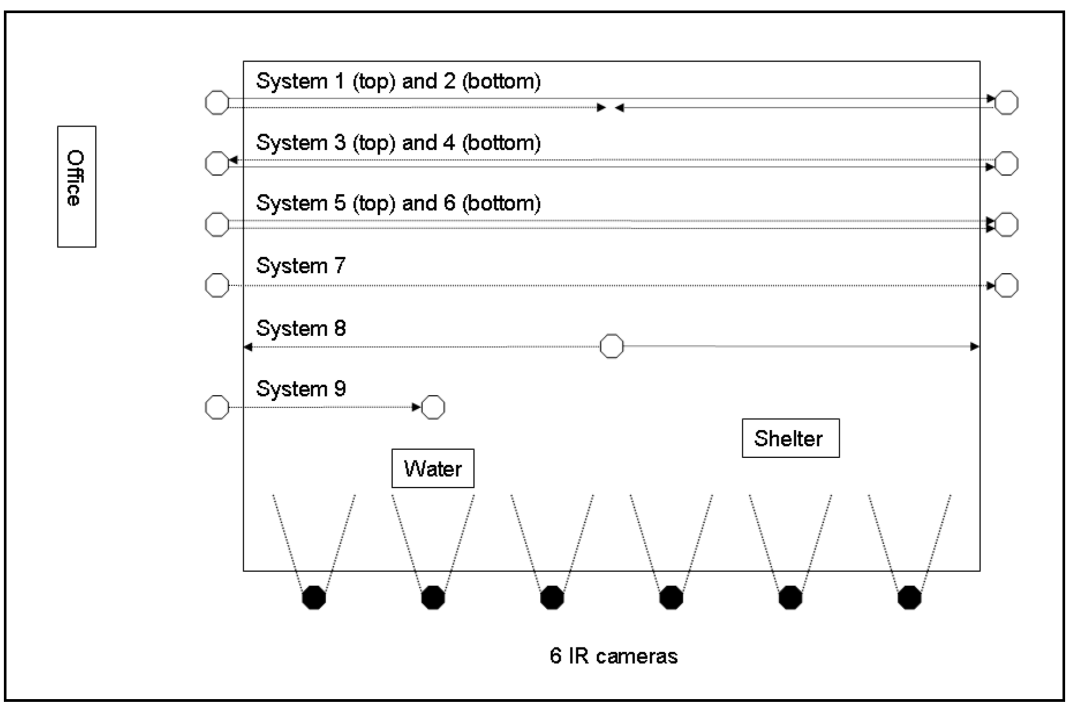

Figure 2. Test-bed design including an animal enclosure, the nine detection systems (open circles represent the sensors), the six infrared (IR) cameras aimed at the enclosure from the side (solid circles), and the office with data recording equipment. The arrows show the direction towards which each sensor or transmitter is pointed.

System number (Figure 2)	Manufacturer and system name	ID number	System type	Signal type	Maximum range	Installation date
1	Xtralis (ADPRO)	7	Area cover	Passive IR	500 ft (152 m)	Sep 21, 2006
2	Xtralis (ADPRO)	5-6	Area cover	Passive IR	200 ft (61 m) (one detector on each side)	Sep 21, 2006
3	STS (RADS I)	1	Break-the-beam	Microwave radio (± 35.5 GHz)	¼ mi (402 m)	Oct 19, 2006
4	STS (RADS II)	2	Break-the-beam	Microwave radio (± 35.5 GHz)	Well over ¼ mi (402 m)	Jul 19, 2007
5	Calonder Energy (CAL 92, LS-WS-WE 45)	1	Break-the-beam	Laser	984 (built-up areas) – 1148 ft (open areas) (300–350 m)	Sep 21-22, 2006
6	Calonder Energy (CAL 92, IR-204-319/M3)	2	Area cover	Passive IR	328 ft (100 m)	Sep 21-22, 2006
7	Camrix (A.L.E.R.T.)		Area cover	IR ITS Camera Technology	300 ft (91 m) (Note: 1 unit detects both sides of a road)	Oct 19-31, 2006
8	Xtralis (ADPRO)	1-2	Area cover	Passive IR	200 ft (61 m) (2 detectors, one facing each way)	Aug 8, 2006
9	Goodson		Break-the-beam	Active IR	90 ft (27 m)	Dec 2006

Table 1. The characteristics of the nine animal detection systems.
See appendix A for manufacturer contact details.

Animal Detection Systems

During the first five tests, which were conducted from January through May 2007, there were eight systems, all installed parallel to each other (Table 1). Five of these were area-cover systems and the other three systems were break-the-beam systems (Table 1). A second STS break-the-beam system was installed on July 19, 2007, resulting in a total of nine systems. Two of the systems required two detectors to cover the 91 m (300 ft) distance. One of these systems (System 8, Xtralis 1-2) had its two sensors installed on a pole in the middle of the 91 m (300 ft) distance, with the sensors facing opposite directions (Figure 2). The other system (System 2, Xtralis 5-6) had a detector installed at each end with the sensors facing each other (Figure 2). In addition, there was one system that did not cover the 91 m (300 ft) and for which only one set of sensors was available (System 9, Goodson). This system was installed across a shorter section, equivalent to the maximum distance for this particular system 27 m (90 ft) (Figure 2).

The six infrared cameras (Fuhrman Diversified, Inc.) were installed perpendicular to the detection systems on November 8–9, 2006. These cameras and a video recording system recorded all animal movements within the enclosure continuously, day and night. The animal detection systems saved their individual detection data with a date and time stamp. These data were compared to the images from the infrared cameras, which also had a date and time stamp, to investigate the reliability of each system. Cones within the enclosure defined the detection zone for each system.

Area-cover systems are designed to detect animals within a certain area and range from a sensor. This area is typically cone-shaped—narrow close to the sensor and wider as the distance from the sensor increases (Figure 3). All area-cover systems tested in this study detect animals based on body heat and motion. Break-the-beam systems consist of a transmitter that transmits a signal to a receiver. Break-the-beam systems detect animals when their body blocks the signal or when the signal received by the receiver is greatly reduced. The break-the-beam systems tested in this study use infrared, laser or microwave radio signals.

The detection area is the area within which area-cover systems should detect large animals, and the detection line is the line between sensors where break-the-beam systems should detect large animals (Figure 3). The detection areas and detection lines were indicated by the manufacturers and were marked with cones that were visible on the images from the individual cameras. Area-cover systems have relatively large, cone-shaped detection areas, whereas break-the-beam systems have a detection line that is linear or mostly linear in shape. However, STS 1 break-the-beam system uses microwave signals and has a 3° angle from the transmitter, which resulted in a detection area that was 2.4 m (7.8 ft) wide at 91.4 m (300 ft) from the transmitter (Pers. com., Lloyd Salsman, Sensor Technologies & Systems, October 10, 2007).

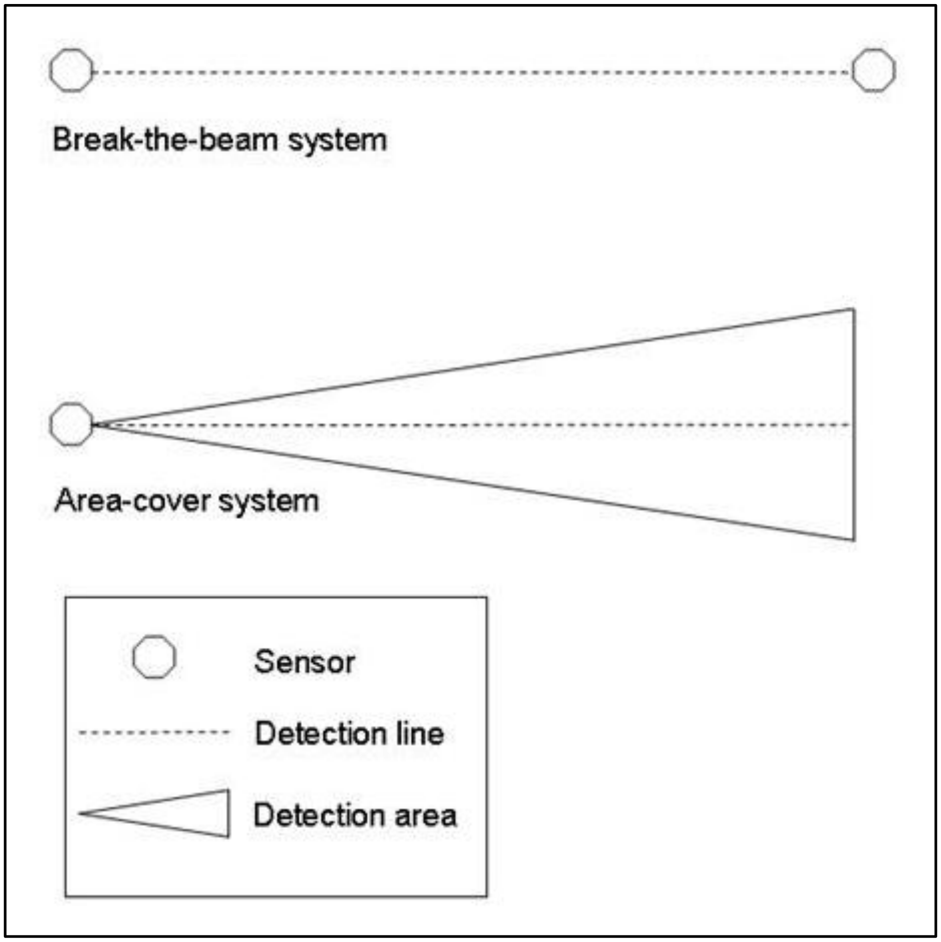

Figure 3. Schematic representation of break-the-beam and area-cover systems showing the detection line (or center line) for break-the-beam and area-cover systems, and the detection area for area-cover systems.

Animal Detection System Technologies

The Xtralis systems detect changes in infrared radiation (8–13μm) (Pers. com., Andreas Hartmann, Xtralis, October 1, 2007), which allows the system to detect the motion of an object against a stationary background. Such motion leads to changes in infrared radiation, which are processed by the system. Filtering and algorithms help distinguish between large animals and other objects to help reduce or prevent false detections. The STS systems transmit microwave radio signals (around 35.5 GHz) (Huijser et al., 2006). These signals are received by a sensor on the other end, and when an animal or object passes between the sensors, the signal is reduced. If certain thresholds are met, the reduction in signal strength results in a detection. STS 2 is more compact than STS 1 and has parts integrated into fewer components. The detection line of the STS 1 system is about 2.4 m (7.8 ft) wide at 91.4 m (300 ft) from the transmitter (Pers. com. Lloyd Salsman, Sensor Technologies & Systems, October 10, 2007). For the STS 2 system the detection line is 40.6 cm (16 in) wide consistently (Pers. com. Lloyd Salsman, Sensor Technologies & Systems, October 10, 2007). In addition, both the STS 1 and STS 2 systems have a wider detection area 4.5 m (15 ft) close to the sensors (Pers. com., Lloyd Salsman, Sensor Technologies & Systems, October 10, 2007). Calonder Energy 1 transmits a laser signal that is received by a sensor on the other end. When an animal or object blocks the laser signal, the system reports a detection. Calonder Energy 1 was installed at 105 cm (41.34 in) above the ground. Calonder Energy 2 detects changes in infrared radiation as a result of objects moving 0.2–5 m/s (8 in/s – 16.4 ft/s) (Pers. com., Giacomo Calonder, Calonder Energy, September 22, 2006; Calonder Energy, not dated). Algorithms help distinguish between large animals and other objects to help reduce or prevent false detections. This system was installed 3 m (9.8 ft) above the ground, pointing downwards at a 3–5º angle. There is a blind spot of approximately 10-12 m (32.8-39.4 ft) directly under the sensor, and the detection area is about 3 m (9.8 ft) wide at 100 m (328 ft) from the sensor (Pers. com., Giacomo Calonder, Calonder Energy, October 10, 2007). This blind spot is normally covered by another passive infrared sensor with a range of 18 m (59.1 ft) (Pers. com. Giacomo Calonder, Calonder Energy, October 10, 2007). The Calonder Energy 2 system (IR-204-319/M3) was discontinued in 2007 and Calonder Energy now offers an ADPRO unit from Xtralis (Pers. com., Giacomo Calonder, Calonder Energy, October 9, 2007). The Animal Location Evasive Response Technology (A.L.E.R.T.) system from Camrix uses a camera, optics, infrared illumination, and a computer to gather and analyze digital imagery (Pers. com., Mike Doyle, Camrix, October 3, 2007). Advanced proprietary machine vision algorithms process the images and decide whether a detection should be declared. The Goodson system (TM 1550) transmits an infrared signal that is received by a sensor on the other end. Whenever an animal or object blocks the infrared signal, the system reports a detection.

Wildlife Target Species and Models

In a North American setting, animal detection systems are typically designed to detect white-tailed deer (*Odocoileus virginianus*) and/or mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*) or moose (*Alces alces*). For this study, which took place within an enclosure, two horses and two llamas were used as models for these wildlife target species. Horses are similar in body shape and size to moose, whereas the body shape and size of llamas is similar to deer (Tables 2 and 3). The body size and weight of the individual horses and llamas used in this experiment are shown in Table 4.

Species	Height at shoulder	Length (nose to tip of tail)	Source
Target species			
Moose	195-225 cm (6'5"-7'5")	206-279 cm (6'9"-9'2")	Whitaker (1997)
Elk	137-150 cm (4'6"-5')	203-297 cm (6'8"-9'9")	Whitaker (1997)
White-tailed deer	68-114 cm (2'3"-3'9")	188-213 cm (6'2"-7')	Whitaker (1997)
Mule deer	90-105 cm (3'-3'5")	116-199 cm (3'10"-7'6")	Whitaker (1997)
Pronghorn	89-104 cm (2'11"-3'5")	125-145 cm (4'1"-4'-9")	Whitaker (1997)
Models			
Feral horse	142-152 cm (4'8"-5')		Whitaker (1997)
Quarter horse	150-163 cm (4'11"-5'4"')		UHS (2007), Wikipedia (2007)
Llama	91-119 cm (3'-3 '11")		Llamapaedia (2007)

Table 2. Height and length of wildlife target species and horses and llamas.

Species	Weight male	Weight female	Source
Target species			
Moose	400-635 kg (900-1400 lbs)	315-500 kg (700-1,100 lbs)	Whitaker (1997)
Elk	272-494 kg (600-1089 lbs)	204-295 kg (450-650 lbs)	Whitaker (1997)
White-tailed deer	68-141 kg (150-310 lbs)	41-96 kg (90-211 lbs)	Whitaker (1997)
Mule deer	50-215 kg (110-475 lbs)	32-73 kg (70-160 lbs)	Whitaker (1997)
Pronghorn	41-64 kg (90-140 lbs)	34-48 kg (75-105 lbs)	Whitaker (1997)
Models			
Feral horse	360-390 kg (795-860 lbs)	270-340 kg (595-750 lbs)	Whitaker (1997)
Quarter horse	386-540 kg (850-1200 lbs)		UHS (2007), Wikipedia (2007)
Llama	113-204 kg (250-450 lbs)		Llamapaedia (2007)

Table 3. Body weight of wildlife target species and horses and llamas.

Individual	Height at shoulder	Weight
Horse 1	152 cm (5')	513 kg (1,130 lbs)
Horse 2	160 cm (5'3'')	658 kg (1,450 lbs)
Llama 1	104 cm (3'5'')	168 kg (370 lbs)
Llama 2	110 cm (3'7½'')	213 kg (470 lbs)

Table 4. Body size and weight of the horses and llamas used in the experiment (Pers. com., Lethia Olson, livestock supplier).

Test periods

There were eight test periods with test animals between January 10, 2007 and December 9, 2007. Each test period with animals lasted 7–11 days. Camera images were recorded on site on a hard drive that is capable of storing 10–14 days of data. Camera images from selected time periods were reviewed and compared to the detection logs of the individual systems to measure the reliability of each system. The selected time periods were based on a stratified random selection with animals present: three, one-hour-long sections of video were randomly selected for each test day for review. A total of 225 hours were analyzed for eight of the nine systems. The ninth system 9 (system 4, STS (RADS II)) was analyzed for 91 hours.

Reliability Parameters

The time periods reviewed were analyzed for valid detections, false positives, false negatives, and intrusions in the detection area. These terms are defined below (see Huijser et al. 2009b for more details).

- *False positives* – A false positive was defined as "when the system reported the presence of an animal, but there was no animal in the detection zone." Thus, each incident in which a system's data logger recorded a detection, but there was no animal present in the detection zone of that system, was recorded as a false positive. The date and time were recorded for all false positives.
- *False negatives* – A false negative was defined as "when an animal was present but was not detected by the system." However, due to animal behavior and the design of some detection systems (i.e., some systems are desensitized by the continuous presence of an animal), there are several ways for a false negative to occur. Therefore, various types of false negatives were distinguished and these were recorded separately.
- *Intrusions in detection area* – An intrusion was defined as "the presence of one or multiple animals in the detection zone." An intrusion began when one or more animals entered the detection zone and ended when all animals left the detection zone.

Results

The results of the reliability tests showed that different detection technologies differ in their reliability with regard to detecting large animals and that some types of systems result in multiple detections if an animal enters the detection zone whereas other types of systems result in one detection. The percentage of false positives (i.e., a detection is reported by a system but there is no large animal present in the detection zone) and the average number of false positives per hour was relatively low for all systems (≤1%; ≤0.10/hr). The percentage of false negatives (i.e., an animal is present in the detection zone but a system failed to detect it) and the average number of false negatives per hour was highly variable (0–31%; 0–1.61/h) (all types of false negatives combined). The percentage of intrusions (i.e., animal movements across the detection line) that were detected varied between 73 and 100 percent. The results suggest that some animal detection systems are quite reliable in detecting large mammals with few false positives and false negatives, whereas other systems have relatively many false negatives. For more details on the reliability of individual systems, please see Huijser et al. (2009b).

Three stakeholder groups—employees of transportation agencies, employees of natural resource management agencies, and the traveling public—were surveyed with regard to their expectations on the reliability of animal detection systems. We analyzed the data and calculated what reliability requirements would satisfy the majority (>50%) of each of the three stakeholder groups. For more details on the calculation of the suggested minimum reliability requirements, please see Huijser et al. (2009b). Based on the results, the researchers recommend the following reliability requirements for the reliability and effectiveness of animal detection systems:

- Animal detection systems should detect at least 91 percent of all large animals that approach the road.
- Animal detection systems should have fewer than 10 percent of all detections be false.

The reliability of the nine different animal detection systems was compared to suggested reliability requirements (Table 5). Five of the nine systems tested met the recommended performance requirements for reliability. However, experiences with installation, operation and maintenance showed that the robustness of animal detection systems may have to be improved before the systems can be deployed on a large scale.

System number (Figure 2)	**Manufacturer and system name**	**ID number**	**Meets false positives (yes/no)**	**Meets false negatives (yes/no)**	**Meets intrusions detected (yes/no)**	**Meets overall recommended norms (yes/no)**
1	Xtralis (ADPRO)	7	Yes	No	Yes	Yes
2	Xtralis (ADPRO)	5-6	Yes	No	No	No
3	STS (RADS I)	1	Yes	No	No	No
4	STS (RADS II)	2	Yes	No	No	No
5	Calonder Energy (CAL 92, LS-WS-WE 45)	1	Yes	Yes	Yes	Yes
6	Calonder Energy (CAL 92, IR-204-319/M3)	2	Yes	Yes	Yes	Yes
7	Camrix (A.L.E.R.T.)		Yes	No	No	No
8	Xtralis (ADPRO)	1-2	Yes	Yes	Yes	Yes
9	Goodson		Yes	Yes	Yes	Yes

Table 5. The reliability of each system in relation to the recommended minimum norms. The percentage of intrusions detected is similar, though not exactly the same as the complement of the percentage of false negatives (see Huijser et al. 2009b).

Discussion and Conclusion

Based on the results of this study, the researchers concluded:

- The results of the reliability tests showed that different detection technologies differ in their reliability with regard to detecting large animals and that some types of systems result in multiple detections if an animal enters the detection zone whereas other types of systems result in one detection. This implies that care must be taken in evaluating the reliability of different technologies, and in comparing them to other systems or minimum performance requirements.
- The percentage of false positives and the average number of false positives per hour was relatively low for all systems (≤1%; ≤0.10/hr). False positives do not appear to be a major concern with regard to the reliability of animal detection systems.
- The percentage of false negatives (all types of false negatives combined) and the average number of false negatives per hour under the test circumstances was highly variable (0–31%; 0–1.61/hr). The percentage of intrusions (i.e., situations where at least one animal was present in the detection area) that were detected varied between 73 and 100 percent. The results suggest that false negatives are a major concern for some animal detection systems but not for others.
- The recommended performance requirements for the reliability of animal detection systems were compared to the results of the reliability tests. Five of the nine systems tested met the recommended performance requirements for reliability. However, experiences with installation, operation, and maintenance show that the robustness of animal detection systems may have to be improved before the systems can be deployed on a large scale.

Biographical Sketches

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

Tiffany Allen received a BSc in fish and wildlife management from Montana State University in Bozeman, MT in 2006 and a BM in music theory from Furman University in Greenville, SC in 2004. She is currently a master's candidate in ecology at MSU and is a graduate transportation fellow with the Western Transportation Institute. Her current research is on the effectiveness of wildlife mitigation measures, including wildlife underpasses, jump-outs and wildlife guards, along Hwy 93 in Montana.

Matt Blank is an assistant research professor at the Western Transportation Institute and the Department of Civil Engineering at Montana State University. Matt earned his Master of Science and Ph.D. in Civil Engineering at Montana State University. He earned his Bachelor of Science in Geological Engineering at the University of Wisconsin-Madison. His research focuses on the interactions of roads and riparian corridors with an emphasis on aquatic connectivity.

Mark Greenwood is an Assistant Professor of Statistics in the Department of Mathematical Sciences at Montana State University in Bozeman, MT. He received a PhD in Statistics from the University of Wyoming in 2004. His research involves nonparametric and nonlinear statistical methods with applications in geosciences, ecology, neuroscience, and economics.

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Literature Cited

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

Gordon, K.M. and S.H. Anderson. 2002. Motorist response to a deer-sensing warning system in western Wyoming. In 2003 Proceedings of the International Conference on Ecology and Transportation. 24-28 September 2001. Keystone, CO, USA. pp. 549-558.

Gordon, K.M., M.C. McKinstry and S.H. Anderson. 2004. Motorist response to a deer sensing warning system. Wildlife Society Bulletin 32: 565-573.

Hammond, C. and 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, USA. Available from the internet. URL: http://www.lrrb.gen.mn.us/pdf/200413.pdf.

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

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

Huijser, M.P., T.D. Holland, A.V. Kociolek, A.M. Barkdoll & J.D. Schwalm. 2009a. Animal-vehicle crash mitigation using advanced technology. Phase II: system effectiveness and system acceptance. SPR3(076) & Misc. contract & agreement no. 17,363. Western Transportation Institute – Montana State University, Bozeman, MT, USA. Available from the internet: http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/2009/Animal_Vehicle_Ph2.pdf

Huijser, M.P., T.D. Holland, M. Blank, M.C. Greenwood, P.T. McGowen, B. Hubbard, S. Wang. 2009b. The Comparison of Animal Detection Systems in a Test-Bed: A Quantitative Comparison of System Reliability and Experiences with Operation and Maintenance. Final report. FHWA/MT-09-002/5048. Western Transportation Institute – Montana State University, Bozeman, MT, USA. Available from the internet: http://www.coe.montana.edu/wti/wwwshare/Report%20FHWAMT-09-002%205048/

Kinley, T.A., N.J. Newhouse and H.N. Page. 2003. Evaluation of the Wildlife Protection System Deployed on Highway 93 in Kootenay National Park During Autumn, 2003. November 17, 2003. Sylvan Consulting Ltd., Invermere, British Columbia, Canada.

Kistler, R. 1998. Wissenschaftliche Begleitung der Wildwarnanlagen Calstrom WWA-12-S. July 1995 – November 1997. Schlussbericht. Infodienst Wildbiologie & Oekologie, Zürich, Switzerland.

Llamapaedia. 2007. The Growing Source for Llama Information! Available from the Internet. URL: http://www.llamapaedia.com/anatomy/basics.html. Accessed September 6, 2007.

Mosler-Berger, Chr. & J. Romer. 2003. Wildwarnsystem CALSTROM. Wildbiologie 3: 1-12.

Muurinen, I. and T. Ristola. 1999. Elk accidents can be reduced by using transport telematics. Finncontact. 7(1):7–8. Available from the Internet. URL: http://www.tiehallinto.fi/fc/fc199.pdf Accessed August 8, 2003.

UHS. 2007. The Ultimate Horse Site. The American Quarter Horse—AQHA Breed. The Ultimate Horse Site. Available from the Internet. URL: http://www.ultimatehorsesite.com/breedsofhorses/americanquarterhorseaqha.html. Accessed September 6, 2007.

Whitaker, Jr., J.O. 1997. National Audubon Society Field Guide to North American Mammals. Knopf, New York, USA.

Wikipedia. 2007. Horse. Available from the Internet. URL: http://en.wikipedia.org/wiki/Horse. Accessed September 6, 2007.