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Implementation and Evaluation of a Buried Cable Animal Detection System and Deer Warning Sign

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Final Report VTRC 19-R28

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
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Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VCTIR 19-R28	2. Government Accession No.:	3. Recipient's Catalog No.:

4. Title and Subtitle: Implementation and Evaluation of a Buried Cable Roadside Animal Detection System and Deer Warning Sign	5. Report Date: May 2019 6. Performing Organization Code:
7. Author(s): Cristian Druta, Ph.D., and Andrew S. Alden, P.E.	8. Performing Organization Report No.: VTRC 19-R28
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903	10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 109863
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation, 1401 E. Broad Street, Richmond, VA 23219 Federal Highway Administration, 400 North 8th Street, Room 750, Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final Contract 14. Sponsoring Agency Code:

15. Supplementary Notes:
This is an SPR-B report.

16. Abstract:

Animal-vehicle collisions (AVC), and deer-vehicle collisions (DVC) in particular, are a major safety problem on Virginia roads. Mitigation measures such as improved fencing and location-specific driver alerts are being implemented and evaluated in Virginia and elsewhere. One of the most promising mitigation methods uses a buried cable animal detection system (BCADS) to provide roadside or in-vehicle warnings to approaching drivers based on the active presence of an animal on or near the roadway. BCADS may also be deployed in combination with exposure controls such as fencing to provide monitored, at-grade, animal crossing zones where conventional passages (e.g. culverts and bridges) are unavailable.

In this study, the Virginia Department of Transportation (VDOT) in collaboration with the Virginia Tech Transportation Institute (VTTI) implemented and monitored the performance of a BCADS on a public road to provide a real-world assessment of system capabilities and possible operation issues. The BCADS has proved effective and reliable in a previous evaluation performed under more controlled and secure conditions at the Virginia Smart Road facility in Blacksburg, VA.

A BCADS was installed on State Route 8 in the town of Christiansburg, VA on a road segment known to have a relatively high rate of DVCs. The system identified crossings of large- and medium-sized animals and provided data on their location along the length of the sensing cable. The BCADS and associated surveillance and communications equipment were powered by a solar photovoltaic system. A cellular modem provided for remote system monitoring and data collection. A flashing light "Deer Crossing" warning sign was installed at the site and was wirelessly linked with the BCADS to alert approaching drivers when an animal crossing was detected. Continuous BCADS and all-weather video surveillance data were collected during an 11-month period (November 2017–September 2018) to monitor animal movement, vehicle traffic, and system performance. Data on driver response to the activated warning sign during the dawn and dusk hours were collected in two separate daily sessions within a 3-month period.

Study findings indicate that the BCADS is capable of detecting larger animals such as deer, and sometimes smaller animals such as coyotes, with approximately 99% reliability. The system also performed well when covered by approximately 60 cm (2 ft.) of snow. Moreover, the system was tested under various vehicle traffic conditions, and rare instances of relatively minor interferences were observed. Vehicle speed and brake light application data collected during warning sign activation showed that approximately 80% of drivers either braked or slowed in response, indicating that the sign was effective.

17 Key Words: Animal detection system, buried cable detection system, deer-vehicle collisions, animal-vehicle collisions, deer crash mitigation	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.

19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 35	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

May 2019
VTRC 19-R28

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ABSTRACT

Animal-vehicle collisions (AVC), and deer-vehicle collisions (DVC) in particular, are a major safety problem on Virginia roads. Mitigation measures such as improved fencing and location-specific driver alerts are being implemented and evaluated in Virginia and elsewhere. One of the most promising mitigation methods uses a buried cable animal detection system (BCADS) to provide roadside or in-vehicle warnings to approaching drivers based on the active presence of an animal on or near the roadway. BCADS may also be deployed in combination with exposure controls such as fencing to provide monitored, at-grade, animal crossing zones where conventional passages (e.g. culverts and bridges) are unavailable.

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Study findings indicate that the BCADS is capable of detecting larger animals such as deer, and sometimes smaller animals such as coyotes, with approximately 99% reliability. The system also performed well when covered by approximately 60 cm (2 ft) of snow. Moreover, the system was tested under various vehicle traffic conditions, and rare instances of relatively minor interferences were observed. Vehicle speed and brake light application data collected during warning sign activation showed that approximately 80% of drivers either braked or slowed in response, indicating that the sign was effective.

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INTRODUCTION

Background and Statistical Data

Animal-vehicle collisions (AVCs) have a major impact on both wildlife and roadway safety. AVCs are associated with significant societal costs due to loss of lives and property damage and adversely affect wildlife populations. Environmental studies have shown that roads create disruptions in the natural movement of wildlife along with physical isolation due to loss of habitat connectivity, both of which lead to increased animal mortality and traffic hazards (Dodd et al., 2012; Hardy et al., 2007). Past research also indicates that more than 1 million deer-vehicle collisions (DVCs) occur in the United States annually, outnumbering collisions with bear, coyote, and other animals (Sullivan, 2011). These collisions and near-collisions have historically increased as deer populations and vehicle miles traveled increase, resulting in elevated risks to drivers, animals, and other road users (Donaldson, 2017). While nearly 10% of AVCs involving large animals result in human injury, DVCs account for over 70% of AVC-related human fatalities. As a result, states with high rates of DVCs are expected to conduct studies to evaluate these collisions and investigate mitigation strategies for locations with high likelihood of DVCs.

State Farm Insurance estimates that more than 60,000 DVCs occur in Virginia yearly, regularly placing the state among the 10 states with the highest number of DVCs (Donaldson, 2017). In some areas of the state, DVCs accounted for over 30% of reported collisions, requiring the Virginia Department of Transportation (VDOT) to spend millions of dollars per year for carcass removal and disposal. Further, these collisions are considered to be significantly under-reported due to the exclusion of accidents with less than $1,000 in property damage, unreported DVCs from drivers, and insufficient crash report details (Donaldson and Lafon, 2008). While location is recorded on police reports, the accuracy of this information is typically insufficient to inform any potential crash mitigation efforts.

AVC/DVC Mitigation Approaches

As the number of AVCs continue to rise due to increases in vehicle-miles-traveled and wildlife populations, many departments of transportation have sought out methods to reduce the frequency and severity of these incidents. The location of crashes is an important aspect of the mitigation process since the pattern of crashes should be strongly influenced by the known activity patterns of wildlife, and deer in particular, for a specific location. Approaches for DVC mitigation can be separated into two major categories: 1) methods aimed at modifying human driving behavior by installing various animal detection systems (ADSs) in concert with warning signs or posted reduced speed limits; and 2) methods intended to alter deer behavior and/or exposure by installing deterrents or barriers along roadways (Nichols et al., 2014).

In the last decade, numerous measures have been applied to mitigate the impacts of vehicle-wildlife interactions with varying degrees of success (Found and Boyce, 2011; Hedlund et al., 2004, Knapp et al., 2004). However, there remains a need for more conclusive information about the effectiveness of these methods (Huijser and McGowen, 2003). Typically, long-term monitoring and site evaluation are required to better understand how mitigation deployments affect AVCs and wildlife movements across roads. The evaluation of such deployments will help guide transportation agencies in future mitigation efforts that will benefit both wildlife and motorists.

Past research has shown that fencing, combined with overpasses and underpasses, along with various warning and deterrence systems, such as flashing signs and electronic deterrents, reduced DVCs by at least 80% more than other methods (Clevenger and Huijser, 2009; Curtis and Hedlund, 2005; Sudharsan et al., 2009; Sullivan, 2011). Other studies have found that a combination of ADSs and warning signs can also reduce DVCs substantially (Dai et al., 2008; Huijser et al., 2009; MnDOT, 2011). The goal of these systems is to prevent or reduce AVCs/DVCs by detecting animals before they enter the road and then warning drivers that an animal is on or near the road at that particular time. When presented with these warnings, drivers are expected to reduce their speed and become more attentive to potential wildlife crossings. Several studies indicate that AVCs were reduced by between 80% and 90% when warning systems were installed by the roadside (Dodd and Gagnon, 2008; Meyer, 2006). The success of these warning systems was attributed to a reduction in driver speed and increased stopping distance (Huijser and McGowen, 2003; Huijser et al., 2006; Khalilikhah and Heaslip, 2017).

In order to reduce the number of AVCs, detection systems must reliably detect animals, and warning signs must be able to influence driver behavior so that drivers can avoid potential collisions. Typically, ADSs are designed to detect large animals such as deer, elk and/or moose as they approach the road; however, some systems, especially aboveground systems, exhibit variations in reliability that lead to false detections (Huijser et al., 2006). Buried sensors appear to be more reliable under various weather and traffic conditions if they are properly installed and calibrated. Buried sensors also have minimal impacts on wildlife habitat and migration patterns (Druta and Alden, 2015). While costs to implement AVC mitigation strategies are a primary prohibitive factor, cost/benefit analyses have demonstrated that the savings in property damage and other associated costs can easily outweigh the costs of the countermeasures (Donaldson et al., 2016).

PURPOSE AND SCOPE

The purpose of this study was to implement and evaluate an OmniTrax® buried cable sensor system to determine its ability to detect deer and potentially other animals in real-world conditions. The evaluation was conducted on State Route 8 in the Montgomery County, Virginia, where a section of the road was marked with “deer crossing” signs by VDOT. In addition, a flashing sign displaying “Deer Crossing” was installed near the BCADS site to warn drivers of the potential presence of deer in the area. The buried cable animal detection system was installed at the proposed location and monitored continually for 11 months.

This study was a continuation of a previous work with the Virginia Transportation Research Council (VTRC) when a similar sensing cable was successfully installed and evaluated in a controlled environment on the Virginia Smart Road.

METHODS

The following tasks were conducted to achieve the study objectives:

1. Select a sensing cable system suitable for the proposed animal detection application.
2. Select a specific site with known DVC occurrences and animal crossings.
3. Conduct detection system installation and calibration including power and data transmission options.
4. Conduct warning sign installation and testing procedure to establish communication between buried cable and sign.
5. Conduct system calibration and testing for data collection, validation and accuracy and assess system performance.

System Selection and Characteristics

A cable sensor with similar characteristics to the sensor installed at the Virginia Smart Roads was selected by Virginia Tech Transportation Institute (VTTI) researchers in consultation with VTRC environmental staff and VDOT’s Traffic Engineering division. The cable sensor was selected based on its previously demonstrated reliability, detection capabilities, and ability to meet all the testing criteria of this study (e.g., required single trench and varying cable spacing).

Based on the space permitted for this installation, a 30-cm (12-in) cable spacing was selected to strengthen the detection field and avoid subsequent adjustments of the detection threshold. This also helped with assessing the potential effects of traffic on BCADS reliability.

Figure 1 shows the transmit (TX) cable, which distributes radio frequency signals along the cable path, and the receive (RX) cable, which receives the signals and returns them to the processor.

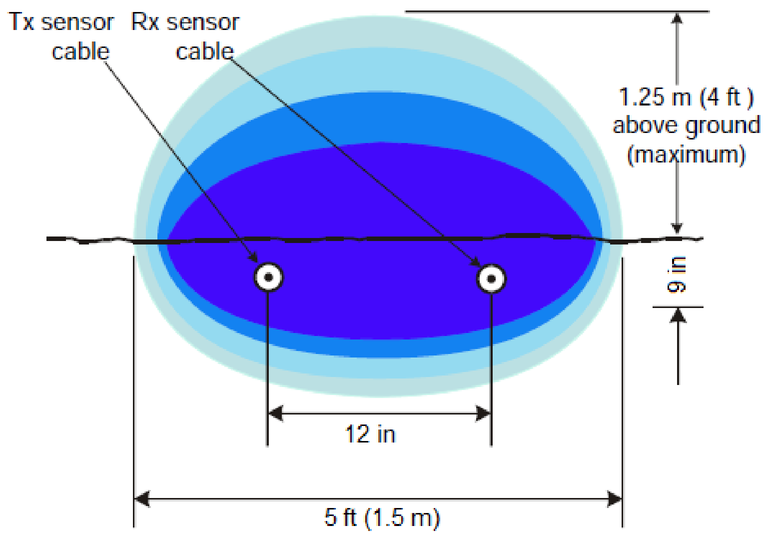

Figure 1. Schematics of the BCADS Showing Cable Spacing along with Detection Field Width and Height. BCADS = buried cable animal detection system.

The radio frequency signals form an invisible electromagnetic detection field around the sensor cables that can detect and locate an animal passing through the field. The processor then triggers an alarm based on animal presence. The system can detect animals or intruders weighing over 32 kg (70 lb) when installed and calibrated according to the manufacturer's directions (Senstar, 2013).

Site Surveying and Selection

Prior to BCADS installation, a site survey was conducted by VTTI researchers to assess existing conditions and to determine the specific installation requirements, including the perimeter length, zone layouts, sensor cable route, cable spacing, and the locations for the system's components. The survey covered aspects regarding possible aboveground and underground obstacles (e.g., pipes, electrical conduits, and cables), soil characteristics, moving objects, paths, access roads, utility vaults, drainage ditches, and other relevant issues.

Two locations were selected on Riner Road: one near Varsity Lane (Figure 2) and one near Life Drive (Figure 3). These locations were monitored for deer activity for three months (October to December 2017). Data were collected using trail cameras installed along the road to identify potential areas where animals might migrate or cross frequently. Video surveillance of the two locations showed deer to be the only animals crossing and/or stopping to graze or search for food on multiple occasions in areas near the road. The analysis of the acquired video data indicated that the site near Varsity Lane was trafficked by more deer (36) than the Life Drive site (11). Therefore, VTTI researchers decided to install the cable sensor at the Varsity Lane location. This location also had the advantage of being bordered by heavy woods and traversed by a creek, features that are attractive to deer as they offer protection and access to water, respectively.

Figure 2. **Test Site at Riner Rd. and Varsity Ln. (Driveway) Selected for Cable Installation.**

Another advantage of the selected site is that the posted speed limit is 16 kph (10 mph) higher than the Life Drive section (88 km/h (55 mph) vs. 72 km/h (45mph)). This higher speed provides a better opportunity to investigate changes in driver behavior when presented with the Deer Crossing flashing sign.

Figure 3. **View of the Alternate Test site at Riner Rd. and Life Dr. Looking Northward along State Route 8.**

Site Installations and Operation

BCADS Sensor Cable Installation

Once the installation area was selected, the cable path was marked to allow for trenching and cable placement. Considering the moderate traffic level of the selected road segment and the manufacturer's specifications regarding soil type (the selected area has dense clayey/rocky soil), VTTI researchers decided to install the sensing cables approximately 5 m (15 ft) away from the pavement edge (6.5 m or 20 ft is recommended for sandy/loamy soils). The lower-limit distance to the road edge provided the opportunity to evaluate how the BCADS reliability was affected by passing vehicles and water runoff from heavy rains. Installation farther away from the road's edge may have created nuisance alarms due to the presence of power and communication cables located farther from the road.

Figure 4 shows an aerial picture of the selected installation area and the detection zones along the cable. The orange line represents the location of the cables. Two OmniTrax® BCADS sensor cables were installed approximately 125 m (375 ft) along a route originating near the Processor Box, crossing the Varsity Lane driveway, and terminating approximately 1m (3 ft) short of the drainage feature as shown in Figure 4. The BCADS was configured with "A" and "B" sensing zones in the system software to allow separate monitoring of the driveway for evaluation of vehicle crossing effects. The detection sensitivity and alerting threshold were configured similarly for both zones.

Figure 4. **Plan View of the Test Site Showing the Location of the BCADS Installation and Respective Detection Zones. BCADS = buried cable animal detection system.**

The cables were installed 30 cm (12 in) apart, and parallel, on the bottom of a trench with a width of 33 cm (13 in) and depth of 28 cm (11 in). As in the previous installation at the Virginia Smart Roads, before laying the cables in the trench, a 5 cm (2 in) layer of crushed stone was used as bedding, per the manufacturer's recommendation. The cables were then placed on top of the aggregate layer at a depth of approximately 23 cm (9 in) with marker tape positioned over them (Figure 5) to prevent cable damage during potential excavating activities. Once the cables were aligned and spaced, they were covered with native soil that was subsequently compacted to the required density (Figure 6).

Figure 5. **Trench Being Backfilled After Cables were Placed on the Crushed Stone Base.**

Figure 6. **Trench Covered with Compacted Native Soil.**

The trench was widened at the south end to house the lead-in cables that connect to the BCADS processor (Figure 7). The cables were installed with some overlap in this area to ensure uniform sensing along the entire length of the cables (Senstar, 2013). Detection field strength and alerting threshold were verified at different spots near the cable terminations before deciding upon the final location of the processor. This procedure was required to identify potential crosstalk (i.e., mutual signal interference) with existing Verizon phone cables and the switch telecom box (Figure 7, upper right corner) near the end of the cable terminals. Interference from the communication cables may trigger occasional false alarms, affecting the performance of the cable.

Figure 7. Lead-in Cables That Connect to the Processor Enclosure.

Telecom Enclosure and Processor Installation

The telecom enclosure housing the processor box was mounted approximately 1 m (3 ft) away from the overlapping cable area. This allowed the cable terminals to properly connect to the processor connectors so that the detection field could reach full strength at the starting point. Typically, the system's field detection starts approximately 1.5 m (5 ft) away from the processor to prevent interference with communication or other devices (e.g., cellular modems and external hard drives) installed in the telecom enclosure.

The processor box was installed 60 cm (2 ft) aboveground to prevent the cable connectors from coming into contact with surface water. (Figure 8). This type of enclosure is typically used for outdoor installations to provide additional security and protect the electronics from the elements.

Figure 8. Weatherproof Processor Box Mounted Inside the Telecom Enclosure (*Left, Cover Removed*) and Processor Board Installed Inside the Weatherproof Box (*Right*).

Before calibration, the manufacturer defined the alarm zones in the processor software so that different zone thresholds could be fine-tuned separately if necessary. The processor operates on a 12–48 VDC range (10 W) power supply and can communicate alarms via dry contact closure or a fiber optics or wireless/cellular interface. The BCADS was powered by a solar photovoltaic (PV) system installed 10 m (30 ft) away from the processor box (Figure 9).

Figure 9. Solar Photo-voltaic System Supplying Power to the Buried Cable and Surveillance Equipment.

The solar power system included two absorbent glass mat batteries and a charge controller to maintain battery charge. Additional equipment, including a surveillance camera, mini-computer (for remote access to the system), external hard drive (for data collection), and cellular modem (for wireless data transfer and real-time access for BCADS surveillance) were also powered by the PV system.

BCADS Calibration and Parameter Setup

To calibrate the BCADS, a setup of the initial configuration parameters, including network type, device type, and communication protocol (IP) address, was required, followed by a sensitivity profile procedure. This information is usually collected automatically by the sensor software using input form the operator. In addition, depending on the site conditions, a fine tune of the BCADS can be performed by adjusting the processor's configuration parameters. System calibration was performed by the manufacturer's representative once the cables were laid in the trench and backfill soil was compacted to the required density in accordance with VDOT specifications. The detection threshold was selected to be 70 dB for the entire cable length, taking into account the traffic level for the chosen road segment. Specific information of the calibration and parameter setup of the detection system can be found in Druta and Alden (2015).

BCADS Wireless Communication

An online connection to the BCADS was established via a cellular modem to allow operation and monitoring of the system from a remote PC. The wireless connection enabled continuous access to the detection system and surveillance camera to monitor the cable alarms and perform detection adjustments as needed via a configuration module (CM) program (Figure 10).

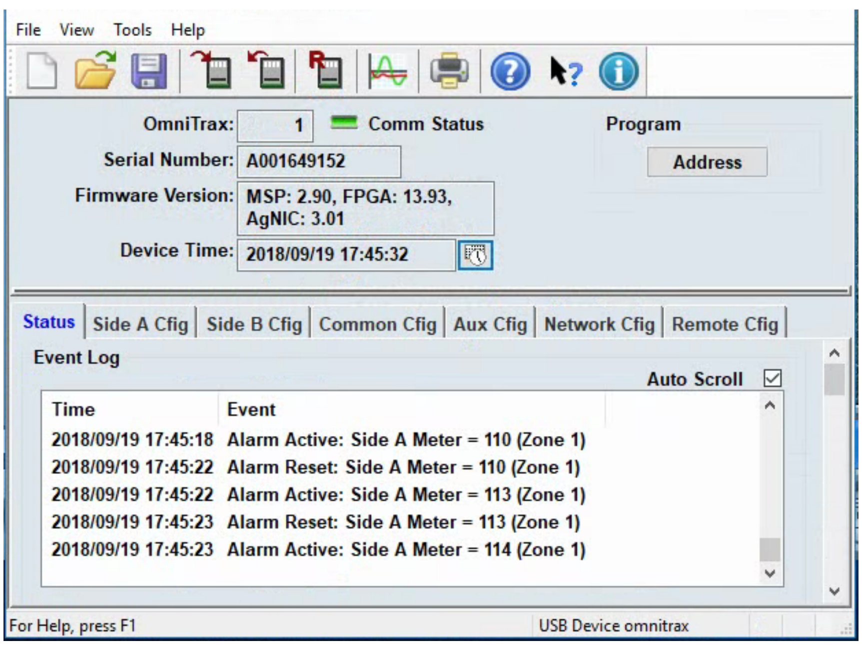

Figure 10. Real-time Detection System Alarm Monitoring Showing the Cable Status, Time Stamp, and Event Log Via a CM Control Window.

The CM also enabled researchers to determine if power outages or signal interruptions occurred so that troubleshooting could be performed promptly. Generally, regular and timely data entry and/or data quality checks are essential to correct errors, retrieve missing data (by checking alarm history), and verify any unusual data. The CM control window allowed for further system configuration (e.g., node synchronization, network interface selection, and cable side selection) and access to the alarm history file. The program module could be queried to retrieve and save old event history files for future reference. Additionally, a separate response plot window allowed for the real-time monitoring of cable activity and continuous collection of signal data on a daily basis (Figure 11). The plots offered details about the time and date of cable signal monitoring along with the crossing location, threshold at that specific location, and magnitude of the signal (dB).

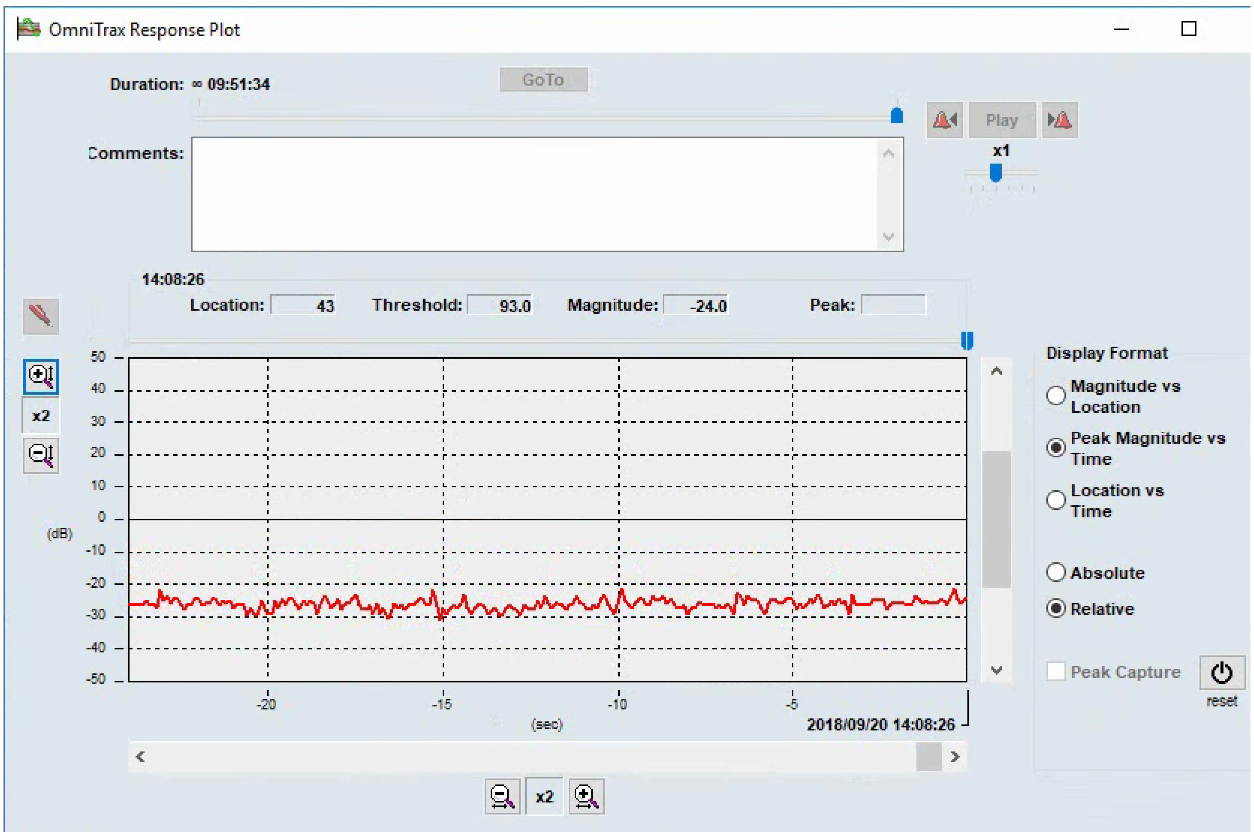

Figure 11. Example Cable Response Plot Used to Identify Real-time Cable Crossing Events. This Signal Response Indicates No Crossing.

Video Surveillance

An infrared surveillance camera and a near-infrared illuminator covering distances ranging from 25 m (75 ft) to 100 m (300 ft) were installed near the processor enclosure to monitor side A of the cable toward the Victory Lane driveway (Figure 12). The camera recorded five-minute video clips and automatically adjusted for day/night recording, defogging, and wide dynamic range sensing for enhanced exposure control. Prior to their on-site installation for continuous data acquisition (video and animal crossing detection), the camera and illuminator were tested to assess their capabilities in different weather and natural light conditions, including nighttime monitoring. The camera and illuminator were powered continually by the solar PV system.

Figure 12. Surveillance Camera (*Top*) and Illuminator Used for Cable/Site Monitoring. The Solar Power System (*Far Right*) and Processor Enclosure (*in the Background*) are also Shown.

A performance verification of the camera recordings and cable signal response program was conducted through continuous data collection and transfer to a storage unit (i.e., an external hard drive) connected to a mini computer in the telecom enclosure. Researchers tested both devices by performing multiple crosses on foot and by driving a vehicle across the buried sensor cables at different locations to ensure that field detection was adequate and synchronous with the camera software.

Warning Sign Installation

A 90 cm × 90 cm (36 in × 36 in) diamond-shaped flashing deer warning sign was installed approximately 200 m (600 ft) from the processor box on the same side of the road as the BCADS (Figure 13). The sign complied with VDOT requirements for temporary signage and was approved by VDOT's Traffic Operations division. The warning sign was operational continuously and inspected weekly to ensure accurate activation upon alarm triggering along with proper power/communication status. The edges of the sign contained eight yellow light-emitting diode (LED) bulbs powered by a 12-V battery. A small solar photo-voltaic panel (15 W) was installed on top of the sign and connected to the battery for continuous charging. A transceiver was also installed inside the sign for long-range (500 m or 1,500 ft) wireless communication with the cable processor.

Figure 13. Deer Warning Sign with Flashing LEDs Installed on Riner Rd. Wireless Transceiver Shown at Bottom Right. LED = light emitting diode.

The wireless transceiver unit communicated with a paired transceiver located in the telecom box and wired to the BCADS' dry contact closure alert relay (Figure 8, left). The system was configured so that closure of the alerting relay would result in transmission of a wireless activation signal to the warning sign. Remote activation of the warning sign was set to flash the LEDs for 30 sec. The warning sign was angled slightly (~5 deg.) toward the road to properly project the LEDs toward oncoming traffic. When the BCADS declared multiple consecutive alarms, the sign flashed continually until 30 seconds passed after the last alarm.

Data Collection and Cable Performance Validation

Data Collection Methodology

To properly collect data, both the CM program and the camera software were synchronized with respect to date and time. Separate monthly folders were created to store the video and alarm recording files for subsequent analysis. The cable configuration (mainly the crossing speed and response margins) was tuned during the first two months of monitoring to improve detection and compensate for environmental effects (e.g., rain and soil subsidence). Periodic cable centerline walks were conducted to ensure that all cable zones provided adequate signal response magnitudes.

Alarm Data Evaluation Method

Data from declared alarms collected using the cable's proprietary software and recorded videos were analyzed to ensure that the system was detecting valid animal, human, and vehicle crossings and not providing false negatives and/or false positives. As a first step in evaluating the acquired data, the event log box of declared alarms (or alarm history file) and the response plots (Figure 11) for the respective day or time range were reviewed to ensure adequate correlation between the two programs (Figure 14).

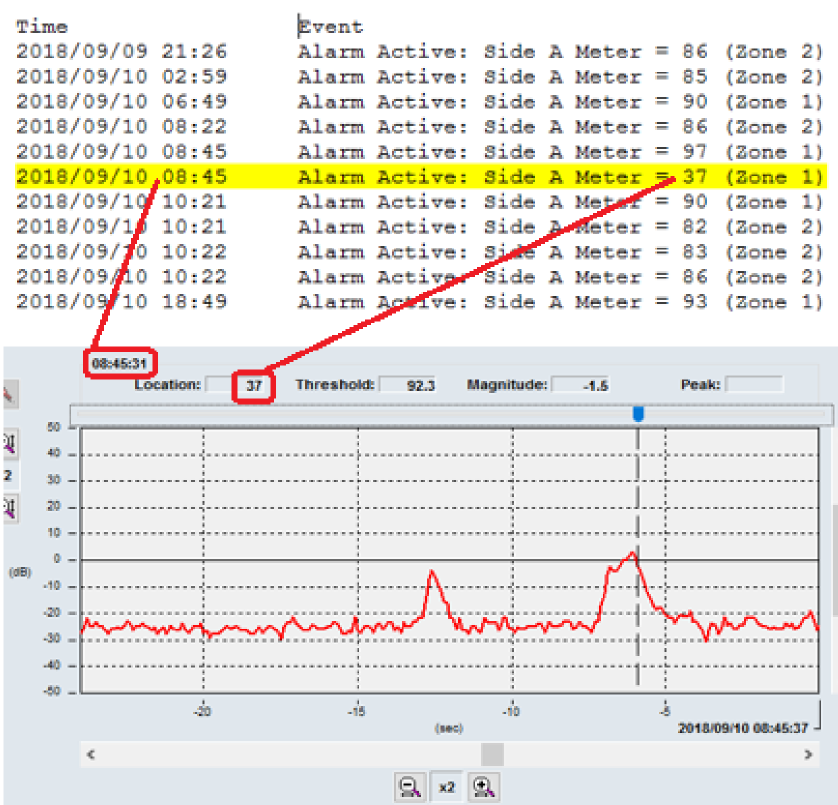

Figure 14. List of Cable System Alarms from the Event Log History File (*Top*) and Cable Response Plot (*Bottom*). Signals Exceeding the 0-dB Threshold Indicate Valid Crossings and Declared Alarms in the Event Log box.

After correlation was verified, the team reviewed the recorded video file with the corresponding date and time to ensure that an animal or other object was present at that specific location. Finally, if an animal/object was present at the recorded date, time, and location on the cable and crossed or was inside the detection field, the declared alarm was considered a "valid detection."

Single or multiple recorded alarms at specific dates, times, and locations on the cable declared by the same or a different target were considered valid detections on the condition that the target crossed or walked through the detection field. In certain situations, when two or more deer crossed the cable simultaneously or within a five-second period, the targets merged and were reported as one, therefore triggering a single alarm.

Figure 15. Example of Valid Animal Detection Event Showing Event Date and Time Corresponding to the Declared Alarm in the Event Log Pane (Figure 14).

As the detection field was approximately 1.5 m (5 ft) wide, any target within 60 cm (2 ft) of its centerline triggered an alarm when the cable was properly calibrated. Targets are detected based on their electrical conductivity, size, and movement (i.e., speed), and the detection probability generally improves with increasing size. Any target weighing less than approximately 14 kg (30 lb) does not trigger an alarm, although a target of that size may disturb the electromagnetic field of the cable and create a small signal response. For situations where various zones of the detection cables pose different threat levels, separate sensitivity thresholds can be set on a per-meter of cable basis. It should be noted that in some situations, animals or vehicles were near the cable sensor but did not trigger any alarms because they neither crossed nor entered the detection field.

In contrast, a "false negative" event occurs when a target crosses over the cable or is inside the detection zone and an alarm is not declared. This event can take place when:

- the detection margin is set too low (12 dB was the default for this BCADS)
- the target speed setting is not tuned for very slow- or fast-moving intruders
- the weight of the target is below approximately 30 lb.

Although no alarms are declared when false negatives occur, the response plots typically record all activity near the cable if programed in the software. Thus, based on the video files and cable responses, adjustments can be made in the software so that this type of event may be avoided.

In a similar manner, a "false positive" event is defined as when the cable system declares an alarm without any animal or target crossing the cable or being close to its centerline. In this case, the CM plot displays a signal peak or multiple peaks, depending on the type of nuisance crossing into the detection zone (i.e., above the 0-dB line), and a corresponding alarm(s) appears in the event log pane. Typically, false positives are triggered by a high level of water flow on sloped terrain (e.g., after a heavy rain) on areas of less compacted soil or where depressions have been created by stationary vehicles or heavy equipment. These alarms can be prevented by adjusting the cable margin values in the software.

Response plot data can be accessed and viewed offline by saving files as necessary. The scroll bar (Figure 14, bottom) can be used to jump from one location to another (on the x-axis) to review the selected event data.

RESULTS

System Operation and Data Analysis

Detection Threshold Adjustments

Cable response plots, declared alarms, and video were collected continuously for 11 months starting in November 2017 and ending in September 2018. Minor tuning was performed on the cable system in the first month to compensate for loose soil and power issues; the detection threshold was increased from an initial value of 12 dB to 13.5 dB and kept at this level until the end of December 2017. Concurrently, the speed setting was set to the intermediate position in the speed range adjustment cursor to balance crossings that occurred at slow or fast speeds. When the processor detected a target with a signal within the set threshold value of the recorded sensitivity profile, an alarm was declared. In this study, only events when animal(s) were crossing or were within the detection field were considered as one of the three possible previously-described scenarios: valid detection, false negative, or false positive. Vehicles or humans that crossed and declared alarms were not considered in the analysis, even though they all triggered alarms.

Data Analysis

Cable Reliability

A detection log containing the most relevant variables (e.g., animal type, valid detection, and crossing time) was created to evaluate cable performance and updated regularly for all events of interest (e.g., declared alarm, animal/vehicle crossing, and traffic) during the cable-monitoring period. A video recording of side A of the cable was verified each time an alarm was declared to determine which declared alarms were false positives and that animal crossings did not yield false negatives.

Reliability, or system performance, was defined as the capability of the BCADS to provide an adequate number of valid detections after being properly installed and calibrated. Table 1 presents the data collected and used to perform a reliability analysis of the cable. Over 96% of the monthly data were related to white-tailed deer activity in the area, followed by coyote (approximately 4%). No bear or fox activity was observed during the 11 months of data collection. Reliability (R) percentage was calculated using the following equation:

$$R = N_{\mathrm{VD}} / N_{\mathrm{RE}} = N_{\mathrm{VD}} / (N_{\mathrm{VD}} + N_{\mathrm{FN}} + N_{\mathrm{FP}})\ (\%)$$

where

N_{VD} is the total number of valid detections (for the respective period)

N_{RE} is the total number of recorded events that occurred during the respective monitoring period

N_{FN} is the total number of false negative events

N_{FP} is the total number of false positive events. N_{FP} was considered to be zero due to a temporary issue with the cable detection, which was subsequently resolved.

As shown in Table 1, the number of valid detections was much higher than the number of animals detected due to the fact that one particular animal triggered multiple alarms when it crossed multiple times or walked or ran along the cable length. White-tailed deer accounted for almost all of the animal activity; the only non-deer crossings observed were four coyote crossings. The false negatives were attributed to fawns, which are lighter than adult white-tailed deer which may weigh between 45 kg (100 lb) and 68 kg (150 lb).

The false positives recorded by the BCADS were not taken into consideration when calculating reliability. They were considered a temporary issue related to interference from construction equipment being driven or parked near the system during paving activities. Infrequent false positives were declared in the CM software by parked vehicles only when regular maintenance work was performed on the power lines in the area.

Table 1. Recorded Animal Detection Events Used to Evaluate System Reliability

Month	Total # of Animals		Valid Detections	False Negatives	False Positives	Hours Analyzed	Reliability R (%)
	Deer	Coyote					
Nov[1]	3	0	3	0	0	336	100 @ 13.5 dB
Dec	26	0	136	0	0	660	100 @ 13.5 dB
Jan	8	0	71	0	0	672	100 @ 12 dB
Feb	14	0	26	0	0	744	100 @ 12 dB
Mar	5	0	38	0	0	720	100 @ 12 dB
Apr	10	0	80	0	0	700	100 @ 12 dB
May	14	0	52	0	3	744	95 @ 12 dB
Jun	34	3	90	2	12	720	98 @ 12 dB
Jul	33	0	83	1	0	744	100 @ 12 dB
Aug	8	1	24	0	0	720	100 @ 12 dB
Sep	17	0	50	0	0	720	100 @ 12 dB
Total	172	4	682	3	0	7480	99.4

[1]Fewer hours were analyzed in November 2017 due to the late installation of the solar PV system and issues related to construction approval by the county. Some video data were not available during other months due to computer-related problems.

The data collected also provided information on the trafficked cable zones during the course of the project (Table 2). The data in the table for the entire monitoring period indicate that both the first and the second portions of Zone 1 were almost equally crossed by deer, whereas the gravel driveway (Zone 2) was much less preferred for crossing. Similar behavior was noted on the Virginia Smart Roads at VTTI and reported in Huijser et al. (2008), where deer elected to cross grassy areas more than access roads. In some instances, the deer preferred to walk along the cable from the second Zone 1 toward the first Zone 1 and then cross the roadway in that area or eventually head toward the woods without crossing.

Table 2. Animal Crossings by Cable Zone

1st Zone 1 (5 to 80 m)	Zone 2 (81 to 86 m)	2nd Zone 1 (87 to 120 m)
86	12	78

Table 3 lists the time of day that animals crossed the cable during the monitoring period. The time from 18:00 to 21:00 corresponds to dusk/evening and the time from midnight to 06:00 to 09:00 corresponds to dawn. These were expected to be the time periods with the most animal crossings (Sullivan, 2011). The alarm data indicated that most deer crossed over the cable during the midnight-to-predawn interval (70%). The lowest number of crossings were recorded during dusk (7%), whereas slightly higher numbers were recorded for dawn (10.5%) and 21:00-to-midnight (12%). These particular time ranges are generally aligned with the time of day that deer and coyotes emerge from the woods to graze or search for prey, respectively. However, increased traffic level due to daily commutes might have affected the deer activity in the time intervals with few crossings. Increased traffic noise and motion may have deterred deer from crossing the roadway. The video data also indicate that traffic levels decreased significantly after 22:00, and even fewer vehicles traveled the road after midnight.

Table 3. Animal Detection Events by Time of the Day

Month	18:00 to 21:00	21:00 to 00:00	00:00 to 06:00	06:00 to 09:00
Nov	2	1	0	0
Dec	3	8	13	2
Jan	0	1	7	0
Feb	1	2	11	0
Mar	0	1	4	0
Apr	1	2	7	1
May	0	3	9	2
Jun	3	2	27	2
Jul	2	3	25	3
Aug	0	2	7	1
Sep	1	1	14	1
Total	13	26	124	12

Warning Sign Operation

Warning sign activation was verified multiple times by VTTI researchers performing various crossings on foot or in a vehicle. The sign flashed for each crossing, regardless of location or speed, indicated 100% reliability. However, the flashing warning affected drivers' speeds differently during dawn/daylight compared to at dusk/nighttime. The speed data indicate that drivers tended to brake or slow more during the dusk-dawn interval, when the flashing LEDs were visible at distances greater than 25 m (75 ft), compared to in daytime, when the flashing LEDs were clearly observable at approximately 8 m (25 ft). Figure 16 shows the warning sign while activated during the day (at 8 m, 26 ft) and at night (at 25 m, 82 ft).

Figure 16. Warning Sign Flashing During the Day (LEDs Appear as White Dots) and at Night. LED = light emitting diode.

Vertical Interference

Generally, there was no interference from traffic during the study, regardless of vehicle size or lane wandering. The CM event log box and plot response program did not record any alarms related to the 0-dB reference line in the plot window. However, in some cases, an oversized vehicle crossed the edge line and entered the detection field, especially near the processor box where the field is wider, resulting in a regular target detection (Figure 17). In these cases, the magnitude of the signal response depends on the vehicle's distance from the center of the detection field. The cable response window (inset in the bottom left of Figure 17) shows a gradual increase in signal toward the control box as the vehicle wandered in the lane. Intersection of the red line with the continuous middle axis indicates a triggered alarm.

Figure 17. **BCADS Interference Occurred at Various Locations along the Cable System Due to Encroachment of Oversized Vehicles into the Sensing Area. BCADS = Buried cable animal detection system.**

Water Effect

On a few occasions, water flow during long periods of heavy rain caused nuisance alarms near the control box or where the slope accommodated larger flows, as shown in Figure 18. Adequate drainage near the cable area and avoiding sloped terrain when installing the cable should prevent such problems. These alarms can also be avoided if the field sensitivity of the specific location can be diminished by adjusting the cable supervision mode in the cable configuration software.

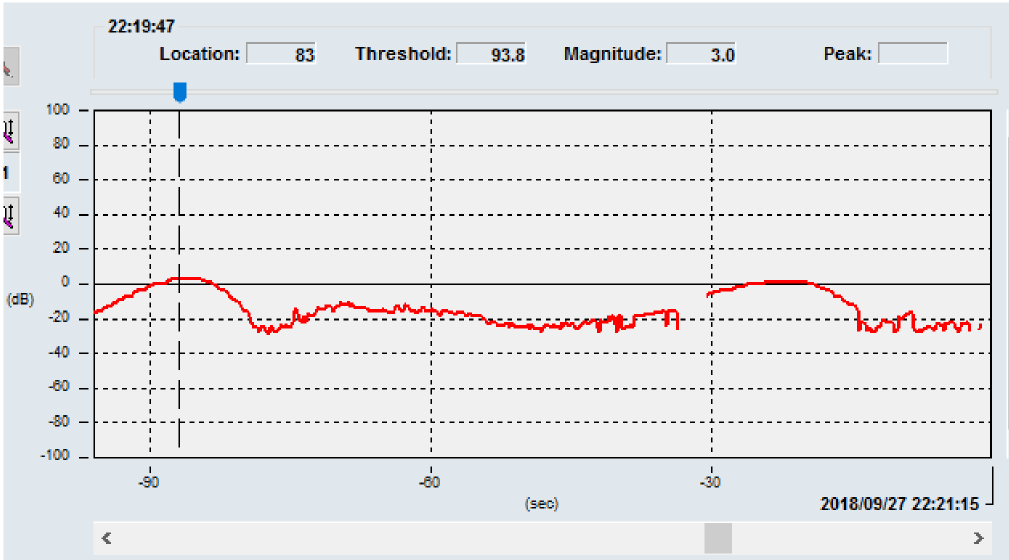

Figure 18. **Detection Cable Response Due to Water Flow near the Driveway. The Location Field Shows Meter 83 For This Event; A Second Event Occurred Later Near the Control Box.**

Snowfall Effect

The threshold was not adjusted to compensate for any adverse snow effects, and system performance showed that snow coverage of the cable as deep as 60 cm (2 ft) did not affect its detection field. In addition, no false positives or other events occurred during or after the snowfall. After being covered by snow, several cable crossings were performed by a researcher to further verify its detection capabilities in such conditions (Figure 19). Crossings were executed at different speeds every 6.5 m (20 ft). Cable responses (i.e., signal magnitudes in dB) similar to those recorded before the cable was covered by snow were recorded during tests of both human and vehicle crossings. Furthermore, no false positives or nuisance alarms were triggered by the melting snow.

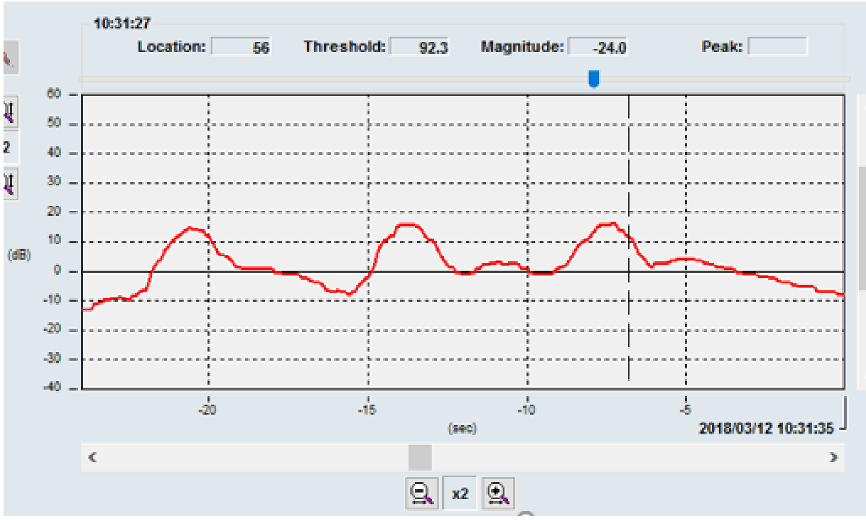

Figure 19. **Detection Cable Response When Crossings were Performed After Snowfall.**

Effects of the Warning Sign on Drivers

After sign installation, vehicle speed data were collected in a total of six sessions at dusk and dawn within three 24-hour periods in June, July, and August (Figure 20). In each session, speeds were measured using a portable radar gun for 30 vehicles as they approached the flashing warning sign while researchers noted their responses (i.e., if the driver braked or slowed during sign flashing). Sessions were also conducted for 30 vehicles when the sign was not flashing (NF) to compare vehicle speed levels between the activated flashing (F) sign vs. the NF sign. The sign was activated by manually closing the relay alarm-triggering circuit on the processor board. Under this scenario, the sign flashed for 30 seconds followed by a five-second pause in a continuous loop when triggered by a single crossing.

Attempts were made to match deer crossing-triggering BCADS alarms to driver behavior using a trail camera while the warning sign was active; however, only one match was made during nighttime in June. The lack of matches is primarily explained by: (1) the small number of deer crossings per day combined with (2) a limited number of vehicles traveling through the BCADS area at the same time of a deer crossing. On a few occasions, the system memory overload occurred before capturing relevant data, especially during the night. To address this issue, VTTI researchers decided to use a surrogate method in which the flashing LEDs were electronically triggered for predetermined periods.

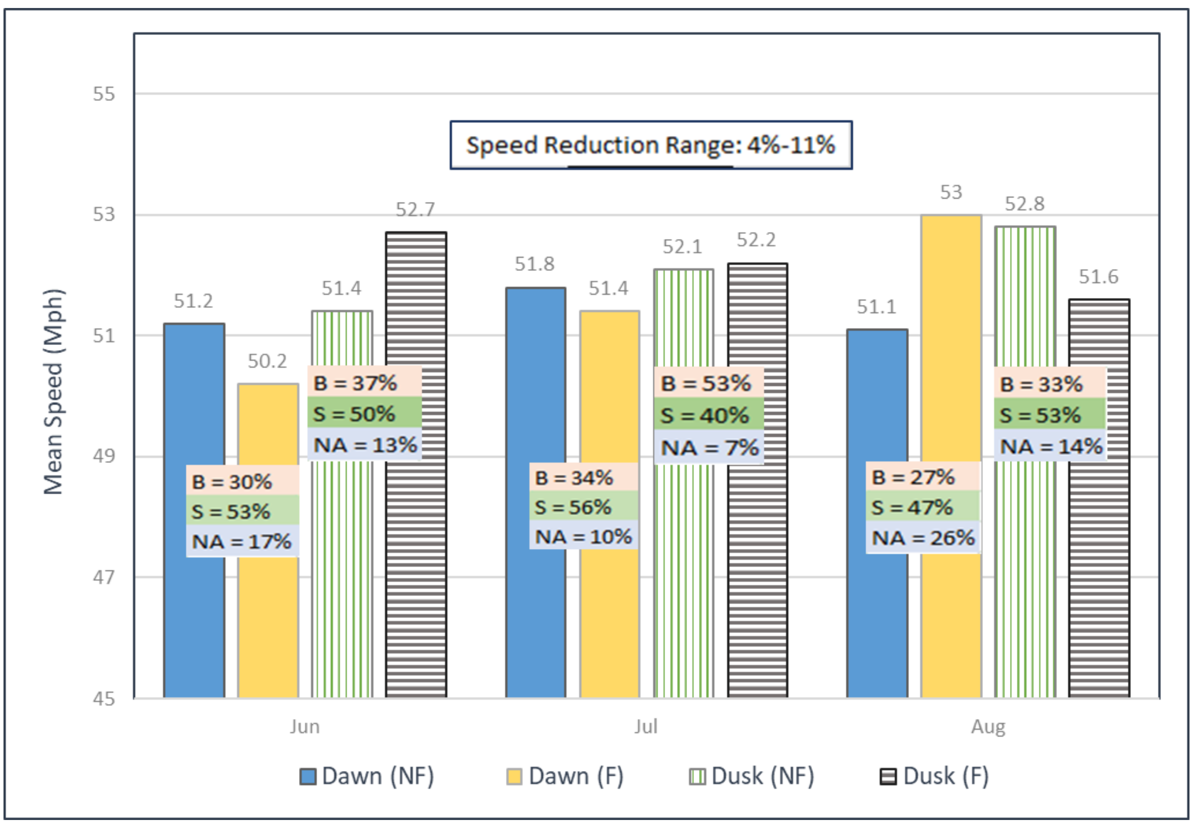

Figure 20. Vehicle Speed and Driver Behavior Related to Warning Sign Operation. B = Braked; S = Slowed; NA = No Action; F = Flashing, NF = No Flashing. Data from 120 vehicles were collected for each month.

Data were collected for vehicles traveling within a minimum of five-second intervals of each other to avoid erroneous radar readings. This interval also allowed the vehicles to perform actions such as braking independently of the leading vehicle (i.e., some following vehicles might have braked as a result of the lead vehicle braking). Figure 20 shows average driver speeds when approaching the area where the warning sign was installed. The speeds were captured both when the sign was inactive and when it was activated during the respective speed recording session.

Although all speeds were below the speed limit posted for that road section (88 km/h, 55 mph), minor differences were noted among various data collection sessions during the three months of data collection. Drivers tended to drive slightly faster at dusk regardless of whether the sign was flashing or not. It is possible that some drivers may have become habituated to the sign and to the fact that they did not see many deer near the road, especially during August. In addition, traffic volume was higher during the dusk-evening period traveling in the direction the sign was facing (more people commuting from work) than during the dawn-sunrise period. The data in Table 3 support this observation, as very few deer were recorded crossing the cable during the dusk and dawn periods: only six deer in June, eight deer in July, and one deer in August were detected. Moreover, some drivers used their high beams while traveling in that area (also seen in the video data), especially when lead traffic was not present, providing improved visibility. Video data analysis did not reveal any DVC during the course of the study, although drivers had to steer over the double line to avoid a potential conflict on a few occasions.

The results show that a higher percentage of drivers, especially those traveling at speeds over 80 km/h (50 mph), braked during the dusk time period than during the dawn timeframe. On average, drivers traveling at dusk braked approximately 10% more than those traveling at dawn, whereas a similar percentage of drivers (approximately 50%) slowed during the same time intervals. Conversely, a higher percentage of drivers did not brake or slow (i.e., no action) at dawn compared to dusk, as their speeds were slightly lower than their speeds at dusk. Whether at dusk or dawn, drivers seemed to be more confident with slowing rather than braking given the higher percentages (~50% or over) for that timeframe.

Higher speeds in August at dawn and dusk (85 km/h, 53 mph) coincided with an increase in the number of drivers who did not brake or slow (no action), especially at dawn. This may indicate that some drivers were aware that deer activity is low at that time of year. However, the percentage of drivers who braked/slowed during dusk was similar to those in June and July (approximately 90% ± 3%).

A statistical analysis based on t-test comparisons of means indicated that speeds were different between dusk and dawn in June and August, but not different in July, as the p values (indicating statistical confidence) were much smaller than the selected coefficient of significance (or threshold) of $\alpha = 0.05$ ($p = 0.0074 \ll 0.05$). Although speeds increased over the three-month period regardless of whether the sign was activated, statistical differences were obtained for speeds in the June–July interval compared to August at dusk, showing a decrease ($p = 0.00062 \ll 0.05$) from 84.8 km/h (52.7 mph) to 83.0 km/h (51.6 mph).

DISCUSSION

Animal detection systems typically use electronic sensors to detect large animals (i.e., deer-sized and larger) that approach the road and then activate signs to warn drivers. These signs are very specific in time and place and depend on traffic volume and roadway environment (e.g., vegetation and shoulder width) along with other parameters. Some states employ dynamic message signs in combination with these detection systems, whereas others prefer the activation of flashing lights (e.g., LEDs and beacons) on enhanced warning signs (Veneziano and Knapp, 2016). Typically, deer crossing signs (whether flashing or not) warn drivers of locations where deer are likely to be encountered based on where deer commonly cross.

The results of this study indicate that the BCADS performed well, with some minor technical issues that are expected for such a detection system and solar PV power installations. All issues were quickly addressed, and their impact on the system was minimal. One major problem encountered was related to the design and installation of the solar PV system. The unavailability of certain components and location and system size approval by Montgomery County took longer than expected, resulting in delays.

Depending on the system location (e.g., the presence of a right of way or private property), certain agreements such as a memorandums of understanding or land use permits (LUPs) must be developed to address legal aspects related to system installation and operation. VDOT typically issues a LUP if a detection system is likely to be installed in the right of way. VDOT staff will also issue permits and verify compliance with standard rules and regulations regarding other installations such as signs or surveillance equipment.

In this work, the magnitude of the cable sensor signal was around 40 dB when a vehicle was driven over the cable, whereas values from 5–10 dB and 10–20 dB were observed for animals and humans, respectively (Druta and Alden, 2015). Minimal interference from traffic within the detection field (response less than 5 dB over the threshold) was noted when tractor-trailers transporting wide-loads encroached into the detection field. Additional nuisance alarms were triggered by large equipment units parked near the BCADS for during periods of time. However, this interference did not affect the cable performance because these events only occurred occasionally, and the resulting signal magnitude showed a distinct pattern different from those created by humans and animals. Based on the received signal data, an operator can elect to either deactivate the specific cable segment or increase the detection threshold for a certain period in response to these events.

The flashing warning sign was located such that drivers had sufficient time to react before reaching the area where the BCADS was installed. On a few occasions, motorists were recorded slowing and even stopping (such as the driver in Figure 15) or slightly crossing into the other lane when deer were spotted near or in the road (engaged in a crossing) to avoid a collision. Time of day also affected driver behavior; more drivers braked at dusk compared to at dawn. Nonetheless, most drivers preferred to slow rather than brake, potentially because they did not observe an animal near or on the road after passing the flashing sign.

Effectiveness of the Deer Warning Sign

The results of this study indicate that the combination of animal detection and driver warning using a flashing sign had a significant effect on driver behavior. Although not all drivers reacted when the sign flashed, a large number (≥ 80%) reduced their speed in response to the visual warning. Based on the data from a three-month period, a large majority of drivers are expected to brake/slow when the sign flashes, whereas a small percentage will not. Although some drivers did not slow when the flashing sign alert was activated, the warning may have increased their vigilance and resulted in a decreased likelihood of an AVC. It should be noted that a much more robust and meaningful analysis of driver response to this type of roadside alert could be performed if driver reactions were recorded using fixed radar and video sensors operating continuously at the site.

Cable Performance and Observations

The results obtained in this study suggest that the BCADS consistently performed well in a roadside environment from an operational standpoint, with few problems encountered throughout the 11-month monitoring period. Table 4 lists some of the problems encountered and lessons learned during the course of the study along with some solutions for these problems.

Table 4. Problems Encountered, Solutions, and Lessons Learned During the BCADS Monitoring Period

Problem	Occasion	Potential Solution	Lesson Learned
False negative event	Few, only for fawns	Increase the detection threshold or adjust the target speed value	Adjustments in the CM software are required to fine-tune the cable for proper detection of animal and other targets.
False positive event	Water flow during heavy rain or heavy equipment parked near the detection system	Ground surface leveling and compaction with or without additional backfill material	If multiple false positives occur within the same or different locations along the cable, a system parameter configuration is required; a site visit should also be planned to assess the field conditions.
Vehicle interference	Only when oversized vehicles wandered into the detection field	Mask the respective region during maintenance work	If the cable is installed at a safe distance from traffic, no interference should occur.
Cellular communication	Network signal being low at times	Proper configuration of wireless communication system	Select a rugged device for outdoor operation.
Soil subsidence	Minor subsidence after periods of heavy rain	Proper leveling and compaction of ground surface	Utilize adequate quality backfill material and compaction methods.

CONCLUSIONS

- *Deer advisory messages on CMSs along an interstate can be an effective DVC mitigation tool.*

- *The results of this study show that the buried-cable BCADS can reliably detect (> 98% confidence) large animals (deer and larger) if properly installed and calibrated.* Smaller animals such as coyote can be reliably detected upon further tuning of the configuration parameters without compromising the overall cable performance.

- *The BCADS detection response (signal magnitude) can clearly differentiate between animals, humans, and vehicles.* Based on these responses, the parameter settings can be adjusted so that certain cable zones or segments can be configured differently in the software to distinguish between large and small animals, or between an animal and a vehicle.

- *Relatively simple and reliable wireless communication can be established between a data collection/storage system (i.e., mini-computer and external hard drive) and a remote computer using an off-the-shelf cellular modem with Wi-Fi capabilities.*

- *A solar PV system is a potential dependable option for powering the BCADS and additional surveillance equipment at locations where regular power is difficult to install.* However, the system has to be properly designed and sized for all the components based on their power requirements.

- *The BCADS performs well under traffic conditions irrespective of passing vehicle size.* Only vehicles that cross the edge line and enter the detection field trigger the alarm. The magnitude of the signal depends on how far the vehicle extends into the detection field. The closer that the vehicle is to the cable centerline, the higher the signal magnitude will be.

- *The BCADS detection threshold is not affected by snowfall.* The system provided valid detections when covered by 60 cm (2 ft) of snow. False or nuisance alarms were not triggered by wind-blown or melted snow. An increased depth of snow (3 ft or higher), however, may result in the elevation of an animal's path with respect to the detection field, leading to a possible crossing without detection (i.e., false negative).

- *The deer crossing warning sign has a significant impact on motorists, with 80% or more braking or slowing when approaching the flashing sign*. However, some motorists did not take any apparent action (they did not brake or slow), although their driving behavior may have been affected through higher awareness.

- *More drivers braked when driving at speeds over 80 km/h (50 mph) compared to those driving at 80 km/h (50 mph) or lower when they encountered the flashing sign*. Motorists traveling at speeds below 80 km/h (50 mph) elected to slow rather than brake.

RECOMMENDATIONS

1. *VTRC should coordinate with VDOT's Traffic Engineering Division to discuss a potential final evaluation of the safety impact of the buried cable animal detection system.* If the Traffic Engineering Division determines that system installation would be feasible from an operational standpoint in areas with high frequencies of deer-vehicle collisions, VTRC will

pursue a final evaluation of the system's effectiveness with regard to deer crash reduction and driver response to warning signs.

IMPLEMENTATION AND BENEFITS

Implementation

With regard to implementing Recommendation 1, VTRC will meet with VDOT's State Traffic Engineer and/or Assistant State Traffic Engineer by September 1, 2019, to discuss a final evaluation of the buried cable animal detection system and the potential for its implementation by VDOT.

If a final evaluation is pursued, adequate sites should include 4 to 6 m (12 to 18 ft) of flat terrain off the shoulder with suitable drainage. Sites with depressed areas (ditches) where water can accumulate or flow, a high volume of oversized/overweight vehicles, metal structures (e.g., fences and guardrails), and communication cables including buried and overhead power lines lower than 4 m (12 ft) should be avoided.

In addition, the many factors that may influence the selection of a DVC mitigation site are subject to change from year to year. These factors include weather and climate, traffic patterns, deer population growth and migration, habitat development, hunting patterns, etc.

Finally, given the relative costs and site-specific limitations of the BCADS, the most cost-effective implementation may include the complementary use of fencing or other barriers and passages along with a strategically placed BCADS-monitored crossing zone at grade.

Benefits

Now that the BCADS has been determined to reliably detect large animals regardless of traffic and weather conditions, implementing Recommendation 1 will allow for the determination of the system's effectiveness with regard to DVC reduction. This is the final phase of evaluation needed to guide VDOT decisions related to the system's use as a DVC mitigation option.

Data from multiple installations across the United States indicate that the costs associated with BCADS are relatively low when compared to alternative systems. Once the systems are properly installed, configured, and calibrated, operational costs typically include only power and communication as operation is straightforward, and maintenance is minimal. According to an AVC reduction report to Congress (Huijser et al., 2008), the estimated cost per AVC, including factors such as property damage, human injury, and carcass removal and disposal, is $8,388. In this regard, financial costs to implement any AVC reduction system are expected to be offset by savings to drivers and the Commonwealth. A simple calculation indicates that if a BCADS the size of the one used in this study were installed at a cost of approximately $200 per meter of coverage, the prevention of just four AVCs over the life of the installation would suffice to cover the initial cost of the installation. Table 5 shows the approximate costs associated with the currently installed system and estimated costs for a comparable system covering a half-mile-long road segment.

Table 5. Costs Associated with the Installation and Operation of the BCADS

BCADS (processor/ cable)	Materials	Personnel/ Equipment	Power	Data Transmission	Surveillance	Warning Sign(s)	Total
$14,000 (160 m cable)	$1,000	$1,000	$9,000 (solar)	$1,000 (cellular yr.)	$1,000	$3,000	$30,000
$55,000 (1/2-mi cable, 805 m)	$5,000	$15,000	$3,000	$2,000	$5,000	$15,000	$100,000

BCADS = buried cable animal detection system

The following aspects should also be considered when comparing the two systems in Table 5 and determining the prospective costs and benefits.

- The systems in Table 5 cover only one side of a roadway. Costs for coverage of both sides of the road would likely double.

- The experimental installation used in this study includes components that may not be suitable or needed in other installations. For example, the video surveillance and cellular communications used in this study site might not be needed elsewhere.

- Solar PV power was chosen for the study site because future VDOT installations may be rural, and grid power may be unavailable or relatively expensive. While grid power may initially cost less to install, monthly power fees would apply.

- The $55,000 cost for 0.5 mile of cable is based on a conversation with a vendor, not a written estimate.

- The costs for materials, equipment, and labor are highly dependent upon site conditions such as soil type, grade, road closure requirements, and roadside feature crossings.

- Communication and surveillance costs are only relevant if video or data site monitoring is planned.

- The warning sign used in this study was solar powered and triggered via wireless signal. No trenching was required for its installation.

The estimated cost for a BCADS with a length of 800 m (½ mile) is approximately $125 per meter. Assuming a service life of at least 15 years for the BCADS and an average of 20 DVCs per year for a location with a relatively high rate of incidents, a half-mile cable installation would yield savings of approximately $1.3 million over the service life of the cable sensor if DVCs are reduced by 50% (i.e., 10 collisions). Moreover, savings of nearly $1.9 million may result if DVCs are reduced by 75%.

Under the same above assumptions, costs for the half-mile installation can be covered in approximately 14 to 16 months if DVCs were reduced by 50% (i.e., 10 to 12 collisions), which translates into $84,000 to $100,000 of crash-related expenses. Savings may be higher if more DVCs are prevented (75%) during seasonal peaks (June–July and October–November).

ACKNOWLEDGMENTS

Research staff at VTTI, in cooperation with VTRC's Environmental Group, conducted this project. The authors acknowledge the cooperation of VTTI's Center for Technology Development engineers for their valuable input and for sharing their experience regarding network communication and data collection and storage. The authors also acknowledge the assistance and direction from the technical review panel: David Morris and Matthew Shiley, Traffic Engineering; Bridget Donaldson and Benjamin Cottrell, VTRC; and Paul Brown, VDOT, Christiansburg Residency.

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