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Where Ideas Become Reality

THE RELIABILITY AND EFFECTIVENESS OF AN ELECTROMAGNETIC ANIMAL DETECTION AND DRIVER WARNING SYSTEM

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March 2012

COLORADO DEPARTMENT OF TRANSPORTATION
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16. Abstract:

This report contains data on the reliability and effectiveness of an animal detection system project along US Hwy 160 between Durango and Bayfield, Colorado. The system that was first installed was a Perimitrax® system from Senstar Corporation. In the fall of 2010 this system was replaced by an OmniTrax® system, manufactured by the same company, Senstar Corporation. The Perimitrax® system was also installed at a controlled access facility near Lewistown, Montana. Here more detailed investigations were conducted into the reliability of the system using horses, llamas and sheep as a model for wild ungulates.

Implementation:

The number of reported large mammal carcasses and crashes with wild animals was highly variable and the number of years that data were available for after system installation in the fall of 2008 was low. Therefore it is difficult to draw conclusions about the potential effectiveness of the system on the number and severity of wildlife-vehicle collisions at this time.

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THE RELIABILITY AND EFFECTIVENESS OF AN ELECTROMAGNETIC ANIMAL DETECTION AND DRIVER WARNING SYSTEM

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EXECUTIVE SUMMARY

In the fall of 2008 an animal detection system and driver warning system (ADS-DWS) was installed along US Hwy 160 between Durango and Bayfield. The system consists of a buried cable that generates an invisible electromagnetic field (Perimitrax® system, manufactured by Senstar Corporation). When a large animal crosses the cable it causes a disturbance in this electromagnetic field, and if a certain adjustable threshold is reached, an alarm is declared, and warning signs are activated urging drivers to be more alert and reduce vehicle speed, which should ultimately result in fewer and less severe collisions with large wild ungulates such as deer and elk. In the fall of 2010 the Perimitrax® system at the site near Durango was replaced by an OmniTrax® system, also manufactured by Senstar Corporation. For this report the researchers investigated the reliability and effectiveness of the ADS-DWS.

In January 2009 the researchers triggered the system at regular intervals to identify potential blind spots and to evaluate whether the sensitivity of the system needed to be adjusted. While all but one of the 105 crossings (99%) of the buried cable could be identified on plots that showed the signal strength, none of the crossings resulted in a peak high enough to meet or exceed the thresholds. This was most likely related to snow depth, and the sensitivity of the 20 individual detection zones was increased so that crossings by humans, and ungulates of similar and greater body size would result in peak values of the signal that would meet or exceed the threshold and that would thus result in activation of the warning signs. In April 2009 the thresholds were raised again as snow melted away. This procedure was conducted for all 20 zones at once. An alternate approach may be to raise thresholds for each zone as snow becomes absent from that zone (i.e., some zones may retain snow longer in spring because of remnant drifts in shady areas thus phasing the raising of thresholds to reflect lingering snowpack in specific zones).

In February 2009 and in February 2011 the researchers conducted snow tracking sessions. On the first day of the snow tracking session all tracks across the entire length of the buried cable were erased using a rake. During the following days, and if the snow cover allowed, the snow was checked for new tracks across the buried cable that must have occurred during in the previous 24 hours. The number of animal crossings across the buried cable was not positively correlated with the number of detections by the system in the different detection zones. The data indicated that a substantial number of the animals that crossed the cable did not result in a detection by the system (potentially only 29% of animals crossing the cable were detected in the detection zones that had fewer detections than tracks of deer and elk). During the summer of 2009 and in January/February 2011 the researchers installed wildlife cameras at selected locations to photograph wildlife, particularly deer and elk, as they crossed the cable. In 2009 a total of 92 deer and 1 elk were photographed crossing the cable. In 2011 only 6 mule deer were photographed crossing the cable. None of these crossings resulted in a detection by the system.

The Perimitrax® system was also evaluated for its reliability 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. This site has been used for the testing of the reliability of different animal detection systems since 2006. In August 2009 the exact same system as was originally installed along US Hwy 160 near Durango (the Perimitrax® system) was installed in the test bed.

The researchers used 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. Horses are similar in body shape and size to moose, llamas represent deer and elk, and sheep represent small deer or pronghorn.

Four ten-day tests with animals were conducted in 2009 and 2010; one in November 2009, one in December 2009, one in July/August 2010, and one in September 2010. The camera and a video recording system recorded all animal movements within the enclosure continuously, day and night. The 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, allowing the researchers to investigate the reliability of the system. The researchers randomly selected three one hour long periods for each test day (120 hours in total) to investigate the reliability of the system. The number of false negatives (0.46%) and false positives (0%) was relatively low or non-existent, and the percentage of all intrusions in the detection area that was detected was relatively high (98.12%). These reliability data were compared to suggested minimum norms for system reliability that were formulated for another project. The Perimitrax® system met these suggested minimum norms for system reliability.

To investigate the potential effect of environmental conditions (such as temperature and precipitation) on system reliability the randomly selected hours form the test periods with animals present in the enclosure (120 hours analyzed) were supplemented by data from two additional ten-day tests in December 2009 and in December 2009/January 2010. During these additional two tests no animals were present and the researchers subjectively selected 10 additional hours for each of the two test periods (20 additional hours analyzed; 140 hours analyzed in total) for analyses based on extreme weather events and suspicious detection patterns. The system generated no false positives and very few false negatives. The low number of errors for the animal detection system did not allow the researchers to conduct a meaningful statistical analysis to investigate which environmental conditions may be associated with these errors. However, the low number of errors should be viewed as a positive characteristic of this animal detection system, and not as a problematic situation.

The researchers planned to investigate the effectiveness of the system at the Durango site if and when the system was found to detect large animals reliably. The effectiveness research consisted of two parts: a speed study and the number and severity of the wildlife-vehicle collisions. However, the researchers found the system at the Durango site, before and after system modifications, not reliable. Therefore the researchers did not conduct the speed study. A speed study with an unreliable system is not meaningful as drivers cannot be expected to respond to unreliable warning signs.

Since carcass removal and crash data were available anyway, the researchers did investigate the effect of the presence of the system on the number and severity of wildlife-vehicle collisions. The average number of large mammal carcasses per year in the years before installation of the animal detection system (mile reference posts 95-96) was 9.0 whereas it was 15.0 after installation. The number of reported large mammal carcasses was relatively low in 2011. However, this did not only apply to the treatment segments (including the segment with the animal detection system) but also to the control segments, suggesting that the low numbers for 2011 may be a reflection of changes in the population size of the large ungulates, or reduced search and reporting effort by road maintenance crews. The average number of reported crashes with wild animals per year in the years before installation of the animal detection system (mile reference posts 95-96) was 5.3 whereas it was 3.0 after installation. The average number of reported injuries per year (complaints of injury, non-incapacitating injury, and incapacitating injury) as a result of crashes with wild animals in the years before installation of the animal detection system (mile reference posts 95-96) was 0.33 whereas it was 0.00 after installation. The number of reported large mammal carcasses and crashes with wild animals was highly variable and the number of years that data were available for after system installation in the fall of 2008 was low (only two or three 3 years). Therefore it is difficult to draw conclusions about the potential effectiveness of the system on the number and severity of wildlife-vehicle collisions at this time.

Based on the results from the different reliability tests the researchers conclude that the reliability of the system (both the Perimitrax® and the OmniTrax® system) along US Hwy 160 near Durango is insufficient whereas the reliability of the system at the test bed in Lewistown easily meets the recommended minimum norms for the reliability of animal detection systems. This suggests that the detection technology as such can reliably detect large ungulates, but that system settings, system integration, or faulty equipment severely affect the reliability of the system along US Hwy 160 near Durango. Perhaps the most noticeable difference between the Lewistown test site and the US Hwy 160 site was the length of cable. The US Hwy 160 site contained numerous sections of cable linked by couplers which appeared to cause false positives. Therefore, a single technical problem at a coupler or along a specific stretch of cable, combined with the numerous loops established at driveway crossings, could have created a multitude of technical problems that resulted in differences in system reliability between the two test sites. In addition, communication of a detection to the warning signs and turning off the warning after a certain amount of time may have caused problems at the US Hwy 160 site.

1. INTRODUCTION

1.1. Background

In the United States the total number of deer-vehicle collisions was estimated at 1-2 million per year and their number is increasing (Conover et al., 1995; Huijser et al., 2008). These collisions not only lead to substantial property damage, but also cause human fatalities, human injuries, the death of individual animals and the loss of associated economic values, and detrimental effects on the population level of certain species (Romin & Bissonette, 1996; Huijser & Bergers, 2000; Huijser et al., 2009a). Over 40 different mitigation measures have been implemented or described to reduce animal-vehicle collisions (Huijser et al., 2008). However, except for wildlife fencing, with or without safe crossing opportunities for wildlife (e.g. Clevenger & Huijser, 2009), and animal detection systems (Huijser et al., 2006; 2009b; c) these measures appear to be largely ineffective in reducing collisions.

Animal detection systems are designed to detect large animals (e.g., deer (*Odocoileus sp.*), elk (*Cervus canadensis*) and/or moose (*Alces alces*)) as they approach the road. When an animal is detected, signs are activated that warn drivers that large animals may be on or near the road at that time. Starting in 1993, animal detection systems have been installed at over 30 locations throughout Europe and North America (see review in Huijser et al., 2006). Some of these systems have been found to be reliable and/or effective in reducing animal-vehicle collisions, whereas other efforts have been abandoned because of technical problems or changes to the road or surrounding landscape (see review in Huijser et al., 2006; Dodd & Gagnon, 2008).

In order to reduce the number of animal-vehicle collisions, animal detection systems need to detect animals reliably, and they also need to influence driver behavior so that drivers can avoid a collision. Most animal detection system technologies are vulnerable to "false negatives" and "false positives". False negatives occur if an animal approaches, but the system fails to detect it. False positives occur if the system reports the presence of an animal, but there is no animal present. Keeping false positives and false negatives to a minimum is important as drivers are expected to respond to the warning signals. Once an animal detection system reliably detects the target species and the warning signals and signs are activated, driver response determines how effective the system ultimately is in avoiding or reducing animal-vehicle collisions. Figure 1.1 splits driver response into two components: increased driver alertness and lower vehicle speed.

A higher state of alertness of the driver, lower vehicle speed, or a combination of the two can result in a reduced risk of a collision with the large animal and less severe collisions (Figure 1.1). A reduced collision risk and less severe collisions mean fewer human deaths and injuries, and lower property damage. In addition, fewer large animals are killed or injured on the road without having been restricted in their movements across the landscape and the road. Furthermore, fewer large dead animals will have to be removed, transported and disposed of by road maintenance crews.

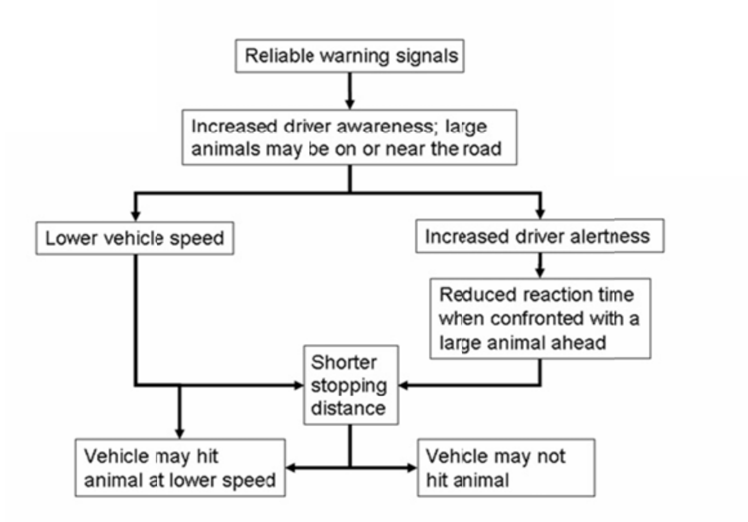

Figure 1.1: Concept of operations

On February 13, 2008 the Colorado Department of Transportation (CDOT) published an invitation for bid for a research project on animal-vehicle collisions (IFB #HAA 08-038-TW) (CDOT, 2008). More specifically, the project aims to investigate the reliability and effectiveness of an electromagnetic animal detection and driver warning system (ADS-DWS) (Magal Senstar, buried cable, 10 detection zones on each side of the road) that was installed in the fall of 2008 along US Hwy 160 between Durango and Bayfield, La Plata County, Colorado (between mile reference posts 95 and 96) (Figure 1.2). This final report summarizes the findings through November 2011. This project has been prepared by a partnership of the Western Transportation Institute at Montana State University (WTI-MSU), SWCA Environmental Consultants (SWCA), and Colorado State University (CSU).

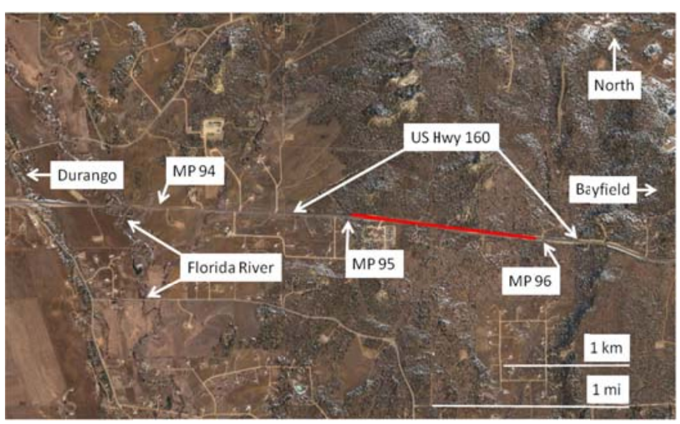

Figure 1.2: Location of the animal detection and driver warning system (red line) along US Hwy 160 between Durango and Bayfield, Colorado, USA.

1.2. Structure of the Report

Chapter 1 contains an introduction to the research topic concerned and the study area. Chapter 2 briefly discusses the technology and the layout of the animal detection system and provides a summary of the experiences with installation and maintenance of the system. Chapter 3 and beyond are structured according to the research questions for this project.

- Chapter 1: Introduction.
- Chapter 2: Technology and the layout of the system.
- Chapter 3: How reliable is the ADS-DWS in detecting large wild ungulates?
- Chapter 4: How reliable is the ADS-DWS in detecting domesticated ungulates in a test-bed?
- Chapter 5: Do environmental conditions influence the reliability of the ADS-DWS?
- Chapter 6: Does the ADS-DWS, when activated, reduce vehicle speed?
- Chapter 7: Does the ADS-DWS result in reduced risk for large ungulates?
- Chapter 8: Does the ADS-DWS result in fewer and less severe collisions with large ungulates?

The large ungulates at the location along US Hwy 160 are primarily mule deer (*Odocoileus hemionus*) and elk (*Cervus canadensis*). However, the system was also evaluated for other large mammal species if they were found to cross the road at the section with the animal detection system or if they occurred in the carcass removal or crash databases for US Hwy 160.

1.3. Definition of Terms

Though Chapter 3 goes into more detail on reliability parameters and their definition, a brief definition is provided here for commonly used terms in this report:

- *Valid detections* – A valid detection is defined as "a large animal crosses the buried cable and the system reports the presence of this large animal".
- *False positives* – A false positive is defined as "when the system reports the presence of a large animal, but there is no animal present near the buried cable".
- *False negatives* – A false negative is defined as "when an animal crossed the buried cable but is not detected by the system".
- *Threshold* – For this particular system the sensitivity can be modified by changing the "threshold". If the change in the electromagnetic field (measured in dB) exceeds a certain "threshold" value, then detection is declared by the system. Changes in the electromagnetic field that do not exceed this threshold do not result in declaring detections. Lower thresholds mean greater sensitivity, higher thresholds result in lower sensitivity.

2. SITE AND SYSTEM DESCRIPTION

2.1. Site and System Description

A Senstar Perimitrax® buried cable was installed along both sides of US Hwy 160 between Durango and Bayfield, La Plata County, Colorado, USA (between mile reference posts 95 and 96). This road section has a traffic volume of about 8,500 vehicles per day, a speed limit of 60 MPH, and varies between two and three lanes (it is a two lane road with incidental passing lanes for one of the two directions at a time). The vegetation on both sides of the road section with the animal detection system is dominated by a mixture of open shrub land, open forest, and grasslands. In addition, there are access roads that lead to houses and energy extraction facilities. This road section has had a history of wildlife-vehicle collisions, especially with mule deer (*Odocoileus hemionus*) and elk (*Cervus canadensis*).

The system is divided into 20 detection zones (Figure 2.1), each about 161 m (528 ft) long, and detects large mammals when they move across the cable. The system is manufactured by Senstar Corporation, Carp, Ontario, Canada, and it is the exact same technology as installed in the test-bed for animal detection systems near Lewistown, Montana, USA. System installation took place in early fall of 2008 and was fully operational by September 29, 2008. The system generates an invisible electromagnetic field and when a large animal crosses the cable it causes a disturbance in this electromagnetic field. The electrical conductivity, size and speed of the animal all affect the magnitude of the disturbance. However, the threshold that needs to be met to declare an "alarm" or "detection" is adjustable and can be set depending on the size of the animal one may wish to detect. Detection messages are transmitted to a computer placed in a cabinet on the south side of the road (between detection zones 1a and 1b). The detection messages are saved in files for later analysis. The detection files can be accessed on site as well as from CDOT's office in Durango.

The distance between the edge of the pavement and the buried cable is about 9.1 m (30 ft). The buried cable was placed in a trench (30 cm (12 inches) deep) and wrapped in sand and geotextile with the center of the cable 23 cm (9 inches) below the surface. To reduce the potential for false positives the cables were run on top of culverts rather than under culverts, and all of the access roads (1 on north side of US Hwy 160, 7 on south side of US Hwy 160) were equipped with a loop detector to eliminate false positives from vehicles turning on and off US Hwy 160.

The warning signs are about 366 m (1200 ft) apart (Figure 2.2). The warning signs are fiber optic blank-out signs and do not display any message when no detection is reported (black sign). In addition, there are signs that alert the driver to the upcoming road section with the animal detection system, and signs that mark the end of the road section with the animal detection system (Figure 2.1)

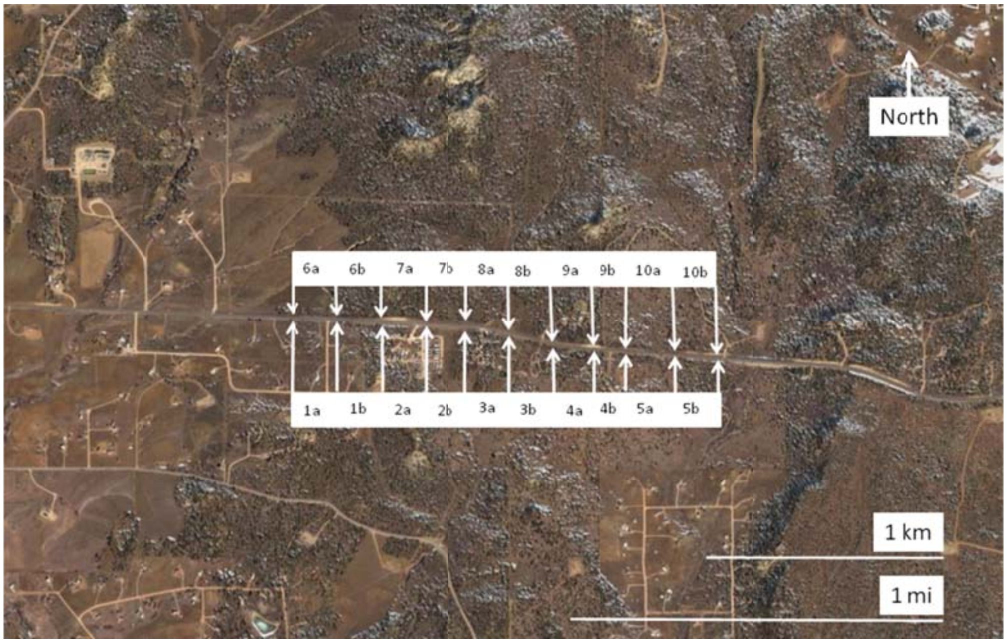

Figure 2.1: Location and name of the detection zones.

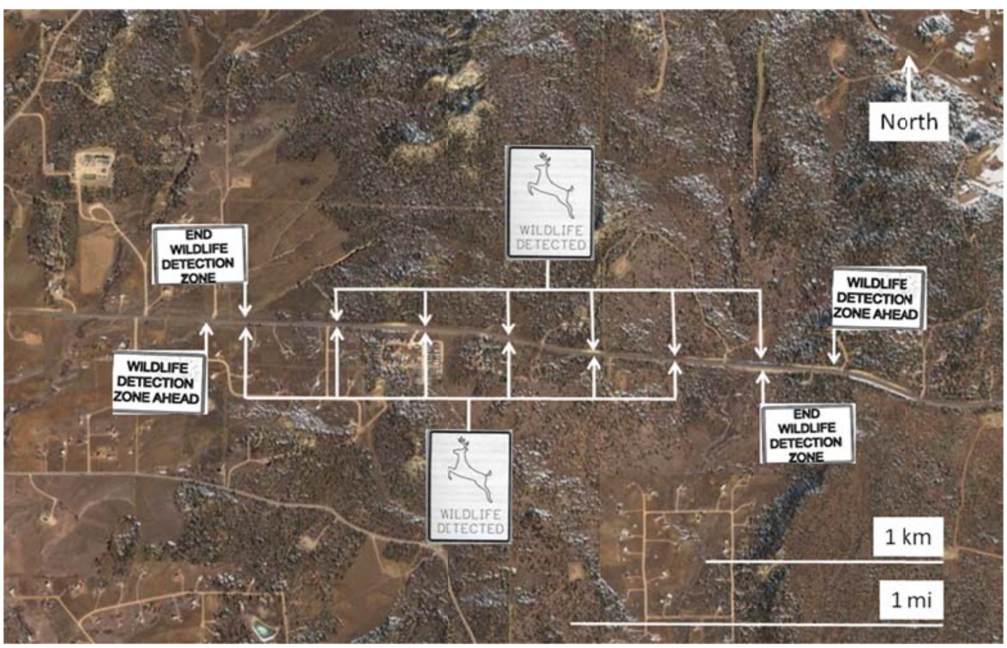

Figure 2.2: Location of the warning signs.

There are seven speed sensors (radar detectors mounted on posts) associated with the animal detection system (five inside the road section with the system, and one on each side, outside of the road section with the system) (Figure 2.3). The speed data are collected through a communication link to CDOT's office in Durango. If one sensor at a time is collecting data, data on individual vehicles are saved. If data are collected from multiple sensors (up to seven) at a time, only binned data are available.

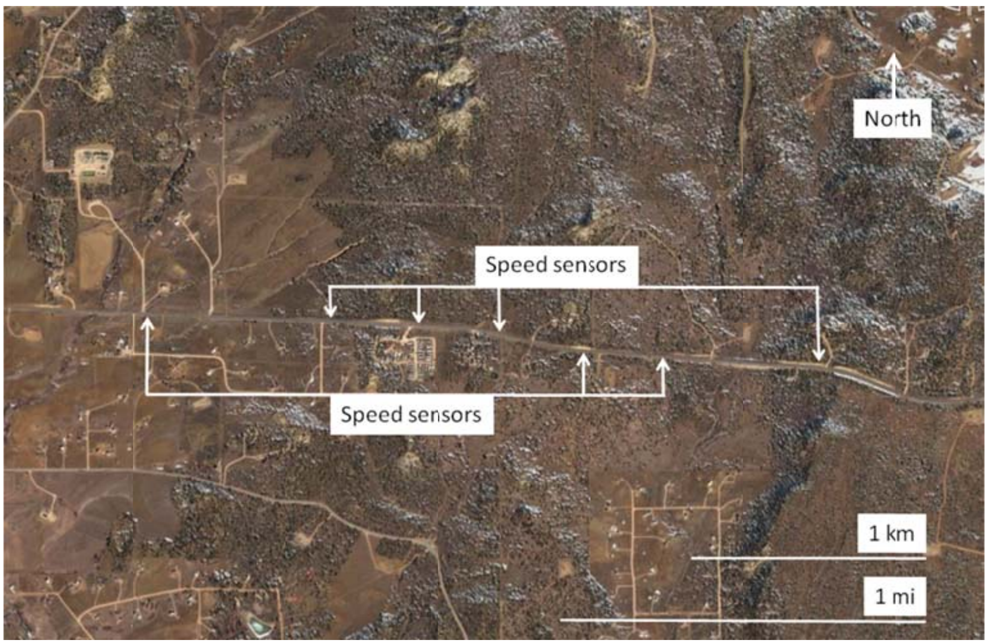

Figure 2.3: Location of the speed sensors.

2.2. Experiences with Installation and Maintenance through August 2010

Over the course of 2008-2010, a variety of technical and operational problems were encountered that limited the functionality of the system. These problems included:

- A number of the sensor modules malfunctioned and were replaced by Magal Senstar.
- Water in the de-couplers between individual detection zones may have caused abundant false positives that remained in 2010 (through August 2010). This suggests that the system, without modifications, could not be used during wet periods (e.g. snow melt, heavy rain) when water may be penetrating the soil and equipment. The manufacturer (Senstar Corporation) looked into these issues and modified and upgraded the entire system (see section 2.3).
- There were multiple problems with the communication between the animal detection system and the warning signs; some of the signs were not activating when tripped by a human crossing the buried cable. In addition, CDOT had to install Arc Suppressors at

each sign relay to address and electrical arching issue that inadvertently would turn on the signs. Some warning signs stay on beyond the programmed 40 seconds with the length of time activated beyond the programmed 40 seconds being variable.

- The Starnet computer at the site did not automatically re-start after a power outage, and has to be manually reset. A battery back-up had to be installed to keep system from shutting down during a power outage.
- Changes in snow depth led to changes in the sensitivity of the system. This means that the thresholds have to be adjusted as snow conditions, and potential other environmental conditions that may influence the signal strength change. More details on recommended modifications in the thresholds are discussed in Chapter 3.
- Water flow across the surface caused false positives. This suggests that the system may not be reliable during certain times of the year (e.g. snow melt in spring, heavy rain or flooding) and that the system may need to be turned off during such periods. On certain slopes the backfilled trench for the cable provides an easy path for water right on top of the buried cable, causing both false positives along long sections of the buried cable and erosion.
- Some crossing events over the buried cable did not exceed pre-established thresholds however the warning signs still activated (signs are programmed to activate when the threshold for that zone is exceeded).

In addition there were problems with the research equipment used to measure vehicle speeds:

- The set up of the speed sensors did not allow for the measurement of individual vehicle speeds at all stations at the same time. Speed data were grouped and averaged in time periods which can be varied in length. Speed data of individual vehicles can only be obtained from one speed station at a time.
- The radar detectors experienced communication problems relaying data to the nearby CDOT Durango office.
- For a speed study it is important that the researchers are able to force all warning signs on for a limited time period. The command to activate all warning signs and the command to return to normal operation were unknown for some time.

Finally, there is an inherent risk with the nature of a system that detects animals as they cross the line of detection; the line of a signal (in this case a buried cable). If an animal lingers in the right-of-way or on the road itself after having crossed the cable, the warning signs may turn off while there still is a potential for a collision. The best way to address this potential problem is to collect information on how much time animals spend in the right-of-way or on the road before they trigger the system again. If plotted in a graph, with time on the x-axis and the percentage of crossings that do not have the warning signs turn off while the animals are still on or near the road, it is a curved line that approaches an asymptote. Therefore the warning signs would have to be on permanently to cover all crossings. Once the values of the curves are known a decision will have to be made on what an acceptable cut-off level would be.

2.3. System Upgrade, Modification and Expansion Fall 2010

Between August 2010 and November 2010 the system along Hwy 160 near Durango was upgraded, modified, and expanded. The upgrade consisted of replacing the Senstar Perimitrax® control modules with the Senstar OmniTrax® control modules. The most important differences between these two systems are:

- The sensitivity of the Senstar OmniTrax® system can be automatically adjusted in calibration mode, allowing for variations in site specific conditions (e.g. soil parameters) within a cable section for each meter (3.3 ft).
- Both the Senstar Perimitrax® system and the Senstar OmniTrax® system report the cable section in which the detection occurred. However, the Senstar OmniTrax® system also reports where the detection occurred within a section, measured in meters from the sensor module. This means that the exact location of a detection (accurate to about 1 m (3.3 ft)) is known with the Senstar OmniTrax® system.
- The Senstar OmniTrax® System also allows for "turning off" segments of a detection cable. Segments can either be turned off indefinitely or during predetermined times of the day. This feature is especially useful at access roads and drainage crossings.

The modification of the equipment included upgrading the sensor modules, addition of fiber optic cabling to the Starnet Computer, software upgrades, and adding Network Interface Units to the system (NIU).

Furthermore the road section equipped with the animal detection system was expanded with 0.25 mi (401 m) in road length, including additional warning signs, on the west side of the system. There is a gap of about 10 m (30-35 ft) between the old and the new system with rip rap to separate two sections with an animal detection system. Two of the driveways in the new section were equipped with loop detectors. All other driveways in the new section were programmed to be switched on only at night to minimize potential false positives caused by vehicles turning on and off the highway.

3. RELIABILITY IN DETECTING LARGE WILD UNGULATES

3.1. Intentional Triggering by Researchers

3.1.1. Introduction

The researchers triggered the original Perimitrax® detection system along US Hwy 160 near Durango at regular intervals to investigate the reliability of the animal detection system. In this case humans served as a model for large wild ungulates such as mule deer (*Odocoileus hemionus*) and elk (*Cervus canadensis*).

3.1.2. Methods

A researcher (approximately 1.82 m (6 ft) tall and weighing 79 kg (175 lbs.)) served as a model for wildlife and crossed the buried cable at approximately 30 m (about 100 ft) intervals (within each detection zone on both sides of the road). For each pass, the zone, time, and other environmental data (e.g. snow depth, presence of pooled water, mud or wet soil conditions) were recorded, in addition to documenting whether or not the driver warning signs associated with a particular zone were activated after a zone was triggered (i.e., after the buried cable was crossed). Reliability testing was conducted on January 15, 2009.

While the researcher crossed the buried cable at regular intervals (Figure 3.1), the system continuously logged the signal strength for the different detection zones. A detection occurred when the signal strength exceeded a specific threshold. This threshold value is adjustable to accommodate different species (e.g. smaller species require a lower threshold) and environmental conditions (e.g. greater snow depths require lower thresholds).

Figure 3.1: Example of a researcher crossing the buried EM cable. The green post in the background represents the location of the buried EM cable (cable extends left to right in photo). Tracks left in the snow by the researcher indicate the nature of the crossing activity by the researcher: perpendicular to the buried EM cable.

Upon completion of the reliability test survey, comparisons were made to the plots with the signal strength for the different detection zones. A pass across the buried cable by the researcher had to be associated with an increase in the signal strength in the detection zone concerned, and the increase in signal strength had to reach or exceed the threshold for a detection to be declared and to activate the warning signs. If the threshold was not met or exceeded with a pass across the buried cable the researchers declared a "blind spot" as the system appeared to have failed to detect the researcher, and potentially a large wild ungulate. An example of how detection events were identified is presented in Figure 3.2.

The plots were also reviewed to evaluate if the thresholds in the different detection zones needed to be adjusted (lower or higher thresholds), for example as a result of varying snow depth at different sections, or changes in snow depth at the same location over time as a result of additional snow fall or melt.

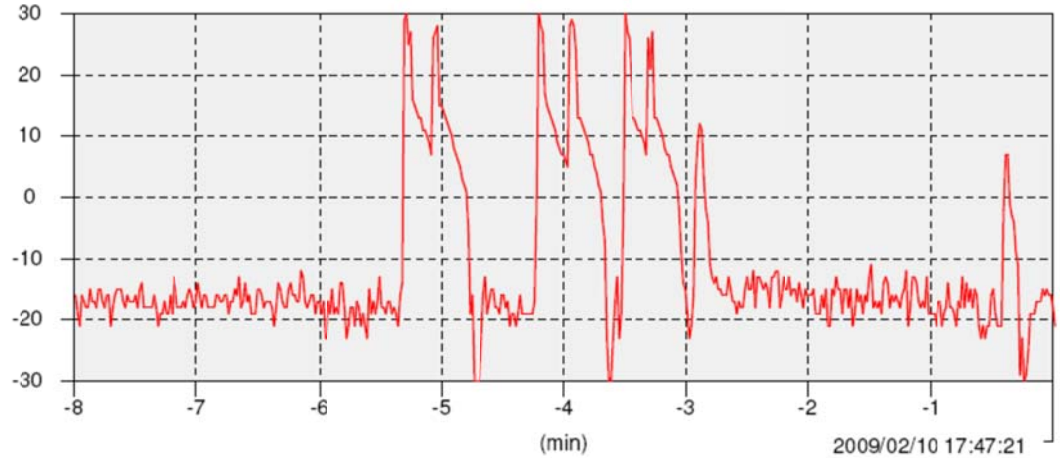

Figure 3.2: Example of a plot generated during reliability testing (x-axis = time; y-axis is signal strength (dB)). In this example, six peaks were identified between 3:00 and 5:30 minutes before the plot was ended. These peaks coincided with a researcher crossing the buried cable at 3 locations (each pass triggered two peaks as the researcher crossed the cable).

3.1.3. Results

The intentional triggering of the system by the researchers resulted in 105 passes of the buried cable. All but one pass (in Zone 6B) were recorded by the detection log (as an increase in signal strength but not necessarily reaching or exceeding the threshold). Snow depth at this pass was 43 cm (17 inches); other passes were recorded in snow depths in excess of 43 cm (17 inches) (up to 51 cm (20 inches)) so it is unclear why the pass did not result in an increase in signal strength. For all passes, in no single case was the threshold value set for a zone exceeded. The highest value reached when the cable was crossed was 24 dB and the lowest value was -4 dB while the thresholds for the different sections varied between 35 and 40 dB above the base signal. Warning signs were triggered, as evidenced by visual surveys, during the majority of crossing events. It is suspected that regardless of what the threshold was set at, the crossing signs still activated upon a crossing event by the researcher. Exceptions to this were crossing events in Zones 1A, 1B, 5A, 5B, 10A, and 10B. These zones were identified as containing problematic sensors, so detections and triggers may have yielded varying results due to these technical problems. The problems with the sensors and couplers or potential interference with the cables could have caused signs to activate when crossed (regardless of what the threshold was set at) or thresholds that were established were not reflective of actual thresholds. Results of tests are presented in Table 3.1.

Table 3.1: Results of January 2009 system testing when activated by researchers crossing the buried cable. Number identified in “Threshold at testing” column indicates the threshold set for that entire zone (e.g. the threshold for zone 1A was 35 dB).

Zone	Snow Depth (in.)	Warning Sign Activated?	Threshold at Testing (dB)	Peak (dB)		Zone	Snow Depth (in.)	Warning Sign Activated?	Threshold at Testing (dB)	Peak (dB)
1A	16	No	35	1		6A		Yes	38	4
1A		No		4		6A	9	Yes		11
1A	15	No		9		6A		Yes		10
1A		No		3		6A	6	Yes		11
1A	13	No		9		6A		Yes		10
1B	14	No	35	7		6B	7	Yes	40	11
1B		No		6		6B		Yes		12
1B	15	No		-2		6B	17	Yes		no detection
1B		No		4		6B		Yes		5
1B	15	No		2		6B	0	Yes		12
2A	14	Yes	38	1		7A	5	Yes	35	5
2A		Yes		9		7A	0	Yes		5
2A	18	Yes		10		7A	0	Yes		17
2A		Yes		3		7A		Yes		12
2A	8	Yes		0		7A	0	Yes		13
2B		Yes	37	7		7B	3	Yes	39	12
2B		Yes		9		7B		Yes		9
2B	2	Yes		9		7B	6	Yes		-1
2B	4	Yes		16		7B		Yes		15
2B	0	Yes		9		7B	8	Yes		10
3A		Yes	37	7		8A		Yes	40	12
3A	12	Yes		6		8A	0	Yes		11
3A	16	Yes		9		8A	0	Yes		22
3A		Yes		7		8A	16	Yes		8
3A	12	Yes		9		8A	16	Yes		8
3A	0	Yes		5		8B		Yes	40	4
3B	0	Yes	37	9		8B	6	Yes		9
3B	7	Yes		11		8B	12	Yes		11
3B	0	Yes		11		8B		Yes		2
3B	12	Yes		2		8B	12	Yes		12
3B		Yes		15		9A		Yes	40	-1
4A	15	Yes	38	2		9A		Yes		3
4A		Yes		9		9A		Yes		15
4A		Yes		-3		9A	0	Yes		24
4A	15	Yes		8		9A	6	Yes		8
4A	15	Yes		3		9B	13	Yes	40	0
4B	20	Yes	40	3		9B		Yes		3
4B		Yes		0		9B	0	Yes		10
4B	18	Yes		14		9B		Yes		10
4B		Yes		22		9B	0	Yes		16
4B	12	Yes		8		10A		Yes	37	11
5A	12	Yes		-4		10A		Yes		11
5A	18	Yes	35	-3		10A	16	No		17
5A		No		2		10A		No		13
5A	12	No		2		10A	7	No		16
5A		No		-2		10B	6	Yes	40	12
5B	15	No	40	0		10B		No		4
5B	18	Yes		10		10B	6	Yes		6
5B	15	Yes		2		10B		Yes		3
5B		Yes		12		10B		Yes		5
5B		Yes		8						

Because of the relatively low signal peaks associated with researcher crossing events, the threshold values were lowered so that crossing events by researchers (or by large wild ungulates of similar size or larger) would result in signal peaks that would meet or exceed the thresholds, and thus result in the activation of the warning signs. For this purpose a researcher communicated with a CDOT engineer stationed at the system control box via radio and indicated to the engineer when crossing the cable. The engineer then observed the peak value recorded during that crossing event and adjusted (lowered) the sensitivity threshold accordingly.

A post-snow testing period was subsequently conducted in April 2009 to readjust the thresholds back to their original values, as identified in Table 3.1. This was conducted in a similar way described above, with the exception that the thresholds were increased rather than lowered. Rather than using this readjustment session as a spring/wet condition testing event we used this effort to refine the sensitivity in the absence of deep snowpack, which was recorded during earlier sensitivity testing events in January. The reasons that the data were not representative for a spring/wet situation are 1) snow, with varying depth, was still present at some of the locations, and 2) there was variation in the soil moisture between areas with snow and recent snow melt versus areas without snow that were typically exposed to the sun.

3.1.4. Discussion and Conclusion

Snowpack was a major factor for the proper sensitivity settings of the animal detection system. Appropriate sensitivity is important as large wild ungulates should meet or exceed the thresholds, and potential false positives because of thresholds that are too low need to be avoided. However, there was no strong relationship apparent between snow depth and the value recorded in the detection log. The highest values (those above 20 dB) were recorded in snow depths between 0 cm (0 inches) (2 events) and 41-46 cm (16-18 inches) (2 events). Values recorded below 0 dB were detected at snow depths of 0 cm (0 inches), 15 cm (6 inches), 30 cm (12 inches), and 38 cm (15 inches). Based on the low readings recorded during snowpack conditions, the researchers recommend lowering detection thresholds during periods of high snow depth (greater than 30 cm (12 inches), as depths above this value seemed to be associated with lower signal peaks). The following recommendations apply to the zones listed below where snow remained through much of the winter (little melt, little snow blowing away):

- Zone 1A and 1B: adjust sensitivity threshold to 5 dB during heavy snowpack events (> 12 inches snow depth).
- Zone 5A: adjust sensitivity threshold to 0 dB during heavy snowpack events (> 12 inches snow depth).
- Zone 10A: adjust sensitivity threshold to 10 dB during heavy snowpack events (> 12 inches snow depth).

One interesting aspect of the signs activating is that even though some crossing events did not exceed the programmed threshold limit for that zone, the signs still activated. Therefore, it is difficult to assess what actually triggered the signs, or whether the pre-programmed threshold values set did not influence whether a sign was or was not activated. As discussed above, several zones were identified as being problematic due to driveway crossings (interference with cables) and faulty sensors so activated signs may have been independent of actual crossing events.

3.2. Snow Tracking

3.2.1. Introduction

To further test the reliability of the system in detecting crossing events by large ungulates, the researchers conducted snow tracking surveys to identify where along the length of the animal detection system large wild ungulates were crossing the buried cable. This effort could only be conducted when snow cover was adequate in terms of snow depth, percentage cover (i.e., the entire length of the buried cable covered by snowpack), and duration (i.e., snow cover would be present to allow for several days of continuous monitoring).

3.2.2. Methods

The researchers conducted snow track surveys along the entire length of the animal detection system and on both sides of US Hwy 160. The winter sampling session occurred from February 8 through February 13, 2009, and consisted of an initial clearing of tracks on the first day followed by 5 consecutive sampling days. Additional snow tracking after the system had been modified (see section 2.3) was conducted between 1 February 2011 and 3 February 2011 and on 7 and 8 February 2011. Surveys were initiated during mid-morning hours to allow for morning wildlife activity to occur with minimal interruption. The initial clearing day entailed researchers erasing tracks that were determined to cross over the buried cable; tracks were “erased” by using a rake to scrape the snow and allow for new tracks to be recorded for a distance of 1-2 meters on either side of the buried cable. On some days the “clearing” was conducted through natural snowfall. When returning 24 hours later, any new tracks (within the previous 24 hours) indicated a cable crossing event, and all such tracks were recorded. For each crossing event, the researchers recorded the location (including the detection zone and GPS location), date, time, species (emphasis was placed on deer and elk, however smaller-bodied species such as coyote, domestic dog, and rabbit were noted; Figure 3.3), and direction of travel of the animal. Direction of travel was categorized as an animal leaving the road, approaching the road, or traveling parallel to the buried cable; the latter of these was documented due to the system potentially detecting wildlife that came in close proximity to the cable (i.e., within about 1 m (about 3 ft) from the cable) but did not actually cross it. The researchers also documented the time that they entered and left a zone so that if the system was triggered by the researcher while observing and clearing tracks there would be confirmation that the event was triggered by the researcher and not by wildlife.

Figure 3.3: Example of a track left by a mule deer. Tracks were identified to species and subsequently “erased” by raking snow over the tracks in preparation for the next day of sampling.

Upon completion of the snow tracking survey, comparisons were made to the detection log and the plots generated by the systems. Correct system functioning should result in cable crossings, as measured through snow tracking, and matching events in the detection logs based on detection zone and time (within the past 24 hours). Detections by the system were identified by spikes in the signal that exceeded either the threshold set for that zone or a substantial increase (greater than 40 dB) in the baseline readings detected along the EM cable, as discussed in Section 3.1.2.

3.2.3. Results

In 2009 (before system modifications) snow tracking surveys resulted in recording a total of 332 crossings of the buried cable, including 122 mule deer, 38 elk, and 172 non-ungulate tracks consisting of coyotes, rabbits, and domestic dogs. Activity was highest in Zones 1A, 3A, 3B, 4A, 8A, and 9A. Comparisons between the number of tracks detected in each zone and the number of crossing events detected by the system log are presented in Table 3.2. Correlation analysis between all zones resulted in a Pearson product moment correlation coefficient (r) of 0.017 ($P > 0.05$), indicating no significant relationship between the number of tracks detected and the number of crossing events detected by the system.

Table 3.2: Comparison of tracks detected through snow tracking and through the detection log and plots by detection zone in 2009. Tracks detected are summed across sampling days.

Zone	Mule Deer and Elk Tracks Detected	Other Tracks Detected	Detections by System
1A	5	23	49
1B	0	12	0
2A	1	11	9
2B	0	7	0
3A	26	5	53
3B	13	11	3
4A	31	1	58
4B	0	0	2
5A	2	0	0
5B	4	3	0
6A	1	19	0
6B	2	5	0
7A	5	12	0
7B	0	18	0
8A	27	14	14
8B	11	7	19
9A	23	7	3
9B	0	11	0
10A	8	6	5
10B	1	7	0

In 2011 (after system modifications) snow tracking surveys resulted in recording a total of 31 crossings of the buried cable, including 14 mule deer, 1 ungulate (deer or elk), and 16 non-ungulate tracks consisting of coyotes, rabbits, and domestic dogs and cats. Activity was highest in Zone 6B. Comparisons between the number of tracks detected in each zone and the number of crossing events detected by the system log are presented in Table 3.3. Correlation analysis between all zones resulted in a Pearson product moment correlation coefficient (r) of 0.063 ($P > 0.05$), indicating no significant relationship between the number of tracks detected and the number of crossing events detected by the system.

Table 3.3: Comparison of tracks detected through snow tracking and through the detection log and plots by detection zone in 2011. Tracks detected are summed across sampling days.

Zone	Mule Deer and Elk Tracks Detected	Other Tracks Detected	Detections by System
1A	1	2	179
1B	2	2	8
2A	0	1	897
2B	2	1	1
3A	0	0	147
3B	0	0	0
4A	0	1	42
4B	0	0	4
5A	0	0	1
5B	0	1	0
6A	1	1	1
6B	7	2	0
7A	0	0	0
7B	2	0	1
8A	0	0	0
8B	0	1	40
9A	0	1	1
9B	0	1	1
10A	0	1	1
10B	0	1	0

3.2.4. Discussion and Conclusion

The number of crossings of the buried cable by ungulates as detected through snow tracking and through interpretation of the detection log generated by the system were highly variable. In many zones, the system suggested poor performance in detecting mule deer and elk crossing the buried cable (for 2009 tracking session especially detection zones 3B, 5A, 5B, 6A, 6B, 7A, 8A, 9A, 10A, and 10B where of the 86 tracks in total only 25 were detected by the system (29.1%)). However, it is also possible that multiple animals crossed close together so that the crossing of multiple animals only resulted in one detection by the system. Several zones had a substantially higher number of detections by the system than the number of tracks observed (for 2009 tracking session notably zones 1A, 2A, 3A, 4A, 4B, and 8B; for 2011 tracking session notably zones 1A, 2A, 3A, 4A, and 8B). Note that this could be due to multiple detections associated with track data (i.e., multiple individuals walked in the same tracks and thus only one track event was recorded by the researcher); potential problems with the vehicle detection loops at side roads and driveways, multiple detections during the crossing of one animal, and perhaps high sensitivity of the (modified) system (i.e. detections may also be caused by small animals that were not recorded in the snow tracking sessions). However the high number of detections in some zones in 2011 compared to the number of other non-ungulate tracks recorded indicates that the system continues to have problems accurately detecting deer and elk passes over the buried cable. Snowfall during the first two days of surveys could have also covered tracks left by wildlife between the point where tracks were cleared on the first day of sampling to when the next day’s visit occurred. These latter zones could also be experiencing false positives.

Several zones had distinctly more system detections than passes by ungulates over the EM cable (in 2009 zones 1A, 3A, and 4A). Possible explanations to the high number of false positives could be related to problems with driveway loops not recognizing vehicles passing over the buried EM cable. Driveway loops were installed at access roads and their purpose is to cancel alarms that would be caused by vehicles leaving the main road or turning onto the main road. In fact, there were many times during a visit to the site when warning signs in these zones were activated, suggesting that vehicles might have triggered the system.

Problems with sensor modules could explain the low rate of detections by the system, particularly in zones 3B, 8A, and 9A. The fact that half of the zones did not detect any crossings might be attributed to problems related to snowmelt, pooled/running water passing over the cable, soil properties, or other unexplained system malfunctions. Alternatively, tracks observed crossing the cable during the first three days of sampling may have been minimal due to fresh, continuous light snowfall potentially “erasing” tracks from the previous nights, thus an apparent over-reporting by the system may have actually been researchers unable to report all tracks crossing the buried cable within a 24-hour period due to those tracks being covered by additional snowfall prior to the researcher collecting the data. Potential over-reporting of the system was observed in Zones 1A, 3A, 4A, and 8B.

3.3. Camera Surveys

3.3.1. Introduction

To further evaluate system reliability relative to ungulate crossings, the researchers also installed wildlife cameras at strategic locations spread along the length of the system. Wildlife passing by within the range of the cameras triggers the cameras to take a series of pictures, allowing the researchers to further evaluate the reliability of the system, especially during the snow-free months including the spring and fall when higher wildlife activity is typical in the area.

3.3.2. Methods

We installed 12 Cuddeback cameras at strategic locations spread along the length of the system. The cameras were installed at locations where wildlife trails were present or where vegetation or other topographical features were present that may encourage large ungulates to travel there. Each camera was positioned so that the view shed included a segment of the buried cable. When an animal triggered the camera, the animal was photographed near or above the cable at that location. Each photo had a date and time stamp, allowing for a comparison to the detection log generated by the system. The cameras operated continuously from April through June 2009 (before system modifications) to capture spring migration events and from 30 January 2011 through 12 February 2011 (after system modifications). The researchers checked the cameras every two weeks to change batteries and memory cards. Cameras were moved to different locations in order to effectively assess the system. Zones sampled included 1B, 3A, 3B, 4A, 4B, 5A, 6A, 7B, 8B, 9B, and 10B.

For each photo, comparisons were made to plots generated on the detection log of the system to verify whether ungulate crossing events were detected by the system. Plots were analyzed and detections were identified by spikes that exceeded either the threshold set for that zone or a significant increase in the baseline readings detected along the EM cable (see section 3.1.2).

3.3.3. Results

During the 2009 camera session the cameras captured a total of 110 crossing events over the cable, including 92 deer and 1 elk; additional species detected at camera stations included coyote (6 camera detections), red fox (1 camera detections), rabbit (5 camera detections), domestic dog (1 camera detections), and domestic cat (4 camera detections). None of these events were captured by the system log. Of the zones surveyed, camera detections were highest in Zones 10A (25 deer; 1 elk), 4A (20 deer), and 3A (18 deer).

During the 2011 cameras captured a total of 6 crossing events over the cable, all of which were mule deer; additional species detected at camera stations included a domestic cat (1 camera detection). None of these events were captured by the system log. Of the zones surveyed, camera detections were highest in Zone 3A (5 deer).

Figure 3.4: Example of photo taken at camera station. Cameras were positioned so as to capture any animals crossing the buried EM cable.

3.3.4. Discussion and Conclusion

The problems with the reliability of the original and modified system in detecting wildlife crossings observed with cameras were similar to those observed by both researcher-triggered events and wildlife crossings detected through snow tracking. The detection plots that were recorded during the camera surveys did not show signature signal peaks at the time an animal was detected crossing the buried cable, as evidenced by the time stamp on each photo triggered by wildlife. This indicates problems with the system detection technology; the crossing event was not accurately logged by the system as wildlife crossed the buried EM cable. Zones with the highest camera detections (for 2009 zone 3A, 4A, and 10A) showed similar results as those experienced during snow tracking events, indicating that problems with system sensors or driveway loops could have caused the system to not detect crossings of the cable in those particular zones.

4. RELIABILITY IN DETECTING DOMESTICATED UNGULATES IN A TEST-BED

4.1. Introduction

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. This site has been used for the testing of the reliability of animal detection systems since 2006 (Huijser et al., 2009c). Note that the test bed is only used to evaluate the reliability of the system using domesticated animals as a model for wild ungulates. Since the test-bed is not located along a road, and since the domesticated animals could not leave the fenced test-bed, there were no warning signs connected to the system in the test-bed and, on this location, no research took place into the effectiveness of the system, e.g., with regard to vehicle speed reduction or animal-vehicle collisions. The advantages of conducting reliability tests at this test-bed site in addition to the reliability tests on-site near Durango are:

- Accurate measurement of 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 occurred. This is in contrast to animal detection system near Durango, where the still cameras only cover a fraction of the length of the system on two sides of the road.
- Sufficient 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 the system under a range of environmental conditions. This is in contrast to animal detection systems along real roadsides where the number of animal movements is unknown and sample size cannot be controlled.
- Measure the effect of environmental conditions on reliability: The researchers propose that this research continues beyond the tests that are 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, where the number of animal movements is likely to be too small for an accurate assessment of system reliability 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.
- Measure the reliability for different sized species: By using horses, llamas, and sheep, as a model for wild ungulates such as pronghorn (*Antilocapra americana*) deer (*Odocoileus* spp.), elk (*Cervus Canadensis*) and moose (*Alces alces*), 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 only one or two species may dominate.

For this project the buried cable system Perimitrax® manufactured by Senstar Corporation was evaluated for its reliability for two 10 day test periods in the winter of 2009-2010 and two 10 day test periods in the summer/fall of 2010. The current annual report does not report on how the reliability of the system may have been influenced environmental conditions. This is yet to be done and will be reported on in a future report.

4.2. Methods

4.2.1. 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. 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 of some types 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 (Figures 4.1 through 4.4). The distance covered by the system tested for this project was about 50 m (164 ft) (from the left to about the middle 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 4.1: The location of the test-bed along a former runway at the Lewistown Airport in central Montana, USA. The current municipal airport is located on the upper right of the photo.

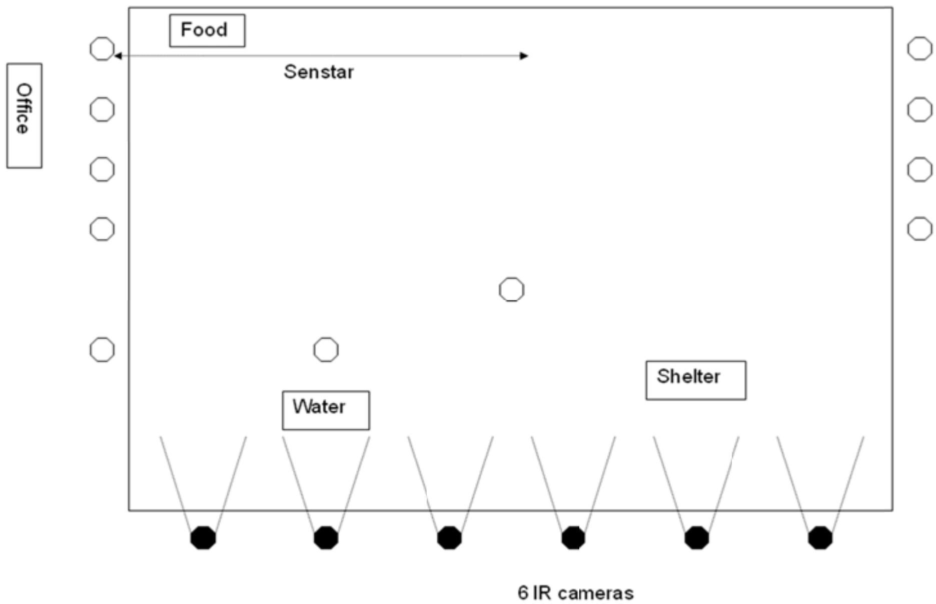

Figure 4.2: Test-bed design including an animal enclosure, the Perimitrax® animal detection system manufactured by Senstar Corporation tested for this project (open circles represent poles on which sensors can be attached), the six infrared (IR) cameras aimed at the enclosure from the side (solid circles), and the office with data recording equipment.

Figure 4.3: 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 4.4: The infrared cameras that monitor animal movements in the enclosure (Photo: Marcel Huijser, WTI/MSU).

4.2.2. Animal Detection System and Recording Equipment

The system tested for this project is a buried cable (Perimitrax®) that detects large mammals when they move across the cable (Figures 4.5 through 4.9). The system is manufactured by Senstar Corporation, Carp, Ontario, Canada, and it is the exact same technology as originally installed along US Hwy 160 near Durango, CO, USA. The buried cable was placed in a trench and wrapped in sand and geotextile nine inches below the surface. System installation took place on 11 and 12 August 2009. The system generates an invisible electromagnetic field and when a large animal crosses the cable it causes a disturbance in this electromagnetic field. The electrical conductivity, size and speed of the animal all affect the magnitude of the disturbance. However, the threshold that needs to be met to declare an "alarm" or "detection" is adjustable and can be set depending on the size of the animal one wishes to detect. Detection messages are transmitted to a computer in the research trailer at the test-bed where they are saved in files for later analysis.

Six infrared cameras (Fuhrman Diversified, Inc.) were installed perpendicular to the detection system (Figure 4.4). These cameras and a video recording system record all animal movements within the enclosure continuously, day and night. The Senstar Perimitrax® 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, allowing the researchers to investigate the reliability of the system. Orange cones marked the location of the cable on the images (Figure 4.10).

Figure 4.5: The installation of the Senstar Perimitrax® cable. The cable is embedded with sand and wrapped in geotextile (Photo: Marcel Huijser, WTI/MSU).

Figure 4.6: The installation of the Senstar Perimitrax® cable. Filling up the trench (Photo: Marcel Huijser, WTI/MSU).

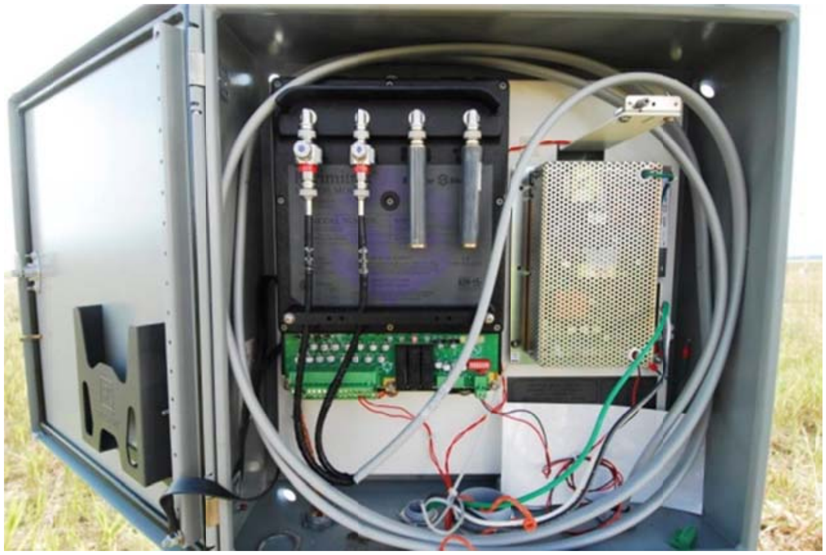

Figure 4.7: The Senstar Perimitrax® sensor module at the pole where the cable comes up from the ground (Photo: Marcel Huijser, WTI/MSU).

Figure 4.8: The Senstar Perimitrax® Network Controller inside the research trailer (Photo: Marcel Huijser, WTI/MSU).

Figure 4.9: The Senstar Perimitrax® interface on a PC in the research trailer during a “walk” test by a human (Photo: Marcel Huijser, WTI/MSU).

Figure 4.10: The orange cones mark the location of the Senstar Perimitrax® buried cable. These cones are visible on the IR video images (Photo: Marcel Huijser, WTI/MSU).

4.2.3. 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 canadensis*) or moose (*Alces alces*). In Montana, it is not legal to have deer, elk or moose in captivity. Therefore the researchers used 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 4.1 through 4.3). The body size and weight of the individual horses, llamas, and sheep used in this experiment are shown in Table 4.3. Some of the test animals are shown in Figures 4.11 through 4.13.

Table 4.1: Height and length of wildlife target species and horses and llamas.

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	3'-3'5" (90-105 cm)	3'10"-7'6" (116-199 cm)	Whitaker (1997)
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), Wikipedia (2007)
Llama	3'-3'11" (91-119 cm)		Llamapaedia (2007)
Goat	25"-30" (64-76 cm)		ADM Alliance Nutrition Inc (2011)
Sheep	25"-50" (63-127 cm)		Minnesota Zoo (2011)

Table 4.2: 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)
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), Wikipedia (2007)
Llama	250-450 lbs (113-204 kg)		Llamapaedia (2007)
Goat	110-225 lbs (50-101 kg)	160-264 lbs (72-119 kg)	ADM Alliance Nutrition Inc (2011)
Sheep	100-350 lbs (45–160 kg)	100-225 lbs (45-100 kg)	Wikipedia (2008)

Table 4.3: Body size and weight of the horses, llamas, and sheep used in the experiment (Pers. com. Lethia Olson, livestock supplier). The measurements were taken in November.

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	2'4" (71 cm)	170 lbs (77 kg)
Sheep 2	2'5" (74 cm)	225 lbs (101 kg)

Figure 4.11: The two horses that were used in the test (Photo: Marcel Huijser, WTI/MSU).

Figure 4.12: The two llamas (foreground and background) that were used in the test (Photo: Marcel Huijser, WTI/MSU).

Figure 4.13: One of the two sheep that were used in the test (Photo: Marcel Huijser, WTI/MSU).

4.2.4. Test Periods

In 2009 and 2010 there were four ten day test periods with animals:

- Test period 1: Start on November 19, 2009 (at midnight), end on November 28, 2009 (end at midnight).
- Test period 2: Start on December 17, 2009 (at midnight), end on December 26, 2009 (end at midnight).
- Test period 3: Start on July 30, 2010 (at midnight), end on August 8, 2010 (end at midnight).
- Test period 4: Start on September 2, 2010 (at midnight), end on September 11, 2010 (end at midnight).

For each test day (24 hours), the researchers selected three random one-hour-long sections of video for review (stratified random). This resulted in a total of 30 hours during which the reliability of the system was investigated for each test period, and 120 hours for the four test periods combined. The images from the time periods that were analyzed were all saved on DVD. Time periods that were not analyzed were not saved.

In addition, there were two ten day test-periods without domesticated animals present in the enclosure:

- Test period 1: Start on December 7, 2009 (at midnight), end on December 16, 2009 (end at midnight).
- Test period 2: Start on January 5, 2010 (at midnight), end on January 14, 2010 (end at midnight).

The detection data from these two periods were screened for the potential presence of detections (which may indicate false positives), and extreme environmental conditions (based on weather data from a nearby meteorological station). The researchers selected 10 hours from this ten day period for review. These hours were non-randomly selected based on potential suspicious detection patterns (i.e., detections were reported while there are no domesticated animals present), and extreme environmental conditions.

4.2.5. 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 Senstar Perimitrax® system continuously reports signal strength and whether the threshold for a valid detection is met. 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 (about 1 m (3 ft) to each side of the cable) of the 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 some animal detection systems (e.g. potential for desensitization of the sensors), 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" (i.e., cable) 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 of some systems are desensitized after a detection and need some time before they can detect another animal. The manufacturer of one of these systems recommends three minutes reset time for the sensors to become fully sensitive again after a detection (see Huijser et al., 2009c).
  - 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 not considered a false negative.

  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 a false negative.

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 (about 1 m (3 ft) to each side of the buried cable) 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.

4.2.6. 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 Senstar Perimitrax® system:

- The average number of valid detections per hour:

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

  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:

$$\overline{F}^{+} = \frac{F_N^{+}}{N_{h(with\ data\ available)}}$$

Where:

F_N^{+} = total number of false positives

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

- The percentage of false negatives:

$$F^{-} = \frac{F_N^{-}}{N_{t\ (center\ line)}} *100 = \frac{F_N^{-}}{N_{d\ (center\ line)} + F_N^{-}} *100$$

Where:

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

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

$N_{d\ (center\ line)}$ = 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:

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

Where:

F_N^{-} = total number of false negatives

$\mathrm{N}_{\mathrm{h\,(with\,data\,available)}}$ = 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

4.3. Results

The results of the reliability tests, with and without domesticated animals present in the enclosure, are shown in Table 4.4 and 4.5. All false negatives in test 1 related to sheep and all false negatives in test 3 related to horses.

Table 4.4: Results of the reliability tests with animals (stratified random).

	Test 1	Test 2	Test 3	Test 4	Total
Threshold (dB)	45	40	40	40	n/a
Hours analyzed (N)	30	30	30	30	120
Valid detections (N)	112	387	675	344	1518
Valid detections/hour (N)	3.73	12.90	22.50	11.47	12.65
False positives (N)	0	0	0	0	0
False positives (%)	0.00	0.00	0.00	0.00	0.00
False positives/hour (N)	0.00	0.00	0.00	0.00	0.00
False negatives (N)	4	0	3	0	7
False negatives (%)	3.33	0.00	0.77	0.00	0.46
False negatives/hour (N)	0.13	0.00	0.10	0.00	0.06
False negatives 1 (N)	0	0	0	0	0
False negatives 1 (%)	0.00	0.00	0.00	0.00	0.00
False negatives 1/hour (N)	0.00	0.00	0.00	0.00	0.00
False negatives 2 (N)	0	0	0	0	0
False negatives 2 (%)	0.00	0.00	0.00	0.00	0.00
False negatives 2/hour (N)	0.00	0.00	0.00	0.00	0.00
Intrusions (N)	62	106	124	70	362
Intrusions detected (%)	94.29	100.00	97.64	100.00	99.54
Downtime (hours)	0:00	0:00	0:00	0:00	0:00
Downtime (%)	0.00	0.00	0.00	0.00	0.00

Table 4.5: Results of the reliability tests without animals (non-random).

	Test 1	Test 2	Total
Threshold (dB)	45	40	n/a
Hours analyzed (N)	10	10	20
Valid detections (N)	0	0	0
Valid detections/hour (N)	0.00	0.00	0.00
False positives (N)	0	5	5
False positives (%)	0.00	100.00	100.00
False positives/hour (N)	0.00	0.50	0.25
False negatives (N)	0	0	0
False negatives (%)	0.00	0.00	0.00
False negatives/hour (N)	0.00	0.00	0.00
False negatives 1 (N)	0	0	0
False negatives 1 (%)	0.00	0.00	0.00
False negatives 1/hour (N)	0.00	0.00	0.00
False negatives 2 (N)	0	0	0
False negatives 2 (%)	0.00	0.00	0.00
False negatives 2/hour (N)	0.00	0.00	0.00
Intrusions (N)	0	0	0
Intrusions detected (%)	n/a	n/a	n/a
Downtime (hours)	0:00	0:00	0:00
Downtime (%)	0.00	0.00	0.00

4.4. Discussion and Conclusion

The number of false negatives and false positives was relatively low or non-existent, and the percentage of all intrusions in the detection area that was detected was relatively high (see Huijser et al., 2009c). Of the seven false negatives that did occur four related to sheep and three to horses.

Based on the values of the false negatives and false positives, the Senstar Perimitrax® system easily meets the recommended minimum norms for the reliability of animal detection systems (see Huijser et al., 2009c). The recommended minimum norms for system reliability are:

- Animal detection systems should detect 91–95% or more of all large animals that approach the road. During the randomly selected test hours the Perimitrax® system did not detect 0.46% of all animals that crossed the detection line and it did detect 99.54% of all intrusions in the detection area. Thus the Perimitrax® system met this norm.
- Animal detection systems that had a false detection rate (false positives) of 6–10% or less would be acceptable. During the randomly selected test hours the Perimitrax® system had zero false positives. Thus the Perimitrax® system met this norm.

The two additional ten-day tests took place in December 2009 and in December 2009/January 2010. During these two tests no animals were present, and the time periods selected for analyses were non-random; they were based on unusual detection patterns and extreme environmental conditions. The data from these two additional test periods will be used to investigate the potential effect of environmental conditions on system reliability.

While the research in the test-bed allows for a detailed investigation of the reliability of animal detection systems, real road-side environments are far more complex and, as a result, systems that perform well in a test-bed can still experience reliability problems in a road-side environment. Examples of the more complex situation along a real road are the longer road section involving multiple detection zones and integration of the different detection zones in one system, more variable terrain (e.g. varying conditions in soil, hydrology, topography, and vegetation), integration with warning signs, and the presence of traffic on the main road as well as access roads.

5. THE EFFECT OF ENVIRONMENTAL CONDITIONS ON SYSTEM RELIABILITY

5.1. Introduction

In this chapter the researchers report on the possible effects of environmental conditions on the reliability of the Perimitrax® buried cable system manufactured by Senstar Corporation.

5.2. Methods

5.2.1. Detection Data Selection

For this chapter both detection data types were included (see also section 4.2.4).

- Stratified random with animals present: There were four test periods with animals present, each consisting of ten test days. For each test day three one-hour-long sections of video were randomly selected for review. This resulted in 120 hours of images analyzed (see table 4.4).
- Non-random without animals present: There were two test periods without domestic animals present, each consisting of ten days (see table 4.5). Non-random time periods were selected from these days. These time periods were chosen based on unusual detection patterns and certain extreme or interesting weather conditions. 10 hours were selected and analyzed for each of the two test periods. This resulted in 20 hours of images analyzed.

The data from non-randomly selected time periods increased the range of values for different environmental condition parameters (see next paragraph), and increased the probability that an effect of environmental conditions, should it indeed be present, could be detected.

5.2.2. Environmental Variables and Animal Species

Environmental variables consisted of weather data and the animal species (horse, llama or sheep) present in the detection area or crossing the detection line. Detections caused by species other than these three domesticated species were not observed.

Weather data from the Lewistown Municipal Airport weather station, about 2.4 km (1.5 mi) distant, was entered in the database and, based on the date and time, linked to each valid detection, false positive, and false negative. Weather reports were typically available in one-hour intervals. The data generated by the weather station included:

- Date of report
- Time of report
- Station type
- Sky conditions
- Visibility—surface statute miles
- Weather type (at time of report)

- Dry bulb temperature
- Wet bulb temperature
- Dew point temperature
- Relative humidity
- Wind speed
- Wind direction
- Wind gusts
- Station pressure
- Pressure tendency
- Net three-hour change
- Sea level pressure
- Report type
- Precipitation total (since the last regular hourly report)
- Altimeter

In addition, the researchers recorded whether it was day or night at the time of each valid detection, false positive or false negative. "Day" was defined as 30 minutes before sunrise through 30 minutes after sunset. "Night" was 30 minutes after sunset through 30 minutes before sunrise. Sunrise and sunset times were reported by the Lewistown Municipal Airport weather station.

5.2.3. Statistical Analyses

The researchers aimed to investigate the effect of environmental conditions on the reliability of the animal detection system through a multinomial logistic regression model with Akaike's "An Information Criterion" (AIC) (Akaike, 1973) with a stepwise model selection procedure to select the most appropriate model.

For this chapter the researchers distinguished two types of situations:

- An animal is in the detection area or crosses the detection line (see chapter 4); and
- The system erroneously reports an animal (denoted as a False Positive or FP).

When an animal is in the detection area or crosses the detection line, then the system can:

- Correctly detect the animal (CD); or
- Fail to detect it (False Negative or FN).

Three different types of false negatives were distinguished (see chapter 4 for details):

- Regular false negative (FN): the animal completely crosses the detection line and is not detected;
- False negative 1 (FN1): the animal lingers in the detection zone before passing through the line of detection and is not detected; and
- False negative 2 (FN2): one animal lingered in the detection zone and other animals passed through the line of detection without being detected.

Thus there were five different possible response categories:

- Correct detection
- False positive
- Regular false negative
- False negative 1
- False negative 2

However, not all responses were observed for all systems (Table 5.1). The researchers set a minimum of ten errors for each type of error before initiating the statistical analysis. This minimum number was not met for any of the error types (Table 5.1). With less than ten errors for an error type the results are very sensitive to the conditions under which these few errors occurred and become very unreliable. Even if more than ten errors would have occurred for one or more error types, it would be extremely easy to find environmental conditions with no errors that would lead to effectively infinite log-odds estimates - basically predicting a probability of 1 for that type of event which becomes computationally problematic in a log-odds formulation. The combination of so few errors and so many predictor variables, results in very unreliable results when attempting to predict those few errors. Instead of conducting a statistical analysis with unreliable results the researchers described the conditions under which the errors occurred.

Table 5.1: The type and number of errors observed for the animal detection system over a time period of 140 hours.

Type	False Negative (FN)	False Negative 1 (FN1)	False Negative (FN2)	False Positive (FP)	Correct Detection (CD)
Count	7	0	0	5	1518

5.3. Results

The number of observed errors of the animal detection system was very low. There were 1518 correct detections with only 7 FNs and 5 FPs. All FNs were observed during the randomly selected evaluation times from different test days and selected hours from two test periods. Four of the FNs were associated with sheep and three with horses, but none with llamas. One FN observation occurred during relatively high wind speeds (over 15 mph) and another was at a time with relatively high humidity (80%).

5.4. Discussion and Conclusion

The low number of errors for the animal detection system did not allow the researchers to conduct a meaningful statistical analysis to investigate which environmental conditions may be associated with these errors. However, the low number of errors should be viewed as a positive characteristic of this animal detection system, and not as a problematic situation.

6. THE EFFECT OF ACTIVATED WARNING SIGNS ON VEHICLE SPEED

The Perimitrax® and the OmniTrax® system at the site near Durango suffered from a range of problems with system integration, including the connectors between the different detection zones, the communication between the animal detection technology and the warning signs, and with the data collection from the speed sensors. Senstar Corporation and CDOT upgraded, modified, and expanded the system in the fall of 2010 (including a system change from Perimitrax® to OmniTrax®). The researchers found the system, before and after system modifications, not reliable. The researchers wanted to see the system detect large animals reliably before initiating a speed study. Conducting a speed study with an unreliable system is not meaningful as drivers cannot be expected to respond to unreliable warning signs. It appears that additional modifications are required for the OmniTrax® system before a speed study is meaningful.

7. POTENTIAL RISK REDUCTION FOR WILDLIFE CROSSING THE ROAD

Comparisons between the control and treatment areas in both ungulate-vehicle collisions and crossings of US Hwy 160 by ungulates were made to investigate the relative risk that ungulates run when crossing the road in the control section(s) and the treatment section. If the ADS-DWS is effective in reducing collisions with large ungulates, then large ungulates that cross the road in the treatment area must have a higher probability of crossing the road successfully than large ungulates in the control sections. Therefore, in addition to conducting snow tracking surveys in the treatment area, similar surveys were conducted in the 1-mile control area to the east of the ADS-DWS. We note that these snow tracking surveys would not result in an absolute estimate of the number of large ungulates that crossed the road; rather, the surveys would allow for a relative comparison in the number of road crossings by large ungulates in the control and treatment areas. When combined with the number of road killed large ungulates in the same areas and same distance, the data will show the relative risk that large ungulates ran when crossing the highway in the control area(s) versus the treatment area.

During 2009, 16 deer and 1 elk carcasses were reported along the stretch of U.S. 160 with the ADS-DWS compared to 15 deer and 1 elk in the control stretch to the west. Crossing rates, as measured through the 5-day snow tracking period, were much higher in the treatment section. Total crossings detected in the treatment section during the 5-day snow tracking period were 55 compared to 12 events in the control section. Thus, although the two stretches of road surveyed displayed similar AVC numbers, the ADS-DWS section had a crossing rate that was over four times greater than crossing rates observed in the control. This difference suggests that the risk to ungulates is much higher without the presence of an animal detection system. However, there may be other factors that differ between the control and treatment section (e.g. visibility to drivers), that influence the likelihood of animal-vehicle collisions.

8. THE EFFECT OF THE PRESENCE OF THE ANIMAL DETECTION SYSTEM ON THE NUMBER AND SEVERITY OF ANIMAL-VEHICLE COLLISIONS

8.1. Introduction

The Perimitrax® and the OmniTrax® system at the site near Durango suffered from a range of problems with system integration, including the connectors between the different detection zones, the communication between the animal detection technology and the warning signs, and with the data collection from the speed sensors. Senstar Corporation and CDOT upgraded, modified, and expanded the system in the fall of 2010 (including a system change from Perimitrax® to OmniTrax®). The system did not detect large animals reliably, not before and not after system modifications. Despite the problems with system reliability and therefore unreliable warning signs, the researcher still summarized the carcass removal data (collected by CDOT personnel) and crash data (collected by Colorado highway patrol).

8.2. Methods

8.2.1. Carcass Removal Data

CDOT maintenance crews and Colorado State Patrol collected carcass removal and crash data along US Hwy 160. Search and reporting effort was characterized as incomplete, but consistent from 2006 onwards (Personal communication: Jeff Peterson, Colorado Department of Transportation). For the purposes of the current report only data between mile reference posts 83.9 and 103.1 (19.2 mile (30.9 km)) were included in the analyses. These data were from 1 January 2006 through 30 September 2011.

The species reported are listed in Table 8.1. Since the system was only designed to detect large animals the researchers only included records of "deer" (most likely all mule deer (*Odocoileus hemionus*) and elk in the analyses.

The researchers summarized the remaining records for the entire road section by year and by month. The data for 2011 were only through 30 September 2011. Therefore the researchers estimated the number of large animal carcasses for the remainder of 2011 based on the percentage of carcasses observed on average between January through September (64%) and between October through November (36%) in the previous years (2006 through 2010).

Table 8.2 provides an overview of the different treatment and control sections along Hwy 160 and the years relating to "before treatment", "during the implementation of the treatment", and "after having implemented the treatment".

Table 8.1: The species reported in the carcass removal database for Hwy 160 between mile reference posts 83.9 and 103.1 between 1 January 2006 through 30 September 2011.

Species	**N**	**%**
'Deer' (*Odocoileus spp.*)	674	92.58
'Skunk'	19	2.61
Elk (*Cervus canadensis*)	10	1.37
Raccoon (*Procyon lotor*)	6	0.82
Dog (*Canis lupus familiaris*)	4	0.55
'Cat' (*Felis catus*)	3	0.41
Coyote (*Canis latrans*)	3	0.41
Porcupine (*Erethizon dorsatum*)	3	0.41
'Rabbit'	2	0.27
'Squirrel'	2	0.27
Beaver (*Castor canadensis*)	1	0.14
'Fox'	1	0.14
Total	728	100.00

Table 8.2: The treatment and control sections along Hwy 160 and the years relating to "before treatment", "during the implementation of the treatment", and "after having implemented the treatment".

Low MP	**High MP**	**Treatment**	**Before**	**During**	**After**
94.75	94.99	System addition	Past - July 2010	Aug-Nov 2010	Dec 2010 - present
95.00	96.00	Original system	Past - summer 2008	Fall 2008	1 Jan 2009 - present
95.00	96.00	Modified system	Past - July 2010	Aug-Nov 2010	Dec 2010 - present
97.00	98.00	Vegetation clearing	Past-2006	2007	2008 - present
99.00	100.00	Control	N/A	N/A	N/A
83.90	93.00	Extended control (2 segments)	N/A	N/A	N/A
99.00	103.10				

8.2.2. Crash Data

Colorado Highway Patrol collected carcass removal and crash data along US Hwy 160. Search and reporting effort was characterized as incomplete, but consistent from 1999 onwards (Personal communication: Dave Reeves, Colorado Department of Transportation). For the purposes of the current report only data between mile reference posts 84.0 and 103.0 (19.0 mile (30.6 km)) were included in the analyses. These data were from 1 January 1999 through 31 December 2010.

The species reported are listed in Table 8.3. All reported species were large ungulate species or species similar to deer in size and/or body weight. Therefore all records were included in the analyses.

Table 8.3: The species reported in the crash database for Hwy 160 between mile reference posts 84.0 and 103.0 between 1 January 1999 through 31 December 2010.

Species	**N**	**%**
‘Deer’ (*Odocoileus* spp.)	501	89.46
Elk (*Cervus canadensis*)	10	1.79
Black bear (*Ursus americanus*)	1	0.18
‘Sheep’	1	0.18
Other	1	0.18
Unknown	46	8.21
Total	560	100.00

The researchers summarized the records for the entire road section by year. Table 8.2 provides an overview of the different treatment and control sections along Hwy 160 and the years relating to “before treatment”, “during the implementation of the treatment”, and “after having implemented the treatment”.

The researchers summarized the injury types of the people involved with wild animal crashes and distinguished between the driver (“driver 1”) and potential passengers (“driver 2”). This data summary was also provided per year.

8.3. Results

8.3.1. Carcass Removal Data

The number of reported large mammal carcasses was highly variable for the different years (between 64 and 167) (Figure 8.1). The treatment road sections (animal detection systems and vegetation clearing in the right-of-way) only related to relatively short road sections of about 1 mile (1,609 m) while the data relate to the entire road section of 19.2 mile (30.9 km). Therefore the relatively low (estimated) number of large mammal carcasses in 2011 is not likely related to the treatments but rather a reflection of changes in the population size of the large ungulates, or reduced search and reporting effort by road maintenance crews.

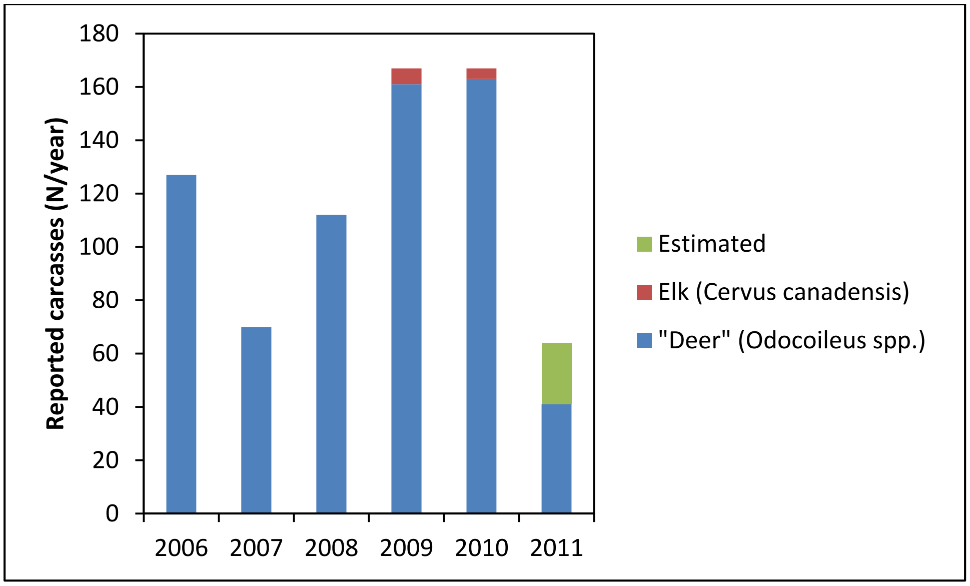

Figure 8.1: The number of reported large mammal per year between 2006 and 2011 for the road section along Hwy 160. Note that the 2011 data included an estimate for the carcasses for the months October through December.

The average number of reported large mammal carcasses was also highly variable for the different months (between 30 and 90) (Figure 8.2). Peaks (March and October-December) may relate to spring and fall migration of primarily mule deer.

The number of reported large mammal carcasses was highly variable between years for the different road segments both before and after "treatment" (Table 8.4). The high variability of the data combined with the limited number of years with available data do not show clear results of the potential effectiveness of the different treatments. The relatively low number of large mammal carcasses in 2011 occurs not only in the treatment segment (including the segment with the animal detection system), but also in the control and extended control segments. This suggests that the low numbers in 2011 are unlikely related to the treatments but they may be a reflection of changes in the population size of the large ungulates, or reduced search and reporting effort by road maintenance crews.

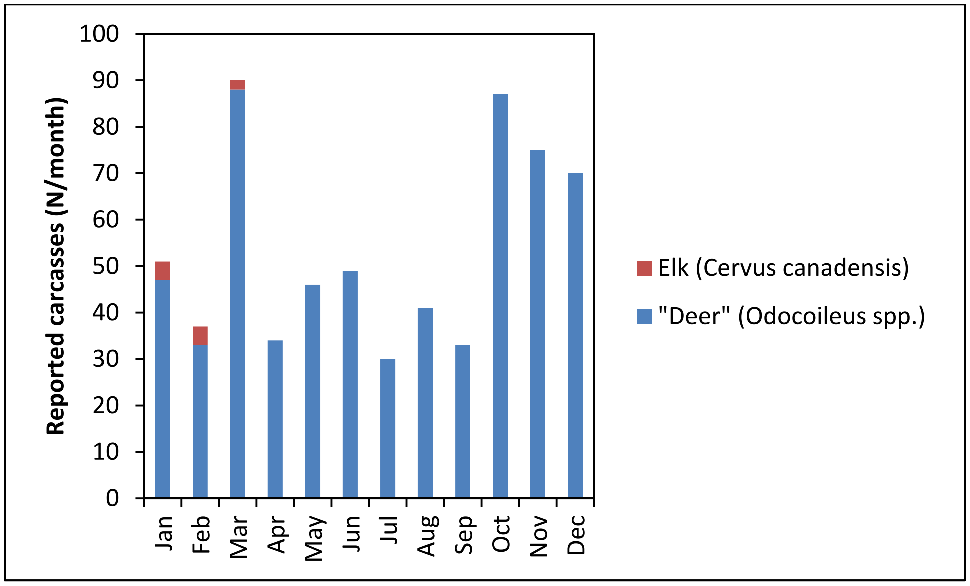

Figure 8.2: The number of reported large mammal per month between 2006 and 2010 for the road section along Hwy 160.

The number of reported large mammal carcasses was highly variable between years for the different road segments both before and after "treatment" (Table 8.4). The high variability of the data combined with the limited number of years with available data do not show clear results of the potential effectiveness of the different treatments. The average number of large mammal carcasses per year in the years before installation of the animal detection system (mile reference posts 95-96) was 9.0 whereas it was 15.0 after installation. The relatively low number of large mammal carcasses in 2011 occurs not only in the treatment segments (including the segment with the animal detection system), but also in the control and extended control segments. This suggests that the low numbers in 2011 are unlikely related to the treatments but they may be a reflection of changes in the population size of the large ungulates, or reduced search and reporting effort by road maintenance crews.

Table 8.4: The number of reported carcasses in the treatment and control sections along Hwy 160 and the years relating to “before treatment”, “during the implementation of the treatment”, and “after having implemented the treatment”.

Mile reference post	Treatment	2006	2007	2008	2009	2010	2011 (estimated)
94.75-94.99	System addition	4	0	1	0	0	0
95.00-96.00	System	14	4	10	19	20	6
97.00-98.00	Vegetation clearing	14	6	5	23	10	2
99.00-100.00	Control	17	3	3	15	18	6
83.90-93.00 and 99.00-103.10	Extended control	89	48	85	98	108	45

Green	Before treatment or N/A
Orange	During treatment
Red	After treatment

8.3.2. Crash Data

The number of reported crashes with wild animals was highly variable for the different years (between 22 and 72) (Figure 8.3). The treatment road sections (animal detection systems and vegetation clearing in the right-of-way) only related to relatively short road sections of about 1 mile (1,609 m) while the data relate to the entire road section of 19.0 mile (30.6 km). Therefore the relatively low (estimated) number of large mammal carcasses in 2008-2010 is not likely related to the treatments but rather a reflection of changes in the population size of the large ungulates, or reduced search and reporting effort by road maintenance crews. The percentage of crashes with wild animals of the total number of crashes (all crash causes combined) was 34.1% on average for the different years.

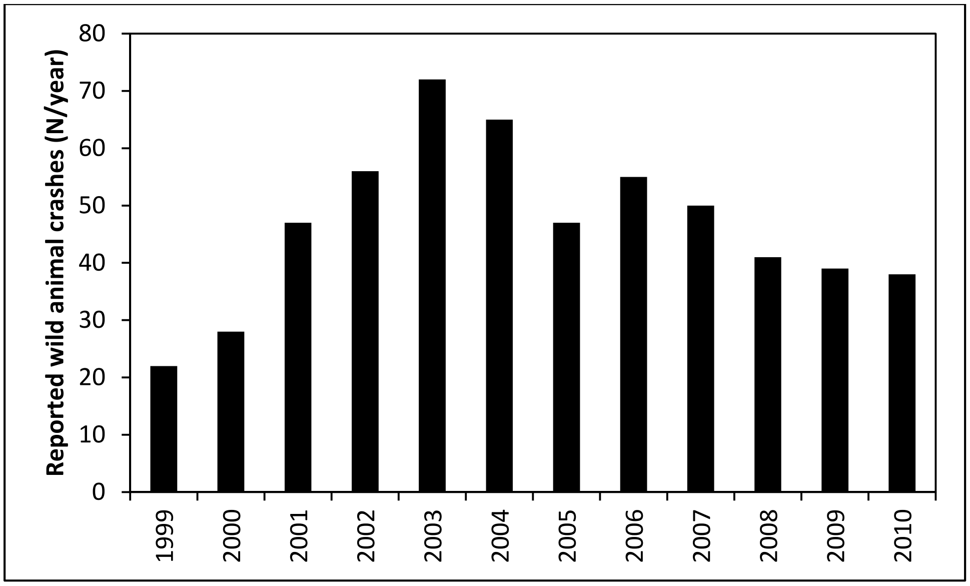

Figure 8.3: The number of reported large mammal per year between 1999 and 2010 for the road section along Hwy 160.

The number of reported crashes with wild animals was highly variable between years for the different road segments both before and after "treatment" (Table 8.5). The high variability of the data combined with the limited number of years with available data do not show clear results of the potential effectiveness of the different treatments. The average number of reported crashes with wild animals per year in the years before installation of the animal detection system (mile reference posts 95-96) was 5.3 whereas it was 3.0 after installation.

Table 8.5: The number of reported crashes with wild animals in the treatment and control sections along Hwy 160 per year.

Mile Reference Post	Treatment	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
94.75-94.99	System addition	0	1	4	1	6	2	2	3	0	1	0	1
95.00-96.00	System	5	2	4	8	5	7	2	8	7	2	4	2
97.00-98.00	Vegetation clearing	0	1	3	8	5	7	7	1	2	1	3	2
99.00-100.00	Control	4	4	5	6	3	6	8	7	2	1	2	2
83.90-93.00 and 99.00-103.10	Extended control	12	16	27	29	46	37	30	33	33	27	25	23

Before treatment or N/A
During treatment
After treatment

Most drivers involved with a wild animal crash sustained no injuries (Table 8.6 and 8.7). However, a limited number of complaints of injuries, non-incapacitating injuries and incapacitating injuries did occur. For passengers (“driver 2”) very few data were available: 6 records with “no injury” with all remaining records containing no data.

Table 8.6: The number and percentage of different injury types for drivers (“driver 1”) involved with wild animal crashes along Hwy 160 between 1999 and 2010.

Type of injury	**N**	**%**
No injury	507	90.54
Complaint of injury	21	3.75
Non-incapacitating injury	12	2.14
Incapacitating injury	3	0.54
No data	17	3.04
Total	560	100.00

Table 8.7: The number of different injury types for drivers (“driver 1”) involved with wild animal crashes along Hwy 160 per year.

Injury type (driver 1)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
No injury	20	24	43	50	56	60	45	51	47	38	37	36
Complaint of injury	1	2	1	5	1	5			2	2	1	1
Non-incapacitating injury	1	1	1	1	3			1	1	1	1	1
Incapacitating injury		1	1					1				
No data			1		12		2	2				
Total	22	28	47	56	72	65	47	55	50	41	39	38

The number and types of injuries before, during and after the installation of the animal detection system (mile reference posts 95-96) was summarized in Table 8.8. The average number of reported injuries per year (complaints of injury, non-incapacitating injury, and incapacitating injury) as a result of crashes with wild animals in the years before installation of the animal detection system (mile reference posts 95-96) was 0.33 whereas it was 0.00 after installation.

Table 8.8: The number of different injury types per year for drivers (“driver 1”) involved with wild animal crashes along Hwy 160 in the road segment with the animal detection system (mile reference post 95-96).

Injury type (driver 1)	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
No injury	4	2	4	8	4	4	2	7	7	1	4	2
Complaint of injury						1				1		
Non-incapacitating injury	1											
Incapacitating injury								1				
No data					1							
Total	5	2	4	8	5	5	2	8	7	2	4	2

Green	Before treatment
Orange	During treatment
Red	After treatment

8.4. Discussion and Conclusions

The high variability of the carcass removal data and crash data combined with the limited number of years for which data are available for (especially for the “after treatment” years) makes it difficult to draw conclusions about the potential effectiveness of the different treatments at this time. This also relates to the road segment where the animal detection system was installed in 2008 (mile reference post 95-96). Fewer large mammal carcasses in 2011 are not necessarily the result of an effective system as the number of large mammal carcasses was also substantially lower in the control zones.

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