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Title: Feasibility Study for Animal Detection Driver Warning Systems on Corridor Q/Route 460

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Abstract:

Corridor Q, as part of the Appalachian Development Highway System, is a 14-mile-long addition to US-460 in Buchanan County, Virginia that is currently under construction. The diverse large- and medium-sized wildlife in this area present risks for drivers, requiring an exploration of the different animal-vehicle crash (AVC) mitigation technologies available to state departments of transportation (DOTs). In addition to the wildlife typically found in the area, which already poses a threat to drivers (and vice versa), a local herd of elk was reintroduced to this area between 2012 and 2014 and are often seen along this new roadway. Elk pose additional dangers due to their large body size, herding behavior, and many other unique qualities that set them apart from other similar local species, like white-tailed deer. Elk primarily feed on low-growing vegetation such as the grasses typically used during construction to prevent roadside erosion. Soon after construction began, the elk were observed feeding on the grass along Corridor Q and tended to remain in the area. GPS collar data from tagged elk near Corridor Q reflect this observation. AVCs involving elk are costly, averaging around $73,196 in 2020 US dollars, with more recent estimates of $80,771. AVC mitigation efforts along Corridor Q must consider the unique challenges elk will present to drivers upon completion of the roadway.

While many different AVC mitigation techniques are in use today, this project focuses on the feasibility of utilizing animal detection and driver warning systems (AD/DWS) as a cost-effective measure to reduce the risk of AVCs along Corridor Q. AD/DWS combine animal detection (AD) with driver warning (DW) systems to effectively alert drivers of animals near the roadway. ADS are electronic systems that use methods such as tracking motion via camera, thermal imagery, or radar, the breaking of an invisible beam, or perturbation of underground sensors, with the goal of detecting the presence of an animal near the roadway. DWS are signage systems, connected to ADS, that give drivers advanced alerts of animal detection locations.

In this study, the Virginia Tech Transportation Institute researched the state of AD/DWS technologies to determine the feasibility for their use on Corridor Q, to review products that are currently available to state DOTs as off-the-shelf solutions, and to identify potential locations for a pilot study site. Interviews with subject matter experts were conducted to help guide this research. To ensure a cost-effective approach, an analysis of the partially completed portion of the roadway, and the activity of the local elk population, was conducted to observe the varying characteristics that could distinguish between areas of higher potential risk of elk-vehicle crashes (EVCs) versus areas of lower risk. In doing so, implementation of AD/DWS can be focused on the areas of higher apparent risk, keeping overall costs down while maximizing the effectiveness of these systems. AD/DWS were considered both as standalone options and in combination with other strategies to assess which method is better.

As this is a new roadway, typical analysis methods used for assessing AVC mitigation strategies, such as historic crash data and traffic volume data, could not be applied. Some elk in the area were collared with GPS tracking devices, allowing for an analysis of their movement around and near the roadway. Additionally, the Virginia DOT (VDOT) provided as-built data of the new roadway, and georeferenced footage was recorded to assist with the analysis.

Ultimately, the roadway was classified into distinct sections where conditions were indicative of a higher risk of EVCs based on an analysis of the data collected for this project. Details on these sections were provided to three vendors with different potential AD/DWS products that VDOT could readily purchase. These vendors provided their assessments and costs of implementing their solutions along Corridor Q.

FINAL REPORT

FEASIBILITY STUDY FOR ANIMAL DETECTION DRIVER WARNING SYSTEMS ON CORRIDOR Q/ROUTE 460

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ABSTRACT

Corridor Q, as part of the Appalachian Development Highway System, is a 14-mile-long addition to US-460 in Buchanan County, Virginia that is currently under construction. The diverse large- and medium-sized wildlife in this area present risks for drivers, requiring an exploration of the different animal-vehicle crash (AVC) mitigation technologies available to state departments of transportation (DOTs). In addition to the wildlife typically found in the area, which already poses a threat to drivers (and vice versa), a local herd of elk was reintroduced to this area between 2012 and 2014 and are often seen along this new roadway. Elk pose additional dangers due to their large body size, herding behavior, and many other unique qualities that set them apart from other similar local species, like white-tailed deer. Elk primarily feed on low-growing vegetation such as the grasses typically used during construction to prevent roadside erosion. Soon after construction began, the elk were observed feeding on the grass along Corridor Q and tended to remain in the area. GPS collar data from tagged elk near Corridor Q reflect this observation. AVCs involving elk are costly, averaging around $73,196 in 2020 US dollars, with more recent estimates of $80,771. AVC mitigation efforts along Corridor Q must consider the unique challenges elk will present to drivers upon completion of the roadway.

While many different AVC mitigation techniques are in use today, this project focuses on the feasibility of utilizing animal detection and driver warning systems (AD/DWS) as a cost-effective measure to reduce the risk of AVCs along Corridor Q. AD/DWS combine animal detection (AD) with driver warning (DW) systems to effectively alert drivers of animals near the roadway. ADS are electronic systems that use methods such as tracking motion via camera, thermal imagery, or radar, the breaking of an invisible beam, or perturbation of underground sensors, with the goal of detecting the presence of an animal near the roadway. DWS are signage systems, connected to ADS, that give drivers advanced alerts of animal detection locations.

In this study, the Virginia Tech Transportation Institute researched the state of AD/DWS technologies to determine the feasibility for their use on Corridor Q, to review products that are currently available to state DOTs as off-the-shelf solutions, and to identify potential locations for a pilot study site. Interviews with subject matter experts were conducted to help guide this research. To ensure a cost-effective approach, an analysis of the partially completed portion of the roadway, and the activity of the local elk population, was conducted to observe the varying characteristics that could distinguish between areas of higher potential risk of elk-vehicle crashes (EVCs) versus areas of lower risk. In doing so, implementation of AD/DWS can be focused on the areas of higher apparent risk, keeping overall costs down while maximizing the effectiveness of these systems. AD/DWS were considered both as standalone options and in combination with other strategies to assess which method is better.

As this is a new roadway, typical analysis methods used for assessing AVC mitigation strategies, such as historic crash data and traffic volume data, could not be applied. Some elk in the area were collared with GPS tracking devices, allowing for an analysis of their movement around and near the roadway. Additionally, the Virginia DOT (VDOT) provided as-built data of the new roadway, and georeferenced footage was recorded to assist with the analysis.

Ultimately, the roadway was classified into distinct sections where conditions were indicative of a higher risk of EVCs based on an analysis of the data collected for this project.

Details on these sections were provided to three vendors with different potential AD/DWS products that VDOT could readily purchase. These vendors provided their assessments and costs of implementing their solutions along Corridor Q.

INTRODUCTION

Animal-vehicle crashes (AVCs), defined as any adverse incident that involves a moving vehicle and animal (typically wildlife, but may include domestic animals) that resulted in damage to a vehicle, have remained a top cause of crashes among drivers in Virginia (Donaldson B. M., 2017; Donaldson & Elliott, 2020). Studies in the state have tested different mitigation techniques, with varying levels of success. One study by the Virginia Department of Transportation (VDOT) utilized fencing along I-64 near Charlottesville to guide wildlife to nearby existing underpasses and culverts, resulting in an average 92% reduction of AVCs in the areas where the fencing was constructed (Donaldson & Elliott, 2020). A separate study, conducted on the same interstate, tested the effectiveness of changeable message signs (CMSs) to alert drivers of deer crossings during temporal peaks of wildlife activity, leading to a 51% reduction in recorded carcasses removed and an average of 1.2 mph decrease in driver speed during periods when the CMSs displayed the deer advisory (Donaldson & Kweon, 2019). These studies demonstrate the potential of AVC mitigation efforts, particularly in southwest Virginia's mountainous and biodiverse environment. In addition, the relatively low upkeep and maintenance needed reflect their cost-effectiveness, as the reduction in AVCs can quickly offset the investment in fencing and CMSs, including required maintenance, over the lifespan of the equipment.

While these efforts can effectively reduce AVCs along existing roadways, new road construction in rural southwest Virginia also poses transportation management and wildlife preservation challenges. Corridor Q, a 14-mile-long addition to US-460 in Buchanan County, Virginia, as part of the Appalachian Development Highway System, aims to improve travel with faster speeds and reduced travel distance. However, its location in a rural area with diverse wildlife presents risks for drivers and danger to wildlife. Implementing effective AVC mitigation efforts before the road's completion can improve driver safety.

While many different AVC mitigation techniques are in use today, this project focuses on the feasibility of utilizing animal detection and driver warning systems (AD/DWS) as a cost-effective measure to reduce the risk of AVCs along Corridor Q. AD/DWS combine animal detection (AD) with driver warning (DW) systems to effectively alert drivers of animals near the roadway. ADS are electronic systems that use methods such as tracking motion via camera, thermal imagery, or radar, the breaking of an invisible beam, or perturbation of underground sensors, with the goal of detecting the presence of an animal near the roadway. DWS are signage systems, connected to ADS, that give drivers advanced alerts of animal detection locations.

In this study, Virginia Tech Transportation Institute (VTTI) researchers investigated the state of AD/DWS technologies to determine the feasibility for their use on Corridor Q, and to review products that are currently available to state DOTs as off-the-shelf solutions. Interviews with subject-matter experts (SMEs) were conducted to help guide this research. To ensure a cost-effective approach, an analysis of the partially completed portion of the roadway was conducted to observe the varying characteristics that could distinguish between areas of higher potential risk of EVCs versus areas of lower risk. In doing so, implementation of AD/DWS can be focused on the areas of higher apparent risk, keeping overall costs down while maximizing the effectiveness of these systems. Researchers studied various methods of AD/DWS

implementation and the feasibility of their use—options included using AD/DWS as a standalone option or in combination with other mitigation strategies like fencing, using variable speed limit signs, installing crossing structures where appropriate, and using electrified mats and fencing to create designated, at-grade crosswalks. These strategies were considered in terms of their potential application along this roadway, as the characteristics of Corridor Q and local wildlife may make some strategies better suited than others. Additionally, an emphasis was placed on the cost effectiveness of each of these mitigation strategies, and the recommendations in this report reflect this emphasis.

Typical wildlife in the Appalachian region of Virginia already pose a threat to drivers (and vice versa). Adding to this hazard, a small herd of 75 elk was reintroduced to this area between 2012 and 2014 (Virginia Department of Wildlife Resources, 2023), which has since grown substantially in size (recent estimates report over 250 elk), and geographic habitat range. Elk pose additional challenges due to their herding behavior (i.e., their tendency to group and move as a unit); their size, which is between three and five times that of an average deer (Sawyer, Merkle, Middleton, Dwinnell, & Monteith, 2018; World Deer, 2023); and many other unique qualities that set them apart from other similar local species, like white-tailed deer. Elk can take an average of 15 seconds to cross a highway and they may stand on the roadway for several minutes (Huijser, Fairbank, & Abra, 2017). Elk primarily feed on grasses and low-growing non-woody, non-grass plants called forbs. While much of Buchanan County is forested, the county also contains large areas that are blanketed by these low-growing grasses and forbs that grow on reclaimed surface mines, utility rights-of-way, economic development sites, and roadsides. The availability of this food source has enabled the elk herd to grow and thrive. Soon after construction began, the elk were observed feeding on the grass that was planted alongside the new roadway to reduce erosion (Virginia Mercury, 2022), and the herd seemed to stay in the area. While eastern elk populations tend to move over smaller areas, versus western populations with larger migration habits, the unique daily and seasonal movement patterns and herding behavior observed in the local population near Corridor Q are concerning for motorists. AVCs involving elk are costly, averaging around $73,196 in 2020 (Ament, Huijser, & May, 2022), with more recent estimates of $80,771 (Donaldson, Hillard, Rosenberger, & Callahan, 2023), and cause significant property damage. Mitigation efforts along Corridor Q must consider the challenges elk will present to drivers upon completion of the roadway.

PURPOSE AND SCOPE

The primary objectives of this research project were to:

1. Explore the current state of AD/DWS and identify the most appropriate system(s) for a potential pilot on the 10.5-mile portion of the 14-mile section of Corridor Q that was analyzed in this study.
2. Determine how to best implement AD/DWS technology either:
    a. independently of other AVC mitigation methods (i.e., wildlife crossing structures and fencing) or

b. in combination with other mitigation methods such as fencing and constructed crossings (pending available funding), such as those explored in the VTRC study (see next section) to achieve enhanced overall system effectiveness.

VTRC Report 24-R8, Evaluation of Wildlife Crossings for Corridor Q

While completing this report, VTTI collaborated with the authors of a related report completed under the Virginia Transportation Research Council (VTRC) that focused on the evaluation of wildlife crossings as a mitigation strategy along Corridor Q (Donaldson, Hillard, Rosenberger, & Callahan, 2023), whereas this report studies the implementation and effectiveness of AD/DWS. The VTRC report was published in September 2023, and provides its own analysis of the roadway, the local elk population, and conclusions and recommendations, specifically on the evaluation and implementation of wildlife crossings. While VTTI worked closely with the primary author of the VTRC report throughout the process, the analysis and conclusions in this report were found independently from the VTRC report in order to provide a separate evaluation of the same roadway and challenges posed by wildlife, and more specifically, the local elk herd. Despite the difference in analysis methods performed by each study, the areas of higher EVC risk indicated within this report reflect a consistency with the findings of the VTRC report. Any other notable similarities and/or differences with the VTRC report are mentioned in this report.

One of the intents of providing these two studies as separate, standalone reports is to give different suggestions of mitigation methods for the same roadway. This allows for the comparison of these mitigation methods to better understand their benefits and challenges, and help determine whether one or a combination of the methods would be more beneficial for Corridor Q.

METHODS

Overview of Approach

The following is a summary of the main tasks carried out to accomplish the research objectives:

- Conducted a literature review to identify the current state of AD/DWS, and explored their potential applications for Corridor Q.
- Collected data on the status of Corridor Q, including proposed and as-built data, GPS collar data from elk, and georeferenced footage to produce a comprehensive map and conduct an analysis of the corridor's features. The study area was defined as the 14-mile-long section of US 460 between the Kentucky state line and the Town of Grundy, with focus placed on the 10.5-mile portion of roadway that was accessible during the collection of the georeferenced video footage (see Figure 1 and Figure 2).
- Developed a comprehensive document on Corridor Q, dividing it into 16 segments of roadway where the apparent risk of EVCs was higher than other sections, by utilizing the previously collected data. To assess the suitability of each segment for AD/DWS, factors

such as density of elk collar data near the roadway, elk crossing density, and roadway characteristics were evaluated.

- Reached out to experts in the field, consultants, and potential vendors, providing them with comprehensive information about Corridor Q. This facilitated the collection of information on available technology, expenses, and factors to consider during the implementation of AD/DWS.

Data Compiling and Collection

During early discussions with VDOT and authors of the VTRC report, VTTI was informed about the activity of the local elk population near the roadway. In these discussions, it was noted that while the elk were introduced in an area south of the study area, the elk had slowly moved northward and stayed near the Corridor Q roadway. It was explained in one discussion that the elk seemed to not only be active near the entire length of the roadway, but it appeared they might also be utilizing the roadway itself as a method to travel from one location in the area to another more easily. To understand the nature of the elk and their interaction with the roadway, this report discusses the analysis that VTTI researchers conducted. However, the VTRC report provides its own analysis and conclusions, supplying a robust study of the geography and surrounding areas of Corridor Q to help explain why the elk prefer this area. Based on several different factors, including the geography, local vegetation, and habitat use, Corridor Q provides an optimal habitat for elk. For more information on this analysis, refer to the VTRC report's sections on elk habitat selection and suitability of Corridor Q (Donaldson, Hillard, Rosenberger, & Callahan, 2023).

While a large-scale approach, such as monitoring the entire roadway with ADS, could be taken, methods could also be used to find the areas along the roadway where more elk activity may be occurring. This would make it possible to target areas where ADS could be focused to reduce the overall cost of such a project. The process of data retrieval, collection, and analysis centered on finding the best methods available to determine whether specific areas of the roadway tend to have more elk activity than others.

Because Corridor Q is a new roadway, where only certain portions have been opened to traffic, publicly available data is difficult to source, much less utilize for an analysis of the roadway. During the analysis, only the westernmost portion, where Corridor Q intersects with State Route 693, was publicly accessible. While completing this report, the next portion opened to traffic in the fall of 2023, which now extends to the intersection of State Route 744 (see Figure 1). As this roadway does not yet provide traffic-related data such as historic crashes or traffic volume, the conventional methods of analysis typically used on a roadway with otherwise similar challenges could not be performed. Accordingly, the data collection process required seeking any other relevant data, from both Virginia Department of Wildlife Resources (DWR) and VDOT sources, as well as by VTTI researchers visiting and gathering data onsite. While Corridor Q contains 14 miles of roadway, between the state border with Kentucky and the town of Grundy, the area analyzed consisted of a roughly 10.5-mile-long portion, as shown in Figure 2.

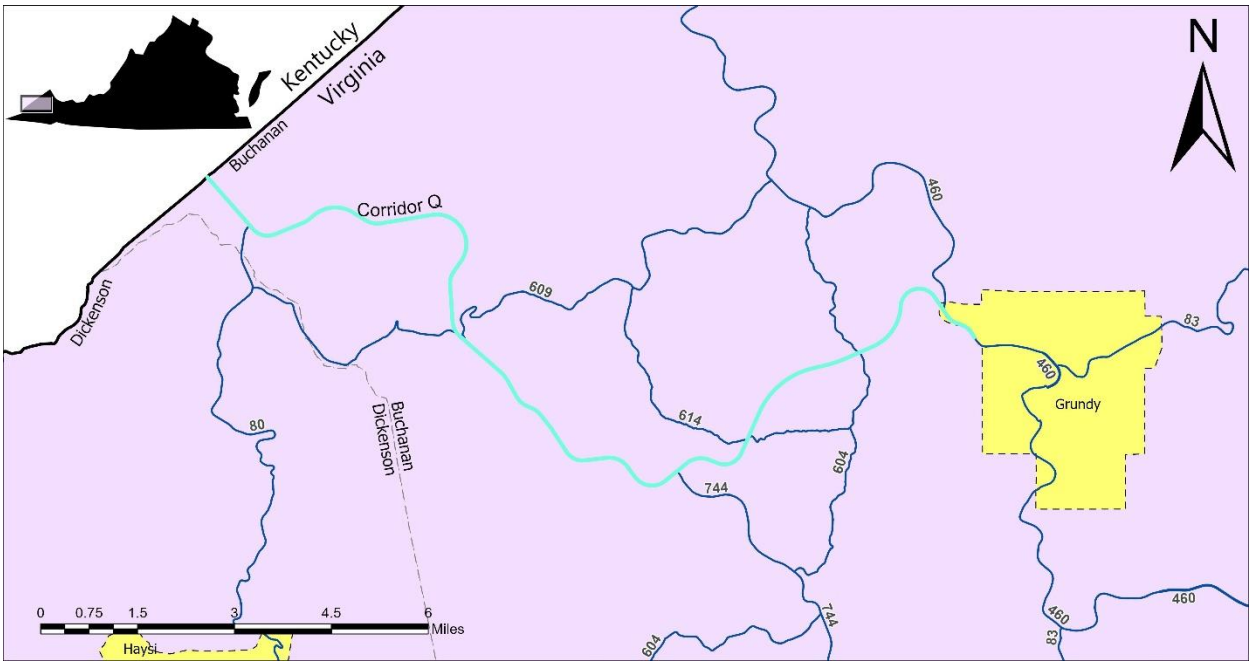


Figure 1. Overview of Corridor Q Study Area

As-built data

VTTI received relevant Corridor Q data from VDOT in a compressed KMZ format, compiled by AECOM, an infrastructure consulting firm. Within this compressed KMZ file, various KML (a version of XML notation) files provided detailed map layers on the construction of the roadway, containing existing, proposed, and as-built data. Among the data, notable layers include proposed and existing elevation contours, roadway characteristics such as the centerline, number of road lanes, pavement/shoulder width, and the presence of guardrails, DOT right-of-way boundaries, fencing, and power/utilities (AECOM, n.d.).

Elk GPS Collar Data

VTTI received data from the Virginia DWR containing GPS collar tracking data from 15 unique female elk, with a fix rate of 4 to 6 hours, and a date range from January 2019 through December 2022. In a discussion with DWR, it was explained that only female elk were collared during the tagging campaigns, as a representation indicative of the herd's geographic range and movements therein. However, DWR explained that the geographic extent may be larger than the data shows, as male elk, especially older individuals, tend to travel further away from the typical geographic range of the female elk in the herd. In addition to GPS coordinates, date, and time, the datasets contained horizontal dilution of precision (HDOP) data, which provides a relative accuracy rating of the coordinates.

As part of the data use agreement with the Virginia DWR, no individual collar data points will be shown in this report, nor any data layer that may lead to providing the specific locations of these data points. The analysis layers, including point density analyses, will be shown, as they do not indicate exact locations or movement of the tagged elk within the herd.

Georeferenced Video

To aid data analysis and visually assess the road conditions, VTTI conducted a site visit to Corridor Q on July 18, 2023. Using a windshield-mounted camera that collected real-time GPS location, elevation, and other telemetric data, video footage was recorded by travelling along the roadway with the camera secured and facing forward in a vehicle operated by VDOT personnel. Footage began at the westernmost section where the borders of Kentucky and Virginia meet, continued to the farthest eastern section of roadway that was accessible by the passenger vehicle driven for this recording, and returned to the western side, where the roadway intersects with Route 693 (see Figure 2). A total of 10.5 miles of roadway was recorded, which informed the portion of roadway that was ultimately analyzed in this study.

While analyzing the elk activity, the research team found that collar data points reflected extremely low to no activity along the remaining eastern portion of the roadway. As such, that area was not analyzed in this report. Once the remaining portion of Corridor Q is completed, the elk activity in this area may change as a result of the roadway and surrounding landscape changing, in addition to the roadway becoming open to drivers.

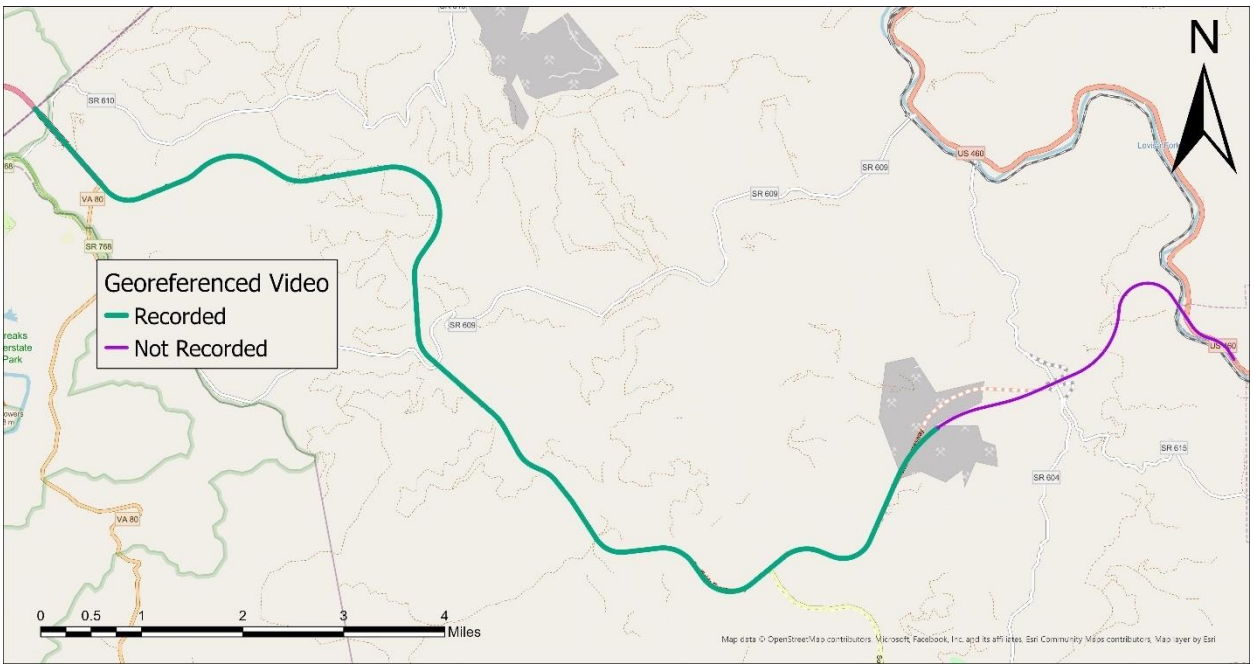


Figure 2. A map indicating the portion of Corridor Q recorded while collecting georeferenced video footage.

Subject Matter Experts and Vendors Methodology

To identify SMEs and vendors to interview for our research on AD/DWS on roadways, a literature review was conducted to find key academic articles, reports, and industry publications related to the subject matter. Personalized messages were sent to various authors of the relevant literature found, expressing interest in their work, and requesting an interview to gain insights into the topic. Unstructured interviews were conducted to collect data from SMEs and vendors of AD/DWS. All interviews focused on AD/DWS relative to Corridor Q and were conducted over

Zoom. Before each interview started, researchers explained the purpose of the interview, that the primary focus was on readily available AD/DWS, and the unique challenges present within Corridor Q. By combining these approaches, connections were established with SMEs and vendors, which provided valuable insights into the advancements, challenges, and future directions of AD/DWS on roadways.

RESULTS AND DISCUSSION

Literature Review – ADS and DWS Technology and Other Mitigation Efforts

AD/DWS are one of numerous methods that have been developed to mitigate AVCs, especially those related to large wild mammals. ADS detect animals nearing the road and, when combined with DWS, alert drivers to take precautionary measures like reducing speed and staying vigilant, thus reducing the risk of AVCs. In a review of the literature, VTTI researchers compiled information on the different forms of AD and DW systems, and how they are used in combination along with other possible methods of mitigation for maximum effect. VTTI submitted a draft report of the literature and technologies reviewed in this project to VDOT on June 12, 2023, and a discussion was held on how the information learned in this review would inform the completion of the remaining project tasks.

Animal Detection Systems

ADS use electronic sensors to detect large animals approaching the roadway and then warn approaching motorists. Most ADS use above ground/area cover sensors such as thermal infrared, microwave, or radio waves; break-the-beam sensors such as active infrared or radio wave beams; or in-ground sensors such as buried electromagnetic cables or seismic sensors. These systems activate upon detecting a disturbance in the signal caused by an animal. Once verified through software post-processing, the system sends a signal to a connected DWS to trigger a warning, such as flashing lights or a light-up message sign, to alert drivers. This can result in reduced speeds and increased stopping distances, thereby lowering the risk of AVCs (Smith, Noss, & Grace, 2015; Mukherjee, Sullivan, Sinha, Liu, & Brake, 2015; Huijser, McGowan, Clevenger, & Ament, 2008; Grace, Smith, & Noss, 2017; Druta & Alden, 2020; Gordon & Anderson, 2001). Monitoring studies reveal that, depending on various factors and combinations with other methods of mitigation, these systems can reduce wildlife crashes by over 90% in some areas (Ament, Huijser, & May, 2022; Gagnon, et al., 2018). For a comprehensive list of the literature on ADS, see "Intelligent Systems Using Sensors and/or Machine Learning to Mitigate Wildlife–Vehicle Collisions: A Review, Challenges, and New Perspectives" in the journal *Sensors* (Nandutu, Atemkeng, & Okouma, 2022).

The following sections detail the different types of ADS and their potential applications if considered for implementation on Corridor Q.

Break-the-beam

Break-the-beam sensors, placed across a pathway, detect animals when they cross, or "break," the signal beam (Huijser, et al., 2009). These sensors require a clear line of sight, which might be challenging in Corridor Q due to the local topography, road curvature, and vegetation

near the roadway. Placing sensors closer to the road can assist with issues caused by vegetation, but can also lead to shorter detection times, causing animals to be closer to the pavement by the time drivers are alerted (Huijser, Fairbank, & Abra, 2017). If the road curvature is too high, more systems would be needed to ensure full coverage, increasing the price of this type of system. False positives may also occur when vehicles or strong winds cause false detections, which may affect the public's perception of ADS as a useful mitigation measure (Sharafsaleh, et al., 2012; Huijser, et al., 2009).

In-ground Sensors

In-ground sensors, such as those used in a buried cable animal detection system (BCADS), are installed underground to detect wildlife ground movement. When an animal walks near or crosses over the cable's location, a change in the electromagnetic field is detected, which then activates a nearby warning sign to alert motorists (Gray, 2009). A BCADS is primarily used to monitor larger animals such as deer, elk, or moose (Huijser, Haas, & Crooks, 2012), as the system may have difficulty detecting smaller animals, especially during snowy conditions that weaken the signal. A study by Druta and Alden (2019) found BCADS to be effective, with a nearly 99% reliability rate in positive detections and driver warnings about large animals, such as deer. These systems are capable of functioning in areas with heavy snowfall, and at least 80% of drivers decreased their speed during times when the warning sign was activated. The study estimated that an 800-m BCADS costs approximately $125 per m, or roughly $100,000 for the entire system, but installation of this system could save approximately $1.3 million over the service life of the cable sensor (assuming 15 years) if vehicle crashes involving deer were reduced by 50%, which in the case of this study would be 10 per year.

While these systems have been proven to function properly under recommended conditions, implementation of a BCADS can require a much more in-depth analysis of roadway conditions than an above-ground solution to determine their suitability for a particular area. For instance, the state of the soil or presence of air pockets or large rocks can affect system functionality, though these types of issues can be accounted for during the installation process, thus reducing the potential of false positives and false negatives. Colorado's DOT completed a study of the effectiveness of this type of sensor for animal detection (Huijser, Haas, & Crooks, 2012), and while the results were inconclusive, local drivers had a negative perception of its use as a mitigation technique due to the level of perceived false positive and false negatives from poor system implementation (DH News, 2017; DH News, 2010). It is important to note that in all of these published reports, a BCADS was used as a stand-alone measure and did not incorporate other mitigation techniques.

Above Ground/Area Cover Sensors

As their name suggests, above ground/area cover sensors are positioned above ground and provide a cone-shaped coverage area, surpassing the coverage area of break-the-beam sensors, as they only detect within a thin, straight line. In this mitigation strategy, infrared and/or radar sensors are used to detect heat and/or motion within their coverage area (Nandutu, Atemkeng, & Okouma, 2022). These sensors are generally useful for both small and large animals but become less sensitive with high winds (Huijser, et al., 2009). Studies have shown

that when coupled with machine learning algorithms, these sensors can detect wildlife with over 90% accuracy (Munian, Martinez-Molina, Miserlis, Hernandez, & Alamaniotis, 2022; Chen, et al., 2019; Antônio, Da Silva, Miani, & Souza, 2019).

Area cover strategies could work on Corridor Q, but likely will not be as effective in areas with line-of-sight issues, such as closed-off sections or sporadic, small openings along a portion of roadway. However, in areas of high line-of-sight visibility, these types of sensors may be useful and more cost effective than any other solution, as few sensors would need to be installed to cover these areas of high visibility. However, fog, rain, snow, wind, and other weather-related factors prevalent in the area of Corridor Q are a concern for the efficiency of these systems.

Summary of ADS

While properly implemented ADS have demonstrated the potential to reduce AVCs involving large mammals, efficacy rates are reported at between 33% and 97%, which is quite a wide range. Many reports stress that ADS as a mitigation strategy are still considered experimental, due to the potential issues with the technology (Huijser, et al., 2021; Huijser, McGowan, Clevenger, & Ament, 2008; Munian, Martinez-Molina, Miserlis, Hernandez, & Alamaniotis, 2022; Smith, Noss, & Grace, 2015). While ADS can reliably detect large animals such as elk, the technology varies and may have a harder time picking up small- to medium-sized animals (Huijser, et al., 2021; Huijser, et al., 2009; Huijser, Camel, & Hardy, 2005). Among the various ADS, a few stand out as possible choices for Corridor Q. More information on these different ADS types are detailed in Table 1. BCADS present a promising option, with successful testing of similar systems along similar roadways (Druta & Alden, 2015; Druta & Alden, 2019; Druta & Alden, 2020) and the ability to overcome the challenges that visual-based ADS may have in the rural, forested area of southwest Virginia. However, there could be difficulties in implementing BCADS within a substrate not suitable for proper detection. The level of testing and real-world use of above ground, area-cover solutions should not be discounted, and these types of solutions may have a higher cost-benefit than any other solution in areas that are better suited, such as large, open areas. Due to the characteristics of Corridor Q, break-the-beam solutions would be challenging to properly implement as a cost-effective measure, and thus were not considered further after the conclusion of the literature review.

Table 1. Description of the Various ADS Technologies and Their Advantages and Disadvantages

ADS Type		Description	Accuracy	Advantages	Disadvantages
Above-Ground Area-Cover	Passive Infrared / Thermal	• Detection occurs when an emitting heat source crosses two adjacent sector boundaries or crosses the same boundary twice within a specified time. [1,2]	• Systems detected between 85.3%–98.85% of intrusions. [1] • Signs activated 96% of the time for elk and 98% of the time for deer following the presence of animals in the detection zone. [3]	• Potentially useful for detecting nocturnal animals and animals that cross the road at night. [4]	• Increase in false negatives during high winds. [1] • Limited range. [5]
	Radar	• Transmits and receives microwave radiation. • Detects whether the strength of the reflected signal is weaker than the one initially sent.	• At least 75.62% of detections were correct. [6]	• Uses fewer sensors/poles to cover roadway than infrared. [6,7] • Height of radar location may reduce risk of theft, vandalism, or accidental damage. [6]	• Can have delayed detection. [6] • Pedestrians and turning vehicles may be detected instead of large animals. [6] • There may be a blind spot under the radar that will need additional sensors. [7]

ADS Type	Description	Accuracy	Advantages	Disadvantages
Break-the-Beam	• Consists of a transmitter placed across a pathway that detects animals when they "break" the signal beam. (2, 8) • Requires a clear line of sight. (8)	• Systems detected between 72.4% and 100% of all intrusions in the detection area. (2)	• Simple method of detection, little processing needed to ensure accuracy of the system.	• Difficult to cover long distances, requires multiple sensors, more expensive and requires additional maintenance. (7) • If placed closer to the road, results in less time for drivers to react. (6) • Requires more hardware resources on curves, slopes, and vegetation landscapes. (8) • May result in false positives when vehicle or strong winds are detected. (2,9)
In-ground (BCADS)	• Generates an invisible electromagnetic detection field around the buried cables. (8) • Adjustable threshold • Detects large- and medium-sized animals crossing over the cable, provides data on their location along the length of the cable. (8)	• BCADS can detect with > 98% confidence large animals if properly installed and calibrated. (10) • Perimitrax® system detected 99.54% of intrusions in the detection area. (5)	• No/very low false positives and false negatives. (5,10) • Can detect large and possibly smaller animals with over 95% reliability. (5,10) • Does not require line-of-sight. • Capable of functioning in areas with heavy snowfall. (10)	• False detections are still possible. (5,10) • Primarily used to detect large animals and may have difficulty picking up smaller animals. (5) • Challenges with installation in soil with air pockets or large rocks.

Note. Information retrieved from (Nandutu, Atemkeng, & Okouma, 2022)[1], (Huijser, et al., 2009)[2],[3], (Munian, Martinez-Molina, Miserlis, Hernandez, & Alamaniotis, 2022)[4], (Huijser, Haas, & Crooks, 2012)[5], (Huijser, Fairbank, & Abra, 2017)[6], (Mukherjee, Stolpner, X., Vrenozaj, & Fei C., 2013)[7], (Gray, 2009)[8], (Sharafsaleh, et al., 2012)[9], (Druta & Alden, 2019)[10]

Driver Warning Systems

In most cases of ADS deployment, systems are combined with DWS. Alternative methods can also be used to warn drivers without the need for ADS, however. Each level of DWS usage has advantages and disadvantages. In this section, the different DWS options available and the level of confidence in their ability to mitigate AVCs are discussed.

Warning Signs: Standard, Enhanced, and Temporal

Static, or standard, animal warning signs are commonly used in areas with concerns about large mammal AVCs. They resemble regular traffic signs, featuring common wildlife images, and are inexpensive.

Enhanced wildlife warning signs, with features like flashing lights and vivid illustrations, are more effective in high AVC zones, although they are more costly. While they can raise awareness, some drivers may see them as sufficient and not support costlier mitigation efforts (Huijser, et al., 2021). Research shows varying effectiveness in different settings, and the signs may become less effective over time due to driver habituation if drivers see the same sign or flashing lights over repeated travel time through the area. Nonetheless, they can still help reduce liability concerns.

Temporal signs are like enhanced warnings but are only active at specific times, with the aim of combatting habituation and raising awareness during peak wildlife crossing times. The data is difficult to quantify, as studies on the signs' effectiveness have varied (Huijser, et al., 2021; Donaldson & Kweon, 2019). Temporal signs work best when aligned with specific wildlife migration corridors and may be less effective in larger areas due to potential sign oversaturation, which can lead to reduced driver attention (Huijser, et al., 2021).

Warning Signs Activated by Roadside ADS

Warning signs can be connected to ADS to alert drivers to animals before the animals reach the roadway (Dodd, Gagnon, & Schweinsburg, 2009; Nowakowski, Sharafsaleh, & Huijser, 2013). Signs that are used as part of an ADS have a much more effective rate of reducing AVCs than standard, enhanced, and temporal warning signs, with a reduction in AVCs of 33% to 97% (Huijser, Mosler-Berger, Olsson, & Strein, 2015). The most significant decreases in vehicle speed happen when signs are connected to mandatory or advisory speed limits, or when road conditions and visibility are poor (Huijser, et al., 2021). There is a liability concern if a wildlife detection system fails or if sudden braking due to a warning sign results in a rear-end collision (Huijser, et al., 2021; Gagnon, et al., 2018). However, compared to static, enhanced, or temporal signs, this type of DWS minimizes habituation to the systems, resulting in a higher rate of intended driver response to these signs (Huijser, Mosler-Berger, Olsson, & Strein, 2015; Huijser, et al., 2021).

Variable Speed Limit Signs

Variable speed limit (VSL) signs are legally enforceable and use sensors to adjust speed limits based on roadway conditions and hazards, such as visibility, crashes, congestion, or construction. VSLs were recently introduced on I-95 in Virginia, with prior use on roads like I-77 and the Hampton Roads and Monitor Merrimac Memorial Bridge-Tunnels (Virginia

Department of Transportation, 2023; WSET, 2022). There is potential to use these signs in tandem with ADS to warn drivers of wildlife crossing and provide a legally enforceable measure to alter driver behavior. This can also be helpful for maintaining better mobility along the roadway during times when wildlife is not crossing and to encourage a lower risk of AVCs during times when wildlife is crossing.

VSL signs can enhance traffic safety, but setting speed limits too far below the highway's design speed can lead to speed dispersion, potentially increasing crash risks. The literature suggests that effective AVC risk reduction may require limiting speeds to 35–40 mph, but this might not be suitable for high-speed corridors like Corridor Q (Huijser, Mosler-Berger, Olsson, & Strein, 2015; Huijser, Fairbank, & Abra, 2017). It should be noted that this strategy was considered in relation to permanently reducing the road's speed limit, rather than using a VSL sign.

In-Vehicle Alert Systems

Connected vehicle technologies provide an opportunity for alerting drivers to AVC-related risk via in-vehicle interfaces. Presently, these capabilities are available via smartphone applications that either provide crowdsourced roadway information, including animal sightings (Donaldson B. M., 2017), or that communicate with infrastructure-based AD/DWS (Druta & Alden, 2020). These applications require that drivers have a capable smartphone, have downloaded and are actively using the app, and that either other drivers have provided information in a crowdsourced app, or that the AD/DWS communicate directly or indirectly with vehicle systems or smartphones. For the purposes of this study, these options were not considered further due to their lack of current widespread availability.

Effectiveness of DWS

Quantifying the effectiveness of DWS is challenging. The goals of a reliable DWS are reflected in Figure 3. The common metric in the literature measures changes in vehicle speed when these signs are active. Post-analysis of past crash data or carcass removal can also be used to evaluate system effectiveness, but these values vary widely, making it hard to predict driver reactions on new roads. Moreover, a DWS is often combined with other mitigation strategies, making it difficult to isolate its specific impact in the results.

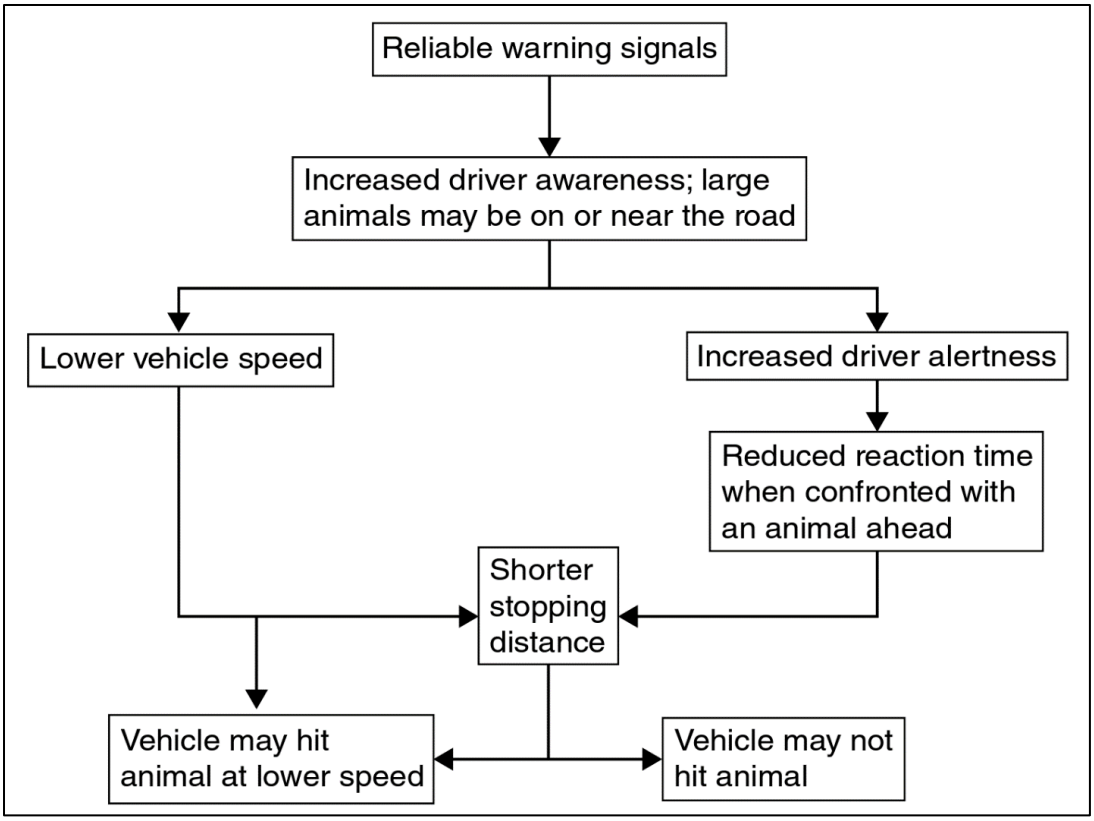


Figure 3. Driver response components dependent on reliable warning signals. Reprinted from The Comparison of Animal Detection Systems in a Test-Bed: A Quantitative Comparison of System Reliability and Experiences with Operation and Maintenance – Final Report, by M. P. Huijser et al., 2009. Copyright 2009 by the Western Transportation Institute. Reprinted with permission.

Roadway Barriers

Roadway barriers, such as wildlife fencing, are used to separate drivers from potential hazards like wildlife. They can be combined with AD/DWS to guide wildlife to safe crossing areas and alert drivers of their presence (Gagnon, et al., 2018; Dodd, Gagnon, & Schweinsburg, 2009). Fencing is commonly used around highways to prevent animals from entering the road and causing accidents (Aresco, 2005; Donaldson B. M., 2005; Dodd, Gagnon, & Schweinsburg, 2009). However, fencing alone can negatively impact wildlife by blocking migration routes and fragmenting habitats, which is known as the "barrier effect." To mitigate these effects, wildlife structures, such as dedicated overpasses, dedicated or pre-existing underpasses, culverts, or breaks in the fencing (i.e., jump-outs) can be used in combination with wildlife fencing (Bouchard, Ford, Eigenbrod, & Fahrig, 2009; Jaeger & Fahrig, 2004; Andrews & Gibbons, 2005; Rees, Roe, & Georges, 2009; Hedlund, Curtis, Curtis, & Williams, 2004; Bhardwaj, et al., 2022). The benefits of properly implementing wildlife fencing would exceed the associated costs in less than 5 years through reduction of AVCs (Gagnon, et al., 2015; Donaldson B. M., 2005; Gagnon, et al., 2018; Dodd, Gagnon, & Schweinsburg, 2009). It is important to involve wildlife experts in the design and implementation process to minimize negative impacts.

Regular maintenance is also crucial to prevent increased wildlife activity and the risk of accidents (Reses & Wood, 2015; Bhardwaj, et al., 2022). In addition, it is important to ensure

that the wildlife crossing structures that the fencing is directing wildlife towards are adequately sized to allow animals to use them effectively, otherwise the barrier effect is further exacerbated. This is particularly true for elk, which have a lower tolerance for smaller structures than white-tailed deer (Gagnon, et al., 2015). If the structures are too small, animals may resort to fence jumping or refuse to use underpasses. In cases where the motivations for crossing the road outweigh the deterrent of the fence, it is recommended to use a 2.4-m woven wire to connect wildlife crossing structures (Gagnon, et al., 2015; Clevenger & Waltho, 2000; Gagnon, et al., 2018). While it is not the focus of this report, more information on the evaluation and implementation of wildlife crossings along Corridor Q can be found in the VTRC report discussed in the "Purpose and Scope" section of this report (Donaldson, Hillard, Rosenberger, & Callahan, 2023).

Electrified fencing and in-ground mats are another option to restrict the movement of animals and guide them in the intended direction. In most cases, vehicles are not impacted by in-ground electrification due to the insulating effect of tires, and humans can be provided with a crosswalk button, like ones used in typical urban crosswalks, to temporarily deactivate the electrified mats and allow for safe passage (Gray, 2009). However, use of these electrified mats can require alterations to the roadway and can cause issues when maintenance crews are preparing for winter weather events or plowing existing snow on the roadway. Additionally, they have been shown to be a danger to smaller animals, with some studies finding dead wildlife on or near the electrified barriers (Huijser & Getty, 2022).

A notable project in Preacher Canyon, Arizona, effectively reduced elk-vehicle collisions by 97% using fencing and AD/DWS at an at-grade crosswalk. Only three total elk collisions occurred along the fenced area in the 9 years following the at-grade crosswalk installation. An electrified mat was also used guide wildlife and reduce collisions (Gagnon, et al., 2018). The implementation of this system relied on modifying both animal and human behavior instead of just one or the other. By using this method, wildlife was still able to freely travel within their habitat range, and simultaneously motorists were warned of animals crossing in these locations.

However, the differences in characteristics and behavior of elk in southwest Virginia may pose challenges for similar implementation. In the west, the herds are much larger and typically cross the roadway to arrive at another location within their habitat range. For the elk near Corridor Q, most of the area surrounding the roadway is their habitat. As there are concerns that these elk are using the roadway itself as a path of travel, it could be possible that elk do not cross an at-grade crosswalk, and instead may enter the crosswalk, then turn and walk parallel to the road, getting stuck in between the roadway and fence, leading to a potential increase of EVC risk. The use of jump-outs (i.e., escape ramps) would be a requirement to ensure trapped animals can exit the roadway safely. Additionally, use of electrified mats or concrete to inhibit this parallel movement could be difficult for this area; unlike the location in Arizona, routine winter maintenance could affect their function. It is worth nothing that fencing can be used in areas that may not be suitable for AD/DWS, and vice versa, improving overall mitigation efforts.

Data Analysis

The analysis began with retrieving the as-built data to gain a better understanding of the roadway's characteristics. The data provided many useful layers to assist with the analysis. The

layers include information on the roadway, such as the centerline, numbers of lanes, and pavement width; elevation contours, both pre-existing and proposed; and other aspects, such as right-of-way boundaries, utilities, stormwater drains, and others. Figure 4 shows an overview of some of the layers provided within the KML files.

In the absence of official, publicly available data, the KML files provide a great overview and visual representation of the roadway when overlaid on a map, showing such information as the exact location of the roadway, shape, pavement width, and lane numbers. The data also provided as-built elevation contours, which can assist in determining sections where the road is accessible by discerning the slope of the roadside and the height of certain structures. Using this data as a visual aid, VTTI decided to conduct a site visit to retrieve quantifiable data that could be used in tandem with the KML files to effectively analyze the characteristics of the roadway.

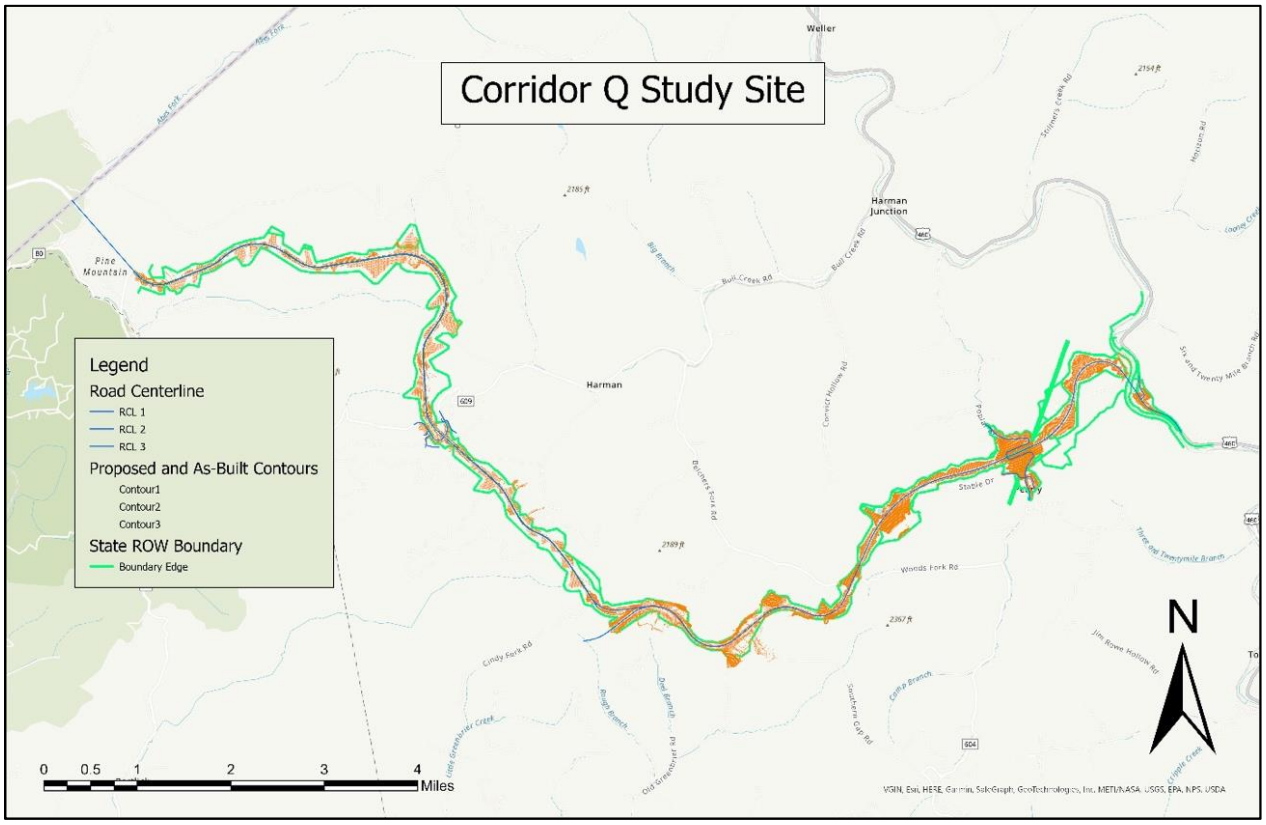


Figure 4. Map depicting the road centerline, proposed and as-built contours, and state right of way boundary layers included in the KML files for Corridor Q.

Roadside Classification

The analysis continued by gathering the georeferenced footage from the site visit (see Figure 5). In lieu of referenceable elevation data, this footage could provide information on the state of the roadside and reveal indicators that a certain area may be more accessible to wildlife than others. The goal of this procedure was to indicate areas along the roadway that appeared more open and accessible for wildlife to enter or interact with the roadway versus areas that seemed more closed off due to topography and any existing structures, and therefore begin to classify all portions of the roadway based on these characteristics. Additionally, elevation data

was included in the recorded telemetric data, which could assist in indicating where fog has a higher potential of occurring more often than at other locations along the roadway.

To begin the assessment of this footage, the telemetric data was extracted and reviewed. Within this data were the latitude-longitude coordinates and timestamps of the video recording at designated points, which could be added to a map and overlaid on the KMZ file's road centerline layer. Because there was information on the exact location to accompany the footage, researchers could then begin to describe the state of the roadside in both directions.

The GPS coordinate data was recorded at a frequency of 60 points per second. Extraneous points from the telemetric data were removed to reduce the dataset to only contain points at 1-second intervals. The video footage was reviewed alongside the newly created 1-second interval dataset to provide a method to tabulate changes to the roadside, which could then be incorporated into the map using the road centerline provided within the as-built data. As the recording was viewed for changes in the state of the roadside, the timestamp in the video was matched to the timestamp within the telemetry dataset, and a classification was given to the points within the dataset. The roadside would be characterized by several options, including cut and fill sections, areas that were more flat or open, intersections, and bridgeways. This was done to denote when the roadside characteristics changed from more open to more closed-off. In both directions of the recording, the area near the roadside on the right was observed, providing a state of the south side and north side to then compare to each other. Considering the state of both sides of the roadway, a level of openness or accessibility from the roadside was assigned to the entire length of recorded roadway (see Figure 6). For this analysis, "open" is defined as an area where both sides of the roadway are flat with relatively high access to the roadway, "closed" means the area is characterized by cut sections of earth, or the elevation is so steep that access to the roadway is likely difficult, and "semi-open" contains a mixture of characteristics of both open and closed sections. While "closed" may mean the roadway is less accessible to wildlife entering from the roadside, this does not necessarily mean that the roadway is entirely inaccessible. Wildlife may enter this area parallel to the roadway, and then cross perpendicular within this section. However, in later sections, it is illustrated that these "closed" areas show less elk activity. The roadway designated "N/A" was not yet open for georeferenced video to be recorded.

Figure 5. A screenshot of the georeferenced video footage reviewed as part of the roadside classification analysis. This area depicts a section that is open on the left side of the road, and closed on the right.

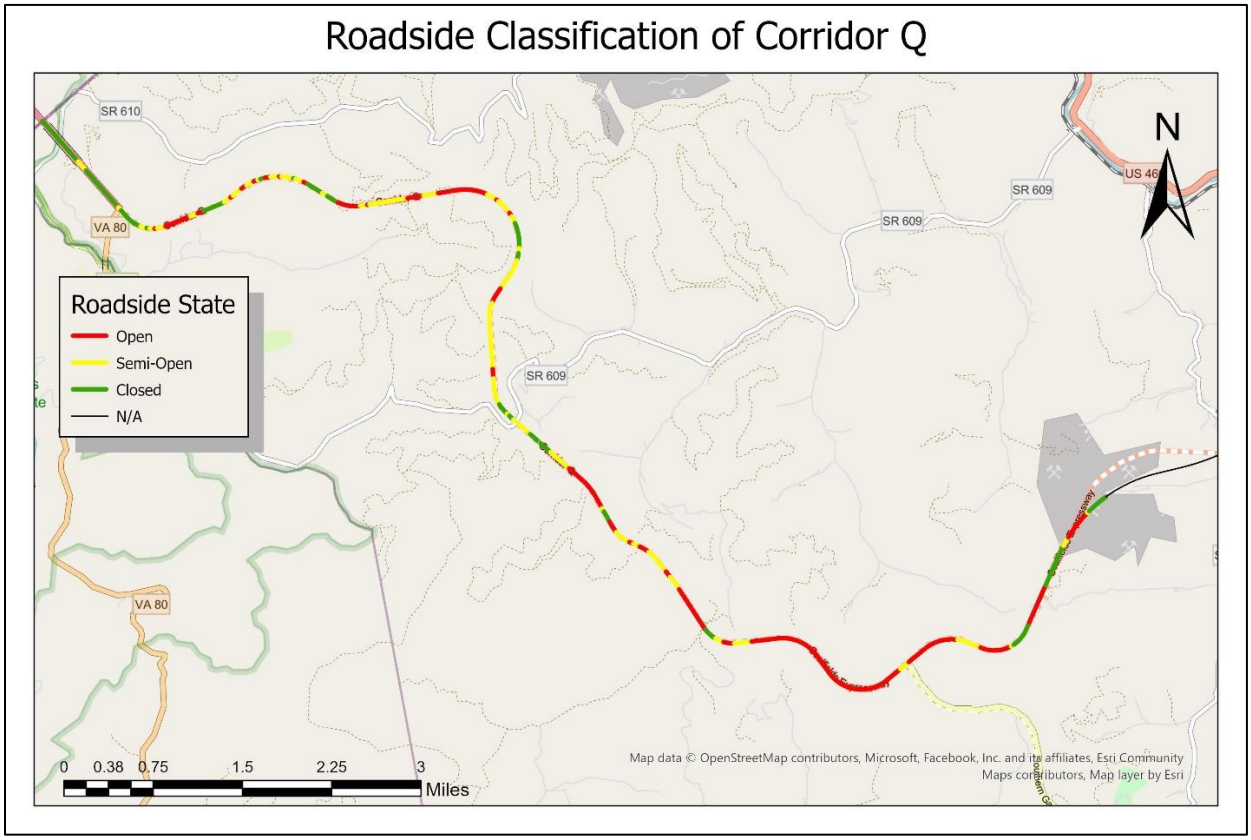
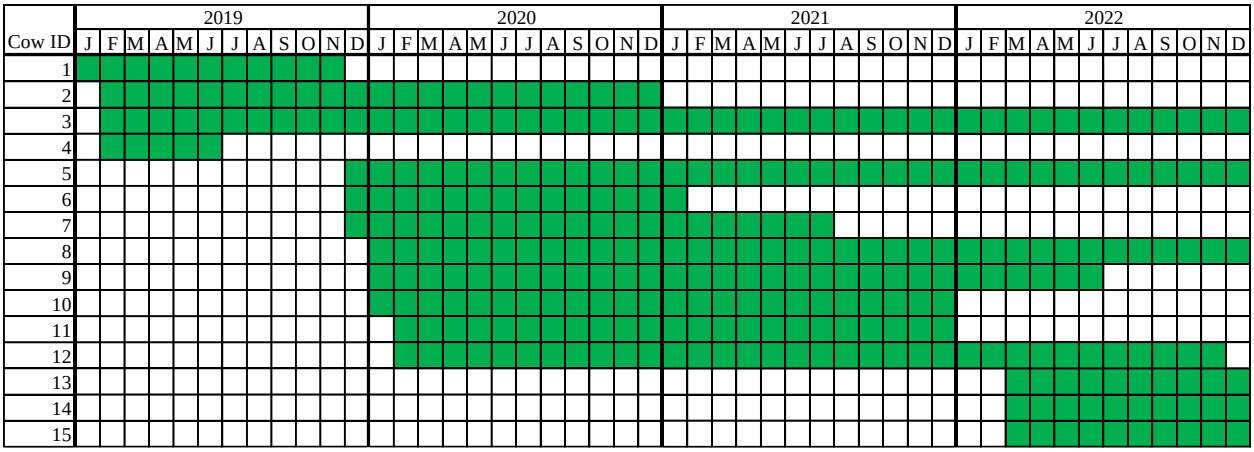


Figure 6. A map of Corridor Q road centerline after roadside classification of the accessible portion of the roadway was completed.

Analysis of the Elk GPS Collar Data

Near the conclusion of the roadside classification analysis, DWR provided VTTI with access to the GPS collar data of the elk herd near Corridor Q. There were a total of 53,303 data point locations provided with this dataset. The date coverage varied between each female elk, as shown in Table 2. The Dates Covered by Each of the Individual Female Elk That Were Included in This Study

Table 2. The Dates Covered by Each of the Individual Female Elk That Were Included in This Study



Because the data only contains information on the local elk population, no determinations can be made with high confidence about how the other wildlife in this area may interact with the roadway and vehicles once it is open to the public. However, due to their unique behavior, this is one of the more important species to consider for crash mitigation. Elk are one of the most dangerous wildlife species to motorists due to their size. Further, because they are a highly vulnerable species, an analysis of this data was considered crucial to understanding the unique challenges that elk pose on the roadway. Multiple analyses were performed using this data to support finding areas where elk activity occurs near the roadway.

Prior to any further analysis, all points with an HDOP value greater than five were removed from consideration, as their values indicate a poor confidence in exact positioning. Of the initial 53,303 points, 53,115 remained after removing the 188 points with high HDOP values. An initial test was performed on the density of GPS collar data points that fell within certain distances of the roadway.

Of the remaining data, 21,411 points (~40%) of all elk activity were recorded within 200 m of the roadway. A total of 14,296 points (~27%) fell within 100 m of the roadway, 7,067 points (~13.3%) within 50 m, 1,866 points (~3.5%) within 20 m, 489 points (~0.9%) within 10 m, and 242 points (< 0.5%) within 5 m. Of these different radial distances to the roadway, the 100 m buffer was chosen to maximize the amount of quality data points near the roadway for analysis, while making it easier to discern between areas of high and low density from a point density analysis.

The data was provided as 15 unique female elk sets and sorted temporally, from the earliest to latest entry. Using this information, straight-line paths generated for each unique elk could be viewed by drawing lines from one point to the next, until each elk's path was tracked.

Unfortunately, it cannot be determined that the lines traced this way were the actual paths the elk traveled, as a time interval of 4 to 6 hours likely meant the elk took a much different path than the generated straight line. Additionally, despite how parallel or perpendicular to the roadway the paths were traced, no determinations could be made of whether an elk used the roadway itself to travel from one point to another, whether it crossed at a certain location, or if it crossed the roadway multiple times within the 4-to-6-hour timeframe. However, by taking every point in which an elk path intersected with the roadway, and conducting a point density on the resultant points, "crossing activity" along the roadway could be mapped and considered for further analysis.

Subject Matter Expert and Vendor Interviews

Seven SME and vendor interviews were conducted to gather information on ADS implementation, current technologies, limitations, and potential challenges. The notable information gathered from the interviews is summarized below. When evaluating vendor information, it's important to consider potential bias with regard to ADS technology, as they may stand to benefit from potential sales or have more particular knowledge about their own systems, and less on other vendors'. This information was gathered to create a full scope of current ADS technology that was not present in the literature reviews. Recommendations given were used to gather the total scope of current ADS technology available for potential use on Corridor Q. Our recommendations were based on analysis done outside of the interviews. Both recommendations and potential challenges for these systems are listed. For the full interviews see Appendix A.

Interview 1 – Marcel Huijser, a senior research ecologist with the Western Transportation Institute. Huijser is an SME with extensive experience in AVC mitigation who assisted with progressing the analysis by offering insight on the benefits and challenges of AD/DWS and suggesting some vendors to contact.

- Crossing structures are preferred in most situations due to their high effectiveness.
- Research on the implementation of ADS is limited.
- Survival rates of ADS projects are poor.
- It is imperative to understand the future of the systems once implemented, for instance, who will maintain the systems once they have been installed.
- Fencing can increase the "barrier effect" of roadways.
- Elk require properly sized crossing structures.
- Other countries take a conservation-centered instead of a safety-centered approach.
- Upkeep and maintenance responsibilities need to be considered.

Interview 2 – Jeffrey W. Gagnon, a statewide research biologist with the Arizona Game and Fish Department. Gagnon is another SME with experience in conducting studies on the use of AD/DWS, specifically in applications for which elk were a primary consideration.

- A thermal system mounted 12 ft off the ground with fencing into a smaller crossing area is recommended.

    - It's effective for large animal detection, such as elk, and with proper filters accuracy can reach 90%+.
- Sensing limits are controlled effectively at 50–100 ft wide.
- The system does not tolerate high winds well, so additional pole support is needed in windy areas.
- Without fencing, more sensors are required, and the error potential goes up exponentially the larger the area you try to cover with just sensors.
- Escape structures within stretches of exclusionary fencing are recommended at a minimum of every half mile.
- It's important to monitor areas where fencing ends to eliminate the end-run effect.
- Electrified concrete can be used as an alternative to electrified mats in snowy regions.
- Upkeep and maintenance responsibilities need to be considered.
- There is potential for hacking and vandalism.
- Gagnon mentions being personally reluctant to put any detection system on a 4-lane road due to the speed (~70 mph) of motorists.
- Detection systems are unique; there is no one-size-fits-all solution.

It should be noted that the recommendations that Gagnon offered are for mitigation strategies in general, and may not apply specifically to Corridor Q, as the characteristics may vary from one roadway and its local wildlife to another.

Interview 3 – Chris Peguesse, a consultant with Senstar, a vendor of advanced security systems. In this interview, the discussion focused on the use of their Omnitrax® system, a buried cable solution that Peguesse has experience in utilizing as an ADS.

- Their Omnitrax® product consists of a single central processor, with cable length up to 400 m in each direction (up to 800 m of linear roadside total with one unit). The system has the following features.
    - Can be powered by solar panels.
    - Is underground, so visibility-based challenges have no effect.
    - Can discern location of animals along the roadway, which could aid in understanding elk movement.
- Metallic structures (i.e., fences or guardrails) near the cable can cause signal disruption.
    - Strategic placement can minimize impact and even boost signal if metallic structures are properly accounted for.
    - If the distance of the guardrails are too close to the pavement, the system may detect passing vehicles.
- Burrowing wildlife may disturb the cable.
    - The cable can be encased in impermeable material to discourage animals from disturbing it.
- Due to elks' physique, the cable's ability to properly detect elk is hindered and can cause false negatives.
    - The system needs to be adjusted to account for this while not detecting smaller wildlife that pose no threat to drivers.
    - A berm placed on top of the cable laid directly on an existing surface is recommended to increase the area of detection.

- The cable cannot discern whether an animal is travelling from the roadside into the road or vice versa.
- This system requires relatively uniform soil with little to no air pockets or large rocks.

Interview 4 – Gert Hamberg is the founder and director of ProWild, a vendor of AVC mitigation technologies. Hamberg discussed the options that ProWild can offer, including break-the-beam and above-ground area-cover systems.

- ProWild can install thermal, lidar, active infrared, passive infrared, and radar and have access to all of these within the same controller.
- Their system has wireless connectivity over 5 km, but wired systems are best.
- Their long-range thermal cameras can look over 2 km and detect specific animals.
- Since the elk stay on the road, additional technology is needed to differentiate them from cars.
- Passive infrared won't work alone as a detector and must be combined with other technology.
- Passive infrared has been added to their active infrared systems to make them safer.
- Active infrared can be sensitive to foggy conditions.
- Lidar technology has recently progressed and needs to be tested again.
- Detection systems are unique; there is no one-size-fits-all solution.

Interview 5 – Tim Hazlehurst is the founder and president of CrossTek, a vendor of AVC mitigation technologies. Hazlehurst has experience in utilizing systems, such as thermal and radar, as AD/DWS solutions.

- CrossTek uses a ground-up engineering approach and develops each system to fit the environment.
- Off-the-shelf systems have limited success. Tim is not aware of an "off-the-shelf" system that has remained in roadway operation. Some didn't work from day one. The rest were decommissioned within 1 to 4 years.
- A mobile-data-collection wildlife detecting radar, with or without wildlife detecting thermal cameras, is an option to test different systems and document wildlife movement across roads in different areas before committing to permanent installation.
- Multiple sensors and cameras can be integrated into one driver warning system.
- Recommended having an area to control the movement of the animals while targeting the bigger crossing areas and considering what the driver will see. I.e., recommended a combination of fencing, radar sensors and thermal sensors (with solid animal detection capabilities) to optimize detection and warning.
- Recommended using fencing and tying it to crossing structures and underpasses for animal flow, when possible.
- Some clear space (minimal vegetation or vegetation maintained at certain height) on both sides of the road is required for line of site detection of wildlife.
- Radar sensors have a 1400-m radius in each direction. Designed for up to 1.6 miles with one radar sensor positioned at a central location of the road corridor. At 1400 meters, the radar can accurately detect a human crawling on the ground.

- A thermal camera can be placed to view the area under the radar to mitigate the blind spot created by the angle of declination. An alternative is to install a short section of game fence (200 feet) behind the radar to steer wildlife away from crossing directly under the radar.
- In the past, passive thermal imaging maxed out at 100–125 ft along the roadway, but CrossTek are now getting strong results out to 250–300 feet.
- Does not recommend turning signs on unless confirmed or very high probability that wildlife are near the roadway.
- Both radar and thermal systems work well in rain, fog and snow. Lidar is less reliable and sometimes exhibits very poor performance in these conditions.
- Motorists need enough time to react to animal detection. This pertains to sign placement and speed of activation upon positive detection.
- Costs will vary based on what state DOTs require in their design plans, such as strict adherence to the Approved Product List or extra reviews for environmental permits or extra steps in developing plan-sets, etc.
- Once the section of roadway is open and traffic is present, the elk's movement patterns may change.
- Weather matters – some sensors will fail or have reduced performance in heavy rain or snow.
- Thermal has limited range but is a good option at the end of fencing or near concentrated crossings.

Interview 6 – Steve Bega and Steve Mars from Animex, as well as Gert Hamberg from ProWild. Animex works in partnership with ProWild to provide AD/DWS and other mitigation solutions for clients around the world.

- Recommended that VDOT apply for grant money for overpasses/underpasses before the roadway is opened to mitigate future costs and potential fatalities with humans and elk.
- There is no one-size-fits-all for ADS.
- Location, budget, elk patterns all need to be considered.
- Has long-range thermal cameras that can view up to 2 km and radar.
- If position is changed, parameters need to be reset.
- Power options can change price significantly.
    - Can always add solar panels later.
- With fencing, active infrared is an option.
- Due to potential fog, 1 km thermal may be better than 2 km
- Multiple sensors/cameras can be added to one main controller to save money.

Interview 7 – Gary Lester has worked with MBP (McDonough Bolyard Peck) as a service executive. Lester offered some insight into the requirements of the implementation of systems along the roadside.

- Recommend getting information from different vendors and systems.
- Likely not a lot of information on ADS, as this is a newer technology.

- Noted the need to know the specifications on the installation procedures for each piece of equipment, so MBP can know what is needed from them.

Key factors from interviews:

- Need to consider the capabilities and limitations of each system, as there is no one-size-fits-all solution.
- Installation procedures and maintenance requirements are important factors to consider.
- Costs can vary based on the specific requirements of each system.
- Thorough research and understanding of different vendors and systems is necessary before making a decision.

Knowledge Synthesis

Based on the culmination of knowledge synthesized from the literature review, analysis of the roadway, interviews with SMEs and vendors, and a review of the VTRC study's report, Figure 7 summarizes at a high level the various possible AVC mitigation strategies that might be implemented, and how they compare to one another, considering various operational characteristic trends. Additionally, recommended mitigation methods for Corridor Q are colored in blue, while methods not recommended are shown in orange. The study area of Corridor Q has several unique attributes which make recommending certain strategies difficult to determine. Due to how the elk are likely utilizing the roadway itself as a path of travel, and the geography of the surrounding area, using improved fencing alongside AD/DWS is difficult to recommend for this roadway until further study is conducted on the elk herd and their interaction with vehicles on the roadway. Currently, the data required to determine the relative cost of the different AVC methods on a per-crash incident basis is not available.

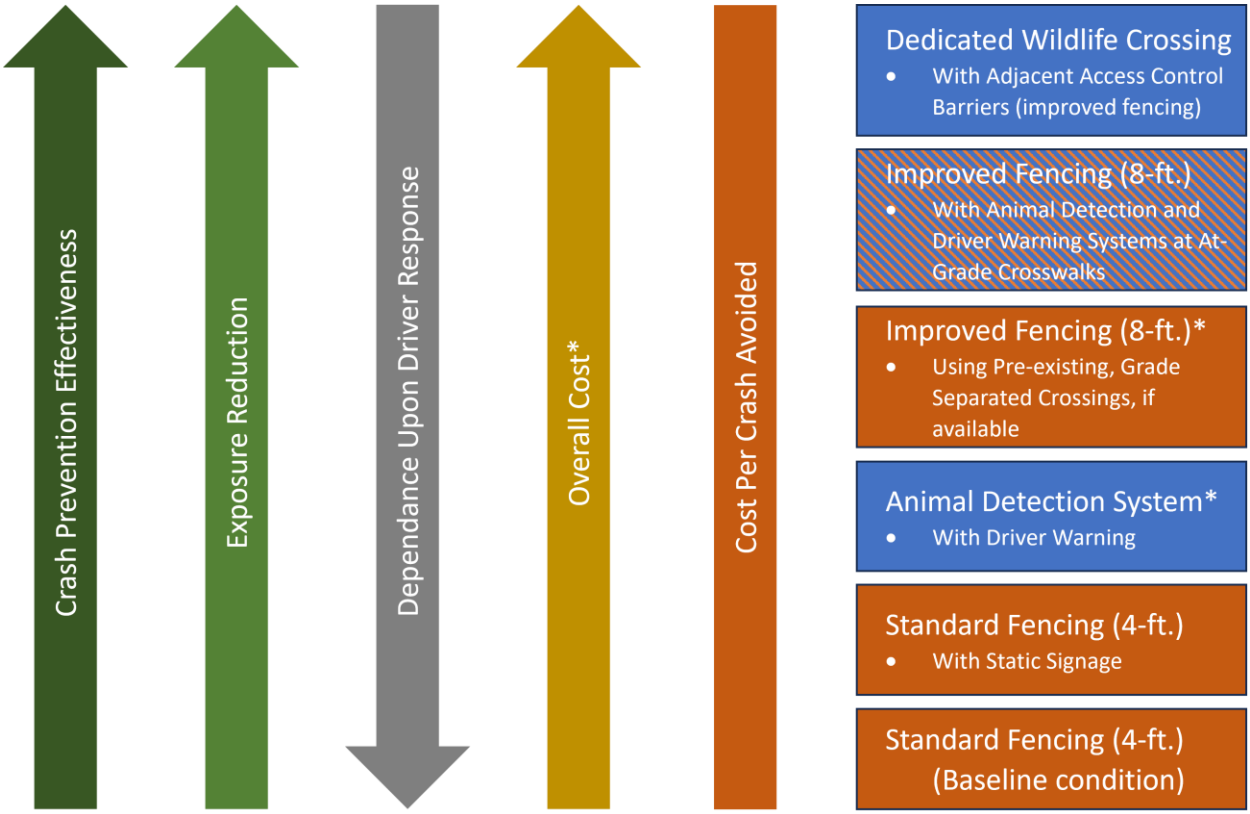


Figure 7. A comparison of AVC mitigation treatment methods versus general operational factor trends. Methods in blue indicate feasible options for Corridor Q, while methods in orange are not recommended or feasible. It is uncertain whether improved fencing with AD/DWS will be beneficial for Corridor Q, based on both the unique behavior of the local elk population and the characteristics of the roadway.

**The Overall Cost trend of Improved Fencing versus ADS as standalone options may be reversed depending on several factors, such as the materials used, installation, and maintenance. All other trends between these methods remain consistent.*

Road Classification and Site Selection Criteria

At the conclusion of the roadway analysis, results of the elk GPS collar data and path tracing analysis appeared to align with the roadside classification. When viewed simultaneously, areas in which the roadside was classified as being more open matched with a higher density of elk GPS activity near the roadway (see Figure 8), and in many cases the density of path tracing intersected with the road centerline more often as well (see Figure 9). Conversely, in areas where the roadside was classified as being more closed-off, GPS collar activity and path tracing were both much lower than in other areas of roadway. From this information, it was determined that there were specific sections along the roadway where elk seemed to congregate nearer to the road, and that there were areas where crossing activity was more likely to be occurring. From these results, it was determined that specific areas along the road would benefit more from AD/DWS installation than others and could provide a more cost-effective approach to system implementation. Additionally, the results of the collar data aligned with the analysis identifying areas of higher EVC risk carried out in the VTRC study of Corridor Q.

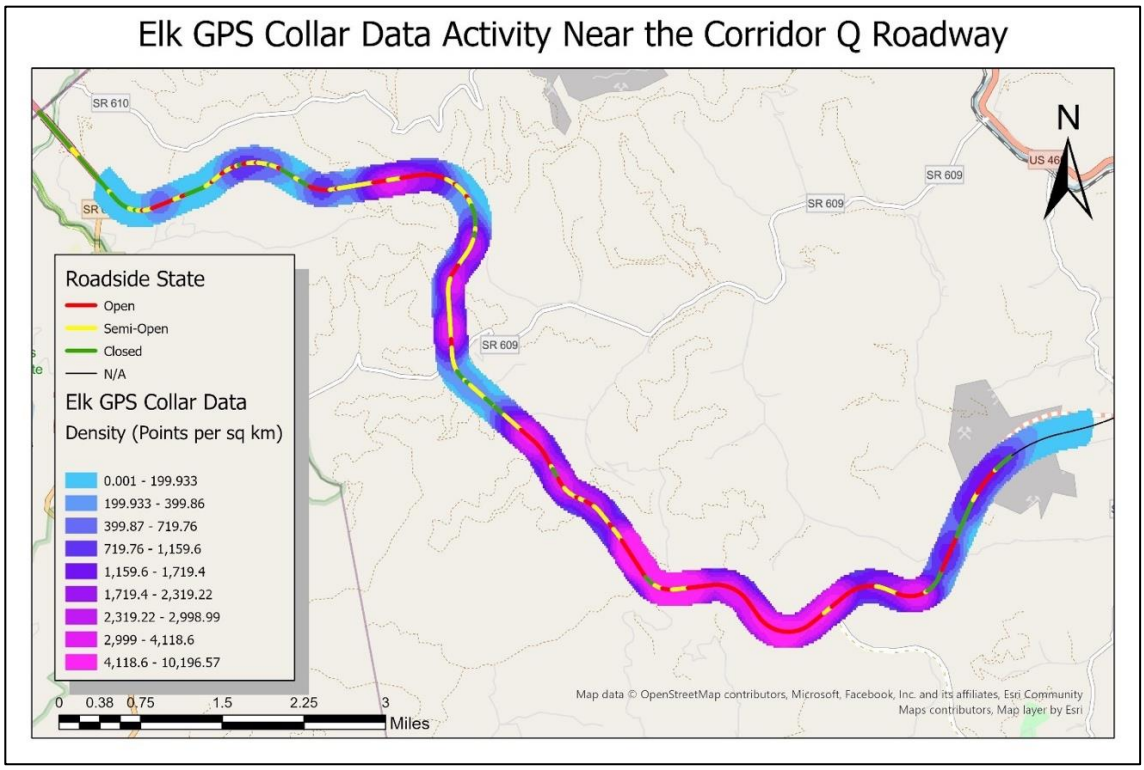


Figure 8. GPS collar tracking activity occurring near the roadway along Corridor Q, with the roadside state layer overlaid.

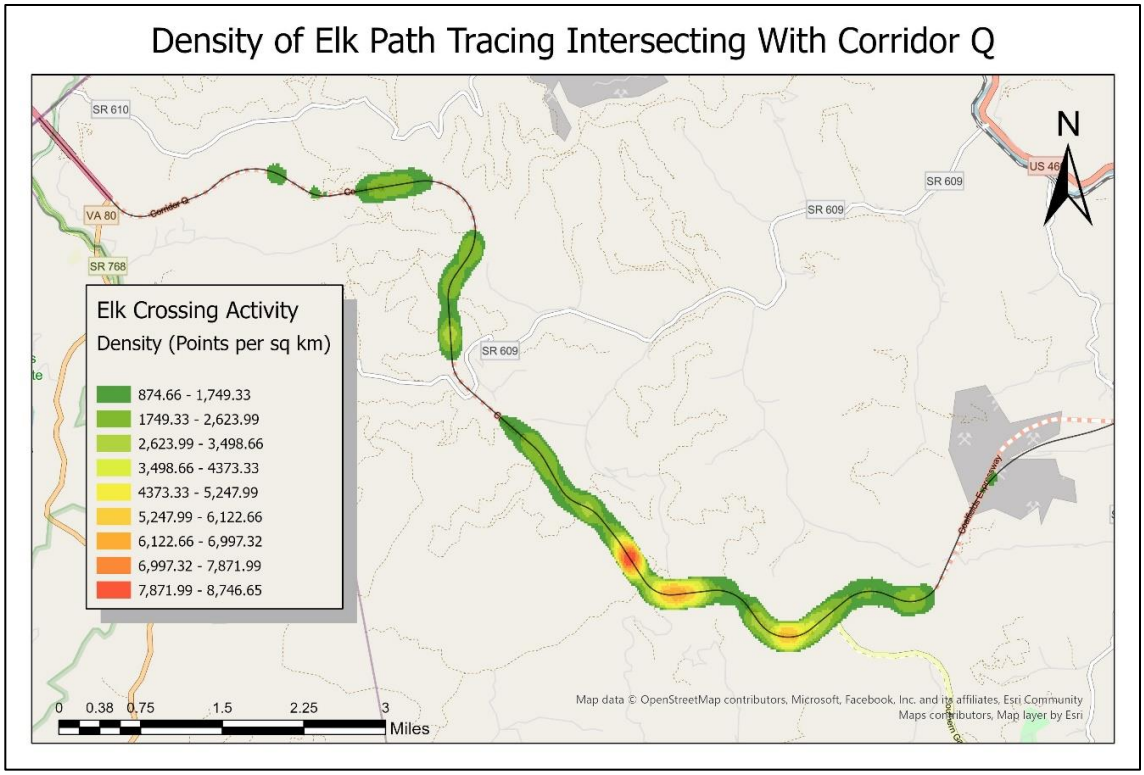


Figure 9. Path tracing of the elk collar data, and the density of the points along the roadway in which the paths intersect.

It should be noted that despite analyzing the path tracing of the elk, allowing for a view into areas of possible crossing density, these paths do not account for the movement of the elk in between each time stamp, which could vary widely from the analysis. However, as this is a point density analysis, it shows an average across the entire roadway, illustrating where crossing activity is more likely occurring. Additionally, the paths can show patterns when overlaid and reviewed visually to determine the general direction of movement, as determined by whether the tracks appear to be more parallel or perpendicular to the roadway.

Roadway Classification

Based on the discussions from the interviews and analyses, the determination was made to classify portions of the roadway by their varying characteristics. This was done to identify areas where AD/DWS strategies could be focused, and to provide this information to each vendor as a method to get a better understanding of how their system could be implemented in a strategic and cost-effective approach.

The site selection process began by using the map data alongside the recorded video footage to note when certain characteristics changed or differed. In order to consider a section of roadway for the installation of AD/DWS, the following criteria were used to determine the level of relative apparent EVC risk. While higher precedence was placed on the elk activity near the roadway, all criteria below were considered important to the site selection process.

- Density of collar data points near the roadway – using point density
    - Low
    - Medium
    - High
- Crossing density – using point density
    - Low
    - Medium
    - High
    - Visual determination of path tracing in relation to roadway
        - Parallel tracks
        - Perpendicular tracks
        - Ratio of parallel vs. perpendicular
- Roadway characteristics – from georeferenced video footage analysis and as-built data. Though all characteristics were important to consider, they are listed here by their level of consideration, from most to least, for the analysis.
    - Line of sight, vertical and/or horizontal
    - Cut/fill/level sections, both sides of roadway
    - Vegetation and other natural structures
    - Number of lanes and non-natural structure presence (e.g., guardrails)

The different sections were classified by analyzing the different areas along Corridor Q, noting where areas transitioned from more closed to open, where the density of elk GPS collar data was higher, and where elk crossing density was higher. The captured footage was observed to classify the state of the roadside as the vehicle drove along the roadway. While there is nuance

depending on the section of roadway being observed, the roadside is generally characterized by either being open (both sides offer access to the roadway), semi-open (one side contains a cut section with tall, near-vertical cliffs), and closed (both sides are cut sections).

A total of 16 sections were noted as distinct areas to consider for the potential of AD/DWS implementation, each with varying characteristics that lead to a higher or lower relative level of risk (see Figure 10). In some cases, it was easy to discern the change in these variables, meaning that there were more discrete, easily distinguishable sections. Some areas appeared to be longer stretches of open roadside and high activity, making it challenging to separate different sections. In addition to the variables discussed, line of sight was also a consideration for transitioning from one area to the next. For some forms of ADS this is more important to note, such as for above-ground area cover options, but others, like BCADS, do not need to take this into account as highly.

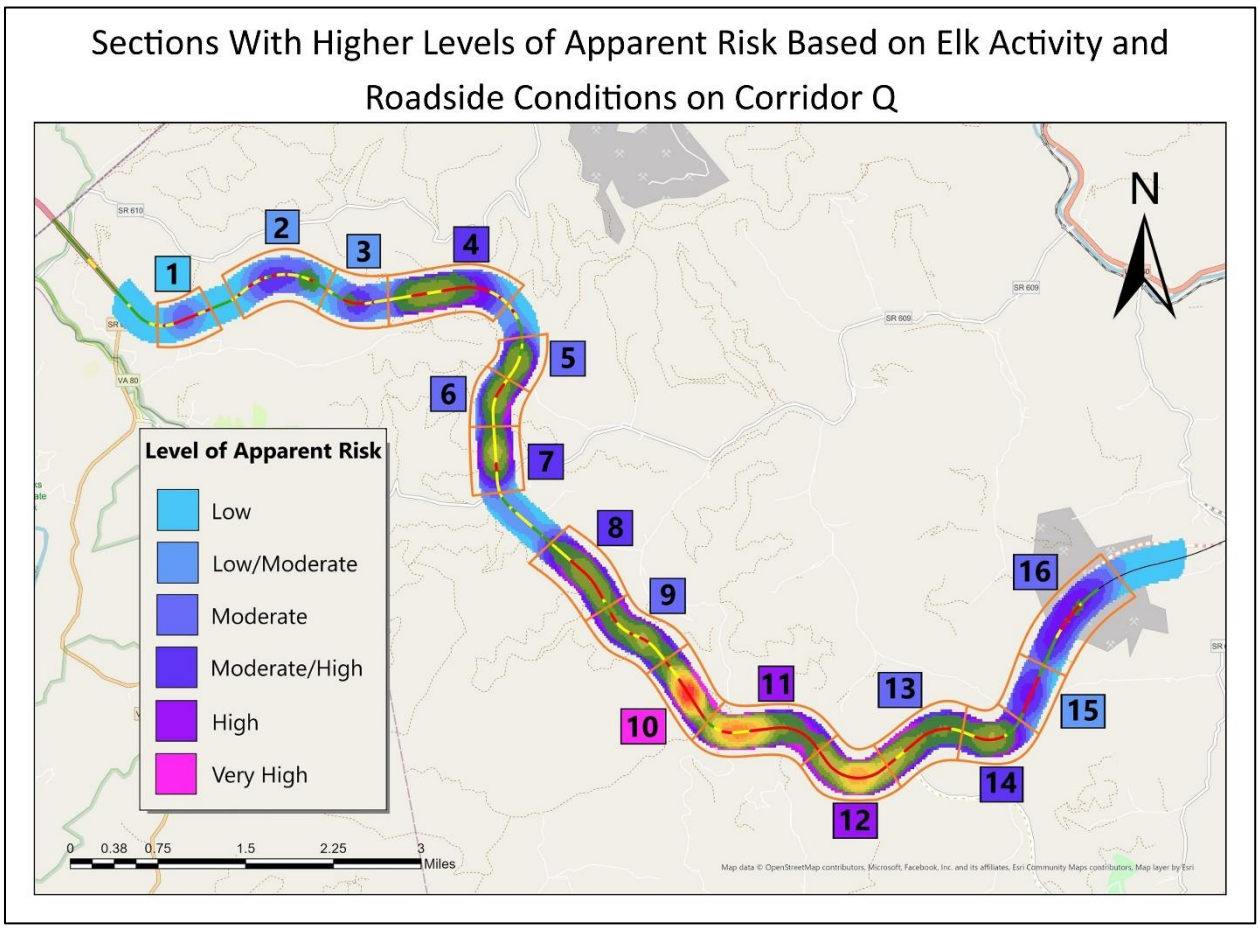


Figure 10. The 16 sections designated as areas to consider for the potential of AD/DWS implementation, and their apparent risk levels of EVCs. Analysis layers are included to show how they influenced the site selection process. For reference of the different layers depicted in this map, refer to Figure 6, Figure 8, and Figure 9.

Informational Packet for Vendors

After the conclusion of the interviews, researchers worked on creating a comprehensive informational packet detailing all relevant aspects of Corridor Q that the vendors had requested prior to providing their assessment of ADS strategies, suitability of using certain ADS based on selected criteria, and ultimately, a cost estimate. It was requested that this estimate include the pricing for parts (ADS unit, communications, power, and any other materials), labor (installation, calibration, training, and any follow-up), and be upscaled to include all areas that the vendors believed to be the sites suitable for utilizing their ADS products.

The following sections detail the information provided to all three vendors that VTTI met with. This informational packet was created using CrossTek's Project Definition Report (see Appendix B) as a guideline to provide all relevant information in a simple, straightforward format that could be given to each vendor for equal opportunity to respond. For the original informational packet, see Appendix C.

Overview

The packet provided a general description of Corridor Q, such as the characteristics of the roadway overall and the challenges of the local wildlife.

Coverage Area

It was explained that most, if not all, of the roadway should be considered an area of concern for wildlife activity. However, an analysis of the roadway shows that several locations can be considered areas where there is higher activity of wildlife. Areas along the roadway range from low to very high activity, depending on location, state of the roadside, access to vegetation, topography, and other factors.

Site Topography, Lines of Sight, and Site Constraints

In some of the sections of higher activity, areas are wider, flatter, and more accessible, but other areas are cut off and more discrete. Some areas may have hills with steep grades that either incline or decline shortly past the side of the roadway, and some have high cliffs on one or both sides of the roadway, causing line of sight obstruction and presenting challenges for detection system location. Some sites blend into the next site, with the only variable being the line of sight, due to the curvature of the roadway.

Signing Strategy

One of the goals of this project is to find an appropriate warning system to alert drivers as animals are approaching, near, or within the roadway itself. This may include flashing lights, imagery, succinct light-up message boards, or other options as part of the signage near the roadway. Specifics of how the drivers should be alerted were not discussed, merely that drivers need to be alerted in some manner.

Sign Imagery/Graphics

There were concerns that if specific images of animals were on a sign along this roadway, such as an image depicting the profile of an elk, that people with nefarious intent could possibly exploit this information to learn where certain species tend to congregate and use the information to poach or otherwise harm these animals. Elk are a protected species in Virginia, and therefore a generic wildlife image, and/or a generic message such as "wildlife detected" is likely to be a better option than species-specific signage.

Sensor Layout

The way in which any sensors are laid out along the roadway will likely vary depending on the section. Accordingly, it was important to consider the likely locations of these possible crossing locations, what characteristics they contain, and how they compare/contrast to other sections. Certain animal detection system sensor types, such as thermal imagery, radar, buried cables, or other considerations, may fare better than others depending on the location.

Power Availability/Connectivity

Gridded vs Off-grid Power

It was explained to the vendors that, currently, there are few to no proposed connected power sources. In all locations, standalone power, such as solar or otherwise, should be considered necessary for powering the systems. Careful consideration should be taken as to the exact location within a section; some areas may be challenging for solar power, as high cliffs/hills can obscure the sun in the early morning, late evening, or both.

Remote Connectivity

For data collection and observational purposes, vendors were asked to consider the use of remote connectivity and include that option in a cost estimate.

Testing and Validation

It was requested that vendors consider the inclusion of visual cameras for surveillance and real-time or historic validation of the alert system. The quantity of these visual cameras would depend on how many cameras are needed to accurately validate the systems.

Warranty, Support, Training, and Documentation Requirements

The importance of including these aspects in the cost estimate were stressed, as was understanding the process for how the systems will be transferred to VDOT once they are installed and validated. This would include the costs of system support and training.

Similarities

When analyzing the various sections, some similarities were noted. To provide more overall information on the roadway characteristics to vendors, each section was described as showing an area in which:

- the density of elk GPS collar data was higher than average,
- the density of elk crossing activity was higher than average, and/or
- observations of the roadside indicate that it is more open and accessible to wildlife, either overall or relative to its surroundings.

Temporal Data

The elk collar data was analyzed temporally to provide more information and context about how the elk appeared to interact with the roadway at different times of day and year. This was done in the event this type of information was relevant—for example, there might be challenges for certain systems to properly function in the daytime vs. nighttime or in the summer vs. winter. When observing the different sections, there were many similarities in both daily and seasonal aspects.

In all areas, more activity concentrated near the roadway was noted during times of sunset and night, with data showing less and more sparsely populated points during sunrise and day. More collar data points were noted as being near the roadway during the winter and fall versus the summer and spring. Generally, the western areas of the roadway appeared to show more activity in winter, and the eastern areas showed more activity in fall.

Additionally, this information can be used in other ways not related to AD/DWS vendor-provided technologies, but which are still useful as a potential mitigation strategy. For instance, temporal information on wildlife activity could be used to determine whether there are certain times of day or year that, should VSL signs be an option to consider, the mandated speed limit could be adjusted during times of peak wildlife activity near the roadway.

Weather/Climate

Weather-related characteristics of the roadway were also considered, but due to the relative similarities along the roadway, this section primarily detailed the characteristics of the region instead of trying to discern the slight differences in how wind or fog may affect the placement of ADS.

- Fog – Corridor Q is mostly flat, and there will therefore be little difference of fog potential for each section.
    - The lowest area that has higher potential is near the bridge, away from most elk collar data points.
    - However, the potential for fog to obscure the roadway is likely along the entire length of roadway, as the sections with lower elevation can be affected by valley fog, while the higher sections can be affected by orographic, or upslope, fog.
- Wind direction and speed will likely not change in most areas, with some possible exceptions depending on the direction of wind over fill sections or between cut sections.
- Access to sunlight will also likely not change among the different areas. The sections where sunlight may be cut off in the morning or evening, such as closed-off areas with high cliffs on either or both sides of the road, show much less GPS collar activity, and have a lower level of priority—most of the highest areas of crossing activity are within the more open sections. There are a few exceptions, such as Sections 1, 14, and 16, as described below.

Differences

The informational packet also described the differences between the sections, which were further detailed for each individual section in the final portion of the packet.

Crossing Zone Types

In the analysis of the roadway, four distinct crossing zone "types" were observed among the 16 total sections, which can assist in determining more broadly the application of certain ADS depending on the similarities between the section types. Below are those types, their characterizations, and the numbers of the sections the typing applies to:

- **Type 1** – These are mostly, to entirely, discrete sections characterized by distinct open areas that are separated on both ends of the section by natural structures such as cut sections of roadway.
    - Sections 1, 3, 8, 15, and 16
- **Type 2** – This type is somewhat like Type 1 in distinction, but as a section is not as discrete, meaning it is not as easy to discern when a section begins and ends along roadway by just observing the footage. These areas are mostly open, but there may be some blind spots in the line of sight. There may be various characteristics to the roadside and there may be transitions between cut and open sections within the area.
    - Sections 2 and 4
- **Type 3** – This type has even less distinction between adjacent sections than the previous type. The roadway can blend between adjacent sections, making it difficult to discern why discrete elk collar activity and crossings occur in the map data; however, the map still shows discrete or semi-discrete hotspots. Line of sight is the best method used to assist in determining section transitions.
    - Sections 5, 6, and 7, and sections 9 and 10
- **Type 4** – This type has the least amount of distinction between sections, with the only difference being line of sight from a vehicle's perspective. These areas are mostly open throughout each section, with lines of sight determined by natural structures when observing the vehicle footage. This type encompasses the Southern Gap area of the roadway.
    - Sections 11, 12, 13, and 14

The final section of the informational packet provided further details of each individual roadway section. This included a determination of overall risk of EVCs occurring within each section using the results of the elk collar data and roadside classification analyses. Table 3 provides these details, which were also given to the vendors in order to receive a more thorough response on system implementation along the entire roadway. The section numbers correspond to the section labels in Figure 10. The wildlife activity, crossing activity, road characteristics, length, line of sight, and natural and non-natural structure columns were compiled from the various roadway analyses to provide all relevant information of each section to the vendors.

Table 3. A compilation of all relevant information on each section from the roadway analyses, including an overall EVC risk based on the results of the elk collar data and roadside classification analyses, provided to the vendors as a method to determine full system implementation.

Section	Type	Overall EVC risk	Wildlife Activity	Crossing Activity	Roadway Characteristics	Length	Line of Sight	Natural Structures	Non-natural Structures
1	1	Low / Very Low	Small amount, low density.	Few crossings, mostly parallel tracks to roadway.	Semi-open, discrete. Cut and open sections throughout.	750 m (0.5 mi)	Some horizontal obscurations from road curvature.	Cut and open sections on north side, vegetation on both sides, fill sections on south side.	2 lanes + climbing lane, eventually 4 lanes. Guardrails proposed on south side.
2	2	Low / Moderate	Small/moderate amount and density.	Some crossings, mainly parallel to roadway.	Semi-open, semi-discrete. Cut, and open sections throughout.	1.1 km (0.75 mi)	Horizontal obscuration, roadway curves southward (from W to E) throughout section.	Cut and fill sections throughout.	2 lanes + climbing lane, eventually 4 lanes. Guardrails proposed for a portion of north side.
3	1	Low / Moderate	Small/moderate amount and density.	Few perpendicular paths, mostly parallel to roadway.	Open, semi-discrete. Open/fill sections throughout.	500 m (0.3 mi)	Horizontal obscuration, roadway curves northward, vegetation obscures vision.	Cut section transitioning to open on south side, vegetation on north side.	2 lanes + climbing lane, eventually 4 lanes. Drainage pond on north side.
4	2	Moderate / High	Moderate amount and density, denser on southern side.	Moderate, multiple perpendicular to roadway.	Semi-open, fairly discrete. Cut and fill sections throughout.	1.5 km (0.9 mi)	Little/no obscuration, straight section.	Cut section on half of north side, some vegetation on south side, but mostly open past cut section.	2 lanes + climbing lane, eventually 4 lanes. Guard rails proposed for half of north side.
5	3	Moderate	Moderate amount and density, more along eastern side.	Low/moderate. ~50/50 on parallel vs. perpendicular to roadway.	Open, semi-discrete (adj to #6). Cut and fill sections.	550 m (0.33 mi)	Little obscuration, roadway curves southward but little vegetation.	Cut section along majority of north side, open on south side.	2 lanes + climbing lane, eventually 4 lanes. Guardrails proposed for a majority of the section. Drainage pond on south side.

Section	Type	Overall EVC risk	Wildlife Activity	Crossing Activity	Roadway Characteristics	Length	Line of Sight	Natural Structures	Non-natural Structures
6	3	Moderate	Moderate amount and density, more along eastern side.	Low/moderate. ~50/50 on parallel vs. perpendicular to roadway.	Open, semi-discrete (adj to #5 & 7). Fill to cut section.	550 m (0.33 mi)	Little obscuration, road curves northward and some cut sections and vegetation.	Cut sections within road section, but mostly open. Some vegetation near southern end.	2 lanes + climbing lane, eventually 4 lanes. Guardrails proposed for majority of section.
7	3	Moderate / High	Moderate/high amount and density, both sides of road.	Moderate, ~50/50 on parallel vs perpendicular to roadway.	Semi-open, semi-discrete (adj to #6). Cut and open/fill sections.	800 m (0.5 mi)	Little to no obscuration, straight section.	Large cut sections on north end of section, opens up on south side.	2 lanes + climbing lane, eventually 4 lanes. Guardrails proposed for majority of section. Drainage pond on north side.
8	1	Moderate / High	Moderate amount, high density near roadway.	Moderate, ~50/50 on parallel vs perpendicular to roadway.	Open, discrete. Fill section throughout.	1.1 km (0.7 mi)	Little to no obscuration, relatively straight section.	Some vegetation, but mostly open, fill section.	Proposed 4 lanes. Guardrails proposed for majority of section.
9	3	Moderate	Moderate amount and density, even distribution along road.	Moderate, ~50/50 on parallel vs perpendicular to roadway.	Semi-open, semi-discrete. Cut and open/hilly sections.	950 m (0.55 mi)	Moderate obscuration, S-bend in roadway and vegetation + cut sections.	Vegetation and cut sections on both sides.	Proposed 4 lanes. Guardrails proposed for most of south side, some of north side. Drainage pond on south side.
10	3	Very High	Very high amount and density, concentrated near open sections.	High, most activity vs. any other segment. Many perpendicular paths.	Open, discrete. Primarily fill/open section throughout.	950 m (0.55 mi)	Little to no obscuration, relatively straight section.	Vegetation on all sides, large cut sections along north side, hills on south side.	Proposed 4 lanes. Guardrails proposed for most of south side, some of north side.

Section	Type	Overall EVC risk	Wildlife Activity	Crossing Activity	Roadway Characteristics	Length	Line of Sight	Natural Structures	Non-natural Structures
11	4	High	High amount and density, esp. on western portion just after cut section.	High, several groupings on either side of road. Many perpendicular paths.	Semi-open to open, non-discrete. Some cut sections, mostly fill/open sections.	1.3 km (0.8 mi)	Some obscurations. S-bend, cut section and vegetation on north side, but rest is open after road straightens. Slight vertical obscuration but is accounted for by splitting between sections.	Hills and cut sections on north side, fill/open on south side.	Proposed 4 lanes. Guardrails proposed for majority of section.
12	4	High	High amount, relatively even distribution, concentrations along southernmost portions.	High, mostly near the center, with groupings on the north and south side. Many perpendicular paths.	Open, non-discrete. Open/fill sections throughout.	1.6 km (1 mi)	Some obscurations from vegetation on both sides and cut section on north side.	On a ridge, some vegetation, primarily on north side.	Proposed 4 lanes. No proposed guardrails.

Section	Type	Overall EVC risk	Wildlife Activity	Crossing Activity	Roadway Characteristics	Length	Line of Sight	Natural Structures	Non-natural Structures
13	4	Moderate	Moderate amount, moderate density mostly on north side.	Low/moderate, primarily on western portion. Some perpendicular paths.	Open, non-discrete. Open and fill sections throughout.	1 km (0.63 mi)	Little to no obscuration, some vegetation on north side on western portion, hill/vegetation section on south side on eastern portion, past intersection.	Much vegetation, some hills.	Proposed 4 lanes. No proposed guardrails. 3-way intersection on south side.
14	4	Moderate / High	Moderate amount, concentrated mostly on north side, but more on south side near opening.	Moderate, several groupings near roadway. Some perpendicular paths.	Mostly open, non-discrete. Cut, open, and fill sections throughout.	750 m (0.5 mi)	Some obscurations from hills and vegetation on both sides.	Hills/vegetation south side, fill section north side.	Proposed 4 lanes. No proposed guardrails.
15	1	Low / Moderate	Low/moderate amount, density concentrated on north side.	Low, few crossings. Even between parallel and perpendicular paths.	Open, discrete. Open and fill sections throughout.	550 m (0.33 mi)	Little/no obscuration. Straight roadway, and little vegetation.	Fill section throughout.	Proposed 4 lanes. Guardrails proposed for majority of both sides of road. Drainage pond on south side.

Section	Type	Overall EVC risk	Wildlife Activity	Crossing Activity	Roadway Characteristics	Length	Line of Sight	Natural Structures	Non-natural Structures
16	1	Moderate	Low/Moderate amount and density on both sides, more on the north side.	Moderate, several groupings on either side of road. Some perpendicular paths between groupings.	Open, discrete. Open and fill sections throughout.	600 m (0.38 mi)	Some obscurations on south side from large hill.	Fill section north side, large hill on south side.	Proposed 4 lanes. Guardrails proposed for majority of north side of road, none on south side.

Vendor Response and Cost Estimates

In this section, the various vendor responses are provided. The details of the cost, including a breakdown of the cost per ADS based on suggested configuration, number of suggested warning signs connected to the ADS, and an estimated cost per unit length of roadway are included in the assessment (see Appendix D). All details of each system suggested by the vendors, such as a breakdown of the cost of individual parts, power requirements, and any other information provided, are included as appendices in this report. A summary of these estimated costs for each system are provided within this section in Table 4.

ProWild/Animex provided several different potential options for systems, including break-the-beam, several forms of thermal area cover, and radar area cover. But due to the unique nature of the elk along Corridor Q, they advised monitoring the roadway itself in addition to the roadsides and surrounding area. Based on their assessment of the various roadway characteristics, they recommended utilizing their most advanced thermal optical bi-spectrum system, which can be used to monitor the roadway, roadside, and surrounding area. With human-sized object recognition ranges of up to 735 m per long-range thermal camera, placing two of these on one post, facing opposite directions, would cover nearly an entire mile of roadway. This type of system may not be the best option for some of the segments, however, especially those sections with line-of-sight concerns. Cheaper alternative thermal camera systems with shorter ranges were discussed as an alternative for these sections. With an array of several of these shorter-range systems, issues due to line of sight are mitigated. However, these short-range cameras can quickly become just as costly, or even more expensive, as the more advanced, long-range cameras, as multiples are needed to cover the same range as the long-range, two-camera system. Additionally, more cables would need to be laid to connect these short-range cameras together and to the main controller. They advised that any area where an array of these cheaper short-range cameras are used will be comparable to the price of one of the long-range, two-camera systems. An example system that they provided, which includes two long-range thermal cameras, a controller box, eight signs (suggestion of approximately two signs per ¼ mile, both facing either direction) each with their own solar unit to power them, and the engineering and software for installation, the expected cost would be $137,250. They advised this does not include items such as tax, labor/construction, cabling, power infrastructure, and any other potential security systems, like standalone visual cameras. A more detailed breakdown of these costs, and the vendor's full response, can be found in Appendix D.

Senstar provided the price of a single unit of their buried cable system, which includes a single unit controller and 800 m of cable, 400 m in either direction from the controller. As these systems could require placement on either side of the roadway, two systems may be needed for a given area. With this information, a single system's cost can be estimated by understanding the length of the areas where these systems would be installed, and doubling the number of systems if the section is over 800 m. In areas where the length of roadway is shorter than 800 m, or less than 1.6 km where two systems are needed, the price would decrease somewhat, as less length of cable is needed to cover the roadway. However, Senstar representative Chris Peguesse emphasized that a thorough investigation of the roadway by Senstar, such as an assessment of the condition of the soil, amount of available space between the roadside and natural structures, and

the presence or proposal of any metallic objects near the roadway, should be completed to provide a more accurate system price.

In a discussion with CrossTekCo, Tim Hazlehurst emphasized the importance of considering fencing as a supplemental mitigation strategy to use with ADS. The discussion reflected on the study completed in Arizona involving an at-grade crosswalk (Gagnon, et al., 2018), and the efficiency of allowing for ADS to be focused on a particular area, closed on both sides by fencing or other structures. While in this case, the width of the at-grade crosswalk was only 20 meters, the same principles apply for funneling wildlife along designated zones that could be as large as 1 mile using wildlife fencing. Reducing the amount of roadway that's necessary to monitor helps to guide where ADS strategies can be most beneficial. Tim Hazlehurst did note that, in several projects that CrossTekCo has been involved with, ADS as a standalone measure appeared, anecdotally, to reduce the number of carcasses that he and his team noted along the roadways their systems were implemented. While Tim believes that strategic placement fencing would improve the overall effectiveness of ADS, using ADS as a standalone measure is also a feasible method of wildlife mitigation.

CrossTekCo offered pricing on radar as an ADS option for Corridor Q. While it may not be suitable for every location along the road, it could serve as a cost-effective approach for a large open area. As these systems can monitor up to 1.6 miles of roadway, their high cost is mitigated by the amount of roadway that can be monitored. CrossTekCo explained that, due to the way these radar systems operate, they are ideally suited for detecting wildlife movements. Tim explained that, if this system is placed near the roadway, fencing can be used as an adjunct inexpensive method to compensate for almost all potential of a blind spot.

In addition to the provided Project Definition Report (see Appendix B), CrossTekCo offered estimated costs of other key components and strategies. With any of these systems, standalone power, such as solar, is required for the controller box, as this will contain all the hardware necessary for the systems to function. CrossTekCo estimates a low-power solar power station, with a 600 W power supply, to cost $6,500, while a more robust 1,440 W power station would cost $9,500. The price of the software can also vary, depending on the complexity of the system, with a range of $1,200 to $18,000. A comprehensive design package would vary as well, with a range of $35,000 to $120,000, depending on DOT requirements. Vendor support is estimated at $25,000, and training of the system and handoff to DOT personnel would cost $9,000. Maintenance contracts for the systems can also be purchased, with an estimate of $14,500 per year. And finally, extended warranties are available, with a typical cost of 7% of the original equipment cost for each year of the extended warranty. A breakdown of these additional costs can be found in Appendix D.

Table 4. An Estimated Cost of Each System, Considering All Components and Other Included Costs, including a Cost Per Unit Length based on the Length of Roadway Each System Covers (For a more detailed breakdown of costs, see Appendix D.)

Vendor	ADS Type	Method	Distance Covered	Est. Single System Cost	Est. Cost per Unit Length
ProWild/ Animex	Area Cover	Thermal, long range	1,470 m (4,823 ft)	$137,250	$93.37/m ($28.46/ft)
ProWild/ Animex	Area Cover	Thermal, short range	368 m (1,207 ft)	$68,250	$185.46/m ($56.54/ft)
ProWild/ Animex	Area Cover	Thermal, short range	736 m (2,415 ft)	$91,250	$123.98/m ($37.78/ft)
Senstar	Underground	Buried cable	800 m (2,625 ft)	$82,180	$102.73/m ($31.31/ft)
Senstar	Underground	Buried cable	800 m (2,625 ft) x2	$138,360	$172.95/m ($52.71/ft)
CrossTekCo	Area Cover	Radar	2,575 m (8,448 ft)	$218,000	$84.66/m ($25.80/ft)

Note: the estimated costs do not include costs such as shipping, taxes, installation, permits, training, and any other follow-on maintenance.

Suggested Sites and Systems for Pilot Studies

In an assessment of the various types of ADS technologies, and how the characteristics of each section denoted in this analysis may mean different technologies will function more efficiently than others, VTTI researchers have presented a suitability breakdown of the technologies for each section in Table 5. Strategically utilizing and placing these different ADS technologies may result in a lower total cost over using a blanket approach of installing systems along the entire length of the roadway without considering the suggested placement location. Due to the layout of some sections, certain ADS technologies could also be placed strategically to reduce the number of systems needed to monitor the same area versus placing systems in each section separately. For instance, a buried cable system or long-range radar system could be utilized in areas that are more open, such as the Southern Gap area, that encompasses four of the sections (11 through 14), separated from each other primarily by line of sight from the roadway. A strategically placed radar system may be able to monitor this area equally as well as other options, but at a significantly reduced cost. Assessments like this, where the entire roadway is considered within the context of the suggested sections to focus ADS strategies, can assist in further reducing the overall cost of a comprehensive system implementation.

Table 5. The suitability of each ADS type provided by the vendors, based on the characteristics of each individual section. Suitability was determined by VTTI researchers from the review of the literature and capabilities of the ADS technologies.

Section	Crossing type	Overall EVC Risk	Radar	Thermal (short range, 1–2 cameras)	Thermal (short range, 3+ cameras)	Thermal (long range, 2 cameras)	Buried Cable[1]
1	1	Low	-	●	○	∗	●/∗
2	2	Low/Mod	○	∗	●	○	○/●
3	1	Low/Mod	○	●	-	○	●/●
4	2	Mod/High	○	∗	∗	●	○/●
5	3	Moderate	-	∗	○	●	∗/∗
6	3	Moderate	○	∗	○	●	∗/○
7	3	Mod/High	●	-	∗	●	○/○
8	1	Mod/High	●	-	∗	●	∗/∗
9	3	Moderate	∗	-	●	∗	●/●
10	3	Very High	○	-	∗	●	○/○
11	4	High	●	-	-	○	○/○
12	4	High	●	-	-	○	●/●
13	4	Moderate	●	-	-	○	●/●
14	4	Mod/High	●	-	-	○	●/●
15	1	Low/Mod	○	●	○	○	∗/∗
16	1	Moderate	○	●	○	○	∗/●

∗ – May be Suitable; ○ – Moderately Suitable; ● – Most Suitable; - – Not Recommended/Suitable

[1]Buried cable contains 2 ratings, one for both sides of the roadway. Assume North/South if roadway is oriented E-W, or East/West if oriented N-S.

Based on the information provided by this analysis, the authors of this report believe the site selection process should be focused on sections where the overall apparent risk of potential EVCs occurring is high. Of the 16 sections denoted from the site selection process, Section 10 is the area with the highest level of potential EVCs and where mitigation efforts can be focused for a pilot test of a single, standalone AD/DWS. Due to the roadway characteristics, a long-range thermal camera system is believed to be the most cost-effective option suitable for this section. The roadway is relatively flat and straight. The roadside conditions vary widely, from steep downslopes to tall, near-vertical cliffs, with the majority consisting of flat or hilly grassy terrain. These characteristics best allow the behavior of wildlife to be monitored to observe interaction with portions of roadway that are more open or closed-off. The section is somewhat discrete on both ends; there are semi-distinct cut sections that separate it from the adjacent sections, which can show how wildlife, and particularly elk, may enter this section. Observations of wildlife travel patterns can also be used to inform whether placement of enhanced fencing may improve the overall AVC mitigation effectiveness.

Additionally, sections 11 through 14 were noted as an area of higher risk for potential EVCs. While only Sections 11 and 12 were designated as areas of high EVC risk, those sections, along with 13 and 14, comprise of a large, open area, known as the Southern Gap, and it is possible that the strategic placement of a radar system as an ADS strategy can allow for this entire portion of the roadway to be monitored at a cost-effective level. However, depending on the limitations of this system, priority should be given to monitoring sections 11 and 12 over sections 13 and 14.

It should be noted that, for any section above, BCADS may also be a viable solution, and consulting with the vendor of a BCADS may be helpful in deciding which of these solutions may be more suitable. In any of these cases, the vendor of the system chosen for the pilot study should be consulted, and a site survey should be conducted by the vendor(s) on the exact placement of system equipment and hardware to ensure the most effective implementation.

CONCLUSIONS

The findings of this report rely heavily on the observed behavior of the local herd of elk and their interactions with Corridor Q. Due to the unique way in which elk utilize the roadway and surrounding area as their habitat, there is a possibility of a shift in their—and other wildlife's—behavior after completion of roadway construction and subsequent increase of vehicular traffic, and the lack of historic crash data typically required for this type of analysis. It is difficult to determine the way the herd will respond to traffic on Corridor Q until the roadway is opened to the public. However, as the VTRC study concluded, based on studies of roadways with EVC data and similar traffic volumes to the anticipated volumes for this roadway, it is possible that elk activity currently observed from Virginia DWR's collar data may not shift once the roadway is complete. Should elk behavior change, continued study would be required to determine and quantify the risks that elk, other wildlife, and traffic on Corridor Q pose and the effects of any AVC mitigation, should it be implemented.

- *Our research experience, review of the literature, and interviews with those having experience with respective systems indicates that, as long as they are properly maintained and calibrated with appropriate monitoring throughout the lifetime of the system, the installation of appropriate AD/DWS technology on Corridor Q in Virginia will likely reduce the rate of occurrence and severity of crashes involving elk and other larger species when compared to no or inadequate action. When compared to other methods for AVC mitigation, AD/DWSs offer improvements over static signage with respect to crash risks.*

- *In general, improved wildlife fencing might be used alongside AD/DWS to further increase overall system effectiveness; one strategy might be used in areas of the roadway where another is not as suitable, or different strategies might be used in tandem to create more dedicated crossing areas, decreasing the length(s) of roadway that an ADS must monitor and where drivers must be vigilant. Due to elk likely using the roadway itself to travel, and the fact that electrified barriers are not appropriate for use on Corridor Q, it is difficult to recommend the use of improved fencing with AD/DWS until further study on the movement of the elk herd is conducted. Caution must be used when considering the length and function of fencing if used with AD/DWS, with extra caution/scrutiny in areas of roadway with three or more travel lanes. Wildlife jump-outs would be required at strategic locations to ensure wildlife do not become trapped in the roadway.*

- *Mitigation scenarios that reduce animal-vehicle exposure, such as using improved fencing to guide wildlife to pre-existing, grade separated crossings like bridges or culverts, or constructing dedicated wildlife crossings like natural overpasses or underpasses with adjacent access control barriers, may be more costly, but are shown to be more effective than AD/DWS strategies because it negates the need for driver response to prevent or mitigate crash incidents.*

RECOMMENDATIONS

1. *If AD/DWS is pursued as a means of reducing EVCs for Corridor Q, VDOT should consider the sections denoted from the site selection process (as seen in Figure 10 and Table 3 and Table 5. The suitability of each ADS type provided by the vendors, based on the characteristics of each individual section. Focus should be placed on areas of higher apparent elk activity and EVC risk, such as Section 10 or Sections 11 through 14.*

2. *If AD/DWS implementation is being considered for Corridor Q, the next steps should include engaging with vendors to arrange a site visit to produce a formal, site-specific proposal.*

3. *VDOT should consider the benefit of including other strategies in combination with AD/DWS, such as fencing, VSL or other changeable message signs, and/or crossing structures, to maximize the overall effectiveness of AVC prevention/mitigation.*

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APPENDIX A

Interview 1 [June 29, 2023] – Marcel Huijser, Ph.D.

The first interview was with Marcel Huijser, a senior research ecologist with the Western Transportation Institute, a transportation research center affiliated with Montana State University. Huijser has been involved with road ecology for nearly 30 years and is one of the leading authorities on the effects of roadways and vehicles on wildlife and vice versa. Huijser has been involved with myriad research reports and has extensive knowledge on AVC mitigation strategies.

The conversation focused on the implementation of ADS on Corridor Q and how this compares to other possible mitigation strategies. Huijser noted that the research on the implementation of ADS is limited, and the survival rates of ADS projects are poor. Most projects are removed after a few years, and follow-on research is very limited once reports are completed. As such, Huijser could not recommend any state DOT to contact that he knew had previously used ADS as a mitigation strategy. He noted that the largest problem with most of the research on ADS implementation is the upkeep and maintenance. A lot of ADS are either removed, abandoned, or fall into disrepair once the research is complete. Huijser emphasized the importance of understanding the future of the systems once implemented, such as who will maintain the systems once they have been installed.

The conversation continued with a discussion of other potential mitigation strategies. Huijser iterated that crossing structures, while costly, will be the best solution for most situations, as their effectiveness is much higher than any other strategy. Additionally, elk demand adequately sized crossing structures to encourage them to cross at these locations instead of continuing to cross the more open roadway.

Huijser also discussed the importance of understanding the goal of any mitigation strategies utilized. For instance, strategies like fencing can inhibit an animal's ability to travel within a habitat range and cut off migration paths, increasing what is known as the "barrier effect" that roadways already create merely by existing.

The interview ended with Huijser emphasizing the importance of structuring the framework of the true goal of any AVC mitigation strategy. He expressed his concern that US-based DOTs tend to have limited mission statements, and that many people do not realize how limited DOT goals are compared to other countries. Generally, other countries take a conservation-centered approach instead of a safety-centered one. While safety is important, it limits the scope to only looking at the impact of AVCs on drivers, and not the other way around. Huijser concluded with a suggestion to not be trapped by artificial boundaries, and that there must be a broader outlook when implementing these kinds of strategies.

Interview 2 [July 17, 2023] – Jeffrey Gagnon

The second person interviewed was Jeffrey W. Gagnon, a statewide research biologist who has worked for the Arizona Game and Fish Department since 1997. Gagnon has previous experience implementing AD/DWS and wildlife crossings on Route 260 in Arizona and Route 550 in New Mexico (Cramer, et al., 2022; Gagnon, et al., 2018).

When shown video for Corridor Q, Gagnon commented, "You have a windy road there, which is a big challenge if you're not going to use fencing. [In lieu of wildlife crossings and fencing as a solution], my personal recommendation [as a cost-effective alternative] is a thermal system, fencing guiding animals to a small area where thermal can detect wildlife as they cross the road." Gagnon discussed the advantages of thermal systems, which he had previously used in Arizona, and how they are effective for detecting larger animals, such as elk. Regarding this technology, Gagnon said,

> *The sensing limits in the area are controlled effectively 50–100 ft wide. Without fencing you must put in more sensors, and your error potential goes up exponentially the further you pull away from an area. Without sensing, you're going to run into some hiccups. The larger the area, the harder it is to deal with it.*
>
> *The thermal systems, we spent a lot of time dealing with false positives and false negatives. The thermals could see mice, which is incredible. We put a filter on it so "coyote size" animals or larger would set it off so not all animals would cause flashing. Then the accuracy became extremely high 90%+ [for elk]. It can detect one-degree heat changes. There are multiple criteria that make the thermal system know it's a [particular animal], such as size, changes in heat, motion, and more. If [the ADS] has all "trues," the flashing [on the DWS] turns on. If it has even one "false," it will not turn on. The thermal component is the key component, but it's really the software that runs everything.*

When asked about a vendor, Gagnon responded, "This system is a CrossTek system. If the detection area is too wide, then the elk look like rabbits to the system and it's harder to filter out. They can be very accurate systems as far as picking stuff up." Regarding potential issues with this system, Gagnon remarked,

> *This system does not seem to tolerate high wind well; it makes the poles vibrate and changes the 'motion' of the thermal reader. I feel most confident with thermal based on what I saw. They were mounted 12 ft off the ground. You would need a stable mount; they didn't have issues in Arizona but New Mexico it would rip signs off, very windy.*

Gagnon mentioned monitoring areas where the fencing ended.

> *For that project (Route 260 Elk Crosswalk), we had a series of wildlife crossings, such as underpasses, for elk and other wildlife. Where the fence ended, it caused an end-run effect. So, we put in an animal detection system at that location. So, if animals didn't use the underpasses, there would be a detection system there to alert drivers instead. New Mexico implemented one there as well. Two ADS on the end of fences that guide animals to existing structures.*

When asked about escape structures, Gagnon responded, "Yeah, for elk we always do it. At a minimum every half mile, to make sure they have opportunities to get out."

Gagnon highlighted the challenge of securing maintenance responsibilities, saying,

> *Because detection systems still have their growing pains, maintenance orgs are not too keen on it. It's a hard sell. Our system went in 2007, but we've upgraded it. We've been trying to get A-DOT to take over maintenance but haven't. The company who made the system ended up taking over the maintenance for much of the duration of the systems existence. DOTs don't want to maintain, and that can be a dealbreaker. Maintenance can kill it in many cases.*

Gagnon mentioned other potential issues such as hacking and vandalism. "We have seen systems get shot a couple of times. We had someone break into our variable message system and type in something," he stated.

Gagnon shared his experience with vendors.

> *I've worked with ElectroBraid, which separated into two companies. I kept working with one of the companies, CrossTek, and there were hiccups, but they seem to be good about going back and adapting if things aren't working. I don't want to claim that everything is going to go smoothly. It's a learning curve for us and the vendors. Detection systems are so unique to the situation you're in. There isn't really a one-size fits all for this sort of thing.*

When discussing alternatives to electrified mats in snowy regions, J.W. Gagnon reported, "There's a product out there that's working relatively well: it's electrified concrete, it's something to keep in the back of your mind. The concrete is a little harder to damage."

"I haven't heard any long-term happy solutions using it," Gagnon shared when asked about break-the-beam. When discussing lidar Gagnon stated, "It has promise but has limitations on distance and needs more work."

He closed by noting,

> *I am personally reluctant to put any detection system on a 4-lane road. Mainly because of the speed, ~70 mph, for motorists. When we had our evaluations on 260, sometimes people would stop in the middle of the road to see the elk, and that caused serious issues with road safety. If this happened on a 4-lane road. someone could have gotten killed. So, it's an important point to consider.*

Interview 3 [July 28, 2023] – Chris Peguesse, Senstar

The third interview was with Chris Peguesse, a consultant with Senstar, a vendor of advanced security systems. Senstar primarily focuses on perimeter security, such as for correctional facilities, airports, and manufacturing facilities. However, Peguesse has been the leader of a group within Senstar that focuses on the application of their equipment for the use of wildlife detection. During his time with Senstar, Peguesse has been working on the function of their Omnitrax product, a buried cable sensor designed for intrusion detection, as an ADS technology. Peguesse has experience working with agencies focusing on the use of Omnitrax as a BCADS solution and was one of the main points of contact with VTTI for ADS studies involving buried cables. In both studies, VTTI worked with Peguesse to ensure proper design and specifications for the areas in which the cables were laid (Druta & Alden, 2015; Druta &

Alden, 2019). Studies like these have helped Peguesse and Senstar to optimize the design of this product to be as functional as possible for this application.

Peguesse explained that the Omnitrax product consists of a single central processor, with a cable length of up to 400 m in each direction, meaning up to 800 m of linear roadside detection is possible with one unit. This processor would remain above ground, while the cables would be buried between 6 and 12 in. underground. Material such as sand or flowable fill would cover the cables, and the earth would be laid on top. The system and any communications can be powered by an array of solar panels.

Peguesse discussed the advantages of this type of system over other options. Because this type of technology functions by being buried underground, visibility-based challenges of above-ground solutions, such as the prevalence of fog, wind, and reduced lines of sight due to road curvature, vegetation, or structures do not affect its operation. This advantage could mean that, in some areas along Corridor Q, BCADS could be the best, and possibly only, solution for animal detection. Additionally, the cable system has the added benefit of being able to discern the location of an animal along the length of roadway on which the system is installed. This could assist with understanding the movement of elk, as it was discussed how they appear to be travelling along the roadway, instead of merely crossing over, in some instances.

The discussion also included challenges of utilizing BCADS. The presence of metallic structures like fencing or guardrails can require some consideration when placing the cables within the ground, as any metallic structure near the cable will cause the signal to be disrupted. However, Peguesse explained that strategic placement of any of these metallic structures can help to minimize any impact. Furthermore, the signal can even be boosted, as these structures are stationary and can be accounted for in the signal. The only concern, Peguesse explained, was the distance of the guardrails to the pavement, and whether they are close enough to cause the sensor to falsely detect passing vehicles. There is also a concern that burrowing wildlife might disturb the buried cable, but by encasing the cable in an impermeable material like flowable fill or sprayable concrete, these burrowing animals are highly discouraged from attempting to disturb the cabling. Additionally, while the cable can detect where along the detection zone an animal is, it cannot discern whether an animal is travelling from the roadside into the road, or vice versa.

The discussion continued with addressing the presence of elk on Corridor Q. Peguesse explained that while the presence of elk does not preclude BCADS as a solution, due to their height and shape, the ability of a buried cable system to properly detect elk is hindered. Because their center of gravity is much higher than other large wildlife in the area, such as deer and bear, there will be less perturbation of the electromagnetic field, which could cause false negatives to become more prevalent. However, Peguesse explained that Senstar already knows how the system can be adjusted to account for this, as elk are similar in their center of mass to humans, which their company is familiar with for the other applications of their technologies. For instance, the cable could be buried at a 6-in. depth, or the sensor's sensitivity could be increased. But these adjustments can cause challenges of their own, such as making it difficult to reduce the sensitivity enough to not detect wildlife too small to be considered a risk to drivers, but not so low that elk are not as reliably detected. Instead, Peguesse suggested that a berm, or a small, raised bank of earth, could be placed on top of a cable laid directly on, or slightly above, the existing ground surface, to drastically increase the area of detection. As elk approach the berm-

inlaid cable, the detection field will "see" the elk much more easily, while not needing to increase the sensitivity, resulting in detection of fewer small animals.

The meeting concluded with a discussion on what information VTTI could provide about the characteristics of Corridor Q to assist with the determination of the feasibility of using BCADS as an option. A buried cable has the benefit of functioning without too many challenges, and the challenges that do exist can be accounted for. However, some characteristics of the roadway do need to be considered more than above-ground solutions. Because this system needs to be buried in soil, the condition of the substrate needs to be understood; the cable's ability to reliably detect wildlife requires a relatively uniform soil, with little to no air pockets or areas with large rocks. A berm avoids this issue, however, and should be considered as a good option for Corridor Q due to the uncertainty of the soil conditions. Beyond this, the location of guardrails and any other metallic material should be considered. It should be noted, however, that the presence of guardrails does not discount BCADS as a solution. Rather, the placement of either the cables or metallic material should be discussed with Senstar to ensure maximum detection efficiency while minimizing the chance of false positives due to passing vehicles.

Interview 4 [August 8, 2023] – Gert Hamberg, ProWild

The fourth interview was with ProWild vendor, Gert Hamberg, who has 25 years of experience in the field. He has spent the last 10–15 years focused on wildlife detection systems.

He emphasized the importance of developing flexible wildlife detection systems. "I keep developing wildlife detection systems since there is not one perfect wildlife detection system for all situations. You need to adapt to the situation. So, you need to be flexible with which technology is used based on the location," Hamberg remarked.

When asked about animal detection, Hamberg responded,

> *We use the standard platform to be able to control different types of detections. We have installed thermal, lidar, active infrared, passive infrared, and radar. We have access to all of them with the same controller. We are going to test lidar again next and see how it works. We've had other results, but technology has progressed so now we are expecting to get good results.*
>
> *Because [the elk] stay on the road, you need additional technology to identify them and differentiate them from the cars. So passive infrared won't work alone as a detector, you must combine it with other technology. Only passive infrared is not recommendable. But, also depending on the area, if it's more open it may work better.*
>
> *We have wireless connectivity over 5 km, [so] each time you need a new controller to control components, we can connect the components wirelessly if needed too. But the best will be a wired system, but it may not always be possible in a remote area. Thermal cameras can also look over 2 km and be able to detect specific animals.*

When asked about the performance of passive infrared systems in adverse weather conditions, Hamberg explained that,

Lidar is supposed to be very resilient to fog and rain and snow. Most of the systems we used are active infrared, and we've added some passive infrared to our active-infrared systems to make them safer. They have several functions such as heat detection. These systems can be sensitive to foggy conditions.

When asked about potential vendors, Hamberg stated,

We are cooperating with Animex in the US. The in-car capability is done with an American company as well. But we try to look for local partners if we can. Animex is also a fencing company and may be convenient. They can be multifunctional, and it can identify and count and detect speeds of the vehicles. It's very nice for the monitoring of the pilot.

Interview 5 [August 11, 2023] – Tim Hazlehurst, CrossTek

The fifth interview was a discussion with wildlife crossing vendor Tim Hazlehurst from CrossTek, with J.W. Gagnon listening in. Tim Hazlehurst shared his background with the research team,

My background is animal science out of college, then I got into electric fencing and energizer design and manufacturing starting in 1990. In 2009, I put on State Route 216 in Arizona the first commercially hardened thermal system, I was aware of, with Jeff and his team conducting research to determine and validation accuracy. We successfully achieved the desired level of accuracy and also upgraded the system for DOT-standard applications, with easy maintenance and long life. We continued to work with thermal imaging as the main system. Getting the right types of sensors and software involved to turn them into accurate detection is a big deal. Off the shelf sensors without special "tuning" and correct sensor types for wildlife environments and wildlife detection to fail quickly. About a year ago, we launched our first radar-based system in Colorado. There's a new one with design complete that will be installed in Florida this Spring. We've taken engineering from the ground-up approach so we could develop the system in tandem with the transportation environment and adjusting the system over the years so that it works in multiple situations. As part of the total design we always consider; how the system will be maintained (our systems are autonomous and edge based for rapid response) and who will maintain, the environmental conditions and seasons, roadway information, objectives for accuracy, validation methods, key performance metrics in addition to detection accuracy, ease of data retrieval and retention, warranty service and more. We've brought all these factors together to create this system.

When asked about finding the best AD/DWS solution, Hazlehurst responded,

We took an engineering approach, instead of using systems off the shelf. I think that's doomed to failure. We're still learning as we install more radar systems. If you can take an engineering first approach, I think you will have more success than just "trying out" random sensors. It looks like you may have issues figuring out where the crossing will occur once the road is active, and some fun projects to figure out how you can control the wildlife and where they cross so you can optimize the sensors. If

you can do something that controls the movement of the animals, while targeting the bigger crossing areas, and considering what the driver will see, that will be the best approach. Motorists need good quality and timely information, so they have enough time to react to the situation. Again, I would consider a mobile-data-collection radar to test out different areas you are uncertain about committing to a permanent system.

The conversation touched on the challenges of deploying sensors effectively. Hazlehurst explained,

If you're talking about lidar, radar, or thermal imaging, you need to have line of sight to where the animals are crossing. Ideally, we have the line of site prior to them crossing, because it can take some time to analyze any image regardless of if its lidar, radar, thermal, or another sensor. A lot of information goes into alerting the vehicle properly. We want to make sure the warning turns on early enough for the driver to get the signal in time. So, you need some clear space around the edges of the road and a line of site. We typically perform a pre-design site analysis to optimize sensor placement.

I don't know how much fencing you'll be able to do. But the sensors have a limited range. The radars we are using now have a radius of 1400 m in each direction. So, to maximize the distance of one radar you would want to see 1400 m on both sides of the road. We want to minimize the infrastructure and maximize the coverage of the area.

Once traffic is put on this roadway it may change elk movement. One thing we are doing is putting radars on a mobile trailer. If you don't have a static situation with crossing, you can use a mobile radar that gathers all the information and warns motorists of wildlife crossing.

Hazlehurst explained that,

For the Colorado project we were only involved in the detection and alerting motorists. There was a major migration occurring with elk, deer, and antelope. What they did was put in combinations of high fence sections and low fence sections. The high fence sections prevent animals from going into the roadway, but the low fence sections allowed wildlife to cross during their migration freely but prevented the cattle from crossing. Even if radar can see long distance, the sight line will be the limiting factor. You need enough clear land on both sides of the roadway. Typically, 35 feet of clear area on each side is adequate. I do think it's important where you can use fencing, to use it or to tie it to underpasses to manage the flow of animals. If we look at (passive) thermal imaging, one camera is maxed out at 200–300 ft along the roadway If it loses too many pixels in the far regions of the field of view (beyond 300 feet) the software has difficulty recognizing (computer learning) the animals. Passive thermal sensors are extremely sensitive and accurate. We can track small mice at 150 feet. It's important to know what the range is on all these sensors. The weather matters too, some sensors will completely fail in certain weather conditions, and some will have a shorter range of accuracy depending on the weather. In heavy rain or snow, even high-quality thermal sensors and radar range will be reduced 10–20%. This is true for every sensor. For lidar, it can go down to 10 ft of visibility in heavy snow. I don't know a lot about buried cable sensors, but we've eliminated it because

it's too hard to calibrate in an environment where you could have snow, rain, moisture, and on/off ramps.

Hazlehurst continued,

What they did in Colorado, where the low and high fence connect, they have a perpendicular fence so that the animal can't turn and get to the high fence and get stuck inside, and they've put in jump-outs in places where needed. They put white stripes on the road at the end of the perpendicular wing-fence taking the right-of-way section and fencing it off. They put in a bunch of large, angular rocks as well to prevent animals from wanting to approach that opening. It's all relatively new, less than a year, so the results will take some time to develop.

The other studies I've been involved in, we found better success with cattleguard and electrified barrier than electrified barrier by itself. One thing we can offer you is our belief in sensors and our history with them. The thermal has a limited range, but good at the end of a fence situation or concentrated crossing. If it's controlled up until that point, it's great. It's good in all weather, and we've had the most success. The radar is newer, we have another test in process in Nevada, so by the end of this year it'll be 3 in the US. We mounted several different sensors on the same trailer. One opportunity is to try a radar or thermal imaging camera, and put it on a mobile platform and move it around to show the Virginia DOT what the capability is on those sensors based on weather, reliability, etc. You could collect data on a permanent solution before you implement it. You couldn't do the buried cable on that, but maybe there's a solution there.

When discussing different challenges for thermal and radar, Hazlehurst elaborated,

So, the big thing is careful placement to optimize line of sight for both radar and thermal. The angle of declination matters. You can integrate different sensors to activate the same set of warning signs. If there's a small blind spot for the radar, you can use a thermal camera to cover that area, if it's only blocking a couple hundred ft and tie it into the same system.

We'd be happy to help you with any sensors and create a mobile platform to provide you with the ability to gather data and present it going forward and show what works and what doesn't along the roadway. Then you can show the DOT what's most effective in terms of accuracy, performance, and cost. Just a suggestion. Thermal is good for rain, fog, etc. Lidar is not good since it is dependent on light, but lidar can be great in certain conditions.

When asked about estimating costs Hazlehurst answered,

We would ask questions on what warranty and maintenance you want; do you want to be able to maintain it yourself, do you want it online, do you want data stored on site and to collect it, what data do you want to keep. If a DOT comes to us and tells us they want wildlife detection on a section. We go out and look at the specific area and do a preliminary report, which usually costs ~$10,000, we would look at the area, power sources, and talk to the stake holders to learn what they want and expect out of this system. I can send you the typical preliminary report outline to show the types of

questions we ask, but we usually need to go on site to look at what we are dealing with. But this is for a permanent installation, fixed in place. If we did a trailer, we set it up to handle all of that and move it around and calibrate it to that area.

He ended the conversation by saying,

I could give you a ballpark estimate on different projects without seeing the site. The track record of people who have just taken radars off the shelf and immediately implement them usually does not work well. Certain radar types are not good at seeing animal movement and some radars are not good at filtering out the background noise we see in the roadway environments. The cost of engineering is important because that's what makes it work. But yeah, I can give you the ballpark for each step. Some of these costs are based on the specific DOT requirements that vary from state to state. So, our costs can change based on what the DOT needs from us. I'll send you the design sheet and put together some ballpark pricing together and maybe one-radar and one-thermal camera.

Hazlehurst offered the following in closing, "One thing I wanted to mention is turning on signs at different times. The concern around habituation is a big one for human driving behavior, especially if the detection is not completely accurate."

Interview 6 [August 17, 2023] – Animex and ProWild

The sixth interview was held with Steve Bega and Steve Mars from Animex, as well as Gert Hamberg from ProWild.

Regarding funding, Mars mentioned,

It would be good to see if they [VDOT] applied for grant money, if they did want overpasses/underpasses. If anyone applies for that money, they're going to get it. Franky, the time to do it is now when there's no hindrance for equipment. The biggest cost will be to close an active roadway, versus a roadway that isn't open yet. In Arizona and Colorado, they are doing a huge initiative, 300 million dollars of putting in underpasses, jump outs, and large fence at I-15 Colorado. They have had too many fatalities with humans and *elk.*

Bega emphasized that Animex could provide support in various capacities. He continued,

We've been in this game for years now, across the world, so we've seen it all and committed to renovation and making sure any project has the best equipment considered and implemented within the budget. It can be the concept phase, pilot, completion. There is no one size fits all for ADS. The location, budget, and elk pattern are going to matter immensely.

Hamberg agreed and asked,

What sections of this road are going to be protected by this technology? What do these sections look like so we can see what technology would fit best on those sections, geography matters? We provide systems and have several types. First 2 km thermal camera and radar should be the first items. Thermal cameras should also set

> *parameters to determine certain areas that need to be detected. If you change the position of a camera you need to reset the parameters. For the components we can get some estimated pricing, but power can change price significantly, so we can give that to you without powering, then can add solar panels later.*

When asked about wind and fog conditions, Hamberg mentioned, "If you had fencing, active infrared would be an option. Also, because of the fog it may be better to use thermal for 1 km [rather] than 2 km, because it'll be more vulnerable to fog."

Hamberg mentioned that if we "have two types of technology, we can add them to our main controller. So that may be a good option to save money on controllers."

Interview 7 [September 26, 2023] – Gary Lester, MBP

Gary Lester has worked with MBP as a service executive in the Abingdon office for the last 3 years. Prior to that, he worked for 30 years at VDOT, and for the last 10 he was the district bridge engineer. It was suggested to the research team to reach out to Lester to discuss the various costs when installing systems and hardware along the roadside.

When asked about getting quotes for pricing, Lester said,

> *I think it would be advantageous to get this data from different vendors and systems. One company could be considered for something and not another. Once you get that info together would be helpful so we wouldn't have to go out to make an estimate. There's probably not a lot of data out on these types of systems. It's pretty new technology. It would help to have that information up front.*

This way his team would not have to talk to the same vendors that were already interviewed.

When asked about what information is needed for a cost estimate, Lester said, "The specification on the installation procedures for each equipment, so we can know what equipment is needed from us." When asked if VDOT would need a permit, Lester responded, "VDOT would have to do the environmental permit, but no construction permits."

APPENDIX B

Project Definition Report, Provided by CrossTekCo, Used to Create Informational Packet for Vendors

Wildlife Detection Systems

Project Definition Report

crosstek™ AFFORDABLE WILDLIFE SOLUTIONS

Capital Budget: $10 - 15,000
Timeline: 2-3 Weeks

Wildlife-vehicle collisions on North American roadways are a significant problem faced by all transportation agencies. These collisions often result in serious personal injuries, endanger various wildlife species, and cost millions of dollars annually.

Wildlife Detection Systems (WDS) are a highly effective tool designed to reduce animal-vehicle collisions, protect wildlife, and improve safety for motorists. CrossTek integrates proven Intelligent Transportation System (ITS) components with high-performance security technologies to solve this very challenging problem.

To implement WDS effectively, the installation must be properly designed to suit an agency's operations, human safety and wildlife concerns while addressing the specific physical configuration of the chosen site. Factors such as site terrain and topography, service availability, remote communications and messaging strategy will influence the design. CrossTek designs WDS for "Long Open Road Corridor Crossings" and "Limited Area Wildlife Crosswalks". The Open Road System relies primarily on Radar sensors whereas the Crosswalk System relies primarily on Thermal sensors. Both systems were developed to be highly flexible, autonomous solutions that can be adapted to suit the needs of the project: sensor placement and type can be adjusted, messaging can be simple or complex, connectivity can be remote or local and power can be on or off-grid. In order to optimize the solution, appropriate engineering needs to be undertaken up front. The recommended first step in the implementation process is the Project Definition Report (PDR). The purpose of the PDR is to undertake the preliminary engineering work necessary to define, plan, and cost the project. The main tasks of the PDR include:

1. Site Assessment
2. Requirements Definition
3. Conceptual Design
4. Implementation Strategy
5. Cost Proposal
6. Report Preparation

Important factors that are reviewed and confirmed as part of the PDR process include the following:

- Problem definition. What challenges are being encountered? Where are collisions occurring? What wildlife types? What time of day/season?
- Coverage area. What segment of the roadway should be covered, including shoulders and adjacent areas?
- Site topography, lines of sight, and site constraints. Are there existing obstructions or intersections?
- Signing strategy. What active components will be used for the motorist advisory messaging? (ex: DMS, flashing beacon). What static imagery should be used?
- Sensor layout. What sensor configuration is optimal to ensure full coverage and accurate detection?
- Power availability and proposed communication architecture. Does off-grid power need to be included? Is remote connectivity required?
- Concept of operations. Overview of how the system will operate, including parameters, functions, and features. Who will interact with the system and in what manner? (ex: reports, alerts, etc.)
- Site design. Are there specific infrastructure standards that need to be adhered to?
- Implementation process. Who will be responsible for what portions of the work?
- Testing and validation. Video coverage is required to support validation. What type and quantity of video cameras are optimal?
- Warranty, support, training, and documentation requirements. How will the project be handed over?

Our team knows how to facilitate discussion among diverse stakeholders and has the proven experience and expertise to assist our clients in answering these questions and refining the proposed solution. The resulting PDR deliverable is a concise engineering report that summarizes all findings and presents recommendations and costs for project implementation so that the client can move forward to approval and construction in an informed manner.

Contact: Tim Hazlehurst
email: Timh@crosstekco.com
phone: (330) 414-1995

WDS OVERVIEW

- Highly accurate and reliable system for detecting wildlife and advising motorists
- Lower costs compared to underpasses, overpasses, wildlife fence and barriers
- Designed to effectively cover long stretches of roadways and shoulder areas or limited area Crosswalks
- Long- and short-range capability achieved by a modular system, with up to 3-mile range sections for a single sensor, resulting in cost-effective installation
- Tailored to all weather conditions
- All components integrated into a single operational platform for ease of use
- Includes support infrastructure to properly validate performance
- Accurately detects all medium to large size animals, simultaneously tracking all animals
- Proven technology and award-winning design and deployment methodology

FEATURES

- Stationary Long Range (RAD-OR™), Mobile (RAD-MD™) and Short Distance Crosswalk (RAD-X™) applications available
- Low false alarm rate
- Low maintenance, autonomous operation
- Straightforward installation
- Modular long-range system
- Ability to integrate multiple detection technologies
- Highly configurable parameters, filters, & rules allow system to adapt and respond to different deployment conditions
- Integrated video and event recording
- Detection events linked to video recording timeline for ease of review
- Remote access allows users to interact without the need to travel to the site
- Automated alerts for system status

ADVISORY SIGN STRATEGY

- System supports any type of electronic messaging
- Flashing beacons
- LED displays
- NTCIP-compliant electronic dynamic message signs

PERFORMANCE METRICS

- Vehicle volumes and speeds
- Quantity of detection events
- Sign activation time
- All system events logged for traceability
- Embedded reporting function for all data

FULL IMPLEMENTATION SUPPORT

- Site analysis
- Requirements definition
- Messaging strategies
- Preliminary and detailed designs
- Turn-key installation and testing
- Training and technical support
- Maintenance service

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APPENDIX C

Informational Packet of Site Selection Characteristics and Criteria provided to vendors

Problem Definition

The Challenge

Corridor Q, a new 14-mile roadway in a rural area of southwest Virginia is nearing completion. Concerns have been expressed about its impact on the local wildlife, primarily a recently introduced population of elk. Due to the limited available information about vehicle activity and how the local wildlife, particularly the elk, may react to the sudden increase of public traffic once the roadway is open to the public, there is much unknown about what wildlife conflict mitigation strategies will work best. In this study, we focus on the feasible potential of using animal detection systems along the roadway to alert drivers as a cost-effective measure to help mitigate potential conflicts occurring on Corridor Q before the roadway is opened.

Collision Data/Information

As this is a new roadway being constructed in the area, there is no historic crash data to reference. Due to its unusual characteristics (e.g., relative flatness, higher proposed speed limit, higher expected vehicle traffic, difference in line of sight) versus nearby roadways, it is difficult to predict what the crash data will look like along this roadway compared to other roadways in the same area.

Wildlife Species in the Area

There are many large and medium animal species present in the area, including bear, deer, fox, turkey, and bobcat. The most notable, however, is a population of elk that was introduced over a decade ago in a nearby location. The herd has flourished since its introduction to the area and has been observed migrating towards Corridor Q from a location south of the roadway. According to GPS collar tracking data, the elk are frequently active near the roadway, and they appear to be using it as their habitat/migration area. These animals are a particular challenge for wildlife-vehicle conflict mitigation due to their size, apparent indifference towards passing vehicles, and tendency to frequently graze on the low-growing vegetation near the roadway.

Temporal Information

Wildlife has been seen along the roadway at all times of the day and year. However, the elk population's GPS collar tracking data shows that they are more active, and tend to congregate near the roadway, in both the fall and winter months and during sunset and at night.

Coverage Area

Most, if not all, of the roadway should be considered an area of concern for wildlife activity. However, an analysis of the roadway shows that several locations can be considered areas of higher activity, all of which are detailed in the Site Selection portion of this packet. Areas along the roadway range from low to very high activity, depending on location, state of the roadside, access to vegetation, topography, and other factors.

Site Topography, Lines of Sight, and Site Constraints

In some of the sections of higher activity, areas are wider, flatter, and more accessible, but other areas are cut off and more discrete. Some areas may have hills with steep grades that either incline or decline

shortly past the side of the roadway, and some have high cliffs on one or both sides of the roadway, causing line of sight obstruction and presenting challenges for detection system location. Some sites blend into the next site, with the only variable being the line of site, due to the curvature of the roadway. More information on each site's characteristics is provided in the Site Selection portion of this packet.

Signing Strategy

The goal of this analysis is to find the best system to warn drivers as animals are approaching, near, or within the roadway itself. This may include flashing lights, imagery, succinct light-up message boards, or other options as part of the signage near the roadway.

Static Imagery

Discussions were held regarding what signage should be used. Concerns were expressed that if specific images of animals were on a sign along this roadway, such as an image depicting the profile of an elk, that people with nefarious intent could possibly exploit this information to learn where certain species tend to congregate and use the information to poach or otherwise harm these animals. Elk are a protected species in Virginia, and therefore a generic wildlife image, and/or a generic message such as "wildlife detected" is likely to be a better option than species-specific signage.

Sensor Layout

The way in which any sensors are laid out along the roadway will likely vary depending on the section. Accordingly, we determined where these possible crossing locations are likely to be, what characteristics they contain, and how they compare/contrast to other sections. Certain animal detection system sensor types, such as thermal imagery, radar, buried cables, or other considerations, may fare better than others depending on the location.

Power Availability / Connectivity

Gridded vs Off-grid Power

Currently, there are few to no proposed connected power sources. In all locations, standalone power, such as solar or otherwise, should be considered necessary for powering the systems. Careful consideration should be taken as to the exact location within a section; some areas may be challenging for solar power, as high cliffs/hills can obscure the sun in the early morning, late evening, or both.

Remote Connectivity

For data collection and observational purposes, we would like to consider the use of remote connectivity and include that option in a cost estimate.

Concept of Operations

System Operation

The primary function of operation is to warn drivers of wildlife close to the roadway. As part of pilot testing, and if there are possible plans for follow-on implementation, access to any reports on the data collected should also be considered, if available, to examine for any indicators of high false-positive or false-negative rates.

Who will interact with the system?

The Virginia Department of Transportation (VDOT) will take full control of the systems once they are fully implemented.

Site Design

This roadway will be a part of the US-460 highway, which connects southwest Virginia to Kentucky. The infrastructure standards should follow whatever standards currently exist for US Highways within Virginia.

Implementation process

Who is responsible for what portions of work?

We would like to know both the cost of standalone systems, and the cost of installation by your company. There is an option to use a contracting company that works closely with VDOT to install the systems, but we would like to consider the option of the vendor completing this process as well.

Testing and Validation

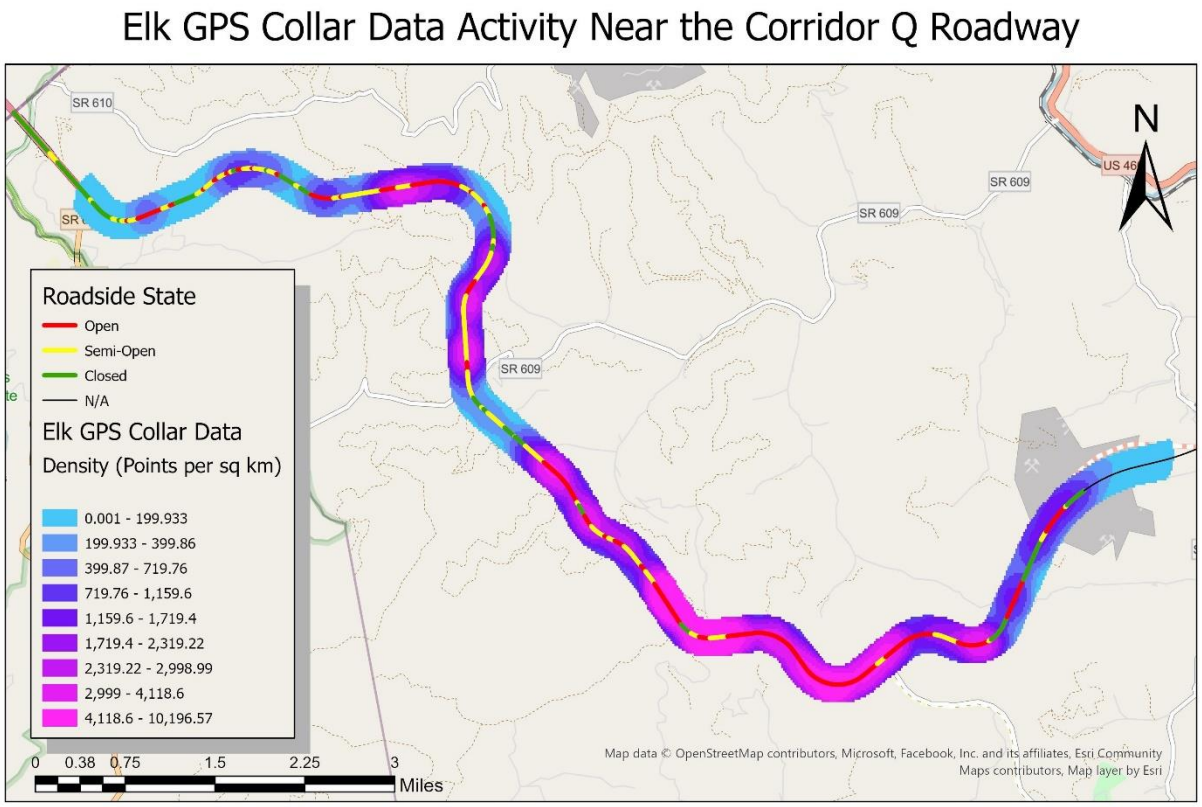
We would like to consider the inclusion of visual cameras for surveillance and real-time or historic validation of the alert system. The quantity will depend on how many cameras are needed to accurately validate the systems. Smaller areas that are using thermal imagery may only need one visual camera, but larger areas may need multiple to cover the entire roadway being monitored by detection systems.

Warranty, Support, Training, and Documentation Requirements

We would like to understand the process for how the systems will be transferred to VDOT once they are installed and validated. This would include the costs of system support and training.

Corridor Q Map Information

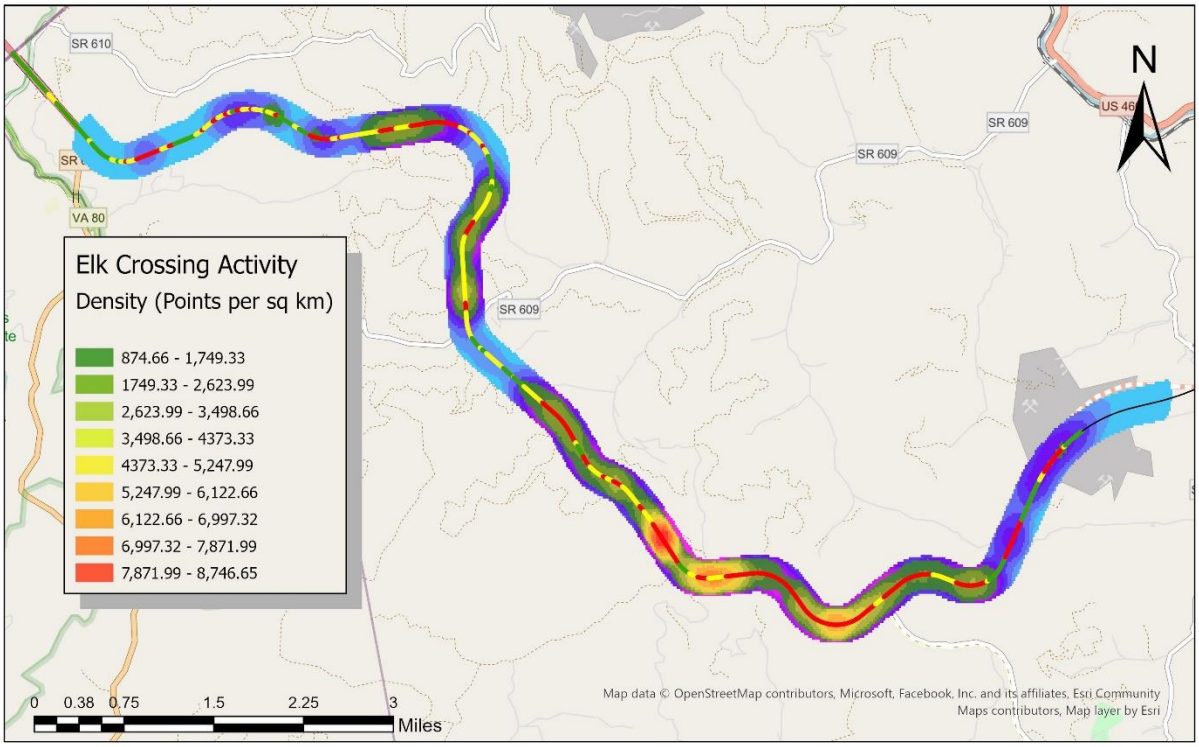
As part of roadway analysis, a point density analysis was performed on elk collar data within 100 m of the roadway. Additionally, roadway footage was observed to classify the state of the roadside as the vehicle drove along the roadway. As this roadway required excavation in some areas and filling in others, the roadside differs in its characteristics. While there is nuance depending on the section of roadway being observed, the roadside is generally characterized by either being open (both sides are clear), semi-open (one side contains a cut section with tall, near-vertical cliffs), and closed (both sides are cut sections). Areas in which the roadway is considered more open, and areas of higher elk activity appear to align in an observation of both layers in a map (see following figure).



GPS collar tracking activity occurring near the roadway along Corridor Q.

For an additional step of analysis, each elk's collar activity was tracked, meaning lines were drawn from one data point to another until the entire path of each elk was drawn. While we cannot assume these are the exact paths that each elk took, the instances where each of the elk's paths intersected the roadway were mapped. This can provide insight on the roadway locations that elk may tend to cross. Another point density analysis was conducted on the locations of these path intersections (see following figure).

Density of Elk Path Tracing Intersecting With Corridor Q



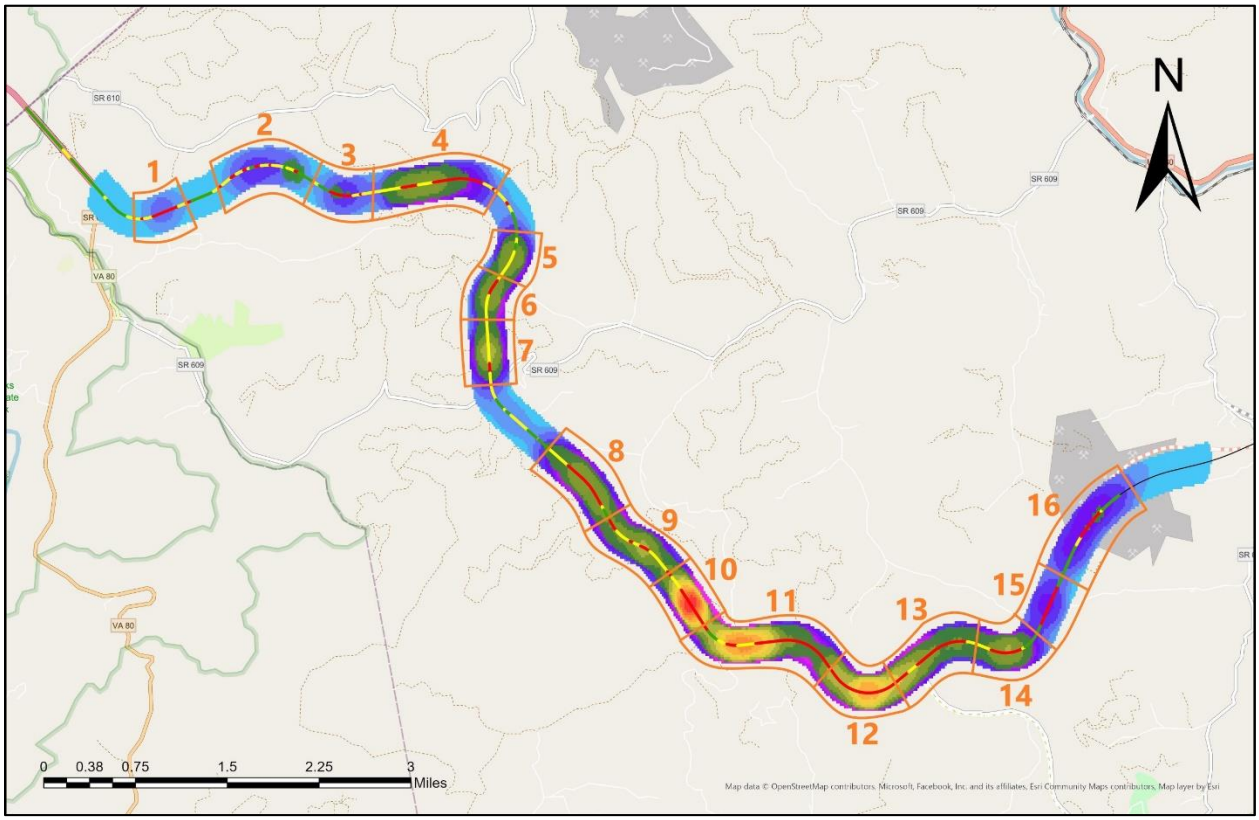
Path tracing of the elk collar data, and the density of the points along the roadway in which the paths intersect.

In the resultant map, the density of elk collar activity near the roadway and the density of the path tracing intersections appear to align with each other and the more open areas from the road classification. And while we cannot definitively say this is where all crossings are occurring, it provides another layer of support for where mitigation efforts could be prioritized.

In the following section, these map layers were used in conjunction with each other to provide a method to select sites along the roadway where efforts can be focused.

Site Selection

Corridor Q:



Criteria

In order to consider a section of roadway for the installation of animal detection systems, the following criteria were used to determine the level of relative apparent risk.

- Density of collar data points near roadway – using point density in ArcGIS.
  - Low
  - Medium
  - High
- Crossing density – from temporal tracking collar data in ArcGIS. Visual determination.
  - Parallel tracks
  - Perpendicular tracks
  - Ratio of one vs. the other
- Roadway characteristics – from georeferenced video footage analysis and as-built data.
  - Line of sight, vertical and/or horizontal
  - Cut/fill/level sections, both sides of roadway
  - Vegetation & other natural structures
  - Number of lanes & non-natural structure presence (e.g., guardrails)

Similarities

To provide more overall information on the roadway characteristics, each section shows an area in which:

- the density of collar data was higher than average,
- the density of crossing activity was higher than average, and/or
- observations of the roadway indicate that it is more open, either overall or relative to its surroundings.

Daily activity

In all areas, more activity concentrated near the roadway was noted during times of sunset and night, with data showing less and more sparsely populated points during sunrise and day.

Seasonal activity

Most collar data was noted as being near the roadway during the winter and fall. Generally, the western areas of the roadway had more activity in winter, and the eastern areas had more activity in fall.

Weather/climate

- Fog – Corridor Q is mostly flat, and there will therefore be little difference of fog potential for each section.
    - The lowest area that has higher potential is near the bridge, away from most elk collar data points.
    - However, the potential for fog to obscure the roadway is likely along the entire length of roadway, as the sections with lower elevation can be affected by valley fog, while the higher sections can be affected by orographic, or upslope, fog.
- Wind direction and speed will likely not change in most areas, with some possible exceptions depending on the direction of wind over fill sections or between cut sections.
- Access to sunlight will also likely not change among the different areas. The sections where sunlight may be cut off in the morning or evening, such as closed-off areas with high cliffs on either or both sides of the road, show much less GPS collar activity, and have a lower level of priority—most of the highest areas of crossing activity are within the more open sections. There are a few exceptions, such as Sections 1, 14, and 16, as described below.

Crossing Types

In an analysis of the roadway, four distinct crossing section "types" were observed among the 16 total sections. Below are those types and their characterizations:

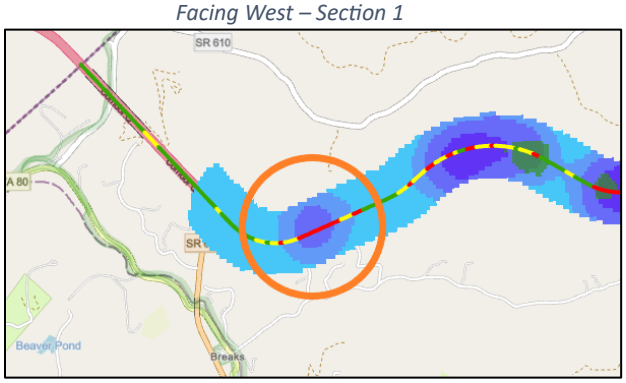
- **Type 1** – These are mostly, to entirely, discrete sections characterized by distinct open areas that are separated on both ends of the section by natural structures such as cut sections of roadway.
    - Sections 1, 3, 8, 15, and 16
- **Type 2** – This type is somewhat similar to Type 1 in distinction, but as a section is not as discrete, meaning it is not as easy to discern when a section begins and ends along roadway by just observing the footage. These areas are mostly open, but there may be some blind spots in the line of sight. There may be various characteristics to the roadside and there may be transitions between cut and open sections within the area.
    - Sections 2 and 4

- **Type 3** – This type has even less distinction between adjacent sections than the previous type. The roadway can blend between adjacent sections, making it difficult to discern why discrete elk collar activity and crossings occur in the map data; however, the map still shows discrete or semi-discrete hotspots. Line of sight is the best method used to assist in determining section transitions.
    - Sections 5, 6, and 7, and sections 9 and 10
- **Type 4** – This type has the least amount of distinction between sections, with the only difference being line of sight from a vehicle's perspective. These areas are mostly open throughout each section, with lines of sight determined by natural structures when observing the vehicle footage. This type encompasses the Southern Gap area of the roadway.
    - Sections 11, 12, 13, and 14

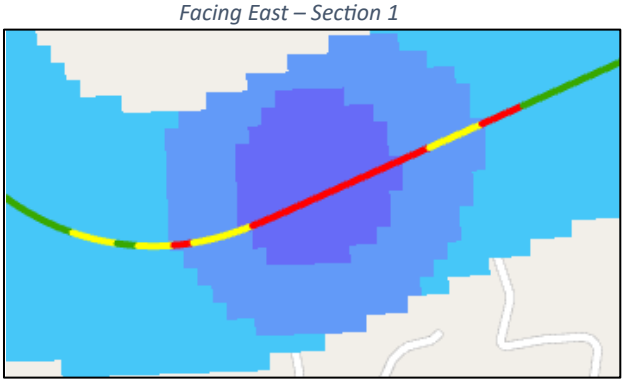
Section #1	
Crossing Type	1
Overall Risk	Low/Very Low
Wildlife Activity	Small amount, low density
Crossing Activity	Few crossings, mostly parallel
Roadway Characteristics	Semi-open, discrete, cut, and open
Length	~750 m (~0.5 mi)
Line of Sight	Some horizontal obstruction
Natural Structures	Cut and open sections on north side, vegetation both sides, fill sections on south side.
Non-Natural Structures	Currently 2+ Climbing lanes, eventually 4 lanes. Guardrails proposed along south side.

Facing West – Section 1

Facing East – Section 1



Map Area – Section 1

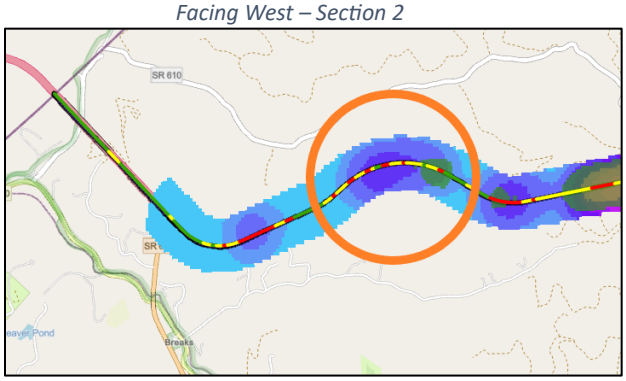


Map Area (Zoomed) – Section 1

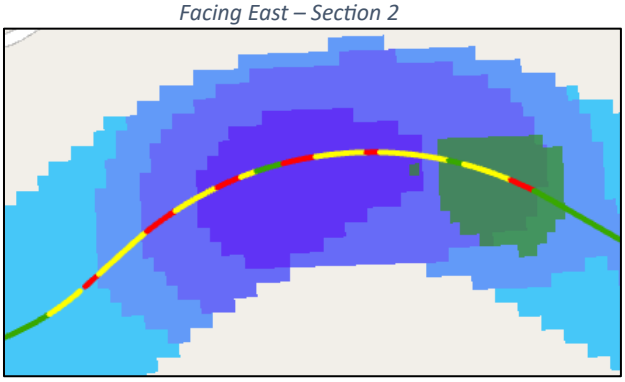
Section #2	
Crossing Type	2
Overall Risk	Low/Moderate
Wildlife Activity	Small/moderate amount, low-moderate density
Crossing Activity	Some crossings, mainly parallel
Roadway Characteristics	Semi-open, semi-discrete, cut, and open sections
Length	~1.1 km (0.75 mi)
Line of Sight	Horizontal obscuration, roadway curves southward throughout section.
Natural Structures	Cut and fill sections throughout.
Non-Natural Structures	Currently 2+ climbing lanes, eventually 4 lanes. Guardrails proposed for a portion of north side.

Facing West – Section 2

Facing East – Section 2



Map Area – Section 2

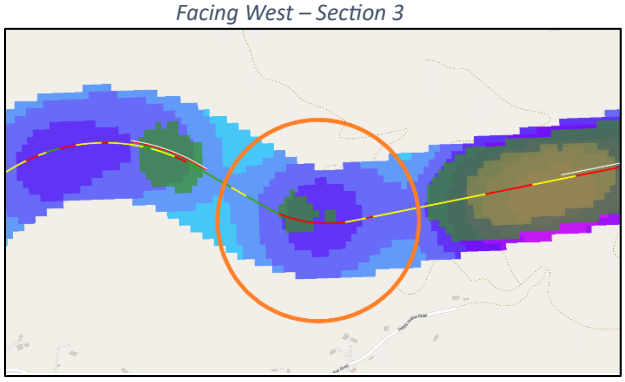


Map Area (Zoomed) – Section 2

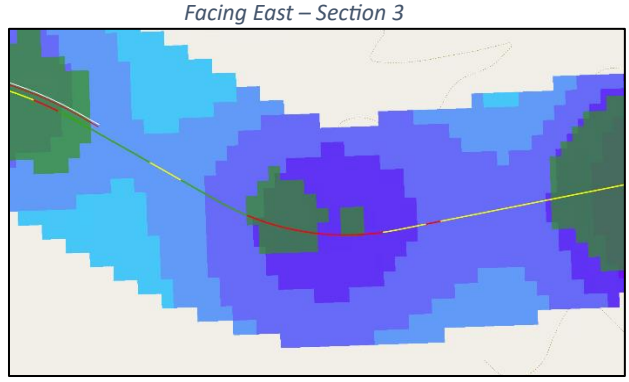
Section #3	
Crossing Type	1
Overall Risk	Low/Moderate
Wildlife Activity	Small/moderate amount, low/moderate density
Crossing Activity	Few perpendicular paths, mostly parallel
Roadway Characteristics	Open, semi-discrete, open/fill sections
Length	~500 m (~0.3 mi)
Line of Sight	Horizontal obscuration, roadway curves northward, vegetation obscures vision.
Natural Structures	Cut section transitioning to open on south side, vegetation on north side.
Non-Natural Structures	Currently 2+ climbing lanes, eventually 4 lanes. Drainage pond on north side.

Facing West – Section 3

Facing East – Section 3



Map Area – Section 3

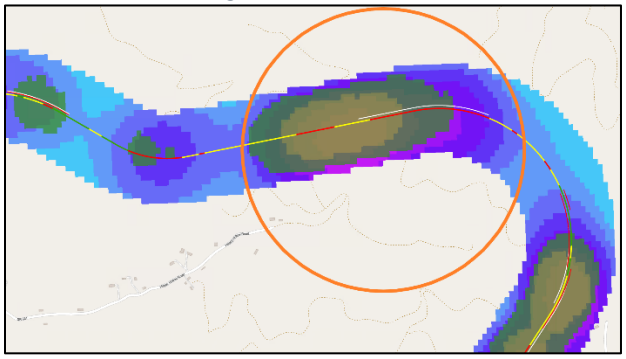


Map Area (Zoomed) – Section 3

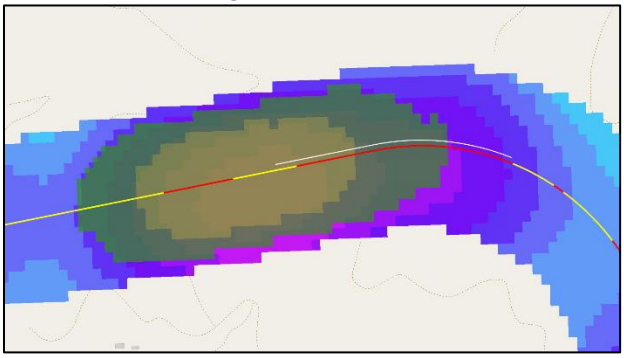
Section #4	
Crossing Type	2
Overall Risk	Moderate/High
Wildlife Activity	Moderate, denser on southern side
Crossing Activity	Moderate, multiple perpendicular
Roadway Characteristics	Semi-open, fairly discrete, cut and fill sections
Length	~1.5 km (~0.9 mi)
Line of Sight	Little/no obstruction, straight section.
Natural Structures	Cut section on half of north side, some vegetation on south side, but mostly open past cut section.
Non-Natural Structures	Currently 2+ climbing lanes, eventually 4 lanes. Guard rails proposed for half of north side.

Facing West – Section 4

Facing East – Section 4



Map Area – Section 4

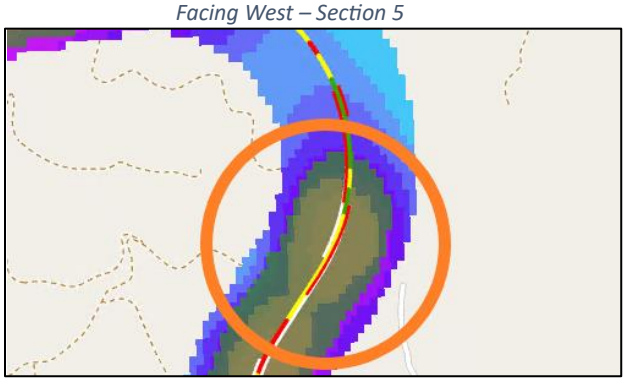


Map Area (Zoomed) – Section 4

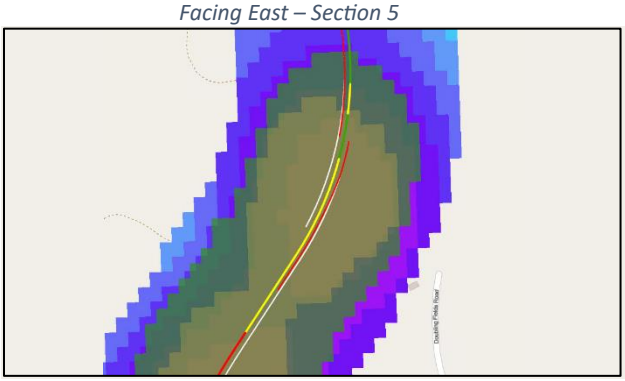
Section #5	
Crossing Type	3
Overall Risk	Moderate
Wildlife Activity	Moderate, more along eastern side
Crossing Activity	Low/moderate. ~50/50 on parallel vs. perpendicular
Roadway Characteristics	Open, semi-discrete (adj to #6), cut and fill section
Length	~550 m (~0.33 mi)
Line of Sight	Little obstruction, roadway curves southward but little vegetation.
Natural Structures	Cut section along majority of north side, open on south side.
Non-Natural Structures	Currently 2+ climbing lanes, eventually 4 lanes. Guardrails proposed for majority of the section. Drainage pond on south side.

Facing West – Section 5

Facing East – Section 5



Map Area – Section 5

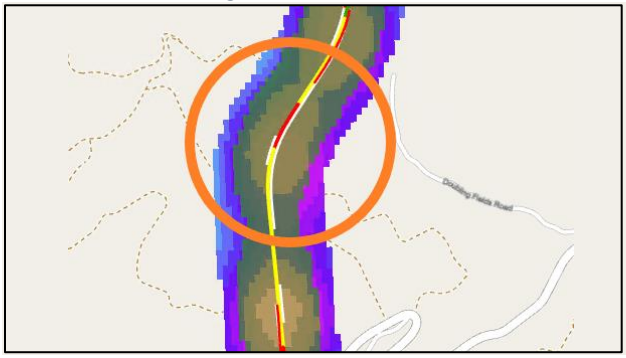


Map Area (Zoomed) – Section 5

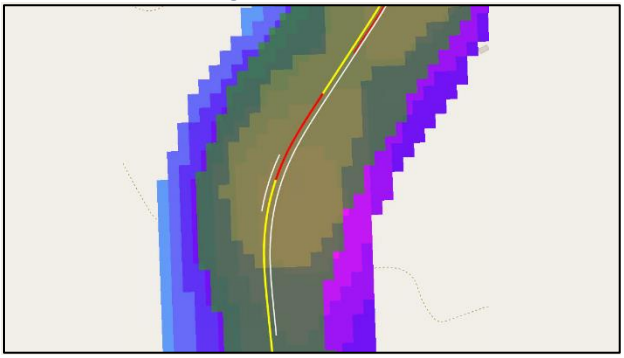
Section #6	
Crossing Type	3
Overall Risk	Moderate
Wildlife Activity	Moderate, more along eastern side
Crossing Activity	Low/moderate. ~50/50 on parallel vs. perpendicular
Roadway Characteristics	Open, semi-discrete (adj to #5 & 7), fill to cut section.
Length	~550 m (~0.33 mi)
Line of Sight	Little obstruction, road curves northward and some cut sections and vegetation.
Natural Structures	Cut sections within road section, but mostly open. Some vegetation near southern end.
Non-Natural Structures	Currently 2+ climbing lanes, eventually 4 lanes. Guardrails proposed for majority of section.

Facing West – Section 6

Facing East – Section 6



Map Area – Section 6

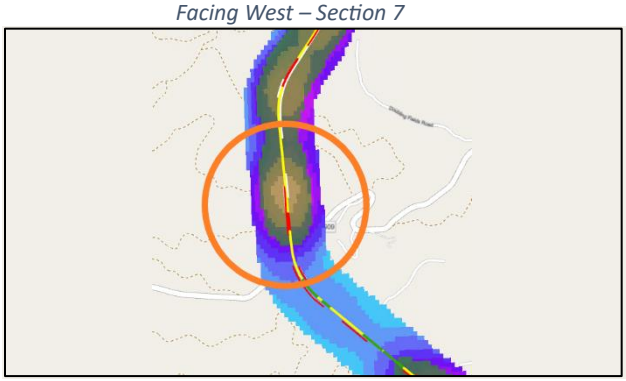


Map Area (Zoomed) – Section 6

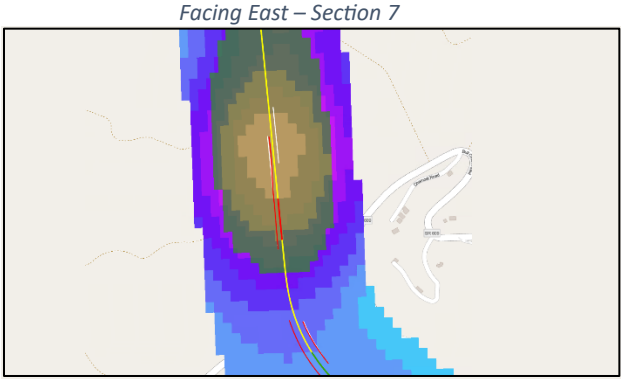
Section #7	
Crossing Type	3
Overall Risk	Moderate /High
Wildlife Activity	Moderate /high, both sides of road
Crossing Activity	Moderate, ~50/50 on parallel vs perpendicular
Roadway Characteristics	Semi-open, semi-discrete (adj to #6) cut and open/fill sections
Length	~800 m (0.5 mi)
Line of Sight	Little to no obstruction, straight section.
Natural Structures	Large cut sections on north end of section, opens up on south side.
Non-Natural Structures	Currently 2+ climbing lanes, eventually 4 lanes. Guardrails proposed for majority of section. Drainage pond on north side.

Facing West – Section 7

Facing East – Section 7



Map Area – Section 7

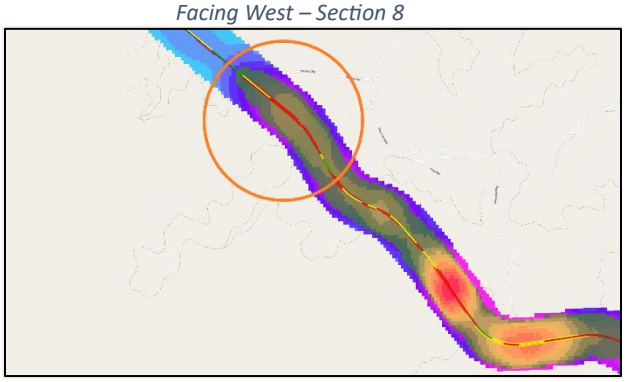


Map Area (Zoomed) – Section 7

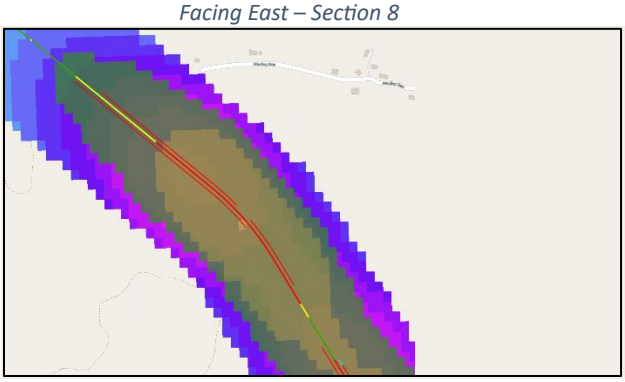
Section #8	
Crossing Type	1
Overall Risk	Moderate/High
Wildlife Activity	Moderate, high density near roadway
Crossing Activity	Moderate, ~50/50 on parallel vs perpendicular.
Roadway Characteristics	Open, discrete, fill section
Length	~1.1 km (~0.7 mi)
Line of Sight	Little to no obstruction, relatively straight section.
Natural Structures	Some vegetation, but mostly open, fill section.
Non-Natural Structures	Proposed 4 lanes. Guardrails proposed for majority of section.

Facing West – Section 8

Facing East – Section 8



Map Area – Section 8

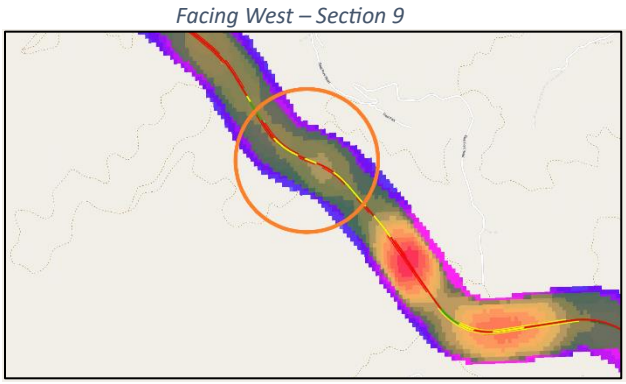


Map Area (Zoomed) – Section 8

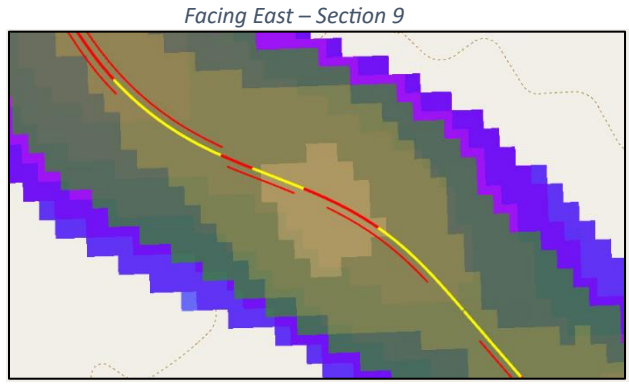
Section #9	
Crossing Type	3
Overall Risk	Moderate
Wildlife Activity	Moderate, even distribution along road
Crossing Activity	Moderate, ~50/50 on parallel vs perpendicular.
Roadway Characteristics	Semi-open, semi-discrete, cut and open/hilly sections
Length	~950 m (~0.55 mi)
Line of Sight	Moderate obstruction, S-bend in roadway and vegetation + cut sections.
Natural Structures	Vegetation and cut sections on both sides.
Non-Natural Structures	Proposed 4 lanes. Guardrails proposed for most of south side, some of north side. Drainage pond on south side.

Facing West – Section 9

Facing East – Section 9



Map Area – Section 9

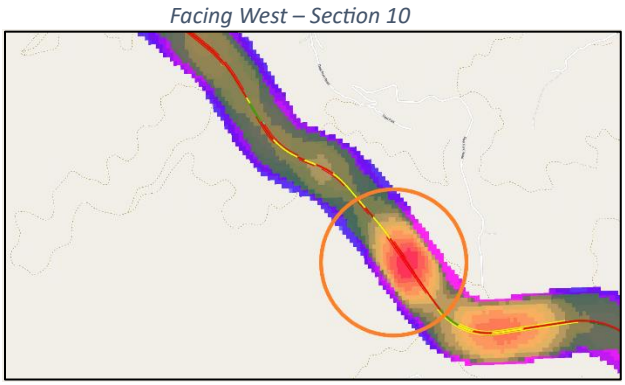


Map Area (Zoomed) – Section 9

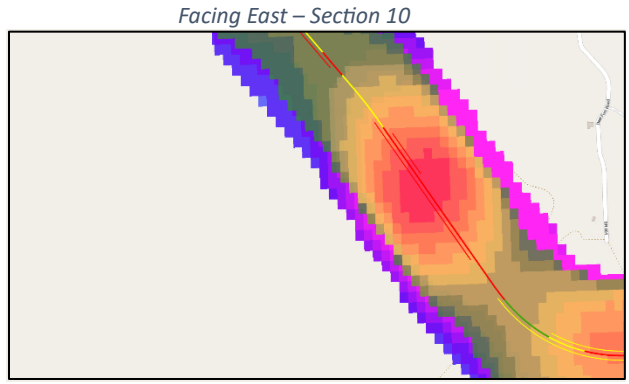
Section #10	
Crossing Type	3
Overall Risk	Very High
Wildlife Activity	Very High, concentrated near open sections.
Crossing Activity	High, most activity vs. any other segment.
Roadway Characteristics	Open, discrete, primarily fill/open section
Length	~950 m (~0.55 mi)
Line of Sight	Little to no obstruction, relatively straight section.
Natural Structures	Vegetation on all sides, large cut sections along north side, hills on south side.
Non-Natural Structures	Proposed 4 lanes. Guardrails proposed for most of south side, some of north side.

Facing West – Section 10

Facing East – Section 10



Map Area – Section 10

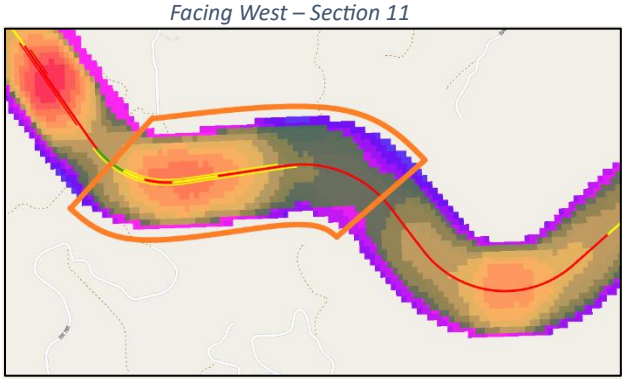


Map Area (Zoomed) – Section 10

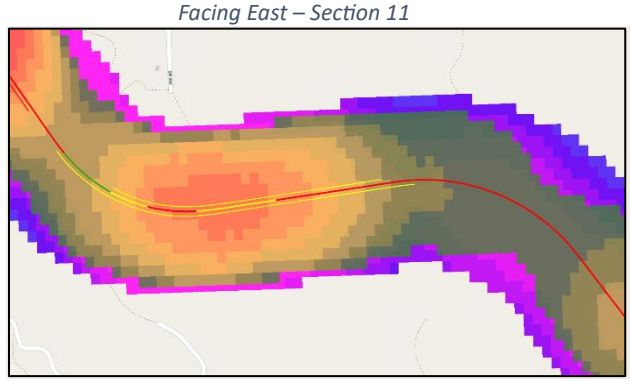
Section #11	
Crossing Type	4
Overall Risk	High
Wildlife Activity	High, esp. on western portion just after cut section.
Crossing Activity	High, several groupings on either side of road.
Roadway Characteristics	Semi-open to open, non-discrete, cut sections, mostly fill/open sections
Length	~1.3 km (~0.8 mi)
Line of Sight	Some obscurations. S-bend, cut section and vegetation on north side, but rest is open after road straightens. Slight vertical obstruction but between sections.
Natural Structures	Hills and cut sections on north side, fill/open on south side.
Non-Natural Structures	Proposed 4 lanes. Guardrails proposed for majority of section.

Facing West – Section 11

Facing East – Section 11



Map Area – Section 11

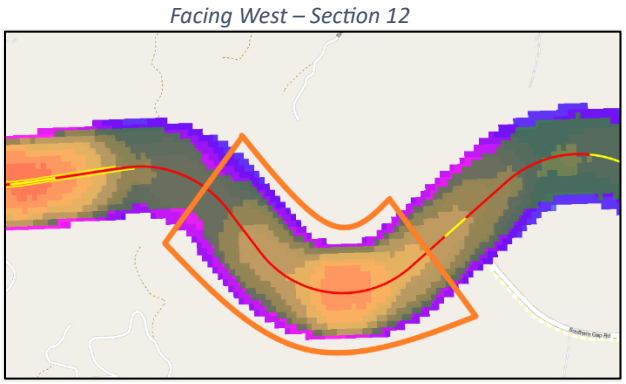


Map Area (Zoomed) – Section 11

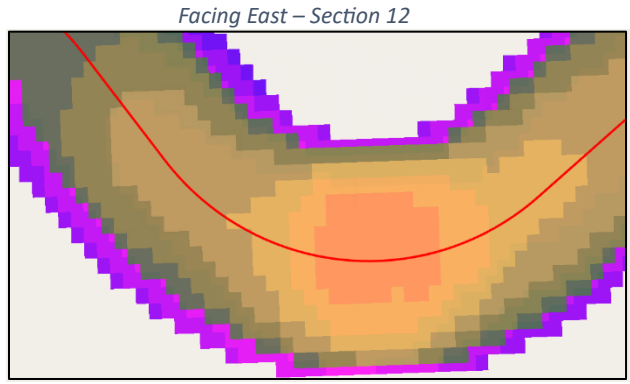
Section #12	
Crossing Type	4
Overall Risk	High
Wildlife Activity	High, relatively even distribution, concentrations along southernmost portions
Crossing Activity	High, mostly near the center, with groupings on the north and south side
Roadway Characteristics	Open, non-discrete, open/fill sections
Length	~1.6 km (~1 mi)
Line of Sight	Some obscurations from vegetation on both sides and cut section on north side.
Natural Structures	On a ridge, some vegetation, primarily on north side.
Non-Natural Structures	Proposed 4 lanes. No proposed guardrails.

Facing West – Section 12

Facing East – Section 12



Map Area – Section 12

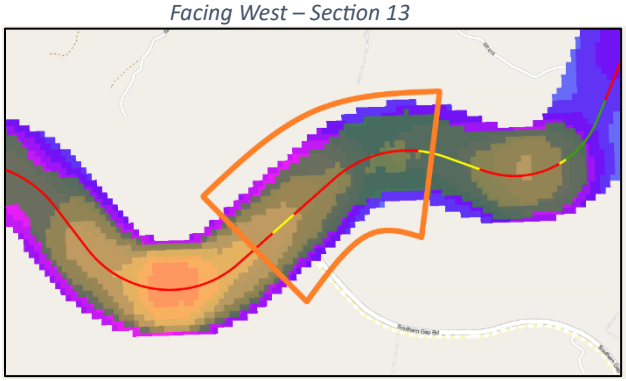


Map Area (Zoomed) – Section 12

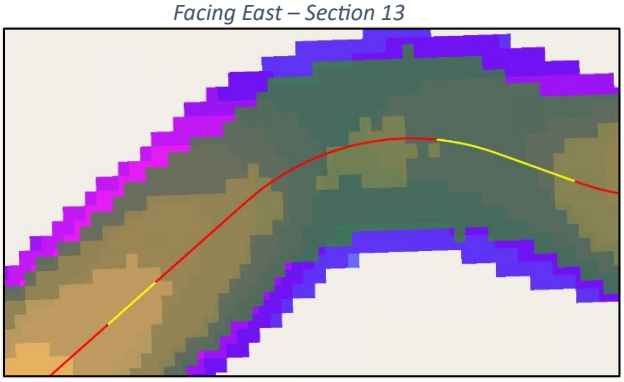
Section #13	
Crossing Type	4
Overall Risk	Moderate
Wildlife Activity	Moderate, mostly on north side.
Crossing Activity	Low/moderate, primarily on western portion.
Roadway Characteristics	Open, non-discrete, open and fill sections.
Length	~1 km (~0.63 mi)
Line of Sight	Little to no obscuration, some vegetation on north side on western portion, hill/vegetation section on south side on eastern portion, past intersection.
Natural Structures	Much vegetation, some hills.
Non-Natural Structures	Proposed 4 lanes. No proposed guardrails. 3-way intersection on south side.

Facing West – Section 13

Facing East – Section 13



Map Area – Section 13

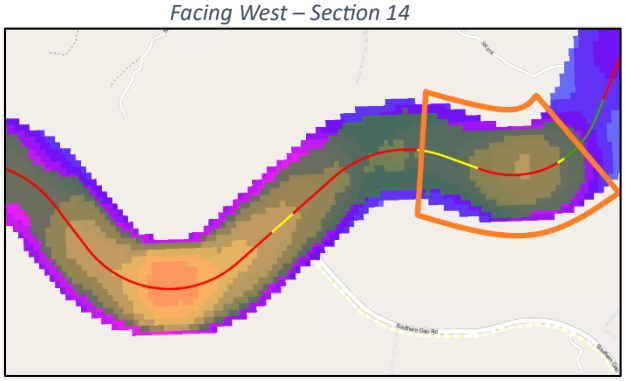


Map Area (Zoomed) – Section 13

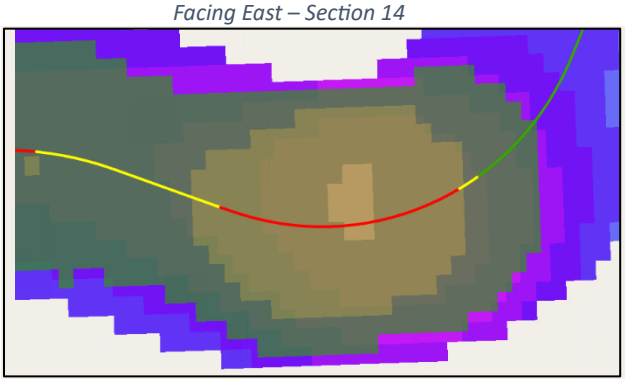
Section #14	
Crossing Type	4
Overall Risk	Moderate/High
Wildlife Activity	Moderate, concentrated mostly on north side, but more on south side near opening
Crossing Activity	Moderate, several groupings near roadway
Roadway Characteristics	Mostly open, non-discrete, cut, open, and fill sections
Length	~750 m (~0.5 mi)
Line of Sight	Some obscurations from hills and vegetation on both sides.
Natural Structures	Hills/vegetation south side, fill section north side.
Non-Natural Structures	Proposed 4 lanes. No proposed guardrails.

Facing West – Section 14

Facing East – Section 14



Map Area – Section 14

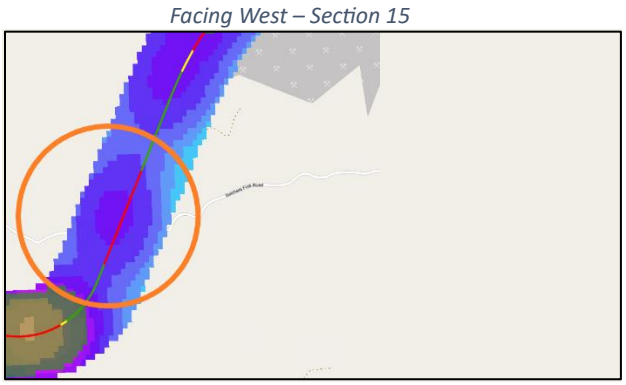


Map Area (Zoomed) – Section 14

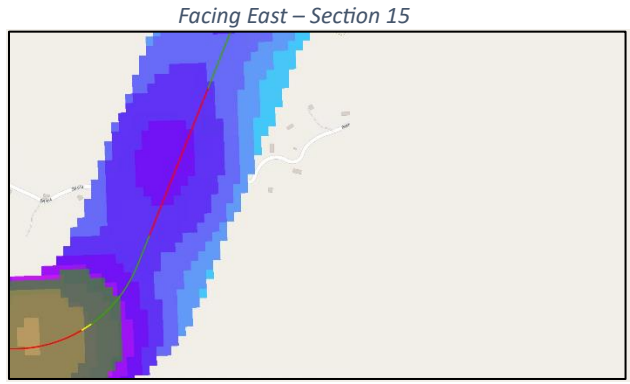
Section #15	
Crossing Type	1
Overall Risk	Low/Moderate
Wildlife Activity	Low/moderate, concentrated on north side
Crossing Activity	Low, few crossings
Roadway Characteristics	Open, discrete, open and fill sections
Length	~550 m (~0.33 mi)
Line of Sight	Little/no obscuration. Straight roadway, and little vegetation.
Natural Structures	Fill section throughout.
Non-Natural Structures	Proposed 4 lanes. Guardrails proposed for majority of both sides of road. Drainage pond on south side.

Facing West – Section 15

Facing East – Section 15



Map Area – Section 15

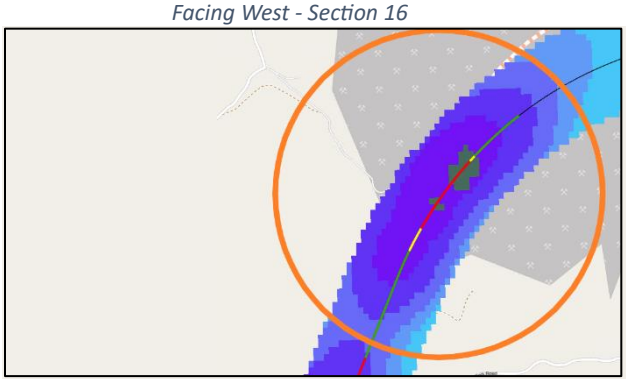


Map Area (Zoomed) – Section 15

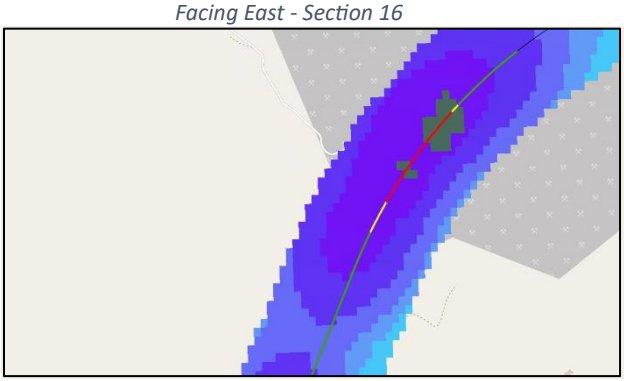
Section #16	
Crossing Type	1
Overall Risk	Moderate
Wildlife Activity	Low/Moderate on both sides, more on the north side
Crossing Activity	Moderate, several groupings on either side of road
Roadway Characteristics	Open, discrete, open and fill sections
Length	~600 m (~0.38 mi)
Line of Sight	Some obscurations on south side from large hill.
Natural Structures	Fill section north side, large hill on south side.
Non-Natural Structures	Proposed 4 lanes. Guardrails proposed for majority of north side of road, none on south side.

Facing West - Section 16

Facing East - Section 16



Map Area - Section 16



Map Area (Zoomed) - Section 16

APPENDIX D

Vendor Responses and Cost Estimates

A breakdown of the estimated cost of system components, and a cost per unit length based on the length of roadway each system covers, using the information provided in the vendor responses (below). Also provides other cost considerations that are not included in the cost per unit length calculation.

Vendor	ADS Type	Method	Distance Covered/ Monitored	Cost per Single System	Other System Costs[1]	Add'l Costs	Single System Total Cost	Cost per unit length
ProWild/ Animex	Area Cover	Thermal, long range	**1,470m (4,823ft)** 2 Cameras, 735m (2,411ft) per camera	**$60,000** 2 Cameras, $30,000 per camera	Controller Cabinet: $32,500 Signage: $2,500 x 8 Solar Units: $1,500 x 8	$12,750 Engineering & Software	$137,250	$93.37/m ($28.46/ft)
ProWild/ Animex	Area Cover	Thermal, short range	**368m (1,207ft)** 2 Cameras, 184m (604ft) per camera	**$15,000** 2 Cameras, $7,500 per camera	Controller Cabinet: $32,500 Signage: $2,500 x 2 Solar Units: $1,500 x 2	$12,750 Engineering & Software	$68,250	$185.46/m ($56.54/ft)
ProWild/ Animex	Area Cover	Thermal, short range	**736m (2,415ft)** 4 Cameras, 184m (604ft) per camera	**$30,000** 4 Cameras, $7,500 per camera	Controller Cabinet: $32,500 Signage: $2,500 x 4 Solar Units: $1,500 x 4	$12,750 Engineering & Software	$91,250	$123.98/m ($37.78/ft)
Senstar	Under-ground	Buried Cable	800m (2,625ft), covering one side of roadway	**$56,180** $36,830 for cabling, $19,350 for components	Signage: $2,500 x 4 Solar Units: $1,500 x 4	$10,000 estimated assessment	$82,180[2]	$102.73/m ($31.31/ft)
Senstar	Under-ground	Buried Cable	800m (2,625ft) x 2, covering both sides of roadway	**$112,360 total** $73,660 for cabling, $38,700 for components	Signage: $2,500 x 4 Solar Units: $1,500 x 4	$10,000 estimated assessment	$138,360[3]	$172.95/m ($52.71/ft)

Vendor	ADS Type	Method	Distance Covered/ Monitored	Cost per Single System	Other System Costs[1]	Add'l Costs	Single System Total Cost	Cost per unit length
CrossTekCo	Area Cover	Radar	2,575m (8,448ft)	$75,000	Controller Cabinet: $65,000 Signage: $6,500 x 12[4]	$15,000 site assessment	$218,000	$84.66/m ($25.80/ft)

[1]*Signage strategy based on ProWild/Animex guidance of ~2 signs per 400 m (1,312ft, ~¼ mi), one oriented in either direction. Solar units to power individual signs.*

[2]*Assuming 800 m buried cable system is installed on one side of roadway.*

[3]*Assuming 800 m buried cable system is installed on both sides of roadway.*

[4]*CrossTekCo Provided their own signage option. Solar power and remote connectivity included.*

A breakdown of other cost considerations, provided by CrossTekCo in their response to price estimates (see iv. CrossTekCo, below).

Other Cost Considerations	
Solar Power (per controller box)	$6,500 – 9,500
Software	$1,200 – 18,000, depending on complexity of the system
Design Package	$35,000 – $120,000, depending on VDOT requirements
Vendor Support	$25,000
Training/ Handoff	$9,000
Maintenance Contract	$14,500 per year (labor only, does not include parts)
Extended Warranties	Approximately 7% of original equipment cost
Shipping, taxes, permits, bonding	Not included
Construction/ Infrastructure	Not included (e.g., trenches, concrete, conduit, etc.)

i. Senstar

SENSTAR. Quotation

Quoted To
Senstar Inc.
13800 Coppermine Road
Herndon, Virginia
United States
20171
Chris Peguesse
chris.peguesse@senstar.com
+1 703 463 3088

Quote #:	Q-48361-2
Date:	10/19/2023
Expiry:	12/31/2023
Payment Terms:	Net 30 Days OAC
Shipping ARO:	TBD at time of order
INCO 2020:	EXW Carp
Currency:	U.S. Dollar

VA Tech VDOT Omnitrax POC

BUDGETARY

Omnitrax Equipment

PART #	DESCRIPTION	QTY	UNIT PRICE	EXTENDED
A4EM0101-002	OmniTrax Sensor Processor, provides electronic processing for two sensor cable sets, in a painted aluminum CSA/UL Type 4X (equivalent to NEMA 4/IP 66) enclosure, without any auxiliary cards.	1	USD 12,805.00	USD 12,805.00
A4MA0200-001	Telecom style protective enclosure for above ground field mounting of Processor enclosure. Includes tamper switch and wiring harness (A4HA0100), mounting brackets, mounting hardware and ground stake. Removable, lockable cover (lock not supplied), light green enamel, 42.5 x 27.3 x 98.4 cm (16.8" x 10.8" x 38.8").	1	USD 980.00	USD 980.00
A4KT1000-002	Kit of four gas-capsule lightning protectors for OmniTrax processor sensor cables. Includes add-on buss bar with ground lug, 4 gas capsules, and one meter of #10 AWG ground strap. One kit handles two cable sets attached to one OmniTrax processor. Compatible with SC1, SC2, and OC2 cables.	1	USD 1,535.00	USD 1,535.00
00BA0303-002	Comm card - Single Mode Fiber Optic for OmniTrax and XField, connects on processor header, supports two data paths (4 fibers). Mounting hardware included. NOTE: A Communications Card is required per Sensor Processor for networked data communications either externally or over OmniTrax Sensor Cables. G1 Silver.	1	USD 605.00	USD 605.00
A4FG0120-002	Pair of OC2 cables each with 400 meter (1312') active section and 20m (65') of integral lead-in. Includes 42 ferrite beads, 6 male TNC connector kits for field installation, and three 305m (1000 ft.) rolls of underground warning tape.	2	USD 18,415.00	USD 36,830.00
A4KT1304-001	OC2 terminator kit. Includes two OC2 termination-cable assemblies, two power-blocking decouplers, and heatshrink tubing	2	USD 1,340.00	USD 2,680.00
00EM0400-001	12V auxiliary power supply module. Mounts inside OmniTrax, XField, or Silver 16I/16O transponder enclosure.	1	USD 745.00	USD 745.00
			Omnitrax Equipment TOTAL:	USD 56,180.00

TOTAL: USD 56,180.00

ii. ProWild / Animex, First Meeting

Animex International

In partnership with: TRAFFIC 2000

821 N 27th St, PMB #289
Billings, MT 59101

Phone: +1 (406) 371-2770
E-mail: info@animexinternational.com

Date:
30 October 2023

Dynamic wildlife detection and driver warning system: "Corridor Q/Route 460"

To whom it may concern.

As discussed, we are proud to offer a wildlife detection systems with various detection and driver warning options.

There is not a "one size fits all" system we can offer so we have compiled information and budgetary costs for a variety of technologies and options.

It may be that this project requires a mixture of different detection and warning systems. We hope this initial information is useful and are keen to work with you to co-ordiante and implement the best system.

The systems incorporate online access to the control systems so that functionality can be monitored and adjusted if necessary. It also makes it possible to download data from such as wildlife movements and crossings so that a good overview of the use and effect of the systems is obtained. This does depend on the presence of an adequate network connection.

Additionally, a CCTV camera can be connected to the system to monitor activities on site (live). This is linked to a 2TB recorder with connection facilities for 8 cameras in the control cabinet.

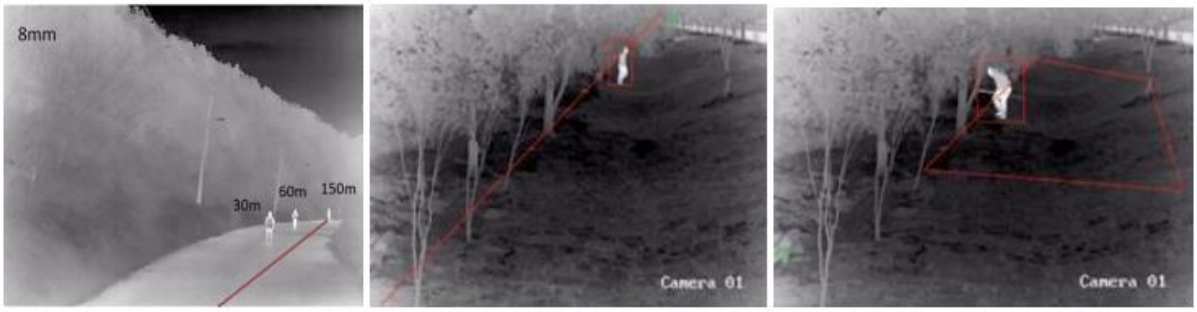
We have used this technology in Europe and we are very enthusiastic about it.

Detection method 1:
Infrared camera
A camera can be set to detect via 3 methods

1. Motion detection in a defined field via infrared
2. A virtual line crossed by an object
3. Motion detection in the camera's field of view

Detection method 2:
Thermal/optical camera

Based on deep learning algorithms, thermal products deliver powerful and accurate behavior analyses, including detections such as line crossing, intrusion, region entrance and exit, and more. The intelligent human/vehicle detection feature helps reduce false alarms caused by vehicles, camera shake, falling leaves, or other irrelevant objects, significantly improving alarm accuracy.
Deep learning-based dynamic source detection takes advantage of security big data, containing over 100,000 samples of global climate information to provide the highest possible detection accuracy.
This front-end device can detect based on raw, frame-by-frame data, ensuring first-hand image analysis and rapid alarm triggering.
Signature thermal technology – bi-spectrum image fusion – combines features from both thermal and visible images, and creates a unique hybrid image that provides extra details for detection.



Detection method 3:
Active infrared detection(AIR)

AIR is based on a sender receiver positioned approximately 100 meters apart. In the housing columns we can install sensors at different heights mostly 30cm and 60cm height. This is depending on the target species at the location and can be determined with the end user. When the beam is interrupted an alarm will be sent to the controller and signs will be activated. Such systems are not suitable when objects spend long periods of time on the roadway.

Detection method 4:
Passive infrared detection(PIR)

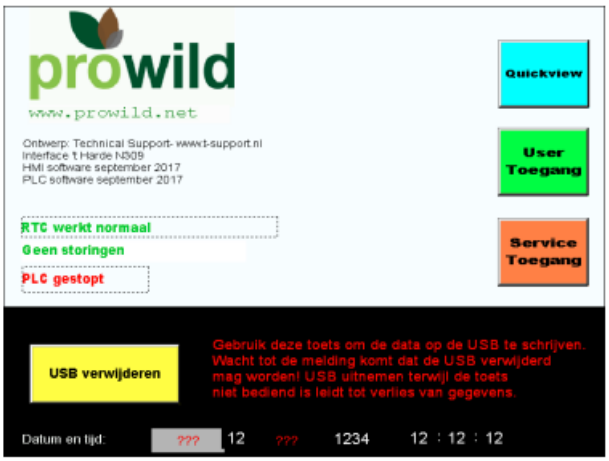
PIR sensors are based on detecting movement and temperature differences. This type of sensors is very sensitive for sunlight and moving branches etc. and operates best in dark circumstances. Such systems can be applied with the use of supporting intelligent technology.

Detection method 5:
Radar detection

Radar uses radio waves to determine the location and movement of objects. These sensors are good at covering large open areas but rely on line of sight and may not me appropriate in areas with lots of roadside vegetation.

General controller:
We provide a complete pre manufactured controller with cabinet, which will handle all tasks like: alarms of the sensors/camera's, activating signs, camera's, communication and create logfiles.
If a proper connection is available we can monitor the system from remote and make adjustments or download files and video's. For connectivity we prefer a local SIM card to be inserted.

The controller's software has been developed entirely in-house. As a result, we are able to make quick adjustments that allow other third-party technology to be connected.



Signs
We have provided a price indication for a fixed traffic sign(triangular shaped with deer symbol) where the red outer triangle is provided with led's which will light up when an animal is detected. The exact symbols and/or text need to be determined at a later stage.

Power supply modules
If net power supply is not possible, power supply for separate components can be done via a solar panel with integrated holder for the battery at the top of the mast. This lowers the risk of theft because the battery is hard to access.
For the control cabinet we need to find the most optimal solar solution depending on the system setup and a higher power consumption.

Above an example of a sign with a solar panel on top of an integrated battery module.

In order to keep (transport) costs low it is preferable to purchase poles locally. We can cooperate with a local company and provide instructions.

Budget indication detection methods

Method 1:

Infrared day and night camera 50 meters infrared range	**$ 850**
Recorder videos when camera is used(possibly in combination with PIR / AIR)	**$950**

Method 2:

Thermal camera option 1: Elk recognition at a distance of 38 meters	**$900**
Thermal camera option 2: Elk recognition at a distance of 48 meters	**$5250**
Thermal camera option 3: Elk recognition at a distance of 184 meters	**$7500**
Thermal camera option 4: Elk recognition at a distance of 735 meters	**$30,000**

Method 3:

Active infrared sensors 100m. two heights on both sides of the road	**$9250**

Method 4:

Passive infrared sensors 50m. 1 on each side of the road excl. AI technology	**$3750**

Method 5:

Radar detection **TO BE CONFIRMED**

Overview of additional costs diverse options:

Dynamic sign	**$2500**
Control cabinet with controller	**$32500**
Solar set on top of the mast including battery	**$ 1500**
Engineering, software, drawings and manuals	**$12,750**

Costs for project management is depending on the scale of the project

Maintenance per year depending on system setup (3 year contract?)

Training costs are depending on many variables and need to be determined at a later stage

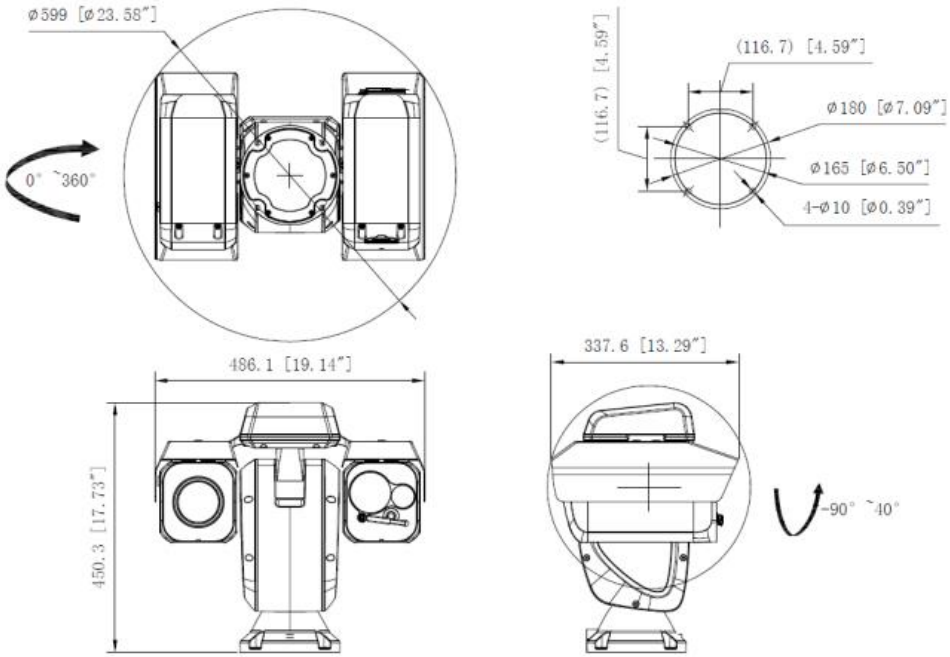
Warranty on materials 1 year

For this project, we recommend the following 2 methods:

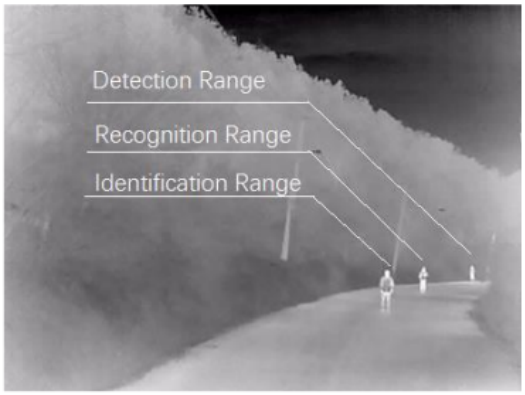
Method 1 : Thermal/video detection

Thermal option 4 (Recommended):

Thermal & Optical Bi-spectrum Network Positioning System



Unit:mm(inch)



DRI Range Table
* The table is only for reference and the performance may vary according to different environment.
* The optimal detection, recognition, and identification distances are calculated according to Johnson's Criteria.
Detection Range: In order to distinguish an object from the background, the object must be covered by 1.5 or more pixels.
Recognition Range: In order to classify the object (animal, human, vehicle, etc.), the object must be covered by 6 or more pixels.
Identification Range: In order to identify the object and describe it in details, the object must be covered by 12 or more pixels.

Detection Range (Vehicles: 1.4 × 4.0 m)	Detection Range (Humans: 1.8 × 0.5 m)	Recognition Range (Vehicles: 1.4 × 4.0 m)	Recognition Range (Humans: 1.8 × 0.5 m)	Identification Range (Vehicles: 1.4 × 4.0 m)	Identification Range (Humans: 1.8 × 0.5 m)
9020 m	2941 m	2255 m	735 m	1127 m	368 m

Smart Function Table

**The table is only for reference and the performance may vary according to different environment.*

VCA Range (Vehicles: 1.4 × 4.0 m)	VCA Range (Humans: 1.8 × 0.5 m)	Temperature Measurement (Object: 2 × 2 m)	Temperature Measurement (Object: 1 × 1 m)	Fire Detection (Object: 2 × 2 m)	Fire Detection (Object: 1 × 1 m)
2100 m	700 m	2340 m	1180 m	5880 m	2940 m

Budget price $ 30,000,- per unit.

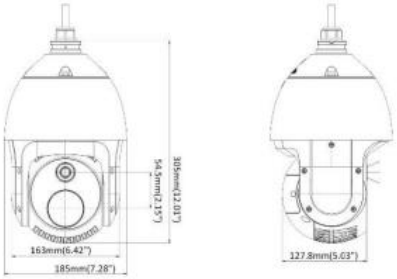
This camera has the advantage that its longer reach means it can be placed in a suitable location with sun for solar energy. As a result, sections with difficult conditions for solar energy can also be covered.

In addition, it is also easier with regard to cabling as this camera can be placed next to the control cabinet. If two cameras are placed here facing opposite directions, a range of 1470 meters can be covered from one location.

Control of the signs can be done by telemetry, eliminating the need for large-scale excavation and cabling.

Thermal option 3 (optional):

Thermal & Optical Bi-spectrum Network Speed Dome



Detection Range Table

** The table is only for reference, the performance may vary from camera to camera.*

Smart functions Range

VCA Range (Vehicles: 1.4×4.0m)	VCA Range (Humans: 1.8×0.5m)	Temperature Measurement (Object:2×2 m)	Temperature measurement (Object:1×1 m)	Fire Detection (Object:2×2 m)	Fire Detection (Object:1×1 m)
750 m	250 m	585 m	295 m	1470 m	735 m

Different targets trigger the VCA events within different range limits.

Wide Range Coverage

There is range limit for detecting, recognizing, and identifying human/vehicle targets.

Detection Range (Vehicles: 1.4×4.0m)	Detection Range (Humans: 1.8×0.5m)	Recognition Range (Vehicles: 1.4×4.0m)	Recognition Range (Humans: 1.8×0.5m)	Identification Range (Vehicles: 1.4×4.0m)	Identification Range (Humans: 1.8×0.5m)
2255 m	735 m	564 m	184 m	282 m	92 m

Budget price $ 7500,- per unit.

At least 8 cameras are needed for a similar range of almost 1 mile. This means communication cables have to be laid and each camera needs a separate provision for power supply.
This also requires more masts which means more obstacles along the road. For maintenance, this will also mean more work and hence costs.

Method 2: Radar detection

WAITING ON INFORMATION

The above budget prices of the various detection methods are only unit prices of the detectors themselves.

Costs for taxes, transport, labour, cabling, installation, travelling and commissioning are not included.

Herewith we expect to have given an interesting proposal and we are looking forward to your reply.

Best regards,

Steve Béga - Animex International Inc.

Gert Hamberg - Traffic 2000 bv

iii. ProWild / Animex, Second Meeting

Animex *International*

IN PARTNERSHIP WITH PROWILD / TRAFFIC 2000

BUDGETARY COST ESTIMATE

ROADSIDE ANIMAL DETECTION SYSTEM

CLIENT: Virgina Tech Transportation Institute
PREPARED BY: Steve Béga // steve@animexinternational.com
821 N 27th St, PMB #289 Billings, MT 59101

CORRIDOR Q / ROUTE 460

This is an illustrative cost based on 16 x 1mile sections of automated roadside animal detection system and driver warning signs. Costs do not include tax, civil labour construction, cabling, power infrastructure and additional security systems. The number of signs should be determined based on local requirements and current literature recommendations.

ITEMS

BASED ON 1 MILE SECTION	UNIT COST	QTY	TOTAL COST
Thermal & Optical Bi-spectrum Network Positioning System	$30,000	2	$60,000
Controller & Cabinet	$32,500	1	$32,500
Engineering & Software	$12,750	1	$12,750
BASED ON 16 x 1 MILE SECTIONS			
Thermal & Optical Bi-spectrum Network Positioning System	$30,000	32	$960,000
Controller & Cabinet	$32,500	16	$520,000
Engineering & Software	$22,750	1	$22,750
SIGNAGE			
Dynamic signs with fixed image	$2500	1	$2500
Small solar unit	$1500	1	$1500

COMPLETE COST EXAMPLE

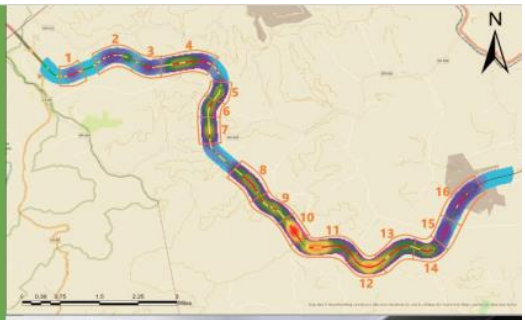
16 MILES INCLUDING 8 SIGNS EVERY MILE			
Thermal & Optical Bi-spectrum Network Positioning System	$30,000	32	$960,000
Controller & Cabinet	$32,500	16	$520,000
Engineering & Software	$22,750	1	$22,750
Dynamic signs with fixed image	$2500	128	$320,000
Small solar unit	$1500	128	$192,000
			TOTAL: ~$2m

THERMAL OPTICAL BI-SPECTRUM SYSTEM

Based on deep learning algorithms, thermal products deliver powerful and accurate behavior analyses, including detections such as line crossing, intrusion, region entrance and exit, and more. The intelligent human/vehicle detection feature helps reduce false alarms caused by vehicles, camera shake, falling leaves, or other irrelevant objects, significantly improving alarm accuracy.

Deep learning-based dynamic source detection takes advantage of security big data, containing over 100,000 samples of global climate information to provide the highest possible detection accuracy.

This front-end device can detect based on raw, frame-by-frame data, ensuring first-hand image analysis and rapid alarm triggering. Signature thermal technology – bi-spectrum image fusion – combines features from both thermal and visible images, and creates a unique hybrid image that provides extra details for detection.



DRI RANGE TABLE

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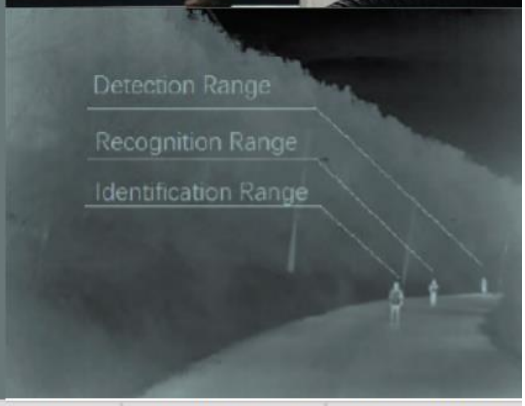
Detection Range: In order to distinguish an object from the background, the object must be covered by 1.5 or morepixels.

Recognition Range:
In order to classify the object (animal, human, vehicle, etc.), the object must be covered by 6 ormore pixels

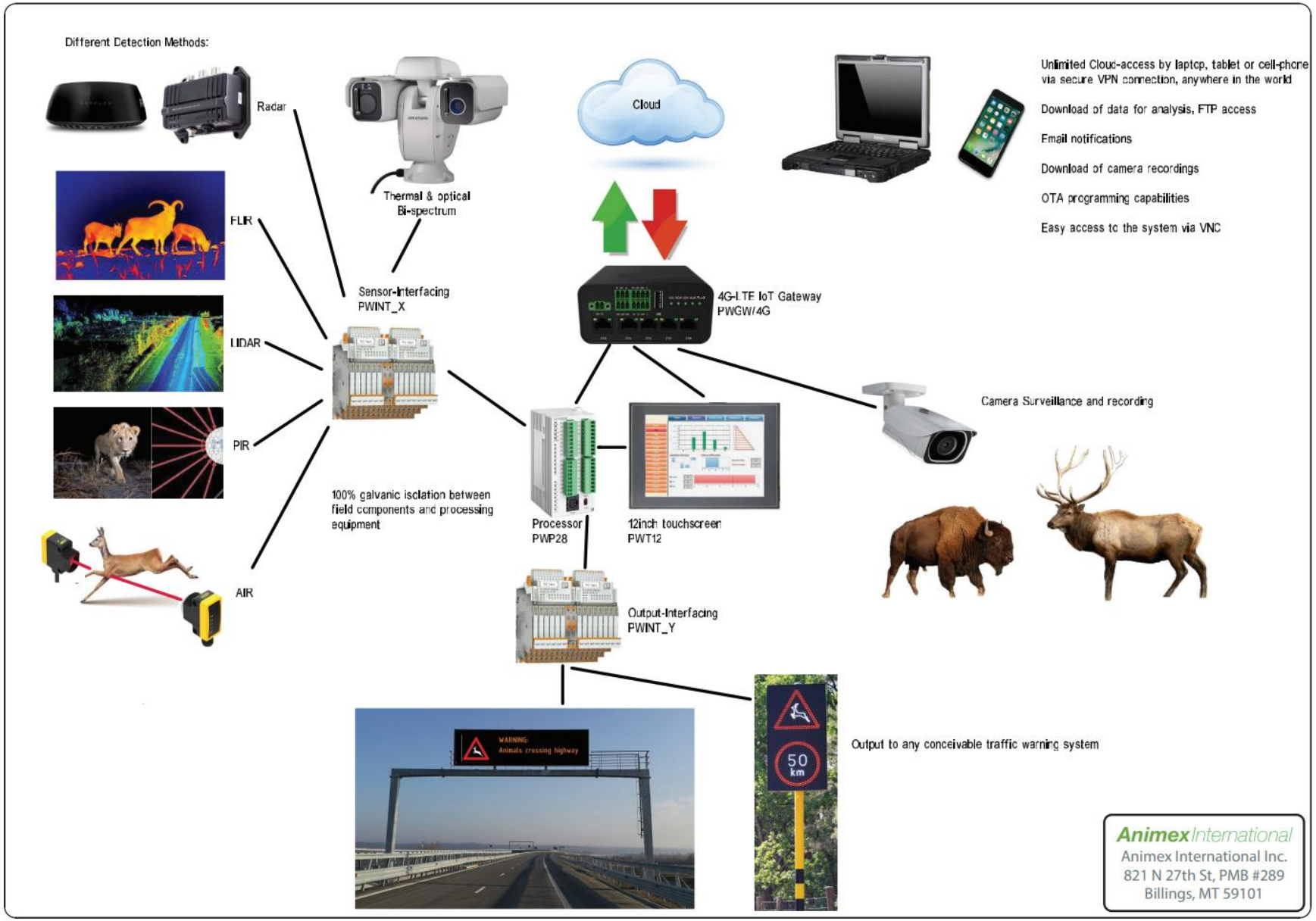
Identification Range: In order to identify the object and describe it in details, the object must be covered by 12 or morepixels

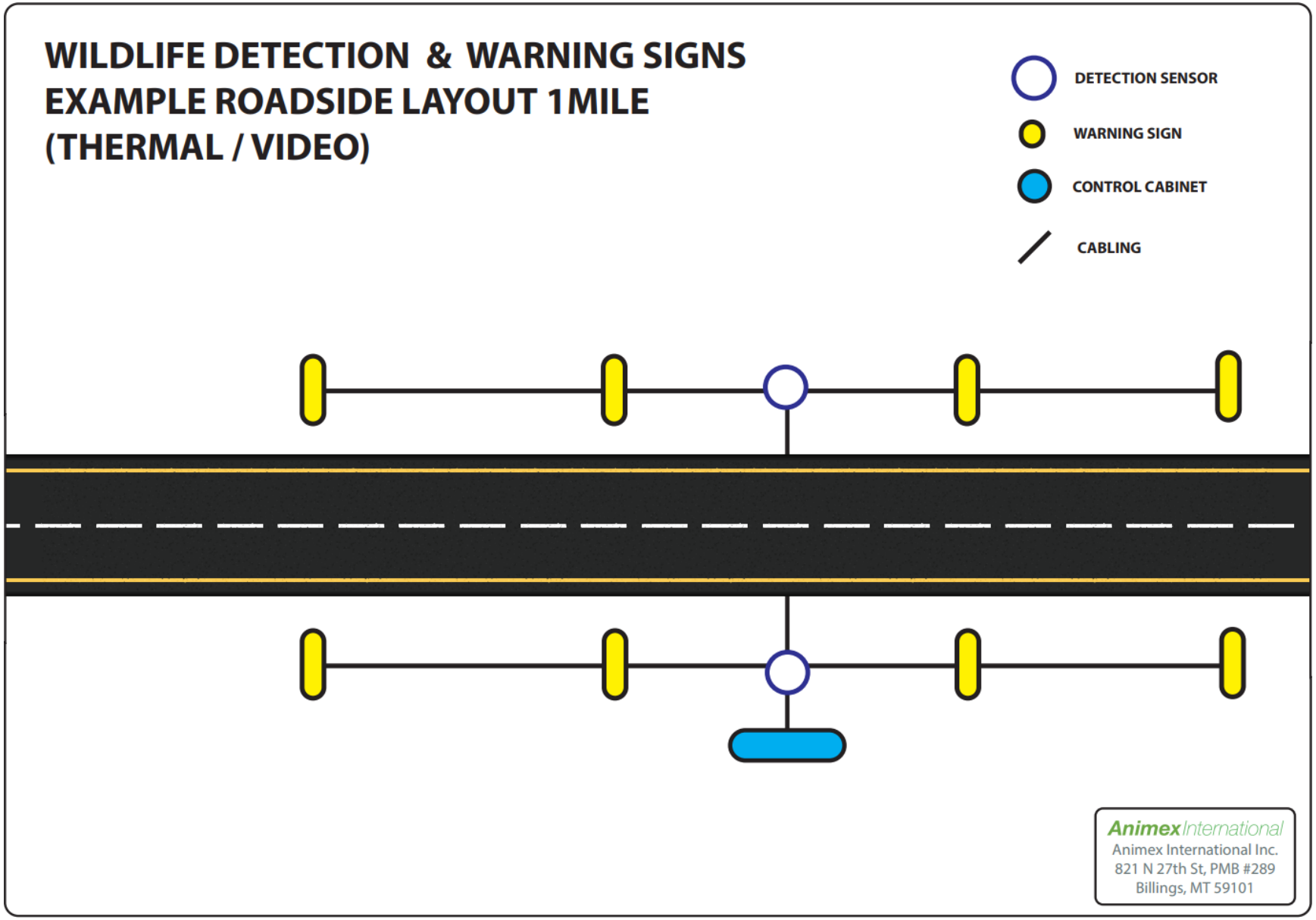


Detection Range (Vehicles: 1.4 × 4.0 m)	Detection Range (Humans: 1.8 × 0.5 m)	Recognition Range (Vehicles: 1.4 × 4.0 m)	Recognition Range (Humans: 1.8 × 0.5 m)	Identification Range (Vehicles: 1.4 × 4.0 m)	Identification Range (Humans: 1.8 × 0.5 m)
9020 m	2941 m	2255 m	735 m	1127 m	368 m

Thermal Module	
Image Sensor	VOx Uncooled Focal Plane Arrays
Resolution	640 × 512
Pixel Interval	17 μm
Response Waveband	8 μm to 14 μm
NETD	≤ 35 mK (@ 25°C,F# = 1.0)
Focal Length	100 mm
Focus Mode	Semi-auto & Manual
IFOV	0.17 mrad
Aperture	F1.0
Field of View	6.23° × 4.98° (H × V)
Min. Focusing Distance	10 m
Digital Zoom	×1, ×2, ×4, ×8
Optical Module	
Image Sensor	1/1.8" Progressive Scan CMOS
Resolution	2688 × 1520, 4 MP
Min. Illumination	Color: 0.0005 Lux @ (F1.5, AGC ON), B/W: 0.0001 Lux @ (F1.5, AGC ON)
Field of View	Wide: 0.92° × 0.52°; Tele: 48.26° × 28.43°
Focal Length	6 to 336 mm, 56x
Aperture (Range)	F1.3-F4.0
Focus Mode	Semi-auto/Manual
Shutter Speed	1.1 s to 1/30,000 s
WDR	120 dB
Optical Defog	Yes
Image Effect	
Picture in Picture	Display partial image of thermal channel on the full screen of optical channel
Target Coloration	Yes. Supported in white hot and black hot mode.
PTZ	
Movement Range	Pan: 360° Continuous Rotate; Tilt: From -90°to + 40° (auto flip)
Pan Speed	Configurable, From 0.01°/s to 110°/s
Tilt Speed	Configurable, From 0.01°/s to 50°/s
Proportional Zoom	Yes
Presets	300 in total
Patrol Scan	8; Up to 32 Presets Per Patrol
Pattern Scan	4; More Than 10 Minutes Per Pattern
Power Off Memory	Yes
Park	Preset/Pattern Scan/Patrol Scan/Auto Scan/Tilt Scan/Random Scan/Frame
PT Status	Turn On/Turn Off
Scheduled Task	Preset/Pattern Scan/Patrol Scan/Auto Scan/Tilt Scan/Random Scan/Frame Scan/Panorama Scan/Doom Reboot/Doom Adjust/Aux Output
Illuminator	
IR Distance	Up to 800 m
IR Intensity and Angle	Automatically adjusted

32 Languages	English, Russian, Estonian, Bulgarian, Hungarian, Greek, German, Italian, Czech, Slovak, French, Polish, Dutch, Portuguese, Spanish, Romanian, Danish, Swedish, Norwegian, Finnish, Croatian, Slovenian, Serbian, Turkish, Korean, Traditional Chinese, Thai, Vietnamese, Japanese, Latvian, Lithuanian, Portuguese (Brazil)
Power	36 VDC ± 20%, 48 VDC ± 20%, two-core terminal block
Power Consumption	5 A, max. 120 W
Work Temperature/Humidity	From -40°C to 65°C (-40°F to 149°F); Humidity: 95% or Less
Wiper	Yes
Protection	Protection Level IP66 Standard; TVS 6000V Lightning Protection, Surge Protection and Voltage Transient
Dimension	486.1 mm × 337.6 mm × 450.3 mm (19.14″ × 13.29″ × 17.73″)
Weight	Approx. 20 kg (44.092 lb)


Different Detection Methods:
Radar
FLIR
LIDAR
PIR
AIR
Thermal & optical
Bi-spectrum
Sensor-Interfacing
PWINT_X
100% galvanic isolation between
field components and processing
equipment
Cloud
4G-LTE IoT Gateway
PWGW/4G
Processor
PWP28
12inch touchscreen
PWT12
Output-Interfacing
PWINT_Y
Unlimited Cloud-access by laptop, tablet or cell-phone
via secure VPN connection, anywhere in the world
Download of data for analysis, FTP access
Email notifications
Download of camera recordings
OTA programming capabilities
Easy access to the system via VNC
Camera Surveillance and recording
WARNING:
Animals crossing highway
50
km
Output to any conceivable traffic warning system
Animex International
Animex International Inc.
821 N 27th St, PMB #289
Billings, MT 59101


WILDLIFE DETECTION & WARNING SIGNS
EXAMPLE ROADSIDE LAYOUT 1MILE
(THERMAL / VIDEO)
DETECTION SENSOR
WARNING SIGN
CONTROL CABINET
CABLING
Animex International
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iv. CrossTekCo

CROSSTEK EB
Costing Estimates - Key WDS Components
10-Nov-23

Item	Description	Est. Cost Each	Notes
1	600 W Solar Power Station/432AH/12VDC/NEMA 3R Pad Mount Cabinet/MPPT Solar Controller, Top Pole Mount 120MPH. Does not include Concrete Pad for Cabinet or Concrete Base for Solar Pole	**$6,500**	Lower power solar system for main cabinet. Size of solar power system required depends on average solar hours at location and level of power usage by main control cabinet. Limited features can be run on lower powered solar system.
2	1440 W Solar Power Station/530AH/12VDC/NEMA 3R Pad Mount Cabinet/2XPS30M/120VAC Invertor, Top Pole Mount 120MPH. Does not include Concrete Pad for Cabinet or Concrete Base for Solar Pole	**$9,500**	This higher-powered solar system for main cabinets is generally adequate for a more robust feature package at the main cabinet. I.e., Cell connectivity, Data storage, environmentally conditioned cabinet, etc.
3	Sign Pole with Solar Powered Radio Controlled Dynamic Dual Amber LED Flasher and Static Text Message, 12 VDC. Does not include Concrete Base.	**$6,500**	Standard DOT pedestal pole package assembly for crosswalks. Cost typically ranges from $4,500 to 10,500 per active dynamic sign assembly with 2 flashing beacons, static sign, solar/battery/regulator - radio controlled. Does not include concrete pole base.
4	Radar, 360-degree, 1400-meter range. One Radar can cover up to 1.6 miles of roadway and detect mid-size animals accurately on the roadside and in the road in line of sight. The maximum range requires positioning if radar in the middle of detection corridor.	**$75,000**	
5	Tactical Software for managing Radar Wildlife Detection, Tracking and Sign Activation accuracy (Base Price)	**$18,000**	
6	Thermal Camera for Wildlife Detection. Area Coverage 60 ft by 150 ft. Roadside coverage. Filters for animal size.	**$9,000**	
7	Software for Thermal Camera - Recording detection events	**$1,200**	

8	CrossTek EB Main Control Cabinet Module Insert - Complete controls for Radar detection, Sign Control, Radar Event Recording, Remote Communications, Computing.	**$65,000**	
9	CrossTek EB Main Control Cabinet Module Insert - Complete controls for Thermal detection, Sign Control, Thermal Event Recording, Remote Communications, computing.	**$35,000**	
10	Site Assessment prior to start of Design Work	**$15,000**	
11	Design Package - Cost depends heavily on WV DOT requirements. This can range from $35,000 to $120,000 depending on scope of project.	**$75,000**	
12	Camera/Radar Vendor Support	**$25,000**	
13	Training/Handoff	**$9,000**	
14	Maintenance Contract per Year	**$14,500**	
15	Extended Warranties are available - Typical cost is 7% of original equipment cost for each tear of extended warranty.		
NOTES:			
1	Shipping, Taxes, Permits, Bonding not included		
2	Construction Cost Not Included		
3	Infrastructure: Trenching, Concrete, Conduit, Conductors, Cabinets, Sensor Poles (for Radar and Thermal Cams) are not included		
4	Maintenance Estimate is for Remote Support and Local Electrician Labor Only. Does not include parts		
Advisory sign recommendations:			
1	We recommend a static gateway entrance sign, notifying driver that they are entering a wildlife detection corridor "Prepare for Wildlife in Roadway When Signs are Flashing"		
2	We recommend a corridor exit sign to notify driver when they have left the wildlife detection and warning corridor: "Leaving Wildlife Detection Zone"		
3	We recommend sign placement (distance between signs) so that at night you can see the flashing amber lights of the next sign at least faintly in the distance upon passing each dynamic advisory sign. Sight distance varies depending on road geometry and sight line obstructions. First dynamically activated sign should be positioned at entry of the detection corridor.		