

Effectiveness of Seasonal Deer Advisories on Changeable Message Signs as a Deer Crash Reduction Tool

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BRIDGET M. DONALDSON
Associate Principal Research Scientist

YOUNG-JUN KWEON, Ph.D., P.E.
Senior Research Scientist

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Bridget M. Donaldson
Associate Principal Research Scientist

Young-Jun Kweon, Ph.D., P.E.
Senior Research Scientist

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ABSTRACT

The Virginia Department of Transportation (VDOT) began posting deer advisory messages on changeable message signs (CMSs) along a 16.7-mile segment of I-64 between Waynesboro and Charlottesville, Virginia, in October 2015. The posting of these messages during the peak of deer activity, October-November from 5 P.M. to 9 A.M., was intended to raise driver awareness and reduce the high number of deer-vehicle collisions (DVCs) in the area.

The effectiveness of deer advisory messages with regard to DVC reduction is largely unknown. This study investigated the effectiveness of seasonal deer advisory messages as a DVC mitigation option. Effectiveness was determined by evaluating deer carcass removal data from three October-November deer advisory posting periods. Vehicle speed evaluations were also conducted to determine whether drivers reduced speed in response to the advisories.

For the 16.7-mile section of interstate evaluated, deer carcass removals were significantly lower when deer advisories were posted than when they were not posted, and this difference was statistically significant. During the time deer advisories were posted, there were statistically significant reductions in speeds of up to 2.8 mph at four of the five vehicle sensor stations. Speed reductions were greater when deer advisories were posted during lower traffic volumes.

Given the findings in the study area, seasonal deer advisory messages on an interstate appear to be an effective form of DVC mitigation. The study recommends that deer advisory messages continue to be posted on the CMSs selected in this study and that the number of postings be increased from the current 29% proportion of the days in the posting period to at least a 50% proportion when possible. Posting seasonal deer advisories every other day on the five existing CMSs in this study's project area is expected to save approximately \$595,500 to \$1.2 million over the service life of the CMSs. The findings of this study will be shared with appropriate VDOT staff so they may consider posting deer advisory messages on CMSs in areas with high frequencies of deer crashes where appropriate.

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Bridget M. Donaldson
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INTRODUCTION

Background and Project Area

Deer-vehicle collisions (DVCs) are among the top three types of collisions in many areas of Virginia (Donaldson, 2017), with more than 61,000 reported for the year ending June 30, 2016 (Miles, unpublished data). The Insurance Institute for Highway Safety reported that from 2008 to 2016, 11% to 13% of all collision claims were associated with striking or avoiding a deer (Wakeman, 2017). Loudoun and Prince William counties in Virginia have the 7th and 14th highest number of DVC claim frequencies, respectively, in the nation (Wakeman, 2018). These collisions can be costly to drivers; estimates from a recent study showed that DVCs were the 4th costliest of the 14 major collision types in Virginia, averaging more than \$533 million per year (Donaldson, 2017).

Since 2011, the Virginia Department of Transportation (VDOT) has targeted a section of I-64 for safety and mobility improvements because of a high number of vehicle crashes. The safety improvement area lies between Waynesboro and Charlottesville and includes a mountainous segment of I-64 (Afton Mountain) with a relatively high proportion of rear-end crashes (from fog events and from drivers of trucks quickly reducing speed as the trucks climb the mountain). Several changeable message signs (CMSs) were installed in the safety improvement area to alert drivers of foggy conditions and traffic incidents.

Although data from police crash reports indicated that DVCs were the third most frequent type of crash on I-64 from Staunton to Charlottesville, an analysis that based DVC estimates on deer carcass removal (CR) data indicated that deer crashes were actually the most common type of collision. They were 5 times higher than what was provided in police crash reports and 2.7 times more frequent than the second leading crash type (colliding with a fixed object off the road) (Donaldson, 2017). Vehicle collisions with black bears in the Afton Mountain area are also frequent; 13 black bears were killed by vehicles in October 2013 alone (Donaldson and Kweon, 2015).

As part of this safety improvement effort, researchers at the Virginia Transportation Research Council (VTRC) conducted a study that evaluated DVC mitigation options between Waynesboro and Charlottesville (Donaldson and Kweon, 2015). The study included 2 years of camera monitoring along the I-64 roadside to evaluate deer activity and their use of existing underpasses. A statistically significant relationship was found between roadside deer activity and DVCs (i.e., as deer activity increased, DVCs increased), and this relationship was strongest in October and November. Deer activity was found to be substantially higher between 5 P.M. and 9 A.M. (Donaldson and Kweon, 2015). Insurance claims data supported these findings; deer crashes are significantly higher in October and November compared to the rest of the year and peak between 5 P.M. and 9 A.M. (Wakeman, 2017).

Given these findings, the study recommended (1) the installation of 1 mile of 8-ft-high fencing at two sites in the project area to exclude deer and other wildlife from the highway and guide them to existing underpasses, and (2) the posting of deer advisory messages in October and November (hereinafter October-November) between 5 P.M. and 9 A.M. on the CMSs between Waynesboro and Charlottesville. Fencing construction was complete at the two underpass sites in early 2018.

On October 26, 2015, VDOT began posting deer advisory messages on four existing CMSs stationed in a 16.7-mile segment of interstate from mile marker [MM] 93.3 to MM 110 between Charlottesville and Waynesboro (see Figure 1, *top*). In 2016, another CMS was added at MM 102.5. Each CMS was positioned to face the traffic heading toward Afton Mountain; the signs at MMs 93.3 and 97 faced eastbound lanes, and the CMSs at MMs 102.5, 104, and 110 faced westbound lanes (Figure 1, *top*). Deer advisory messages were scheduled to be posted every 2 days rather than daily, with the intent of minimizing driver habituation, but other safety messages (i.e., for fog events and traffic incidents) were to be prioritized over deer advisories. Corresponding to the study recommendations, deer advisories were posted from 5 P.M. to 9 A.M. in October-November, 2015-2017. This overnight period encompassed daily peaks in deer activity and high traffic volumes during commuting hours (Donaldson and Kweon, 2015). Messages alternated between two frames of text (see Figure 1, *bottom*).

In addition to the deer advisories, VDOT posted a “floodgate message” on the VDOT 511 traffic information website. The messages ran along the top of the website and included the text “Stay Alert. Watch for increased deer activity, particularly near dawn and dusk.” Another message included the number of DVCs that had occurred in the Afton Mountain area the previous year. Similar to the CMS deer advisories, the floodgate messages were posted every other day from 5 P.M. to 9 A.M. in October-November (to correspond with the CMS posting periods). Posting other safety incidents on the website took priority over posting the deer messages.

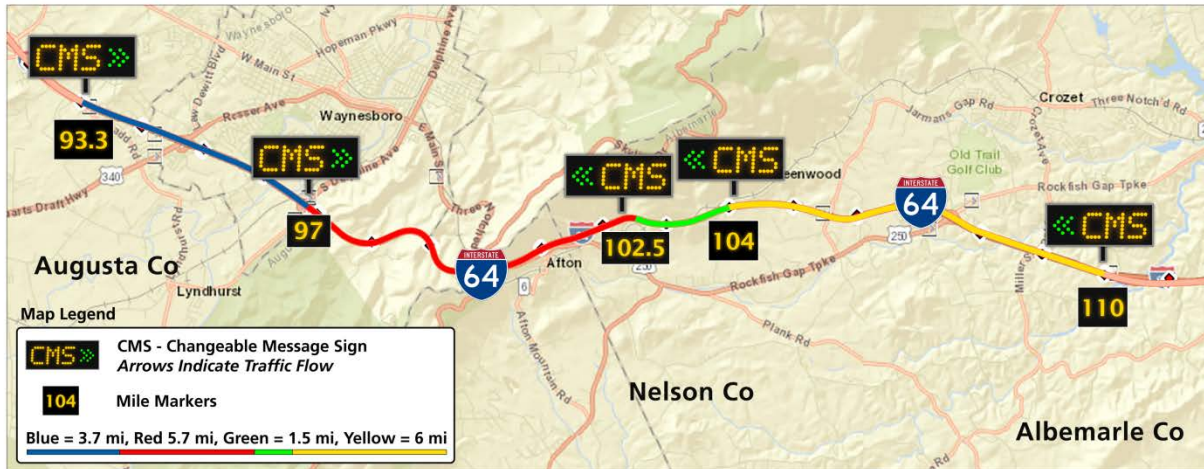


Figure 1. *Top: Project Area Illustrating the Location of the Changeable Message Signs; Bottom: Text of the Deer Advisories (each sign alternates between 2 frames of text).*

Research on Animal Advisory Messages

The purpose of CMSs, also known as dynamic message signs, is to increase driver safety by calling attention to unexpected conditions. The aim is to increase driver alertness and often to reduce driver speed (Federal Highway Administration, 2000).

Studies suggested that drivers can reduce the chance of a collision with wildlife by reducing speed and remaining alert in areas with abundant wildlife (Haikonen and Summala 2001; Khattak, 2003). In general, reducing speed has been found to decrease the number of accidents and the severity of injuries regardless of the type of collision (Elvik, 2005). Several studies have found lower numbers of animal crashes in areas with lower speeds (Allen and McCullough, 1976; Case, 1978; Gunther et al., 1998; Rolley and Lehman, 1992).

Studies on the effectiveness of animal advisory messages or enhanced animal signs (with flashing lights or large graphic images) have typically focused on driver speed reduction rather than DVC reduction. Most studies have shown a reduction in driver speed in response to the signs or messages (Al-Ghamdi and AlGadhi, 2004; Hammond and Wade, 2004; Hardy et al.,

2006; Pojar et al., 1975; Sullivan et al., 2004). Researchers have attributed the success of animal detection driver warning systems (whereby a flashing warning sign is triggered when a sensor detects an animal along the roadside) to a reduction in driver speed and stopping distance (Huijser and McGowen, 2003; Huijser et al., 2006).

In an experiment in which drivers in a simulator were exposed to either standard deer warning signs or enhanced deer warning signs with a flashing light, the average vehicle speeds while the lights were flashing were 2.3 mph lower than with both standard signs and signs with the flashing lights turned off (Hammond and Wade, 2004). In another study comparing six enhanced animal crossing signs with standard signs, mean speed reductions of 1.9 to 4.3 mph were found with the enhanced signs (Al-Ghamdi and AlGadhi, 2004). Hardy et al. (2006) found that animal advisory messages on CMSs were generally effective in reducing average driver speeds, particularly during dark conditions. Speed was reduced by 1% to 9% (a reduced stopping distance of 6 to 72 ft). However, in a study that evaluated driver speed in response to animal crosswalk signs (installed where wildlife fencing led animals to a crossing area), speed reductions were not found (Lehnert and Bissonette, 1997).

Research on the effectiveness of animal advisories with regard to a reduction in DVCs is limited. Although Pojar et al. (1975) found reductions in driver speed up to 7.9 mph in response to an animated and lighted deer crossings sign in Colorado, DVCs were not significantly reduced. Conversely, a study evaluating temporary enhanced animal crossing signs during mule deer migration periods in the western United States found a 50% reduction in DVCs (Sullivan et al., 2004).

Driver vigilance is also likely to be associated with DVC risk. A study in a national park in South Africa was conducted to monitor driver behavior and vehicle speed when researchers placed a fake snake in the road. They found that the observation levels of the driver, not driver speed, were the key factor in whether a vehicle struck the snake (Collinson, 2016).

As a state that is consistently among the 10 states with the highest number of DVCs (Donaldson, 2017), Virginia is in need of effective countermeasures. Although underpasses with fencing are known to be the most effective method of reducing wildlife collisions (Bissonette and Rosa, 2012; Clevenger et al., 2001; Dodd et al., 2008), it is difficult and sometimes impractical to implement this type of mitigation in every area with high volumes of wildlife crashes. If animal advisory messages on CMSs are found to be effective, this would be an inexpensive and simple option for VDOT and other transportation agencies to implement.

PURPOSE AND SCOPE

The purpose of this study was to determine the effectiveness of seasonal deer advisory messages on CMSs as a DVC reduction tool. Effectiveness was determined by comparing the number of CRs when deer advisories were posted to the number of CRs when they were not posted. Vehicle speed evaluations were also conducted to determine whether drivers reduced speed in response to the advisories.

The project area included a 16.7-mile segment of I-64 between Waynesboro and Charlottesville, Virginia. Evaluations included up to 6 years of CR data and 4 months of vehicle speed data.

METHODS

Carcass Removals

The primary project area included five CMSs on I-64, extending from the westernmost CMS that posted deer advisory messages (MM 93.3) to the easternmost CMS (MM 110). For general CR data analyses that were used as a context for some of the evaluations, the evaluated segments of I-64 were as long as 60 miles (MM 89 to MM 149).

Deer Advisory Postings

At the conclusion of each of the three deer advisory posting periods in October-November, 2015-2017, the researchers contacted VDOT's Traffic Operations Center (Northwest Region) to obtain the deer advisory posting dates. Deer advisories were generally scheduled to be posted every other day in October-November for a 16-hr duration (from 5 P.M. to 9 A.M.), but the posting of other safety advisories took precedence.

Carcass Removal Data for I-64

Deer carcasses were removed by interstate maintenance contractors; contractors recorded the date and location (to the nearest 0.1 mile) of the CR on paper forms. CR data along much of I-64, including the project area, have been provided to VTRC for this and previous studies since 2012. VDOT maintenance staff from the Staunton and Culpeper districts sent the CR data to VTRC at monthly intervals. It is important to note that the actual number of DVCs is likely higher than what was reflected by CR records, as some deer flee or survive after colliding with a vehicle.

Carcass Removals Before and During Deer Advisory Posting Periods

The first analysis of CR data was similar to a before and after evaluation. The number of CRs in the project area (MM 93.3 to MM 110) in the 3 years before deer advisories were compared to the number of CRs in the project area after the posting of deer advisory messages began in October 2015. The number of CRs in October and November before the advisories (2012-2014) were compared to the number of CRs during the deer advisory posting periods (2015-2017). The posting periods included days the deer advisories were posted and days they were not posted.

Similar to the first evaluation, the second evaluation included a comparison of pre-deer advisory CRs to CRs that occurred during the advisory posting periods but assessed whether differences could be detected in the number of CRs at individual CMS locations. The interstate segments between the five CMS locations extended from 1.5 to 6 miles (Figure 1, *top*). Several segment lengths were evaluated at each CMS location, ranging from 2 to 5 miles. Each segment

evaluated began at the CMS and extended in the same direction of travel. Because CR data collectors often did not record the lane of travel when documenting a CR, each segment analyzed included all CRs in that segment (both east- and westbound lanes).

These simple analyses were intended to provide an indication of whether a difference could be detected in CRs given the implemented posting frequency of the deer advisories. It was expected that significant differences would be difficult to detect with this analysis because of the numerous variables that can influence DVCs and driver behavior from one year to the next. These include weather (i.e., precipitation can affect vehicle speed and deer movement), deer population, deer road crossing volume, and vehicle volume. The evaluation was expected to provide useful general information on DVCs in the project area over a 6-year period (2012-2017).

Differences between the number of CRs before and during the posting periods were evaluated with a *t*-test. *P*-values less than 0.05 were considered significant.

Carcass Removals During Deer Advisory Posting Periods

The next analyses evaluated only the CR data from the three October-November posting periods in 2015-2017. The number of CRs on days a deer advisory was posted was compared to the number of CRs on days a deer advisory was not posted. Days a deer advisory were “not posted” included days that (1) a CMS had no message of any kind, and (2) the CMS had a non-deer-related message.

A deer CR that was documented on a day that a deer advisory posting ended (9 A.M.) was considered as having occurred during the deer advisory posting. For example, if a CR was documented October 20 and a deer posting began October 19 at 5 P.M. and ended October 20 at 9 A.M., the carcass that was removed on October 20 was considered to have been removed during the deer advisory posting that began on October 19. This corresponds with the workdays of maintenance staff; they typically begin their interstate maintenance work at 9 A.M. and end it by 5 P.M. (Nicholson, personal communication). For any deer carcass reported by a motorist at the start of a workday, the deer was assumed to have been struck after the worker ended his or her 5 P.M. shift the previous evening. In addition, nearly 75% of DVCs occur between 5 P.M. and 9 A.M., with the peak activity period beginning at dusk and ending at dawn (Wakeman, 2018). It is therefore likely that a CR recorded during the 9 A.M. to 5 P.M. workday occurred during the previous 5 P.M. to 9 A.M. timeframe.

Maintenance staff did not remove animal carcasses from the evaluated section of interstate on weekends (except for rare emergencies); carcasses of deer struck on the weekends were therefore removed the following Monday (Nicholson, personal communication). Because it could not be determined whether the CRs that occurred on Mondays were of deer struck on the previous Friday evening after 5 P.M., Saturday, or Sunday, all Monday CR data were excluded from the analyses.

Control Evaluation

A control section of the interstate was selected. An evaluation of CRs during the October-November posting periods in the control section was conducted identically to the evaluation of CRs in the project area. The control segment had no CMSs (and therefore no deer advisories). The number of CRs in the control segment that occurred on days a deer advisory was posted in the project area was compared to the number of CRs in the control segment that occurred on days a deer advisory was not posted in the project area. This comparison was conducted to help validate that any findings of statistical differences in the project area were a result of the deer advisories rather than external factors (such as variabilities in climate, traffic volume, and deer activity and crossings from day to day).

The control segment along I-64 was selected for important similarities to the project area, including proximity to the project area, CR volume, and land cover. In order to find a segment with a similar CR volume, the control segment was slightly longer (2.3 miles) than the project area, but the other important characteristics were similar between the two sites. The control area began 22 miles east of the project area and extended from MM 132 to MM 151. It was the same distance from the Charlottesville city boundaries as the project area but in the opposite direction. At the project area and control area, the surrounding land cover was predominantly wooded with interspersed open areas and numerous riparian streams that were directed beneath the interstate.

Subsequent evaluations were conducted on the individual segments between each CMS in the project area. In each of the four segments between the CMSs, the number of CRs when deer advisories were posted was compared to the number of CRs when the advisories were not posted.

Consideration of Factors That May Influence CRs

Several factors that could potentially influence DVCs were considered with regard to their inclusion in the CR analyses. For each factor, it was determined whether (1) data were available, and (2) the degree to which that factor was expected to differ between the periods the deer advisories were posted or were not posted. The first variable included the frequency of deer movement across the interstate (and the associated likelihood of a collision). The difficulty and cost required to answer this question were outside the scope of this study. It was therefore not applied to the CR analysis; it was assumed that the frequency of deer movement across the interstate did not differ depending on whether the deer advisories were posted or were not posted.

Precipitation was the second variable considered because of its potential to reduce driver speed and potentially reduce the risk of a DVC. Hourly weather data were reviewed for precipitation events during the deer advisory posting periods (National Oceanic and Atmospheric Administration, 2018). Precipitation occurred 46 of the 859 total hours that deer advisories were posted (0.05%). It was therefore determined that if there was an effect of precipitation on CRs, the effect would not result in a greater decrease in speed and any associated CR reductions when deer advisories were posted than when they were not posted. Precipitation was therefore not applied to the CR analyses.

Traffic volume can also affect DVCs, but because the time of each DVC was unknown, traffic volume at the time of the DVC could not be determined. However, the fact that the analyses targeted only weekday (not weekend) periods from 5 P.M. to 9 A.M. reduced the variability of traffic volume in the analyses. It was therefore assumed that any effects traffic volume may have had on DVCs did not substantially differ based on whether deer advisories were posted or were not posted.

The final variable considered with regard to a potential influence on DVCs was the frequency with which the DVC mitigation was applied (i.e., the driver's amount of exposure to the deer advisories). As noted previously, deer advisories were scheduled to be posted every other day, but any other safety-related messages had higher priority. It was decided that any disparity in the proportion of days deer advisories were posted and were not posted was important to account for in the CR analyses. To explain further, the CR analyses were conducted by categorizing each CR as having occurred either (1) when a deer advisory was posted, or (2) when a deer advisory was not posted. However, a larger number of days when deer advisories were not posted than when deer advisories were posted would result in greater exposure to the risk of hitting a deer (or vice versa). The weight was applied to account for any difference in the proportion of time the advisories were or were not posted and thereby to provide a more balanced analysis of the data. The weight (Burriss and Appiah, 2004) applied to the number of CRs when the advisory was posted was calculated by the following equation:

$$W_{ON} = D_P / D_{CRP}$$

where

W_{ON} = weight

D_P = number of days the deer advisory was posted

D_{CRP} = number of days one or more CRs occurred when the deer advisory was posted.

The weight applied to the number of CRs when the advisory was not posted was calculated by the following equation:

$$W_{OFF} = D_{NP} / D_{CRNP}$$

where

W_{OFF} = weight

D_{NP} = number of days the deer advisory was not posted

D_{CRNP} = number of days one or more CRs occurred when the deer advisory was not posted.

W_{ON} was multiplied by the number of CRs that occurred when the advisory was posted. W_{OFF} was multiplied by the number of CRs that occurred when the advisory was not posted. Given the equation for the weight (whereby a larger value [D_P or D_{NP}] would typically be divided by a smaller value [D_{CRP} or D_{CRNP}]), the weight factors were expected to be greater than 1.

Multiplying the CR values by the weight was therefore expected to result in greater weighted CR values than unweighted CR values.

Before statistical analyses were conducted, the distribution of the CR data was evaluated to determine whether the data were bell-shaped or skewed in one direction. Because the data were right-skewed (positive skewness), three transformations were employed (log-transformation, square root, and reciprocal). CR data were then evaluated with a pairwise *t*-test. *P*-values less than 0.05 were considered significant. To increase assurance of the findings, a *t*-test was performed on four variants of the weighted number of CRs (non-transformed, log-transformed, square root of, and reciprocal of the weighted number). Results were reported as statistically significant only if the statistical results did not differ, depending on which variant of the *t*-test was performed.

Vehicle Speed

Traffic speed and volume data in the project area were provided by staff in VDOT’s Northwest Region Traffic Operations Center. Data were collected by HD-125 Wavetronix “side fire” radar. Data from five sensor stations were analyzed. Stations were located at MMs 98, 99, 101, 102, and 104 (Figure 2). Data from September-December 2015 were analyzed to allow for a comparison of periods when deer advisories were posted and periods when they were not posted. Various analyses were conducted with speed, including traffic volume, the type of message posted on the CMS, and day versus night conditions.

Day and night periods were defined by sunset and sunrise times at MM 100 (latitude = 38.032686 and longitude = -78.860555), which is approximately the center of the project area. Day was defined as after sunrise and before sunset, and night was defined otherwise. The National Oceanic and Atmospheric Administration (2018) solar calculator was used to determine sunset and sunrise times.

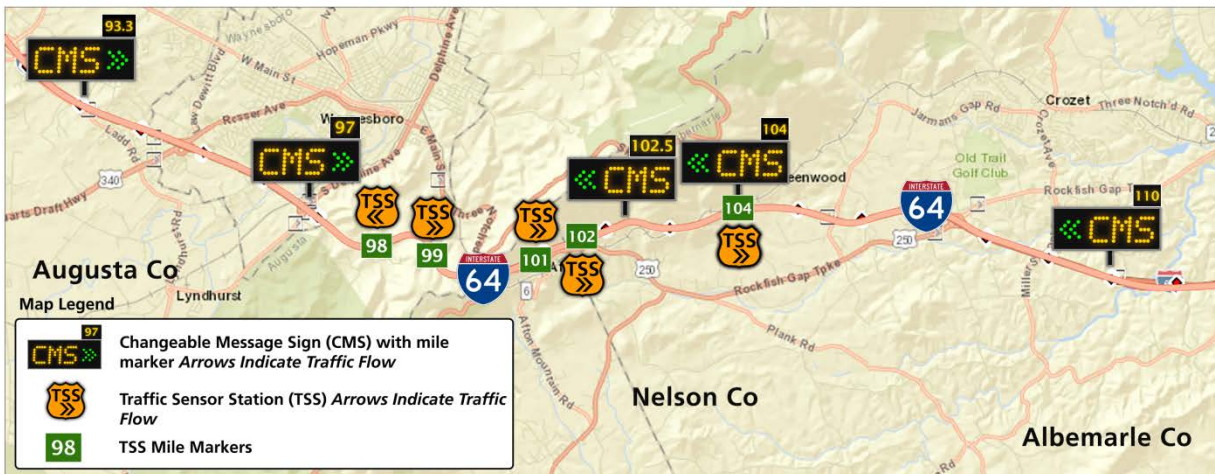


Figure 2. Locations of Traffic Sensor Stations in Project Area Relative to Locations of Changeable Message Signs (CMS)

Vehicle speed evaluations were not intended to be comprehensive but rather to provide a general indication of whether average speeds differed during periods when deer advisories were posted and periods when they were not posted. Weather conditions were evaluated to determine whether the analyses should account for precipitation effects on speed. Precipitation occurred 6 of the 363 hours (0.02%) the deer advisories were posted during the October-November 2015 period in which speed was evaluated. Precipitation was therefore not accounted for in the analyses, as it was not expected to cause speed reductions during deer advisories.

Various statistical analyses were applied to the speed and volume data. Omnibus tests were first conducted to verify that the explained variance in the data was significantly greater than the unexplained variance. One-way analysis of variance tests were then performed to make pairwise comparisons among different CMS messages (i.e., deer, fog, and safety messages). Three variants of the *t*-test (no adjustment, Bonferroni’s adjustment, and Holm’s adjustment), controlling for Type I error, were performed in two different assumptions on standard deviations (pooled and non-pooled). Finally, generalized additive models (GAMs) were conducted to assess the CMS message’s relationship with speed and volume (differentiated by day and night).

RESULTS

Carcass Removals

Deer Advisory Postings

Table 1 lists the number of days deer advisories were posted at each CMS in the project area. Postings were as few as once per week when multiple fog and other safety advisories took precedence. In 2015 and 2017, postings did not begin until mid- or late October. On some occasions, fog postings split the 16-hr posting period; deer advisory postings for these instances were counted as one-half of a posting (0.5). Not including the number of deer advisories at the MM 102.5 CMS (since it was installed a year later than the other CMSs), the number of deer advisory posting days averaged 54 of the 183 days in October-November from 2015-2017 (29%).

Table 1. Deer Advisory Posting Days on Changeable Message Signs (CMSs) October-November

CMS Location (MM)	No. of Deer Advisory Postings ^a				Proportion of Days Posted (%)
	2015	2016	2017	Total	
93.3	16	18.5	15	33.5	27
97	16	25.5	15	56.5	31
102.5	NA	25.5	15	56.5	31
104	16	25.5	15	56.5	31
110	16	18.5	15	49.5	27

^aInstances when fog and deer advisories split the 5 P.M. to 9 A.M. posting period were counted as 0.5.

Carcass Removal Data for I-64

From 2012-2017, approximately 2,400 deer carcasses were removed from a 60-mile segment of I-64 (MM 89 to MM 149) and 603 were removed from the project area. As Table 2 shows, 44% to 65% of the annual CRs occurred in October and November. There was a large fluctuation in CRs from year to year (for the extended segment, the mean per year = 399, and the standard deviation = 39; for the project area, the mean per year = 101, and the standard deviation = 19).

Table 2. Number of Carcass Removals Along I-64 (2012-2017)

Year	Project Area (MM 93.3 to MM 110)		Extended Segment (MM 89 to MM 149)	
	Full Year	Proportion in Oct.-Nov.	Full Year	Proportion in Oct.-Nov.
2012	90	42 (47%)	421	188 (45%)
2013	87	45 (52%)	392	171 (44%)
2014	132	73 (55%)	448	228 (51%)
2015	86	42 (49%)	354	229 (65%)
2016	117	68 (58%)	426	246 (48%)
2017	91	43 (47%)	355	158 (45%)

Carcass Removals Before and During Deer Advisory Posting Periods

Entire Project Area

In the entire 16.7-mile project area (MM 93.3 to MM 110), there were 160 CRs in the three October-November periods before the implementation of deer advisory postings (2012-2014) and 153 during the three deer advisory posting periods (2015-2017). This small difference was not statistically significant.

As noted previously, this was expected given the large fluctuations in DVCs from one year to the next (Table 2). In addition, deer advisories were posted an average of 29% during the October-November posting period. Although posting these advisories on a daily basis may increase the risk of driver habituation to the messages, any effect that deer advisories may or may not have might become more evident if the messages are posted a higher proportion of the posting period.

At Individual CMSs in the Project Area

At the five CMS locations, there was one area (beginning at the CMS at MM 97) with statistically significant differences between the number of CRs in the October-November timeframes before deer advisories were posted on the CMSs (2012-2015) and that during the October-November timeframe when deer advisories were posted (2015-2017). At this location, CRs were significantly lower in the 2-mile, 3-mile, and 4-mile segments beginning at this CMS during the 2015-2017 deer advisory posting periods. This reduction was not found with distances greater than 4 miles from the CMS. Table 3 lists the results for the 3-mile segment analyses.

Table 3. Carcass Removals in 3-Mile Segments of Project Area Before and After CMS Installation (October-November)

CMS (Traffic Direction) (MM)	CMS Segment (3 mi) (MM)	No. of Days Deer Advisories Posted (Percentage)	No. of Carcass Removals Before CMS Installation (2012-2014)	No. of Carcass Removals After CMS Installation (2015-2017)	Significant Difference?
93.3 (East)	93.3 to 96	49.5 (27%)	23	35	No ($p = 0.1$)
97 (East)	97 to 100 ^a	56.5 (31%)	32	19	Yes ($p = 0.02$)
102.5 ^a (West)	102.5 to 99.5	56.5 (31%)	11	15	No ($p = 0.2$)
104 (West)	104 to 101	56.5 (31%)	15	11	No ($p = 0.2$)
110 (West)	110 to 107	49.5 (27%)	21	27	No ($p = 0.2$)

CMS = changeable message signs.

^a Although most segments were analyzed to compare carcass removals for 3 years before CMS installation to carcass removals 3 years after CMS installation, the CMS at MM 102.5 was not installed until 2016; therefore, carcass removals for only 2 years before CMS installation and only 2 years after CMS installation were compared.

As referenced previously, this particular evaluation (i.e., comparing CR data in the years before postings to CR data in the years during postings) was conducted to provide some general information of interest. Extracting meaning from the statistical findings should be limited, however, given the high variability in DVCs from year to year.

Carcass Removals in Deer Advisory Posting Periods

Entire Project Area

Because this CR evaluation focused solely on the 2-month deer advisory posting periods, the annual variability of factors that potentially influence DVCs (namely, deer population) was greatly reduced; this analysis was thereby a more robust assessment of the effectiveness of deer advisories. Excluding Monday CR data, there were 31 CRs when deer advisories were posted and 71 CRs when deer advisories were not posted. The weighted mean CRs per day in the project area were 51% lower when deer advisories were posted (2.4 CRs/day) than when they were not posted (4.9 CRs/day), and this difference was statistically significant (Table 4).

Table 4. Carcass Removals in the Project Area and Control Segment With Deer Advisories Posted and Not Posted (October-November, 2015-2017)

Deer Advisory Status		N (Days With Carcass Removals)	No Weight Factor			Weight Factor Applied		
			Total Carcasses ^a	Mean per Day	Standard Deviation	Total Carcasses ¹	Mean per Day	Standard Deviation
Project Area	Posted	23	31	0.4	0.7	191	2.4 ^b	5.2
	Not Posted	58	71	0.9	0.7	395	4.9 ^b	4.3
Control	Posted	31	43	0.6	0.2	63	0.9	1.4
	Not Posted	36	51	0.8	0.9	96	1.4	1.8

^a Analyses did not include carcasses of deer removed on Mondays (which were assumed to have been struck over the weekend).

^b Indicates statistically significant difference in CRs between posted and not posted periods.

Table 4 includes the unweighted mean CRs per day to present the actual number of CRs with and without deer advisories. The unweighted mean CRs per day during deer advisories were 56% lower than when deer advisories were not posted, which was also a statistical difference (Table 4). In the control segment, the unweighted and weighted CRs were 25% and 36% lower, respectively, on the days deer advisories were posted compared to days they were not posted, but these differences were not statistically significant (Table 4). The findings of no significant differences in CRs in the control area provided greater credibility to the findings in the project area.

Individual CMS Locations

At the four segments between CMSs, CRs were 42% to 100% lower when deer advisories were posted than when they were not posted. These differences were statistically significant at two of the segments (MM 93.3 to MM 97 and MM 102.5 to MM 104). Although the other two segments (MM 97 to MM 102.5 and MM 104 to MM 110) had 42% and 47% fewer CRs during the postings, respectively, these differences were not statistically significant (Table 5). It is possible that findings may be significant for these segments with larger sample sizes (i.e., additional years of CR data).

Table 5. Carcass Removals for CMS Segments When Deer Advisories Were Posted and Were Not Posted (October-November, 2015-2017)

CMS Segment (Length) (MM)	Deer Advisory Status	Carcass Removal Data Summary				
		N (Days With Carcass Removal)	Mean Carcass Removals per Day (Weighted)	Standard Deviation	Statistically Significant Difference?	Percent Difference
93.3 to 97 (3.7 mi)	Posted	7	1.4	2.4	Yes	66
	Not Posted	20	4.1	3		
97 to 102.5 ^a (5.5 mi)	Posted	8	2.5	3	No	42
	Not Posted	11	4.3	4.1		
102.5 ^a to 104 (1.5 mi)	Posted	0	0	0	Yes (but small sample size)	100%
	Not Posted	4	3.2	0		
104 to 110 (6 mi)	Posted	6	3.2	7.8	No	47
	Not Posted	25	6	5.5		

^a Because the CMS at MM 102.5 was not installed until 2016, segments that include this CMS were analyzed for the 2016-2017 period; other segments were analyzed for the 2015-2017 period.

Vehicle Speed Evaluations

General Speed and Volume Evaluations

Table 6 lists the speed and volume characteristics of the data evaluated. Data were provided in 5-minute aggregates. Cases with at least 1 vehicle per 5 minutes were included for analysis. Traffic volumes varied considerably across the sensor stations. For example, an average of 11 vehicles were recorded for 5 minutes at MM 98, whereas 61 vehicles were recorded at MM 99. There was little variation in speeds across the stations; means ranged from approximately 66 mph at MM 98 to 68 mph at MM 101.

Table 6. Data by Sensor Station

Sensor Station (MM)	Variable	No. of Observations ^a	Mean	Standard Deviation	Minimum	Maximum
98	Volume (veh/5 min)	68,100	11.29	9.13	1	67
	Speed (mph)	68,100	65.88	5.24	8	88
99	Volume (veh/5 min)	140,362	60.65	43.55	1	293
	Speed (mph)	140,362	64.06	4.93	6	88
101	Volume (veh/5 min)	139,778	58.34	43.73	1	284
	Speed (mph)	139,778	68.45	7.85	1	113
102	Volume (veh/5 min)	102,406	12.99	9.53	1	72
	Speed (mph)	102,406	67.44	6.53	2	108
104	Volume (veh/5 min)	138,904	53.29	43.62	1	250
	Speed (mph)	138,904	67.68	6.24	1	118

^aData include observations with at least 1 vehicle/5 minutes.

Speed and Volume by Day Versus Night

Table 7 illustrates volume and speed data according to day and night conditions. There was a large difference in traffic volumes between day and night, and speeds were slightly different. Day speeds were 2.7 mph higher than night speeds on average.

Table 7. Data Analyzed by Period of Day

Day/Night	Variable	No. of Observations	Mean	Standard Deviation	Minimum	Maximum
Day	Volume (veh/5 min)	265,460	69.72	43.32	1	293
	Speed (mph)	265,460	68.24	5.93	1	101
Night	Volume (veh/5 min)	324,090	23.64	28.1	1	247
	Speed (mph)	324,090	65.54	6.79	2	118

Speed and Volume by CMS Message

Vehicle speed and volume according to the type of CMS message are summarized in Table 8. On average, speeds were lowest during the 5 P.M. to 9 A.M. posting periods when fog advisories were the only posting and when fog advisories occurred within the same posting period as deer advisories. Figure 3 illustrates the interactions among CMS message posted, traffic volume, and day/night conditions.

Table 8. Speed and Volume Analyses for CMS Advisories (September-December 2015)

CMS Message	Variable	No. of Observations	Mean	Standard Deviation	Minimum	Maximum
Deer and Fog ^a	Volume	3,014	36.46	37.71	1	171
	Speed	3,014	62.01	6.46	30	89
Deer	Volume	43,008	30.84	37.48	1	236
	Speed	43,008	66.41	5.63	21	108
Fog	Volume	113,908	42.98	39.62	1	225
	Speed	113,908	63.89	8.03	1	112
Other ^b	Volume	429,620	46.17	43.44	1	293
	Speed	429,620	67.58	5.95	4	118

CMS = changeable message signs.

^aPosting periods that were split between deer advisories and fog advisories.

^bIncludes periods with no CMS message and periods with CMS messages other than deer or fog advisories.

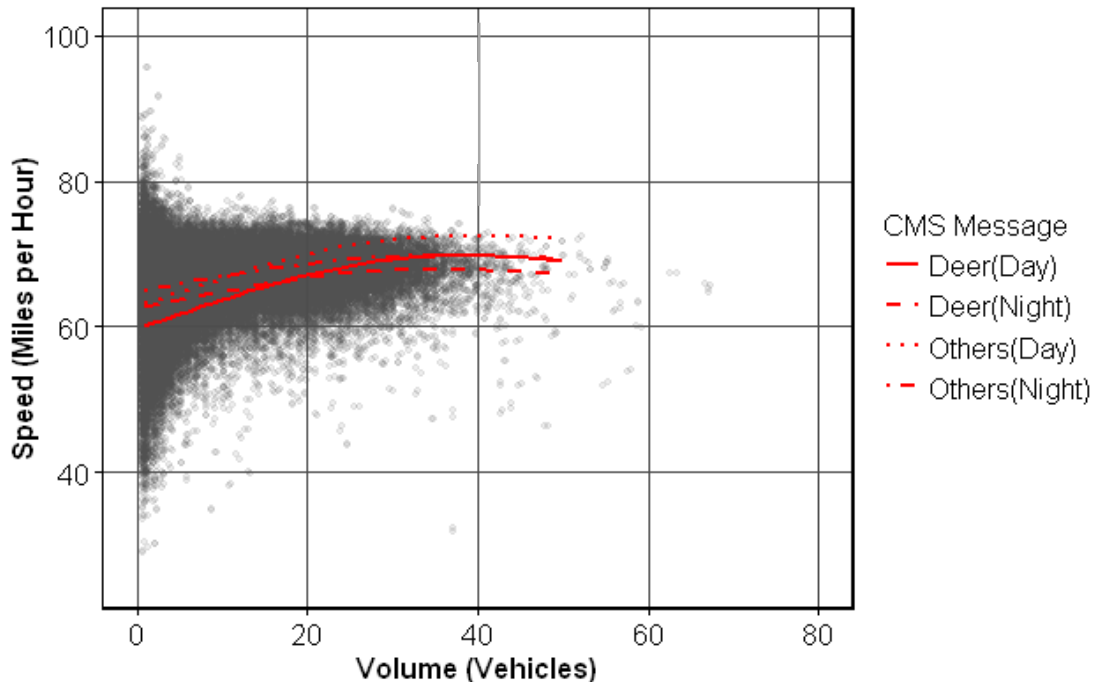


Figure 3. Relationships Between Traffic Volume (per 5 min) and Speed When Deer Advisory Messages Were and Were Not Posted (September-December 2015) at MM 101. Fog postings were excluded from the analysis because fog is associated with reduced vehicle speeds. CMS = changeable message sign.

Speeds during deer advisories were an average of 1.2 mph lower than speeds during periods other than deer or fog advisories (a reduced stopping distance of 7.5 ft). The largest speed reductions occurred when deer and fog advisories both occurred within the same 5 P.M. to 9 A.M. posting period; speeds with this scenario were 5.6 mph lower on average than speeds during periods other than deer or fog advisories. Speeds during fog advisories were 3.7 mph lower than speeds during periods other than deer advisories.

From an evaluation of individual sensor station data, four of the five sensor stations showed statistically significant speed reductions during deer advisories compared to speeds during periods other than during deer or fog postings. These significant reductions were found at MM 99, MM 101, MM 102, and MM 104 and ranged from 0.5 mph to 2.8 mph.

It is unknown whether an average speed reduction of up to 2.8 mph makes a practical difference with regard to driver safety. It is important to keep in mind that because this is an average value, many drivers' speed reductions were less than 2.8 mph and many were greater. Reducing speed from 68 to 65.2 mph (a 2.8-mph reduction) decreases stopping distance by 18 ft, which may be sufficient to avoid a collision with a deer that is ahead of the vehicle. Speed reductions may also be associated with increased driver vigilance because of the deer advisories, but this potential association was not evaluated.

As noted previously, precipitation occurred only 0.01% of the time deer advisories were posted and was therefore not considered in the analyses. The speed reductions found during periods with deer advisory postings were therefore conservative, as precipitation and any speed

reductions associated with precipitation occurred predominantly when deer advisories were not posted.

As noted previously, the interactions among CMS message posted, traffic volume, and day/night conditions were analyzed (Figure 3). For the analysis, fog postings were excluded because fog is associated with a reduction in speed. In general, when traffic volume was light, vehicle speeds were lower when deer messages were posted than when they were not posted. When traffic volume became heavier, vehicle speeds when deer messages were posted approached speeds when deer messages were not posted (Figure 3). In other words, speed reductions were greater when deer advisories were posted during lower traffic volumes.

Study Limitations

Although typical safety studies are often based on large datasets, the CR data on which this study was primarily based included 102 CRs across the 81 days in which carcasses were removed in the study period. Had it been possible to include the Monday CR data in the analysis, the CR numbers would have been 33% greater. However, it could not be determined on which day between Friday evening and Monday morning the DVC occurred (or whether a deer advisory was posted when the DVC occurred). Despite this limitation, there was a high degree of statistical confidence in the findings, which indicate that deer advisory messages are a promising strategy to reduce DVCs. The effectiveness of future seasonal deer advisory postings in the project area should be evaluated to determine whether the CR reductions found in this study continue.

SUMMARY OF FINDINGS

- *In an analysis of CRs for the years when deer advisories were posted compared to CRs for the years before deer advisories were posted, there were no statistically significant differences in CRs. In the four individual segments between CMS, CRs were statistically lower for a distance up to 4 miles in one of the segments (MM 97 to MM 101). The results of this analysis were useful as a context for the study, but given the annual variability in influencing factors such as deer population and crossing attempts, the results have limited value as an indication of the effectiveness of the deer advisories.*
- *In an analysis of CRs for the three 2-month deer advisory posting periods for the entire 16.7-mile study area, CRs were 51% lower when deer advisories were posted than when they were not posted, and this difference was statistically significant. In the control segment that had no deer advisories, there was no statistically significant reduction of CRs during those same posting / non-posting time segments.*
- *In a comparison of vehicle speeds during the posting of CMS messages, speeds during deer advisories were 1.2 mph lower on average and up to 2.8 mph lower at individual sensor stations than speeds during periods other than periods of deer or fog postings. These reductions were statistically significant and equated to an average reduced stopping distance*

of up to 18 ft. It should be noted that the analyses assumed that the potential influences of variables that may affect speed were evenly distributed across days deer advisories were and were not posted.

- *Speed reductions were greater when deer advisories were posted during lower traffic volumes.* When traffic volume became higher, vehicle speeds when deer advisories were posted approached speeds when they were not posted

CONCLUSIONS

- *Deer advisory messages on CMSs along an interstate can be an effective DVC mitigation tool.*
- *Deer advisory postings appear to be associated with reduced vehicle speeds.* In this study, speed reductions during deer advisories also corresponded with a decrease in traffic volume.

RECOMMENDATIONS

1. *VDOT's Regional Operations Director of the Culpeper and Staunton districts should establish a standard practice for the posting of seasonal deer advisory messages along I-64 at the five CMSs evaluated in this study and should increase the number of postings to a frequency of at least 50% of the October-November posting period when possible.* Posting deer advisories every day that other safety or advisory messages are not prioritized may be an effective means of achieving a minimum of a 50% posting frequency.
2. *VTRC should provide the study findings regarding the CR reductions to VDOT's regional operations directors, regional transportation operations managers, and district transportation engineers.* This information may be useful for decisions regarding DVC mitigation in areas with high frequencies of DVCs. Previous research by VTRC researchers found that deer carcass removal data can be up to 8.5 times greater than what is documented in police crash reports (Donaldson, 2017). When considering areas with high DVC frequencies, VDOT should consider multiplying police-reported DVCs by a factor up to 8.5 (Donaldson, 2017).

IMPLEMENTATION AND BENEFITS

Implementation

Recommendation 1 has been implemented by the Regional Operations Director of VDOT's Northwest Region and the Transportation Operations Manager of VDOT's Northwest Region. A standard of practice document for the seasonal posting of deer advisory messages along I-64 on the CMSs in the northwest operations region each October and November from 5 P.M. to 9 A.M. has been developed. To achieve a posting frequency of up to 50% during this

period, these messages will be posted on odd-numbered days in October and even-numbered days in November.

Recommendation 2 will be implemented by the VTRC authors of this report. By November 1, 2018, VTRC will contact VDOT's regional operations directors, regional transportation operations managers, and district transportation engineers and provide this report and a brief overview of the findings of this study. Because these groups have regular monthly meetings, VTRC will offer to present the study results at these meetings.

Benefits

A cost analysis was conducted to determine the costs saved from a reduction in DVCs during periods of deer advisory postings on CMSs in the project area. The CRs used in the calculation included the range of CRs in the project area in October-November from 2012-2014 (the years before deer advisory postings). The analyses assumed a posting schedule of every other day in October-November and a 25% to 51% decrease in DVCs on deer advisory posting days. This range was chosen in order to provide a conservative estimate of savings in the event that other locations that post deer advisories have a lower CR reduction than that found in this study.

The analysis was based on the area evaluated in this study, where CMSs had already been purchased and were initially used only for messages other than deer advisories. It was assumed that a CMS had an effective range of 3 miles; this was a conservative estimate based on the findings of this study that a statistically significant reduction in CRs occurred along a segment length of up to 3.7 miles (Table 5). A DVC was valued at \$6,617; this value predominantly comprises the average property damage cost from a DVC; it also includes carcass removal expenses (Huijser et al., 2009). The service life of a CMS was estimated at 15 years (U.S. Department of Transportation, 2018).

Table 9 lists the savings from posting deer advisories on one CMS. If the 51% reduction of DVCs found in this study remains throughout the service lives of the CMSs, posting seasonal deer advisories on the five existing CMSs in this study's project area every other day would result in a savings of nearly \$1.2 million over the service lives of the CMSs.

The benefit of implementing Recommendation 1, establishing a standard of practice, will be a reduction in DVCs in the project area on days deer advisories are posted. If deer advisories are posted every other day and there is a 25% to 51% CR reduction (the latter of which was found in this study) over the service lives of the CMSs, this would result in a savings of approximately \$595,500 to \$1.2 million over the service lives of the CMSs.

The benefit of implementing Recommendation 2, in which the findings of this study will be provided to regional operations directors, regional transportation operations managers, and district transportation engineers, is that the findings will be useful for decisions regarding strategies for DVC reduction in areas with frequent DVCs. As public safety is one of VDOT's

strategic priorities, the addition of deer advisory postings to VDOT’s toolbox of safety measures will help support VDOT safety efforts.

Table 9. Cost Savings From Posting Seasonal Deer Advisories on a Changeable Message Sign

CRs in October-November ^a				Savings From Deer Advisories on 1 CMS (25% to 51% reductions)		Savings From Deer Advisories on 5 CMSs (25% to 51% reductions)	
In Project Area	Per 3 Mi	Avoided as a Result of Deer Advisories per 3 Mi ^b		Per Yr	15 Yr	Per Yr	15 Yr
		25% Reduction	51% Reduction				
42 (Low)	7.5	0.9	1.9	\$5,955 to \$12,572	\$89,325 to \$188,580	\$29,775 to \$62,860	\$446,625 to \$942,900
53 (Avg.)	9.5	1.2	2.4	\$7,940 to \$15,881	\$119,100 to \$238,215	\$39,700 to \$79,405	\$595,500 to \$1,191,075
73 (High)	13.1	1.6	3.3	\$10,587 to \$21,836	\$158,805 to \$327,540	\$52,935 to \$109,180	\$794,025 to \$1,637,700

^a Based on the number of CRs per year in the 16.7-mile project area over the 3 years before deer advisory postings (2012-2014).

^b CRs avoided by posting deer advisories every other day (50%) in October-November.

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REFERENCES

- Al-Ghamdi, A.S., and AlGadhi, S.A. Warning Signs as Countermeasures to Camel-Vehicle Collisions in Saudi Arabia. *Accident Analysis and Prevention*, Vol. 36, 2004, pp. 749-760.
- Allen, R.E., and McCullough, D.R. Deer-Car Accidents in Southern Michigan. *Journal of Wildlife Management*, Vol. 40, No. 2, 1976, pp. 317-323.
- Bissonette, J.A., and Rosa, S. An Evaluation of a Mitigation Strategy for Deer-Vehicle Collisions. *Wildlife Biology*, Vol. 18, No. 4, 2012, pp. 414-423.
- Burris, M.W., and Appiah, J. An Examination of Factors Affecting the Frequency of Quickride Usage. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1864, 2004, pp. 22-30.
- Case, R.M. Interstate Highway Road-Killed Animals: A Data Source for Biologists. *Wildlife Society Bulletin*, Vol. 6, 1978, pp. 8-13.
- Clevenger, A.P., Chruszcz, B., and Gunson, K. Highway Mitigation Fencing Reduces Wildlife-Vehicle Collisions. *Wildlife Society Bulletin*, Vol. 29, No. 2, 2001, pp. 646-653.
- Collinson, W. Email to Bridget Donaldson, August 24, 2016.
- Dodd, N.I., Gagnon, J.W., Manzo, A.I., and Schweinsburg, R.E. Video Surveillance to Assess Highway Underpass Use by Elk in Arizona. *Journal of Wildlife Management*, Vol. 71, Issue 2, 2006, pp. 637-645.
- Donaldson, B.M. *Improving Animal-Vehicle Collision Data for the Strategic Application of Mitigation*. VTRC 18-R16. Virginia Transportation Research Council, Charlottesville, 2017.
- Donaldson, B.M., Kweon, Y.J., and Lloyd, L.N. *An Evaluation of Roadside Activity and Behavior of Deer and Black Bear to Determine Mitigation Strategies for Animal-Vehicle Collisions*. VTRC 16-R4. Virginia Transportation Research Council, Charlottesville, 2015.
- Elvik, R. Speed and Road Safety: Synthesis of Evidence from Evaluation Studies. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1908, 2005, pp. 59-69.
- Federal Highway Administration. *Manual on Uniform Traffic Control Devices for Streets and Highways*. Washington, DC, 2000.

- Gunther, K.A., Biel, M.J., and Robison, H.L. Factors Influencing the Frequency of Road-Killed Wildlife in Yellowstone National Park. In *Proceedings of the International Conference on Wildlife Ecology and Transportation*, G.L. Evink, P. Garrett, D. Zeigler, and J. Berry, Eds. FL-ER-69-98. Florida Department of Transportation, Tallahassee, 1998, pp. 32-42.
- Haikonen, H., and Summala, H. Deer-vehicle Crashes: Extensive Peak at 1 Hour After Sunset. *American Journal of Preventive Medicine*, Vol. 21, 2001, pp. 209-213.
- Hammond, C., and Wade, M.G. *Deer Avoidance: The Assessment of Real World Enhanced Deer Signage in a Virtual Environment*. Minnesota Department of Transportation, St. Paul, 2004.
- Hardy, A., Lee, S., and Al-Kaisy, A.F. Effectiveness of Animal Advisory Messages on Dynamic Message Signs as a Speed Reduction Tool. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1979, 2006, pp. 64-72.
- Huijser, M.P., and McGowen, P.T. Overview of Animal Detection and Animal Warning Systems in North America and Europe. In *2003 Proceedings of the International Conference on Ecology and Transportation*, C.L. Irwin, P. Garrett, and K.P. McDermott, Eds., Raleigh, North Carolina, 2003, pp. 368-382.
- Huijser, M.P., McGowen, P.T., Camel, W., Hardy, A., Wright, P., Clevenger, A.P., Salsman, L., and Wilson, T. *Animal Vehicle Crash Mitigation Using Advanced Technology: Phase I: Review, Design and Implementation*. FHWA-OR-TPF-07-01. Western Transportation Institute, Montana State University, Bozeman, 2006.
- Huijser, M.P., Duffield, J.W., Clevenger, A.P., Ament, R.J., and McGowen, P.T. Cost-Benefit Analyses of Mitigation Measures Aimed at Reducing Collisions With Large Ungulates in the United States and Canada: A Decision Support Tool. *Ecology and Society*, Vol. 14, Issue 2, Article 15, 2009.
- Khattak, A.J. Human Fatalities in Animal-Related Highway Crashes. In *Statistical Methods and Modeling and Safety Data, Analysis, and Evaluation*. Transportation Research Board, Washington, DC, 2003, pp 158-166.
- Lehnert, M.E., and Bissonette, J.A. Effectiveness of Highway Crosswalk Structures at Reducing Deer-Vehicle Collisions. *Wildlife Society Bulletin*, Vol. 25, No. 4, 1997, pp. 809-818.
- National Oceanic and Atmospheric Administration. Earth System Research Laboratory, Global Monitoring Division, 2018. <https://www.esrl.noaa.gov/gmd/grad/solcalc/>. Accessed February 15, 2018.
- Pojar, T.M., Rosence, R.A., Reed, D.F., and Woodard, T.N. Effectiveness of a Lighted, Animated Deer Crossing Sign. *Journal of Wildlife Management*, Vol. 39, No. 1, 1975, pp. 87-91.

Rolley, R.E., and Lehman, L.E. Relationships Among Raccoon Road-Kill Surveys, Harvests, and Traffic. *Wildlife Society Bulletin*, Vol. 20, 1992, pp. 313-318.

Sullivan, T.L. Williams, A.F., Messmer, T.A., Hellinga, A., and Kyrychenko, S.Y. Effectiveness of Temporary Warning Signs in Reducing Deer-Vehicle Collisions During Mule Deer Migrations. *Wildlife Society Bulletin*, Vol. 32, No. 3, 2004, pp. 907-915.

U.S. Department of Transportation. Costs Database, Sample Unit Cost Entries.
[https://www.itscosts.its.dot.gov/its/benecost.nsf/DisplayRUCByUnitCostElementUnadjusted?ReadForm&UnitCostElement=Dynamic+Message+Sign&Subsystem=Roadside+Information+\(RS-I\)](https://www.itscosts.its.dot.gov/its/benecost.nsf/DisplayRUCByUnitCostElementUnadjusted?ReadForm&UnitCostElement=Dynamic+Message+Sign&Subsystem=Roadside+Information+(RS-I)). Accessed April 9, 2018.

Wakeman, K. Email to Nelson Lafon, June 15, 2017.

Wakeman, K. Email to Bridget Donaldson, March 1, 2018.