Evaluation of the Reliability of an Animal Detection System in a Test-Bed

Final Report

by

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16. Abstract This report contains a brief description of an animal detection system site along Hwy 3 (Ft. Jones Rd.) near Ft Jones, CA. In addition, this report summarizes the decision process for selecting an animal detection system, and it reports on reliability tests of the selected system.		
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ABSTRACT

This document reports on the work related to an animal detection system project in northern California. It describes the site that was selected for the installation of an animal detection system, the rationale for the selection of a particular animal detection system technology, and a reliability test of the system at a controlled access facility.

The system that was selected is a microwave break-the-beam system manufactured by ICx Radar Systems (Scottsdale, AZ). The reliability test took place at a test-bed specifically constructed to investigate the reliability of animal detection systems. The test-bed consists of an animal enclosure, space for multiple animal detection systems, and six infrared cameras with continuous recording capabilities. The animal enclosure includes shelter, water, and an area alongside the fence that was designated for feeding. These three resources are located in different parts of the enclosure to maximize animal movement through the detection areas.

The detection system recorded the date and time of each detection. In addition, there were infrared cameras and a video recording system that recorded all animal movements within the enclosure. The detection log was compared to the images from the infrared cameras, which also had a date and time stamp, to investigate the reliability of the system. Horses, llamas, and sheep were used as a model for wild ungulates (e.g. deer, elk, and moose).

The reliability tests showed that there was 1 false positive in the 18 hours that detection data were available for. The percentage of false positives was 0.007% (1 false positive / 140 valid detections). In addition, there were 4 false negatives in the 18 hours that detection data were available for. The percentage of false negatives was 0.03% (4 false negatives / 140 valid detections). All 4 false negatives related to sheep. Furthermore, there were 148 intrusions in the detection area, of which 144 were detected, resulting in detecting 97% of all intrusions in the detection area. The detection system went out of operation on the 7th day of the 10 day test period. This coincided with a snowstorm. The beam appeared to have come back in operation by itself after the test was completed. Since the beam was out of operation for 4 of the 10 days of the test the "downtime" of the system was 40%.

The number of false negatives and false positives of the system was relatively low, and the percentage of all intrusions in the detection area that was detected was relatively high (see Huijser et al., 2009c). The false negatives that did occur all related to sheep, the shortest of the three species that were present in the enclosure. This suggests that the false negatives may have been the result of the beam shooting over the heads and shoulders of the sheep in some places due to depressions in the terrain, rather than an unreliable detection technology. Lowering the beam several inches, in combination with mowing the grass-herb vegetation in the enclosure may reduce or eliminate the false negatives.

Based on the values of the false negatives and false positives, the RADS III systems easily meets the recommended minimum norms for the reliability of animal detection systems (see Huijser et al., 2009c). However, the substantial downtime of the system (40%) during the test is a major concern, suggesting that the system may not be operational for substantial lengths of time. Since the beam went out of operation in a snowstorm, snow and ice may have built up on the sensors. This may have caused the beam to go out of operation. As temperatures warmed and time progressed the snow and ice may have eventually melted or slid off, allowing the system to resume normal operation.

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), with the total number of deer–vehicle collisions estimated at one to two million per year (Conover et al., 1995; Huijser et al., 2008). These collisions were estimated to cause 211 human fatalities, 29,000 human injuries, and over $1 billion in associated costs per year (Conover et al., 1995). These numbers have increased even further over the last decade (Hughes et al., 1996; Romin & Bissonette, 1996; Anonymous, 2003; Huijser et al., 2008). 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, for some species a monetary value (e.g., hunting, recreation) is lost to society once an individual animal dies (Romin & Bissonette, 1996; Conover, 1997; Huijser et al., 2009a).

Historically, animal–vehicle collisions have been addressed through signs warning drivers of potential animal crossings. In other cases, wildlife warning reflectors, mirrors or wildlife fences have been installed to keep animals away from the road (e.g., de Molenaar & Henkens, 1998; Clevenger et al., 2001). However, conventional warning signs appear to have only a limited effect because drivers are likely to habituate to them (Pojar et al., 1975) and wildlife warning mirrors or reflectors may simply not be effective (Reeve & Anderson, 1993; Ujvári et al., 1998). Wildlife fences can isolate populations, but have been combined with wildlife crossing structures to address these limitations (e.g., Foster & Humphrey, 1995; Clevenger et al., 2002). Primarily due to their high upfront cost, such crossing structures are limited in number and size.

For this project, the Western Transportation Institute at Montana State University (WTI/MSU), as a subcontractor to California PATH, investigated a relatively new mitigation measure aimed at reducing animal–vehicle collisions while allowing animals to continue to move across the landscape: animal detection systems. Animal detection systems detect large animals (e.g., deer, elk, moose, or pronghorn) as they approach the road. When an animal is detected, signs are activated warning drivers that large animals may be on or near the road at that time. Previous research has shown that, depending on road and weather conditions, the warning signs can cause drivers to reduce their speed (see review in Huijser & McGowen, 2003; Kinley et al., 2003; Dodd & Gagnon, 2008; Huijser et al., 2009b). Warning signs may also result in more alert drivers (Green, 2000), which can lead to a substantial reduction in stopping distance: 20.7 m (68 ft) at 88 km/h (55 mi/h) (Huijser et al., 2006). Finally, research from Switzerland has shown that animal detection systems can reduce ungulate–vehicle collisions by as much as 82% (Kistler, 1998) or 81% (Romer et al., 2003). Similar results come from Arizona (91%; Dodd & Gagnon, 2008) and Montana (58–67%; Huijser et al., 2009b). Since the effectiveness of animal detection systems depends on driver response, reliable warning systems are very important.

Objectives

For this project WTI/MSU assisted with:

- Site description: The general description of the selected site for the installation of an animal detection system along a road in California.
- System selection: The selection of an animal detection system type and manufacturer given the location and potential other requirements.
- System reliability: Investigation of the reliability of the system at a controlled access facility in central Montana.

These objectives are discussed in the following chapters.

SITE DESCRIPTION

Originally, an animal detection system was scheduled to be installed along Hwy 1, near Orick, CA (Cody & Huijser, 2005). However, that site was abandoned and, after review by PATH and discussion with WTI-MSU, a new site was selected: an about 1.3 km (0.8 mi) long section of Hwy 3 (Ft. Jones Rd.), near Ft Jones, CA (Figure 1).

Below is a brief description of the site near Ft Jones, CA, where the animal detection system was installed in the summer of 2009. The road section near Ft. Jones was primarily selected because of its history of collisions with black-tailed deer (*Odocoileus hemionus columbianus*) and the interest of California Department of Transportation (CALTRANS) District 2 personnel in the project.

Figure 1. The road section (in red, about 0.8 mi (1.3 km) long) of the location of an animal detection system along Hwy 3 (Ft. Jones Rd.) near Ft Jones, CA.

Caltrans maintenance personnel recorded deer carcasses removed between 18 June 2008 and 12 December 2008 between mile reference posts 33.50 and 38.50. To increase the consistency and spatial accuracy, Caltrans personnel installed reference signs at every tenth of a mile on the road section. During this time period of about six months, 23 black-tailed deer carcasses were recorded on the five mile long road section (4.6 per mile), with one carcass recorded between mile reference posts 36.60 and 37.30, the approximate future location of the animal detection system. Caltrans personnel will continue to record carcass removal data until a few years after system installation.

SYSTEM SELECTION

System selection took place based on the following criteria:

- Reliability and effectiveness data from previous publications (Huijser et al., 2006).
- Preliminary results from reliability tests for multiple systems in a test bed near Lewistown in central MT (Huijser et al., 2007).
- Site specific conditions and requirements, including:
  - The system must be able to continue to operate with (ice) fog that occurs occasionally at the site.
  - The desire from Caltrans and California PATH to implement an animal detection system over a longer road section (about 1 mile in length) rather than at a gap in a wildlife fence. The road length over which the system is implemented is especially important for the driver behavior part of the study which is focused on tracking vehicles and measuring driver behavior as the vehicles approach, travel through, and leave the road section with the system.
  - The need to keep the number of sensors at a minimum to reduce the costs associated with the animal detection system and the associated equipment (including poles and foundations).

The site specific conditions ((ice) fog) ruled out optic based systems (active infra red or laser signals). The combination of the road length that needed to be covered in combination with minimizing the number of sensors ruled out passive infra red systems that typically have a short range (e.g. up to about 98 ft (30 m)). These considerations, in combination with the results of previous studies (Huijser et al. 2006; 2007) favored the selection of a microwave break-the-beam system that is not influenced by fog and that allows for relatively great distances between the sensors (about 1,312 ft (400 m) or more, depending on site conditions). Thus a system manufactured by ICx Radar Systems (formerly Sensor Technologies and Systems (STS), Scottsdale, AZ, USA) was selected for implementation at the site near Ft Jones.

ICx Radar Systems had developed a 3rd generation of their animal detection technology equipment. This equipment was installed at the site near Ft Jones in September 2009.

SYSTEM RELIABILITY

Introduction

The reliability testing of the animal detection system took place in the test-bed for animal detection systems near Lewistown, central Montana. This site consists of an enclosure for domesticated animals, posts and underground conduit for animal detection systems, infrared cameras that record the location of the animals in the enclosure 24 hours a day, and a mobile office space in which the data are stored (Figures 2 through 4). This site has been used for the testing of the reliability of animal detection systems since 2006 (Huijser et al., 2007; Huijser et al., 2009c). This site, and the associated equipment, was not available at the time (2005) the original proposal was written for the animal detection system test bed in California. The advantages of using this site for the current project are:

- Evaluate false positives and false negatives: Because the IR cameras aimed at the enclosure cover the entire detection area of the animal detection system, it is always certain whether an animal was present or absent from the detection area and whether false positives or false negatives occur. This is in contrast to animal detection system in California, where the video cameras will not cover 100% of the length of the road section with the animal detection system and where the researchers cannot be certain that there really was or was not an animal present if a detection occurred, and where a false negative does not trigger the animal detection system and is therefore not recorded by the video recording system. In addition, the researchers will not be able to see deer that trigger the animal detection system in CA during the night. While system acceptance tests and detailed analyses of the detection data at the CA site may provide an indication of false positives and false negatives, the evidence is circumstantial as it is based on patterns in the detection data only without having a verification that an animal was or was not there. Furthermore, while triggering the system at regular interval using humans as a model for wildlife does allow for investigation of false negatives, these efforts are limited in number compared to animal movements in an enclosure.
- Sample size: By using domesticated animals in an enclosure as opposed to wildlife in unfenced areas the researchers can assure that sufficient animal movements are recorded to allow for a precise assessment of the reliability of animal detection systems under a range of environmental conditions. This is in contrast to animal detection systems along real roadsides, such as the one in California, where the number of animal movements is unknown and sample size cannot be controlled.
- Effect of environmental conditions: The researchers propose that this research continues beyond the test that is reported on in this manuscript, and that additional tests are conducted in different seasons. The nearby location of a weather station allows the researchers to investigate the effect of environmental conditions on the reliability performance of the animal detection system. This is in contrast to animal detection systems along real roadsides, such as the one in California, where the number of animal movements are likely to be too small for an accurate assessment of system reliability, where reliability assessments cannot be done at a similar scale, and where data on environmental conditions may not readily be available. In summary, this effort not only allows the researchers to measure the reliability of the system, but also allows the

researchers to understand which environmental conditions may influence the performance of the system. The current project only includes one ten day test (Huijser, 2009).

- Different sized species: By using horses, llamas, and sheep, as a model for deer, elk and moose, the reliability of the system is evaluated for a range of differently sized species. This is in contrast to animal detection systems along real roadsides, where one species may dominate. At the study site in California, only black-tailed deer are present; there are no elk or moose in the area.

For this project the microwave radio signal break-the-beam system manufactured by ICx Radar Systems was evaluated for its reliability for one 10 day test period. The reliability of the system was not related to environmental conditions as the 10 day test period did not cover a wide range of environmental conditions. The potential effect of environmental conditions on system reliability can only be investigated in combination with additional tests in different seasons.

Methods

Test-Bed Location and Design

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 3.1). 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, space for multiple animal detection systems, and six infrared cameras with continuous recording capabilities (Figures 2 through 5). The distance covered by the system tested for this project was 91 m (300 ft) (from the left to the right side of the enclosure). The animal enclosure includes shelter, water, and an area alongside the fence that was designated for feeding. These three resources are located in different parts of the enclosure to maximize animal movement through the detection areas.

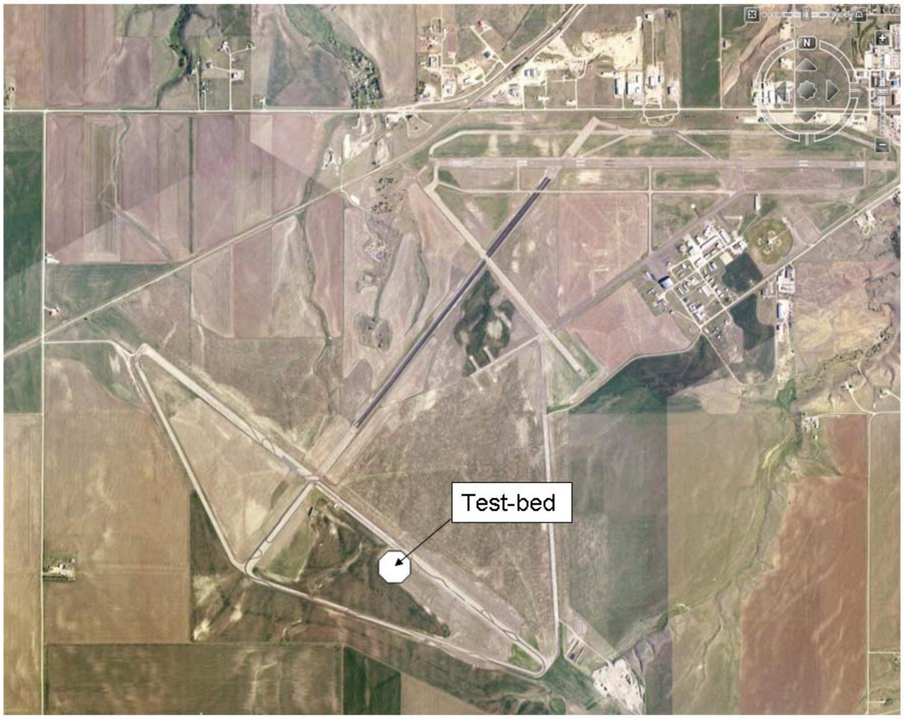

Figure 2. The location of the test-bed along a former runway at the Lewistown Airport in central Montana. The current municipal airport is located on the upper right of the photo.

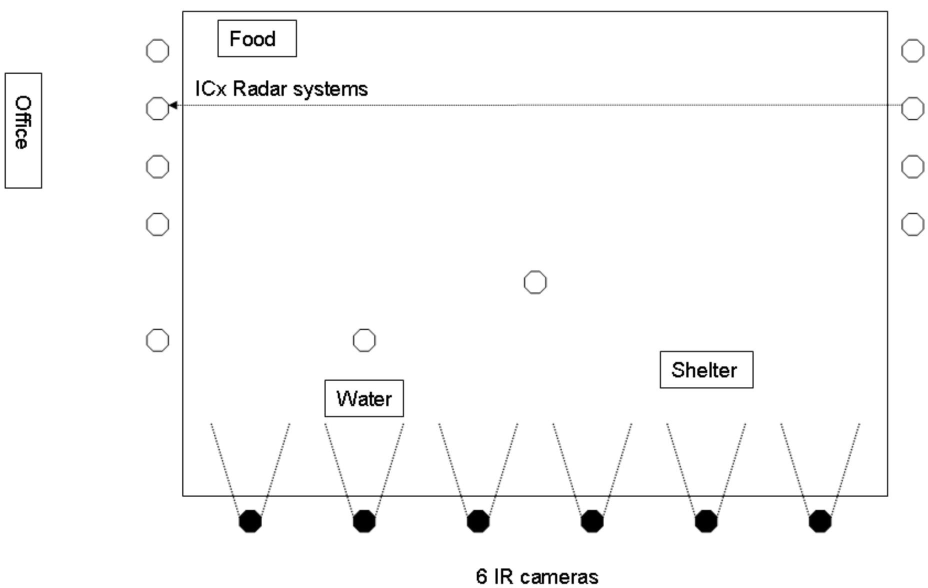

Figure 3. Test-bed design including an animal enclosure, the animal detection system tested for this project (open circles represent poles on which sensors can be attached), the six infrared (IR) cameras aimed at the enclosure from the side (solid circles), and the office with data recording equipment. The arrow shows the direction towards which the transmitter is pointed.

Figure 4. The test bed with the remote office, poles on which sensors can be attached, the shelter, and a llama (Photo: Marcel Huijser, WTI/MSU).

Figure 5. The infrared cameras that monitor animal movements in the enclosure (Photo: Marcel Huijser, WTI/MSU).

Animal Detection System and Recording Equipment

The system tested for this project is a microwave radio signal break-the-beam system manufactured by ICx Radar Systems (Scottsdale, Arizona (formerly Sensor Technologies and Systems, Inc.). The system is the third generation of this detection technology (RADS III) (Figure 6). Previous generations (RADS I and RADS II) were evaluated for their reliability in an earlier project (Huijser et al., 2009c). The RADS III is the exactly the same detection technology as was installed near Ft Jones, CA, in September 2009. The delivery of the system for the test site in Lewistown, MT was delayed and the equipment was not received until 24 September 2009. Certain parts were not functional and were shipped back to the manufacturer for repair and replacement. Functional equipment was received on 14 December 2009, and the system was successfully installed in Lewistown, MT on 16 December 2009. The center of the beam was set at about 73.7 cm (29 inches) above the ground. However, because of rises and depressions in the terrain, the center of the beam was estimated to have varied between 71.1 and 76.2 cm (28-30 inches) above the ground. Setting the center of the beam lower may have resulted in false positives as a result of the grass-herb vegetation in the enclosure.

Figure 6. The receiver of the third generation break-the-beam system manufactured by ICx Radar Systems. Note: the transmitter looks similar to the receiver.

The RADS III system transmits microwave radio signals (around 35.5 GHz). These signals are received by a sensor on the other end, and whenever 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. The detection line is the line between the transmitter and receiver sensors where the break-the-beam systems should detect large animals. The detection line was marked with cones just adjacent to the actual detection line to prevent interference with the microwave radio signal (Figure 7). The cones were visible on the images from the individual cameras. For the RADS III system the detection line is 40.6 cm (16 in) wide consistently (Pers. com. Lloyd Salsman, ICx Radar Systems). In addition, RADS III has a wider detection area 4.5 m (15 ft) close to the sensors (Pers. com., Lloyd Salsman, ICx Radar Systems).

The six infrared cameras (Fuhrman Diversified, Inc.) were installed perpendicular to the detection system. These cameras and a video recording system record all animal movements within the enclosure continuously, day and night. The RADS III animal detection system saved its 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 the system.

Figure 7. The detection line was marked with cones to be able to record the position of the animals (Photo: Marcel Huijser, WTI/MSU).

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*). In Montana, it is not legal to have deer, elk or moose in captivity. Therefore the researchers use domesticated species as a model for wildlife. For this study, which took place within an enclosure, two horses, two llamas, and two sheep were used as models for these wildlife target species. Horses are similar in body shape and size to moose, llamas represent deer and elk, and sheep represent small deer (Tables 1 and 2). The body size and weight of the individual horses, llamas, and sheep used in this experiment are shown in Table 3. Some of the test animals are shown in figures 8 through 10.

Table 1: Height and length of wildlife target species and horses and llamas. *1 Black-tailed deer are a subspecies of mule deer.

Species	Height at shoulder	Length (nose to tip tail)	Source
Target species			
Moose	6'5"-7'5" (195-225 cm)	6'9"-9'2" (206-279 cm)	Whitaker (1997)
Elk	4'6"-5' (137-150 cm)	6'8"-9'9" (203-297 cm)	Whitaker (1997)
White-tailed deer	27-45" (68-114 cm)	6'2"-7' (188-213 cm)	Whitaker (1997)
Mule deer*1	3'-3'5" (90-105 cm)	3'10"-7'6" (116-199 cm)	Whitaker (1997)
Black-tailed deer	3'0" (91 cm)		Western Hunter (2008)
Black-tailed deer	2'3"–3'9" (68–114 cm)		National geographic (2008)
Pronghorn	2'11"-3'5" (89-104 cm)	4'1"-4'-9" (125-145 cm)	Whitaker (1997)
Models			
Feral horse	4'8"-5' (142-152 cm)		Whitaker (1997)
Quarter horse	4'11"-5'4" (150-163 cm)		UHS (2007), Wikepedia (2007)
Llama	3'-3'11" (91-119 cm)		Llamapaedia (2007)
Goat	23"-30" (59-75 cm)		
Sheep	26"-50" (65-127) cm		

Table 2: Body weight of wildlife target species and horses and llamas.

Species	Weight male	Weight female	Source
Target species			
Moose	900-1400 lbs (400-635 kg)	700-1100 lbs (315-500 kg)	Whitaker (1997)
Elk	600-1089 lbs (272-494 kg)	450-650 lbs (204-295 kg)	Whitaker (1997)
White-tailed deer	150-310 lbs (68-141 kg)	90-211 lbs (41-96 kg)	Whitaker (1997)
Mule deer	110-475 lbs (50-215 kg)	70-160 lbs (32-73 kg)	Whitaker (1997)
Black-tailed deer	Some are >140 lbs (63 kg)		Western Hunter (2008)
Black-tailed deer	150–310 lb (68–141 kg)	90–211 lb (41–96 kg)	National geographic (2008)
Pronghorn	90-140 lbs (41-64 kg)	75-105 lbs (34-48 kg)	Whitaker (1997)
Models			
Feral horse	795-860 lbs (360-390 kg)	595-750 lbs (270-340 kg)	Whitaker (1997)
Quarter horse	850-1200 lbs (386-540 kg)		UHS (2007), Wikepedia (2007)
Llama	250-450 lbs (113-204 kg)		Llamapaedia (2007)
Goat	111 lbs (50 kg)	144-156 lbs (65-70 kg)	
Sheep	100-350 lbs (45–160 kg)	100-225 lbs (45-100 kg)	Wikepedia (2008)

Table 3: Body size and weight of the horses, llamas, and sheep used in the experiment (Pers. com. Lethia Olson, live stock supplier). The measurements were taken in November 2009.

Individual	Height at shoulder	Weight
Horse 1 (Bubba)	5’ (152 cm)	1130 lbs (513 kg)
Horse 2 (Buster)	5’2’’ (157 cm)	1450 lbs (659 kg)
Llama 1 (Sparkle)	3’9’’ (114 cm)	350 lbs (159 kg)
Llama 2 (Cocoa)	3’9’’ (114 cm)	470 lbs (213 kg)
Sheep 1	71 cm (2'4")	To be measured
Sheep 2	74 cm (2'5")	To be measured

Figure 8. The horses that were used in the test (Photo: Marcel Huijser, WTI/MSU).

Figure 9. One of the two llamas that were used in the test (Photo: Marcel Huijser, WTI/MSU).

Figure 10. One of the two sheep that were used in the test (Photo: Marcel Huijser, WTI/MSU).

Test Period

The ten day test period started on 17 December 2009 (at midnight) and it ended on 26 December 2009 (end at midnight). Three, one-hour-long sections of video were randomly selected for each test day for review (stratified random). This resulted in a total of 30 hours during which the reliability of the system was investigated. The images from the time periods that were analyzed were all saved on DVD. Time periods that were not analyzed were not saved.

Video Review and Reliability Parameters

The time periods reviewed were analyzed for valid detections, false positives, false negatives, intrusions in the detection area, and downtime. These terms are defined below.

- *Valid detections* – A valid detection was defined as "the presence of an animal in or immediately adjacent to the detection line in conjunction with a corresponding detection recorded by the system's data logger." The number of valid detections depends on the frequency with which a system "scans" for the presence of an animal. The RADS III system reports the beam status, including potential detections, once every minute, and whenever a change in the beam status occurs. If an animal blocks the signal for some time, the beam becomes desensitized, and after the animal moves out of the beam again, the system may need three minutes before it can report the next detection. For the time periods reviewed, the date, time, and species were recorded for all valid detections. Note: there were no non-target species (e.g. deer, birds etc.) observed crossing the detection line for the time periods that were analyzed.
- *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 line or immediately adjacent to it". Thus, each incident in which the 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. Note: should non-target species have been present and caused a detection, they would have been considered a valid explanation for a detection and would not have resulted in a false positive.
- *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 the system (i.e., the RADS III system can become 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. The date, time, and species were recorded for each type of false negative.

  The simplest type of false negative, recorded as "false negative," occurred when an animal completely passed through "the line of detection" without lingering but was not detected by the system. If an animal lingered in the detection zone but did not completely cross the line of detection or centerline, it was not deemed a false negative. After a valid detection at least three minutes had to pass before another animal movement across the centerline could be viewed as a false negative. However, if two or more animals passed the centerline within three minutes of each other, and if they were all detected, all passages were considered a valid detection across the centerline. The three minute "reset" period was put in effect because:

- The sensors are desensitized after a detection and need some time before they can detect another animal. The manufacturer of the RADS III system recommends three minutes reset time for the sensors to become fully sensitive again after a detection.
- The warning signs of an animal detection system need to stay activated for a certain amount of time after a detection has occurred anyway. Therefore it is not essential to have an animal detection system detect multiple animals within a short time. Based on an analysis of patterns in the detection data from a field site it was concluded that it seemed appropriate to have warning signs be activated for three minutes after a detection had occurred (Huijser et al., 2009b). The three minute time period was found to be an appropriate balance between warning the drivers for animals that may still linger on or close to the road and not exposing drivers to unnecessary warnings.

Another type of false negative, recorded as "false negative 1," occurred when an animal lingered in the detection zone before completely passing through the line of detection without a detection by the system. If the system did not detect the animal as it completely passed through the line of detection, and if it was three minutes or longer since the system last detected an animal, it was considered a false negative. If the system did not detect the animal as it completely passed through the line of detection, and it was less than three minutes since the system last detected an animal, it was considered neither a false negative nor a valid detection.

A third type of false negative, recorded as "false negative 2," occurred when one animal lingered in the detection zone without a detection by the system, while a second animal (or multiple animals) completely passed through the line of detection. If the system did not detect the second animal as it completely passed through the line of detection, and it was three minutes or longer since the system last detected an animal, it was considered a false negative. If the system did not detect the animal as it completely passed through the line of detection, and it was less than three minutes since the system last detected an animal, it was considered neither a false negative nor a valid detection.

In addition to valid detections, false positives and false negatives, the total number of times an animal should have been detected was recorded. The number of times an animal should have been detected was the sum of the number of times an animal crossed the line of detection and was detected and the total number of false negatives, regardless of the type of false negative.

Cases in which humans, birds, dogs, or other non-target species would have entered the enclosure would not have been considered in evaluating false negatives. However, when deer would have entered the enclosure, the incident would have been included in the analysis.

- *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. Each intrusion resulted in one of the two event types described below. The event types were hierarchical—while an intrusion was in progress, the classification could change from E2 to E1, but not from E1 to E2.

The first type of event, classified as "event 1" or "E1," occurred when an animal was in the line of detection or immediately adjacent to it and was detected by the system.

The second type of event, classified as "event 2" or "E2," occurred when an animal completely crossed the line of detection but was not detected by the system. After each valid detection, there was a reset time of three minutes before evaluating the system for an event 2.

- *Downtime* – Downtime was defined as "the time when the system was not working at all or when it was not working according to the expectations of the researchers or the specifications of the vendor." Date, time, and duration of downtime were recorded for each system.

Data Analyses

Time periods that were classified as downtime or time periods for which no detection data were may have been available due to external circumstances (e.g., power outage) were excluded from the analyses.

The following parameters were calculated for the RADS III system:

- The average number of valid detections per hour:

$$\overline{N}_{t(valid\ detections)} = \frac{N_{t\ (valid\ detections)}}{N_{h(with\ data\ available)}}$$

Where:

$N_{t\ (valid\ detections)}$ = total number of valid detections

$N_{h\ (with\ data\ available)}$ = total number of hours for which detection data were available

- The percentage of false positives:

$$F^{+} = \frac{F_N^{+}}{N_{t\ (detections\ recorded\ by\ system)}} * 100 = \frac{F_N^{+}}{N_{t\ (valid\ detections)} + F_N^{+}} * 100$$

Where:

F_N^{+} = total number of false positives

$N_{t\ (detections\ recorded\ by\ system)}$ = total number of detections recorded by a system

$N_{t\ (valid\ detections)}$ = total number of valid detections

- The average number of false positives per hour:

$$\overline{F}^{+} = \frac{F_N^{+}}{\mathrm{N}_{\text{h(with data available)}}}$$

Where:

F_N^{+} = total number of false positives

$\mathrm{N}_{\text{h (with data available)}}$ = total number of hours for which detection data were available

- The percentage of false negatives:

$$F^{-} = \frac{F_N^{-}}{\mathrm{N}_{\text{t (center line)}}} * 100 = \frac{F_N^{-}}{\mathrm{N}_{\text{d (center line)}} + F_N^{-}} * 100$$

Where:

F_N^{-} = total number of false negatives (false negatives, false neg. 1, and false neg. 2)

$\mathrm{N}_{\text{t (center line)}}$ = total number of times an animal crossed the line of detection and should have been detected

$\mathrm{N}_{\text{d (center line)}}$ = total number of times an animal crossed the line of detection and was detected

Note that the percentage was calculated for false negatives, false negatives 1, and false negatives 2 individually. Since the total number of false negatives varied between these categories, the sum of the percentages for false negatives, false negatives 1, and false negatives 2 do not equal the percentage of the total number of false negatives.

- The average number of false negatives per hour:

$$\overline{F}^{-} = \frac{F_N^{-}}{\mathrm{N}_{\text{h(with data available)}}}$$

Where:

F_N^{-} = total number of false negatives

$\mathrm{N}_{\text{h (with data available)}}$ = total number of hours for which detection data were available

Note that the percentage of false negatives was also calculated for false negatives, false negatives 1, and false negatives 2 individually.

- The percentage of intrusions detected (i.e., animal presence in or immediately adjacent to the line of detection):

$$I_{\%\,detected} = \frac{I_d}{I_t} * 100 = \frac{E_1}{E_1 + E_2} * 100$$

Where:

I_d = total number of intrusions detected

I_t = total number of intrusions

E_1 = total number of event 1

E_2 = total number of event 2

Results

There were 140 valid detections in 18 hours that detection data were available for, resulting in an average of 7.78 valid detections per hour.

There was 1 false positive in 18 hours that detection data were available for. The percentage of false positives was 0.007% (1 false positive / 140 valid detections). There were 0.06 false positives per hour (1 false positive in 18 hours).

There were 4 false negatives (all false negatives; there were no false negatives 1 or false negatives 2) in 18 hours that detection data were available for. The percentage of false negatives was 0.03% (4 false negatives / 140 valid detections). All 4 false negatives related to sheep. There were 0.22 false negatives per hour (4 false negatives in 18 hours).

There were 148 intrusions in the detection area, of which 144 were detected, resulting in detecting 97% of all intrusions in the detection area.

The beam went out of operation in the early hours of 23 December 2009. This coincided with a snowstorm. The beam appeared to have come back in operation by itself after the test. Since the beam was out of operation for all time periods analyzed for 23, 24, 25, and 26 December 2009, the total number of hours that the system was "down" was 12 out of the 30 hours analyzed (40%).

Discussion and Conclusion

The number of false negatives and false positives was relatively low, and the percentage of all intrusions in the detection area that was detected was relatively high (see Huijser et al., 2009c). The false negatives that did occur all related to sheep, the shortest of the three species that were present in the enclosure. This suggests that the false negatives may have been the result of the beam shooting over the heads and shoulders of the sheep in some places due to depressions in the terrain, rather than an unreliable detection technology. Lowering the beam several inches, in combination with mowing the grass-herb vegetation in the enclosure may reduce or eliminate the false negatives.

Based on the values of the false negatives and false positives, the RADS III systems easily meets the recommended minimum norms for the reliability of animal detection systems (see Huijser et al., 2009c). However, the substantial downtime of the system (40%) during the test is a major concern, suggesting that the system may not be operational for substantial lengths of time. Since the beam went out of operation in a snowstorm, snow and ice may have built up on the sensors. This may have caused the beam to go out of operation. As temperatures warmed and time progressed the snow and ice may have eventually melted or slid off, allowing the system to resume normal operation.

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