VTRC
Virginia Transportation Research Council

We Bring Innovation to Transportation

# Improving Animal-Vehicle Collision Data for the Strategic Application of Mitigation

http://www.virginiadot.org/vtrc/main/online_reports/pdf/18-r16.pdf

**BRIDGET M. DONALDSON**
**Senior Research Scientist**

Final Report VTRC 18-R16

VIRGINIA TRANSPORTATION RESEARCH COUNCIL
530 Edgemont Road, Charlottesville, VA 22903-2454
vtrc.virginiadot.org

**Standard Title Page - Report on Federally Funded Project**

| | | |
|---|---|---|
| 1. Report No.: FHWA/VTRC 18-R16 | 2. Government Accession No.: | 3. Recipient's Catalog No.: |
| 4. Title and Subtitle: Improving Animal-Vehicle Collision Data for the Strategic Application of Mitigation | | 5. Report Date: December 2017 |
| | | 6. Performing Organization Code: |
| 7. Author(s): Bridget M. Donaldson | | 8. Performing Organization Report No.: VTRC 18-R16 |
| 9. Performing Organization and Address: Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903 | | 10. Work Unit No. (TRAIS): |
| | | 11. Contract or Grant No.: 107900 |
| 12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation, 1401 E. Broad Street, Richmond, VA 23219; Federal Highway Administration, 400 North 8th Street, Room 750, Richmond, VA 23219-4825 | | 13. Type of Report and Period Covered: Final |
| | | 14. Sponsoring Agency Code: |
| 15. Supplementary Notes: | | |

16. Abstract:

Virginia is consistently among the 10 states with the highest number of deer-vehicle collisions (DVCs), with more than 61,000 reported for the year ending June 30, 2016. Whereas DVCs represented 1 in 11 of the vehicle insurance claims nationwide in 2014, they represented 1 in 6 of the claims in Virginia. Although the insurance data provide some information on the magnitude of the DVC problem, insurance data do not provide location information for these crashes.

Decision makers rely on reliable crash data to identify problem areas and determine the magnitude of the problem. Although the literature shows that animal-vehicle collisions (AVCs) are underrepresented in police crash report data, more detailed analyses are needed to determine the scale. Effective mitigation approaches to the AVC problem in Virginia are limited until a means to access and/or collect adequate data is identified.

In this study, quality and cost evaluations of DVC data in Virginia were conducted that indicated an AVC underreporting phenomenon that is a problem nationwide. The study found that DVCs represent a considerable safety hazard in Virginia, but the magnitude of this problem is not apparent from the data that are currently available. According to deer carcass removal records, the number of DVCs in the evaluated areas was up to 8.5 times greater than what was documented in police crash reports, and DVCs were the most frequent type of collision in the areas evaluated. The underrepresentation of DVCs understates the costs of these collisions. DVCs were estimated to be 6 times costlier on average than what was indicated from police crash report data. The estimates used in this study put the DVCs as the fourth costliest of the 14 major collision types in Virginia, averaging more than $533 million per year.

The underrepresentation of deer-related crash volumes relative to other collision types create missed opportunities for DVC mitigation in Virginia. Reliable data can be used to identify DVC hotspots for strategic mitigation, and the success of countermeasures such as wildlife underpasses with fencing have led to an increase in such mitigation in the United States in recent decades.

The study recommends that a carcass removal element be added to the Virginia Department of Transportation's Highway Maintenance Management System (HMMS), currently in development. The HMMS is intended to provide a means for maintenance staff to track road maintenance activities digitally. Adding a module to the HMMS that would provide an efficient and accurate means to collect carcass removal records would lead to a high-quality DVC dataset if routinely used by maintenance staff. With better information, the Virginia Department of Transportation can address these collisions in a manner that is consistent with their impact on the driving public.

| | |
|---|---|
| 17 Key Words: Animal-vehicle collisions, deer-vehicle collisions, wildlife collisions, animal carcass data | 18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161. |

| | | | |
|---|---|---|---|
| 19. Security Classif. (of this report): Unclassified | 20. Security Classif. (of this page): Unclassified | 21. No. of Pages: 27 | 22. Price: |

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

**FINAL REPORT**

# IMPROVING ANIMAL-VEHICLE COLLISION DATA FOR THE STRATEGIC APPLICATION OF MITIGATION

**Bridget M. Donaldson**
**Senior Research Scientist**

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

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

Charlottesville, Virginia

December 2017
VTRC 18-R16

## DISCLAIMER

The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks is for identification purposes only and is not to be considered an endorsement.

## ABSTRACT

Virginia is consistently among the 10 states with the highest number of deer-vehicle collisions (DVCs), with more than 61,000 reported for the year ending June 30, 2016. Whereas DVCs represented 1 in 11 of the vehicle insurance claims nationwide in 2014, they represented 1 in 6 of the claims in Virginia. Although the insurance data provide some information on the magnitude of the DVC problem, insurance data do not provide location information for these crashes.

Decision makers rely on reliable crash data to identify problem areas and determine the magnitude of the problem. Although the literature shows that animal-vehicle collisions (AVCs) are underrepresented in police crash report data, more detailed analyses are needed to determine the scale. Effective mitigation approaches to the AVC problem in Virginia are limited until a means to access and/or collect adequate data is identified.

In this study, quality and cost evaluations of DVC data in Virginia were conducted that indicated an AVC underreporting phenomenon that is a problem nationwide. The study found that DVCs represent a considerable safety hazard in Virginia, but the magnitude of this problem is not apparent from the data that are currently available. According to deer carcass removal records, the number of DVCs in the evaluated areas was up to 8.5 times greater than what was documented in police crash reports, and DVCs were the most frequent type of collision in the areas evaluated. The underrepresentation of DVCs understates the costs of these collisions. DVCs were estimated to be 6 times costlier on average than what was indicated from police crash report data. The estimates used in this study put the DVCs as the fourth costliest of the 14 major collision types in Virginia, averaging more than $533 million per year.

The underrepresentation of deer-related crash volumes relative to other collision types create missed opportunities for DVC mitigation in Virginia. Reliable data can be used to identify DVC hotspots for strategic mitigation, and the success of countermeasures such as wildlife underpasses with fencing have led to an increase in such mitigation in the United States in recent decades.

The study recommends that a carcass removal element be added to the Virginia Department of Transportation's Highway Maintenance Management System (HMMS), currently in development. The HMMS is intended to provide a means for maintenance staff to track road maintenance activities digitally. Adding a module to the HMMS that would provide an efficient and accurate means to collect carcass removal records would lead to a high-quality DVC dataset if routinely used by maintenance staff. With better information, the Virginia Department of Transportation can address these collisions in a manner that is consistent with their impact on the driving public.

**FINAL REPORT**

# IMPROVING ANIMAL-VEHICLE COLLISION DATA FOR THE STRATEGIC APPLICATION OF MITIGATION


**Bridget M. Donaldson**
**Senior Research Scientist**


## INTRODUCTION

### Background

A 2008 report to Congress estimated that 1 to 2 million collisions between vehicles and large animals occur every year (Huijser et al., 2008). Collisions with hoofed mammals such as deer are often given the most attention by departments of transportation (DOTs) because of their risks to human safety. Deer are responsible for the highest number of animal-related human deaths in the U.S., causing more deaths than dogs, bears, sharks, and alligators combined (Lopez, 2016). More than 1.3 million collisions with deer (*Odocoileus* spp.) occurred in the United States for the year ending June 30, 2016 (Miles, unpublished data). When deer populations increase, deer-vehicle collisions (DVCs) increase, and the same holds true for an increase in vehicle miles traveled (Raynor, 2016).

According to State Farm's annual assessments of vehicle insurance claims, Virginia is consistently among the 10 states with the highest number of DVCs (Miles, unpublished data), with more than 61,000 reported for the fiscal year ending June 30, 2016. Whereas DVCs represented 1 in 11 of the vehicle insurance claims nationwide in 2014, they represented 1 in 6 of the claims in Virginia (Miles, unpublished data). Although insurance data provide information on the magnitude of the DVC problem, they do not provide location information for these crashes.

### Importance of Reliable Animal-Vehicle Collision Data

Many states, including Virginia, rely on police crash report data to prioritize safety efforts on the roadway system. Staff of the Virginia Department of Transportation (VDOT) has sought guidance from the Virginia Transportation Research Council (VTRC) on addressing specific animal-vehicle collision (AVC) problem areas identified at the local level (Donaldson and Kweon, 2016). However, studies have shown that AVCs are underestimated in police crash reports (Donaldson and Lafon, 2008; Huijser et al., 2007). Because many drivers do not notify the police after a collision with an animal, the police records have been found to underrepresent the actual number of AVCs in most states (Huijser et al., 2007). This is consistent with findings in Virginia; Donaldson and Lafon (2008) found that the number of DVCs reported in police crash reports was more than 9 times lower than DVC estimates derived from animal carcass removal records in Rockbridge County. This has important implications; if AVCs are underreported, it is more difficult to identify the highest priority locations for potential mitigation.

AVC data are also used by organizations and researchers outside VDOT. VTRC receives numerous requests each year for AVC data from other state agencies, local governments, university researchers, and county police departments. Reliable data are needed for various safety analyses and mitigation planning by these entities.

Because measures to reduce DVCs depend on the locations and magnitude of the problem, further evaluations are needed with regard to the quality of Virginia's DVC data and the scale of DVC underreporting. This includes more detailed information on the sufficiency of police crash report data and VDOT databases that include information on DVCs. If DVC data are found to be insufficient in all data sources currently available to VDOT, a potential means to improve the data collection method and/or the data should be identified. Effective mitigation approaches to the AVC problem are limited until reliable and accurate means of data collection are implemented. With better information, VDOT can give DVCs the attention that is consistent with their impact to the driving public.

## PURPOSE AND SCOPE

The purpose of this study was to conduct DVC data quality and cost analyses to determine if AVCs were underreported in Virginia and if so to assess the scale of underreporting with regard to volume and costs. A 15-month study was conducted from April 2016 through August 2017 to achieve the study objectives. The evaluation included analyses of up to 4 years of police report data and deer carcass removal data (2012 through 2016).

In this report, the terms "AVC" and "DVC" reflect information that indicates that a vehicle collision with an animal (or deer, specifically) occurred. This information includes not only police crash reports of AVCs but also records of animal carcasses identified along or removed from Virginia roads.

## METHODS

Five tasks were conducted to achieve the study objectives.

1. Conduct a literature review on successful approaches and strategies used by other states with regard to AVC data collection and AVC mitigation.

2. Identify sources of DVC data in Virginia and assess the data with regard to quality and volume.

3. Use carcass removal records to evaluate the volume of DVCs relative to other types of collisions.

4. Estimate the cost of DVCs relative to other collision types.

5. Identify opportunities to improve the DVC dataset and/or data collection process.

## Literature Review

To determine the applicability of AVC data, the online sources of literature were searched for (1) AVC data collection practices that are used by states to identify strategic locations for mitigation and (2) methods used by states and regions to reduce AVCs. The literature search was intended to provide a brief overview of successful mitigation strategies and AVC data collection tools used by other states.

## Sources of Virginia DVC Data and Quality and Volume Assessment

VDOT databases that track road maintenance activities and road incidents were evaluated to determine whether and to what extent DVC information is documented. DVC data were first evaluated to determine how well the data enable a user to identify DVC problem areas efficiently and accurately. The data quality of each database was evaluated according to four criteria:

1. The DVC data can be easily queried (i.e., automatically separated from other records and evaluated by certain time periods and locations).

2. The records provide information on whether the animal is a deer or another species.

3. The records provide detailed location information.

4. The DVC locations can be easily mapped as a group (i.e., location data can be uploaded into a mapping program such as GIS).

## Carcass Removal Records and Evaluation of Volume of DVCs Relative to Other Collision Types

The volume of DVCs from existing data sources was compared with the volume of carcass removal records collected on a Virginia interstate (I-64) as part of a previous study (Donaldson and Kweon, 2016). These carcass removal records were also used to compare the volume of DVCs to that of other collision types.

VDOT does not systematically collect carcass removal records, although some maintenance areas have kept such records for defined periods at the request of researchers for particular studies. Carcass removal records have been collected by a VDOT maintenance contractor for more than 5 years along a segment of I-64 for previous and ongoing studies (Donaldson and Kweon, 2016). The contractor or VDOT maintenance employee documents the date, species, and location of the carcass to the nearest 0.1 mile in accordance with posted mile marker (MM) signs.

Previous studies that evaluated carcass removal records, whether documented in the form of hand-written records or with the use of a handheld device and AVC collection software, have shown that carcass removal records provide the best available depictions of the volume and locations of DVCs (Donaldson and Lafon, 2008; Huijser et al., 2007). For this evaluation, therefore, carcass removal records were considered the standard by which to compare other types of DVC data.

## Cost of DVCs Compared to That of Other Collision Types

With new transportation projects and safety evaluations, VDOT planning staff evaluate the last 3 years of police crash reports to determine the most common types of collisions (Mannell, personal communication). A similar evaluation was conducted by comparing the volume of various collision types (including DVCs) documented in police crash reports with the volume of carcass removal records.

In transportation safety evaluations, the costs of collisions (which are calculated based on number and severity) are also commonly used as an indicator of the magnitude of crash problem areas (Herbel et al., 2010). A method was therefore developed to estimate the costs of DVCs in Virginia and compare them to the costs of other collision types (i.e., rear end, head on, etc.).

The costs ascribed to collisions based on severity (i.e., property damage, incapacitating injury, minor injury, and fatality) were obtained from the *Highway Safety Improvement Program (HSIP) Manual* (Herbel et al., 2010), a resource routinely used by states (including Virginia) in conducting collision cost analyses. Because the substantial cost attributed to a single fatality (i.e., more than $4 million) is more than 18 times higher than the cost attributed to the second most severe collision type (i.e., an incapacitating injury with a value of $216,000), any annual differences in fatalities can substantially affect the evaluation. Fatalities were therefore excluded from the analysis. This type of omission is not unusual in evaluations of collision data when the goal is to illustrate a more consistent comparison among collision types (Martin, unpublished data).

## Strategies to Improve Virginia's DVC Data

VDOT staff that have a role in managing or developing existing or forthcoming systems or databases related to road incidents or maintenance activities were identified and contacted. Discussions included the feasibility of adopting particular procedures with regard to improving or developing an improved system of DVC data collection. Any new sources of DVC data were evaluated with regard to data accuracy and reliability.

# RESULTS

## AVC Data Collection Strategies and Mitigation Used in the United States

### AVC Data Collection

With any road safety problem, the identification of problem areas and the effectiveness of applied countermeasures rely on the adequacy of data collection and reporting methods. AVC data are used for two main purposes: to assess and minimize the safety risk for humans and to assess and minimize the effect of mortality on the population size or population viability of selected animal species (Huijser et al., 2007). A reliable source of AVC data is not only an important element for evaluations conducted by transportation organizations but is also a valuable resource for various safety analyses and mitigation planning by organizations, other state agencies, local governments, researchers, and police departments.

According to a 2007 survey conducted as part of a synthesis of state AVC data collection practices, police crash reports were the primary source of AVC data for 63% of the 30 responding states. Animal carcass removal data, on the other hand, which are typically collected by highway maintenance personnel at the site of a carcass pickup, were collected by 9 of the 30 state survey respondents (Huijser et al., 2007). This number has increased in recent years with the availability of mobile applications designed for roadway animal carcass reporting (Cramer, unpublished data).

For example, the Utah DOT uses a smartphone-based system to collect carcass removal data. The application uses smart device global position system capabilities to provide precise location information, which is collected in a state database that is populated in real time. An interactive mapping system allows analyses of the data by Utah DOT highway managers. The data drive project decisions in the design of roadways and mitigation efforts (Jacobsen, 2014). The Utah DOT maintained that the access to digital and streamlined AVC data improved efforts to increase road safety and reduce accident costs related to vehicle damage, injury, and incident response (Olson et al., 2014). Given the success of this system in providing reliable collision data, other states are working toward the adoption of this type of carcass removal data collection (Cramer, unpublished data).

A similar type of mobile application is under development by the Road Ecology Center at the University of California, Davis. The application allows users to document each carcass visible along the road and/or removed from the road. Data can be mapped and analyzed to determine AVC problem areas (Fraser, unpublished data).

Some states now use web-based systems that allow citizens to report locations of animal carcasses along the roadway. These citizen reporting programs use a map and database to allow users to record the locations of these incidents (Fraser, 2016; Maine Audubon, n.d.).

Although the increasing accessibility of mobile reporting systems is likely to encourage more use by state DOTs, carcass removal data are not documented at a statewide level in most states (Huijser et al., 2007). As a result, AVCs are underrepresented; and the spatial precision of the data is usually relatively low (Slater, 2002; Romin and Bissonette, 1996; Huijser et al., 2007; Huijser et al., 2008; Donaldson and Lafon, 2008). This has important implications; if AVCs are underreported, they are likely to be underprioritized as a safety problem. Projects to mitigate AVCs may be more difficult to justify until reliable and accurate means of data collection are implemented.

**AVC Mitigation**

Accurate AVC data are needed to inform mitigation planning. In general, the goal of AVC mitigation is to keep animals off of roadways and/or to increase the vigilance of drivers. The most successful types of AVC mitigation have been well documented over the past two decades. These measures can be grouped into those designed to influence driver behavior, such as deer signs and driver warning systems, and those designed to influence animal behavior, such as roadside deer reflectors and wildlife crossings (overpasses or underpasses used by wildlife to cross over or under a road). An extensive literature review conducted as part of a report to Congress on AVC mitigation (Huijser et al., 2008) noted that more than 40 mitigation methods have been tested and/or implemented in the last decade to reduce AVCs. The most effective methods were (1) certain types of animal detection driver warning systems, and (2) wildlife crossings used in conjunction with fencing (Huijser et al., 2008). These measures reduced AVCs by more than 80% (Bissonette and Rosa, 2012; Clevenger et al., 2001; Dodd and Gagnon, 2008; Forman et al., 2003).

The success of these measures and the increase in collisions with deer and other ungulates in the United States have led to an increase in the implementation of AVC mitigation over the last 20 years (Best, 2017). Most states now have overpasses and/or underpasses designed for wildlife passage across a road corridor (Best, 2017). The majority of these states have constructed structures designed for large animals (i.e., ungulates, bears, mountain lions) (Best, 2017). Currently, the Washington State DOT is undertaking “the most ecologically comprehensive mitigation project . . . in North America and likely the world” where 24 underpasses and 3 overpasses are being constructed with the widening of a 15-mile segment of the Snoqualmie Pass highway (Best, 2017).

Recent decades have seen an increase among some states in efforts combining driver safety with habitat connectivity efforts. Actions include adopting AVC mitigation guidance and best management practices; incorporating habitat connectivity considerations (i.e., wildlife crossings) into design and operations processes (AASHTO, 2014; Sharif, 2016; Smith, 2017); and/or hiring specialists in transportation ecology and habitat connectivity to identify habitat connectivity opportunities in their state (AASHTO, 2014). For example, state DOTs in Idaho, Montana, and Nevada have adopted or are in the process of adopting a statewide prioritization process for identifying areas for wildlife crossings (Cramer, unpublished data).

The use of animal detection driver warning systems is also increasing in the United States. These systems sense large animals as they approach the roadway. Once detection is verified, a warning system can be used to alert drivers to the danger, resulting in a reduction in vehicle speed and stopping distance (Huijser et al., 2006). A study in Arizona found a 91% DVC reduction following the installation of such a system (Dodd and Gagnon, 2008). In a study of a buried cable animal detection system installed along a test road in Virginia, Druta and Alden (2015) found that with proper installation and calibration, the system detected large animals with more than 95% reliability. A "real world" evaluation of the system on a public road in Virginia is underway.

The positive impact of AVC mitigation (on both driver safety and wildlife) at the state level has led to regional and even national involvement with the issue. Multiple regional efforts in the United States (Conservation Northwest, 2017; Landscape Conservation Cooperative Network, n.d.; Staying Connected Initiative, 2017) have been established to restore and enhance landscape connections across roads and state boundaries. Guidelines have been created for crossing structures (Clevenger and Huijser, 2011), associated fencing (Huijser et al., 2015), and incorporation of habitat connectivity considerations into the highway facility design process (Clevenger and Huijser, 2011). In a project under the National Cooperative Highway Research Program, a decision support tool was developed to assist DOTs with identifying and recommending solutions for habitat fragmentation and associated AVCs (Louis Berger Group, Inc., 2011). Finally, an international effort is underway to establish conservation connectivity areas. As a part of this effort, a roads working group was formed to advise and provide direction regarding transportation infrastructure so that it avoids, minimizes, and/or mitigates impacts to wildlife movement and mortality within habitat connectivity areas. One of the missions of the group is for connectivity area designations to be comparable to other protected area designations such as national parks and wilderness areas (International Union for Conservation of Nature, 2017).

Although the rise in some state and regional efforts to address habitat connectivity and decrease the impact of roads on wildlife suggests a continuing trend, most states have not incorporated AVC mitigation strategies at a programmatic scale or even at a local scale with regularity (AASHTO, 2014). Costs to implement mitigation are a primary prohibitive factor (Louis Berger Group, Inc., 2011), although cost/benefit analyses have demonstrated that the savings in property damage and other costs associated with an AVC can easily outweigh the costs of the countermeasures (Donaldson and Kweon, 2016;; Huijser et al., 2009).

## DVC Data Quality: Comparing Data Sources

Four VDOT databases that contain information on AVCs (and DVCs, specifically) were identified: Roadway Network System (RNS), Crash Analysis Tool, Customer Service Center (CSC), and Asset Management System (AMS). RNS and Crash Analysis tool include police report data. Table 1 provides information on how each of these databases performed according to the four criteria described previously.

Although insurance claims can be available to VDOT staff upon request, they are not readily available and are not used by VDOT staff for safety analyses. Insurance data, therefore, were not included in Table 1. Insurance data are available for DVCs only as a statewide number; there is no information regarding locations or other crash details.

**Table 1. Performance of VDOT Databases With Information on AVCs and DVCs in Accordance With the Four Study Criteria**

| Database | Study Criteria | | | |
|---|---|---|---|---|
| | **1. AVC Data Can Be Easily Queried** | **2. Species (i.e., Deer) Can Be Determined from Records** | **3. Records Provide Detailed Location Information** | **4. Large Groups of Records Can Be Easily Mapped** |
| Police Crash Report Data | Yes | Yes | Yes | Yes |
| Customer Service Center | Yes | Sometimes | Sometimes | No |
| Asset Management System | Yes | Sometimes | Sometimes | No |

VDOT = Virginia Department of Transportation; AVCs = animal-vehicle collisions; DVCs = deer-vehicle collisions.

## Police Crash Report Data

As described previously, police crash report data are the primary source of DVC data for most states (including Virginia), as they are often the only available statewide source of systematically collected DVC data. As transportation projects are developed, VDOT planning staff evaluate the last 3 or more years of police crash report data to determine whether safety measures should be considered in certain areas.

Police crash report data are provided by the Virginia Department of Motor Vehicles and incorporated into web-based tools created by VDOT (RNS and Crash Analysis Tool). Both tools comprise efficient means to access detailed information in police crash reports. Specific areas and roads can be queried and descriptive attributes can be selected, including whether the crash was caused by a deer. Because latitude and longitude data are provided for each police crash report, large groups of data can be easily mapped.

RNS and Crash Analysis Tool differ greatly with regard to how deer-related crashes can be queried, which affects the query results. For example, with RNS, "deer" can be selected in a "Collision Type" drop-down list. Crash Analysis Tool has the same "Collision Type" selection feature but includes an additional drop-down selection, "Animal (Deer)," whereby the user can select "deer," "no deer," or "all." This query allows the inclusion of all deer-related crashes, even those for which "deer" is not entered under "Collision Type" in the police crash report. For example, "Rear End" might be entered under "Collision Type," but under the "Crash Description" entry of the police crash report, the text may explain that the driver's vehicle was rear ended after the driver applied the brakes quickly to avoid striking a deer. Queries conducted in Crash Analysis Tool, therefore, result in a higher volume of DVCs. For example, a search of "deer" in RNS for 2016 resulted in 5,593 records whereby a search for "deer" in the "Animal (Deer)" heading in Crash Analysis Tool resulted in 7,544 records in 2016. For this reason, AVC data from Crash Analysis Tool was used in the comparisons with AVC data from Customer Service Center and Asset Management System.

### Customer Service Center and Asset Management System

VDOT's Customer Service Center (CSC) allows the public to report a road problem or a work request. Through a call to a CSC telephone number or a web-based form, the public can report the occurrence and location of a dead animal along the roadway. The information is documented in the CSC database, which interfaces with VDOT's Asset Management System (AMS). VDOT maintenance staff receives and tracks work order requests through AMS.

AMS work orders, including those for dead animal removal, are primarily based on information obtained from the CSC database, but maintenance tasks can also be added to AMS by VDOT staff. With AMS, users can query "dead animal" work orders statewide or in certain locations. In order to access the location information, however, each record must be evaluated individually, as descriptions for the same location can vary greatly. For example, a carcass removal work order at I-64 MM 115 can be written as "I 64 115" or "I-64 MM 115" or "64 at 115," etc. In addition, specific locations are not always provided. To retrieve animal species information, each record needs to be evaluated to determine whether the description in the "Comments" column includes information on the species of animal, and this information is often not available. Determining species information in this way is time-consuming and difficult for long road sections or regions of the state.

Similar to AMS, each dead animal record in the CSC database must be evaluated separately to retrieve information on the location. Although some records include a specific address, many include only a road name and no other identifying factors, such as the nearest intersection. More detailed information such as species of animal is sometimes available through viewing the "Comment" link for the individual record. Neither AMS nor the CSC database provides latitude and longitude coordinates that would allow for easy mapping of numerous records at a time. In cases where more than one person provides VDOT a report of a dead animal, both AMS and the CSC database may have the same incident documented more than once.

## DVC Data Volume: Comparing Data Sources

### Insurance Claims, Asset Management System, and Police Crash Reports

Figure 1 compares DVC volumes among statewide sources. Insurance data were included given that they are available as a statewide number. CSC data were not included because the data available for querying go back only 6 months. From 2012 through 2016, DVCs in the police crash reports represented 1 in 7.7, or 13%, of DVC insurance claims. The volume of DVCs from AMS data was more than twice that from police crash reports but was substantially smaller than the volume from insurance data.

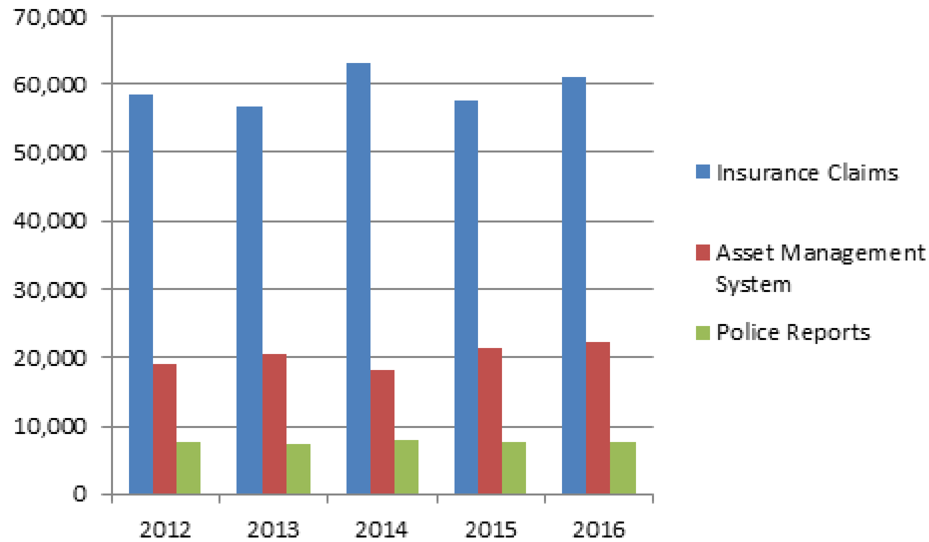


**Figure 1. Statewide Comparison of Annual DVC Data From Insurance Claims, VDOT's Asset Management System, and Police Crash Reports (2012-2016)**

It should be noted that some auto insurance policies cover deer crashes but do not necessarily cover crashes with fixed objects such as a guardrail or a tree. If drivers filed false deer crash claims in order to be covered for a collision, this would result in more deer claims that actual collisions with deer. On the other hand, not all deer crashes are included in the insurance claims data because not all drivers have auto insurance and the claims data do not include drivers who do not report their collisions with deer (e.g., in cases in which the collision causes minimal to no damage or the driver does not choose to repair the vehicle).

### Carcass Removal Data, Asset Management System, and Police Crash Reports

As noted previously, contractor carcass removal data for a segment of I-64 have been collected for other research projects for the past several years. These data were compared with AMS data and police crash report data for the portion of I-64 in Albemarle County, from MM 102 to MM 131 (Figure 2).

The AMS dataset for carcass removals was typically greater than that for police crash reports, but the volume of carcass removal data was substantially larger than for AMS and police crash report data. From 2013 through 2016, the volume of carcass removal records was an average of 4 times higher than the volume of DVCs in police crash reports and 2.6 times higher than DVCs in AMS data.

Although carcass removal data provide a substantially larger set of data than that available from AMS or police crash reports, the data do not represent all collisions with deer. Not all deer collisions result in a dead deer on or along the road that can be removed by VDOT; some proportion of struck deer are not killed or they die from injuries outside the right of way.

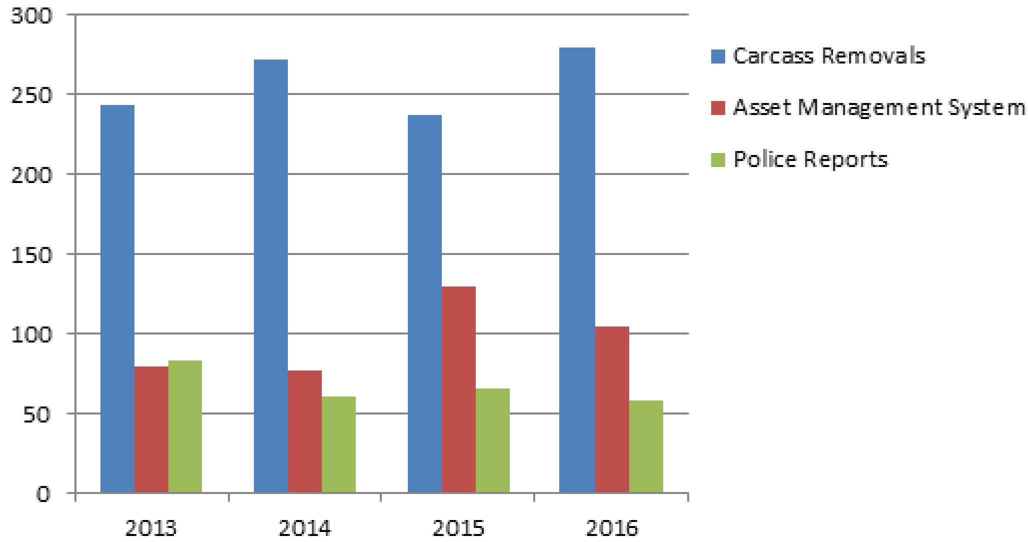


**Figure 2. Comparison of DVC Data From Carcass Removal Records, VDOT's Asset Management System, and Police Crash Reports Along I-64 in Albemarle County (MM 102 to MM 131) (2013-2016)**

## Police Crash Reports Versus Carcass Removal Data

*Albemarle County*

VDOT safety analyses include evaluations of not only the volume of collisions over the past 3 or more years but also the most common types of collisions. Roadway designs and other safety improvements can then be planned to reduce those collision types.

Figure 3 illustrates an analysis of collision types along the 30-mile segment of I-64 in Albemarle County for which carcass removal data were available (2013-2016).

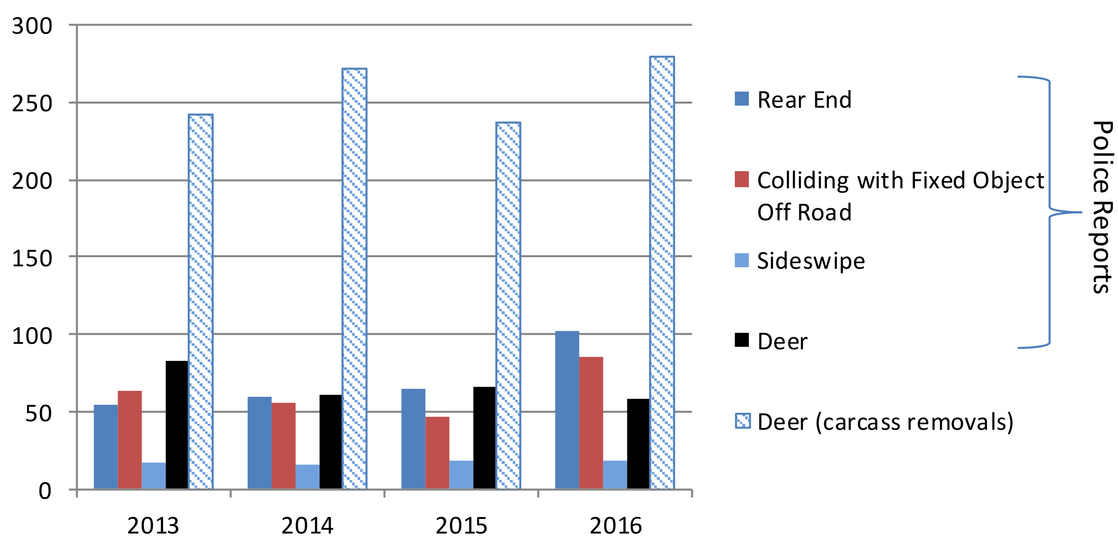


**Figure 3. Most Frequent Types of Collisions in Police Crash Reports From the 30-Mile Segment of I-64 in Albemarle County Compared to Carcass Removal Data (2013-2016)**

The figure compares police crash reports (varying by collision type) and carcass removal records. Although DVCs were among the most common collision types from police crash reports, it is clear that carcass removal numbers were considerably greater in volume than (1) DVCs in police crash reports and (2) numbers of all other types of collision. According to carcass removal data, DVCs were approximately 3 to 5 times higher than the next two most frequent types of collisions (i.e., rear end and colliding with fixed object off road) along the evaluated interstate segment.

*Afton Mountain Safety Evaluation*

A similar analysis was conducted based on a real-world example of the application of police crash report data. In 2011, VDOT targeted a section of I-64 for safety and mobility improvements because of a high number of vehicle crashes. The safety improvement area included a mountainous 8-mile segment of I-64. Using police crash reports, VDOT safety engineers found DVCs to be the third most frequent type of crash in this area (VDOT, unpublished data). Vehicle collisions with black bears were also frequent; 13 black bears were killed from vehicles in this area in October 2013 alone (VDOT, unpublished data).

In Figure 4, the first three bars (police crash reports) illustrate the type of findings that precipitated the safety improvement analysis. These include the top three crash types according to police crash reports from 2012 through 2016 along the evaluated segment. The fourth bar represents the actual number of DVCs according to carcass removal records. DVCs according to carcass removal records were 8.5 times higher than what was reflected by police crash reports and 1.8 times higher than the next leading type of collision (fixed object off road). Actual DVCs represented 42% of the collisions in this area.

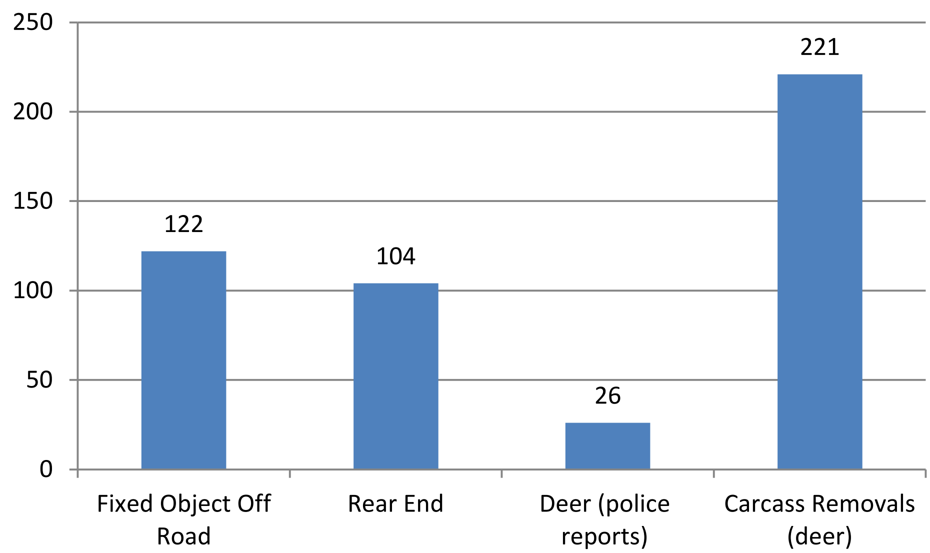


**Figure 4. Analysis of Crash Data Similar to That Conducted for VDOT's Safety Improvement Analysis of an 8-Mile Segment of I-64 But With the Addition of Deer Carcass Removal Data (2012-2016)**

When the same analysis was expanded to include a larger segment of interstate (i.e., a 30-mile segment from Staunton to just west of Charlottesville that was evaluated in an earlier study (Donaldson and Kweon, 2016), carcass removal data indicated that deer crashes were 5 times more frequent than DVCs in police crash reports and 2.7 times more frequent than the second leading crash type (i.e., fixed object off road).

**Summary of DVC Data Comparisons**

As Figures 1 through 4 illustrate, the volume of DVCs retrieved from VDOT databases is not reflected by the number of DVCs according to insurance claims, nor does it approximate the volume of data obtained by documenting carcass removals. These illustrations of DVC data demonstrate that DVCs can represent a considerable safety hazard in certain areas of Virginia and the magnitude of this problem is not reflected by the data that are currently available to VDOT staff.

Although improvements to the way DVC records are documented or organized in AMS or the CSC database may be feasible, such as reporting latitude and longitude data and more clearly reporting species information for each record, the volume of DVC data available in these databases is insufficient to justify improvements. For this reason, other potential strategies were identified that would more accurately reflect the number of DVCs across the state. Better data will illustrate the magnitude of the problem and the locations that should be targeted for mitigation.

## Estimate of Costs of Statewide DVCs

A cost analysis was conducted with the use of the police crash report dataset (which provides information on collision type but is insufficient with regard to DVC volume) and the insurance claims dataset (which is the best available statewide data for DVC volume but does not provide information on collision type). Assumptions were applied in order to estimate the total costs of DVCs statewide.

As shown in Table 2, DVC data from police crash reports for the previous 3 years were separated by crash severity. The DVC volume from police crash reports was subtracted from the DVC volume from insurance claims in order to determine the number of remaining DVCs for which no severity information was available. (It was assumed that the collisions in the police crash reports were included in the insurance claims dataset.) DVC data from insurance claims, for which the severity data are unknown, were handled with the assumption that they were property damage only collisions. This results in a conservative cost estimate of DVCs, given that a proportion of deer-related injury accidents (which are more costly than property damage only accidents) is not reported to the police (M. Davis and Co., 2015).

**Table 2. Description of Cost Estimations for DVC Cost Analysis (2014-2016)**

| Source | DVCs 2014 | DVCs 2015 | DVCs 2016 | Collision Severity Designation |
|---|---|---|---|---|
| Insurance Claims | 63,145 | 57,503 | 61,141 | Collision severity information is unavailable. |
| Police Crash Reports | 7,289 | 7,647 | 7,543 | Collisions are designated according to severity (e.g., injury, property damage only). |
| Difference (Insurance DVCs minus Police DVCs) | 55,856 | 49,865 | 53,589 | Collisions are designated as property damage only (for the purpose of this study). |

For all police crash report data, each collision severity was attributed a dollar value (Table 3). This approach was based on VDOT safety evaluations that are conducted as part of the VDOT Highway Safety Improvement Program, in which dollar values are attributed based on the severity of the collision (Table 3). DVC costs were calculated by adding the severity values for DVCs in police crash reports to the severity values for the property damage only designations (Table 2). As mentioned previously, fatalities were excluded from the analyses. Fatalities were a small proportion of crashes; they averaged 0.6% of the total number of non-deer crashes.

Finally, the calculated DVC costs were compared to the costs of the top 7 of the 14 major collision types listed in the police crash reports (Figure 5). Despite the conservative designation of DVCs as predominantly property damage only accidents, estimates of the costs of DVCs based in part on insurance claims data placed them as the fourth costliest of the 14 types of collisions in Virginia in each of the 3 years evaluated. Based on these estimates, DVCs were 6 times costlier on average than what was indicated by police crash report data alone, averaging more than $533 million per year.

**Table 3. Costs According to Collision Severity**

| Collision Severity | Cost |
|---|---|
| Incapacitating Injury (A) | $216,095 |
| Minor Injury (B+C) | $56,272 |
| Property Damage Only | $7,428 |

*Source:* VDOT (2015).

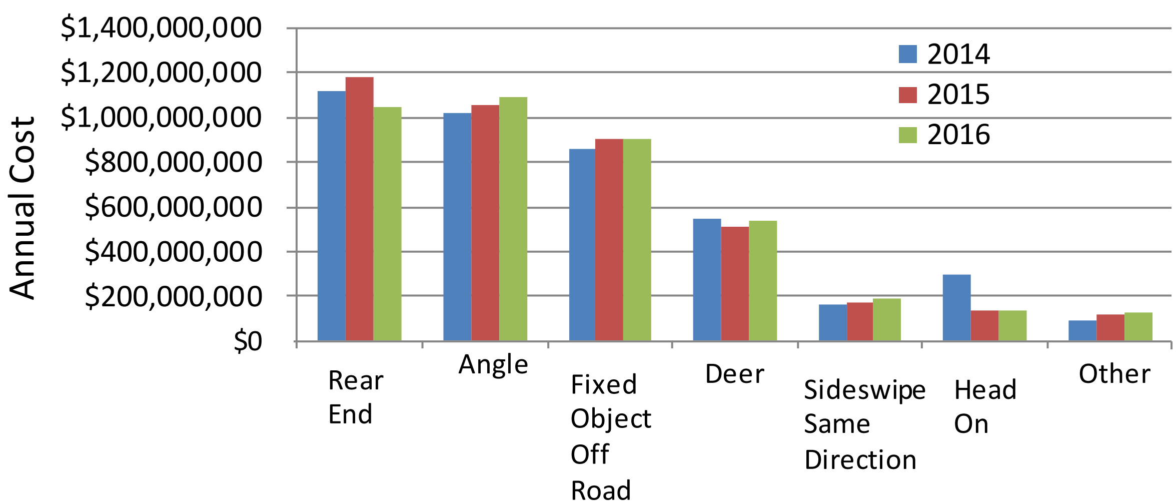


**Figure 5. Comparison of DVC Cost Estimates With Those of the Other 6 Costliest Collision Types in Virginia (2014-2016)**

The most frequent non–deer-related collisions had higher injury rates than deer-related collisions.  On average, from 2014 through 2016, 13% of Virginia DVCs appearing in police crash reports resulted in injuries whereas 35% of rear end crashes and 38% of angle crashes resulted in injuries.  However, the high volume of DVCs placed them among the costliest type of collision in the state.

## Strategies to Improve VDOT's DVC Data

Two potential means of acquiring better DVC data were identified:  WAZE and VDOT's Highway Maintenance Management System.  These methods are part of larger VDOT efforts to provide efficient sources of reliable information for VDOT staff and the driving public.

### WAZE

*Background*

In December 2016, VDOT launched a partnership with WAZE, a real-time crowdsourced navigation application.  This partnership is part of the WAZE Connected Citizens Program whereby WAZE partners with agencies to share publicly available data.  The WAZE data complement the traveler information tools available on VDOT's 511, such as traffic alerts and other real-time information that could affect drivers.  VDOT 511 is also available as a mobile application.

Like WAZE, Virginia Traffic, or 511, includes information that would have an impact on travelers (e.g., accidents, detours, closures, floods, etc.).  Unlike WAZE records, which are entered by travelers, information from Virginia Traffic is populated with incidents reported by a variety of sources, including the public, local and state police, VDOT staff, and general contractors.  Both Virginia Traffic and WAZE data are mapped for the public on a 511 website and the 511 application.

At the beginning of the partnership, VDOT's Operations Division asked VTRC to evaluate the quality of the WAZE data and compare them to the VA Traffic database with regard to accuracy and reliability.  The animal reporting portion of this evaluation was conducted as part of this study.  Although information on animal-related accidents is not documented in Virginia Traffic, the carcass removal data for I-64 served as a useful comparison to the WAZE data. WAZE allows users to enter sightings of animals on the road.  Users can document a sighting under headings termed "roadkill" (for dead animals) or "animals."  The "animals" option is presumably to document live animals on or alongside the road, though this is not clearly specified in the application.  For roadkill and animal entries, the species of animal is not recorded unless the user types in the species under a "description" heading.

*Determining the Reliability of Animal/Roadkill Entries in WAZE*

The comparison between WAZE and carcass removal data (a known reliable source of DVC data) was conducted using 21 days (February 5-25, 2017) of WAZE animal and roadkill data that were obtained as part of the larger VTRC analysis of WAZE data. Carcass removal data for 56 miles, from I-64 MM 91 to MM 147, were compared to the WAZE animal and roadkill records for the same road segment. Table 4 includes the results of this analysis.

**Table 4. Comparison of Carcass Removal Records and WAZE Data (February 5-25, 2017, I-64 MM 91-147)**

| Data Source | No. of Records | AVC Data Can Be Easily Queried? | Double Counts of Same Event? | Species (i.e., Deer) Can Be Determined From Records? | Records Provide Detailed Location Information? | Large Groups of Records Can Be Easily Mapped? |
|---|---|---|---|---|---|---|
| Carcass Removal Records | 13 | Yes | No | Yes (all records) | Yes | Yes |
| WAZE | 34 “roadkill” 35 “animal” | Yes | Yes (5 instances) | For 1 of 69 records | Not necessarily (depends on where user is when entering the data) | Yes |

Based on comparisons of the time and location entries between the carcass removal data and the WAZE data, there were 5 WAZE records that appeared to match 1 of the 13 carcass removal records (38%). (A record was considered a match when a WAZE entry was recorded within 36 hours and 1 mile of the carcass removal entry.) Two of these WAZE matches were entered as “animal,” and 3 were entered as “roadkill.” For all 5 matching records, the time span between when the carcass was reported and when the carcass was removed from the roadway was greater than 23 hours. This is logical, given that the opportunity for a WAZE user to see a carcass along the road increases with the length of time the carcass is there. Carcasses removed within a few hours seemed less likely to be reported in WAZE.

As is the case from January through March each year (when deer are less active), there was a relatively low number of carcass removal entries (n = 13). The WAZE “roadkill” entries were substantially greater in volume (n = 34), as were the “animal” entries (n = 35). For the “animal” entries, however, the data did not indicate whether the user saw a live animal on or along the road or whether the user saw a dead animal as the result of a collision.

The WAZE data, as they exist in their present form, do not represent an accurate and reliable source of AVC data for the following reasons:

- There was a low percentage of matches between carcass removal records and WAZE entries (38%).

- The volume of WAZE roadkill entries was 2.6 times greater than the carcass removal data, but it was difficult to determine occasions when multiple entries of the same animal were made.

- The accuracy of the WAZE roadkill/animal location data is unknown (as it is dependent on the user’s location when the data were entered).

- Species is rarely recorded (1 of 69 “animal”/“roadkill” entries).

- There were several instances of what appeared to be the same animal reported by more than one WAZE user.

### Highway Maintenance Management System

VDOT is currently developing a web-based software program that will allow the digital documentation of road maintenance activities. With the program, named the Highway Maintenance Management System (HMMS), maintenance staff will be provided handheld devices for tracking road maintenance work orders. VDOT expects to bring the system online for initial use by the end of 2017.

Because HMMS will allow users to enter spatially accurate location information (similar to applications that allow users to enter roadkill sightings or carcass removal records), the feasibility of adding a carcass removal element to the software was investigated. As was discussed previously, carcass removal data sources are superior to other DVC data sources in Virginia and elsewhere. The addition of such a carcass removal element that would yield accurate spatial data at the site of a carcass removal would produce a high-quality DVC dataset if the element was routinely used by maintenance staff.

During HMMS development, the HMMS steering team is focused on capturing the data that are essential to managing VDOT's maintenance program. The HMMS steering committee recommended that VTRC and the steering team discuss the potential addition of a carcass removal element to HMMS in late 2017, once the system is online.

## DISCUSSION

The findings of this study exemplify an underreporting phenomenon concerning AVCs that is a problem nationwide. Currently, governmental bodies in the United States lack reliable national estimates of AVCs because the data collection methods used by most states do not provide an accurate representation of this safety problem. The evaluations conducted in this study demonstrated the degree to which DVCs can be underrepresented in a state's available data sources, particularly with regard to police crash reports that are used by DOT staff for safety assessments. The magnitude of this problem is not reflected in the police crash report databases used by planners and traffic and safety engineers. It is also not reflected in other databases that, though they contain information on animal carcasses along the road, are not part of a systematic data collection process.

As part of a National Cooperative Highway Research Program synthesis on AVC data collection practices, DOTs were surveyed and asked what changes would need to be made before their agency began collecting carcass removal data (Huijser et al., 2007). The most common response was "the need to do so should be demonstrated" (Huijser et al., 2007). The analyses conducted in this study established the need to prioritize the systematic collection of carcass removal data. According to deer carcass removal data, the volume of DVCs in the evaluated areas was up to 8.5 times greater than what was documented in police crash reports and DVCs were the most frequent type of collision in many areas. DVCs were found to be 6 times costlier on average than what was indicated based on police crash report data, averaging more than $533 million per year.

These findings have important implications with regard to a DOT's routine analyses of collision data. In safety evaluations, planners and other transportation staff identify the most common types of crashes in an area in order to determine whether mitigation is needed. When the DVC data do not represent the actual number of deer-related crashes, as was demonstrated in this study, there are lost opportunities for collision mitigation. Successful mitigation, namely wildlife crossings and animal detection driver warning systems, has been well researched and found to reduce DVCs by more than 80% (Best, 2017; Dodd and Gagnon, 2008). Given that an evaluation conducted in this study found DVCs to represent 42% of all collisions on a segment of I-64, an 80% or more reduction in areas with frequent DVCs would have substantial benefits for driver safety

As was the case with the I-64 safety evaluation, the fact that DVCs were the third most frequent type of crashes in the area according to police crash reports brought the matter to VDOT's attention and led to research and mitigation to address this problem. Carcass removal data subsequently illustrated that DVCs were the most frequent type of collision, nearly twice as frequent as the next leading collision type. Two forms of mitigation have been implemented as a result of the I-64 safety evaluation and subsequent VTRC research, including the addition of fencing to existing underpass structures used by wildlife (Donaldson and Kweon, 2016). These mitigation projects are benefiting from the use of carcass removal data that were collected as part of the targeted safety effort. Though it is too early to report conclusive findings, there have been no AVCs in the fenced segments to date. With an accurate DVC data source, DVCs might be identified as among the most frequent collision types in other areas of the state, increasing the prospects for similar strategic safety improvements.

With regard to new potential sources of DVC data, the analysis of WAZE AVC data did not find them to be a reliable and accurate source for DVC data in their present form. However, VDOT's HMMS may provide an ideal opportunity for improved AVC data: the addition of a carcass removal element to the software. As was demonstrated in a previous study, whereby VDOT maintenance staff used a handheld device to log each animal carcass removal location in Rockbridge County (Donaldson and Lafon, 2008), carcass removal data are a source of AVC information that is far superior to other data available statewide. In addition, maintenance crews that collected carcass removal data maintained that the effort was minimal and did not increase their workload (Donaldson and Lafon, 2008). With the planned distribution of handheld devices to VDOT maintenance staff through the HMMS project, VDOT may have the opportunity to collect digital streamlined data that can be used to identify high-risk DVC locations.

Research reports and manuals are available to guide transportation organizations with regard to AVC reduction measures, from implementing individual mitigation projects to adopting broader programmatic approaches to connect wildlife habitat across roads (Clevenger and Huijser, 2011; Huijser et al., 2015; Louis Berger Group, Inc., 2011). VTRC and VDOT's central office planning staff have discussed the potential development of a guidance document for central office planning staff to provide to district planning staff after better data collection methods have been implemented (B. Mannell, personal communication). The document could provide guidance with regard to identifying strategic locations for AVC countermeasures and the types of effective countermeasures. VTRC can also provide VDOT traffic engineers and localities this type of guidance.

## SUMMARY OF FINDINGS

- *The literature on wildlife crash mitigation indicated that the increase in collisions with deer and the success of certain countermeasures have led to an increase in the implementation of AVC mitigation in the United States over the last 20 years*. State DOTs are increasingly constructing wildlife crossings and other forms of mitigation; adopting AVC mitigation guidance; and incorporating habitat connectivity considerations into design and operations processes. The objective consideration of mitigation decisions requires accurate and reliable data.

- *For most states, including Virginia, police crash reports are the primary source of collision data, including DVCs.* Recent years have seen an increase by state DOTs in the use of mobile applications on handheld devices to collect animal carcass removal records that provide precise location information.

- *In Virginia, police crash reports are currently the best available statewide data source for DVCs, but DVCs are substantially underrepresented in police crash reports, as demonstrated by the following comparisons with carcass removal records:*

    — *Along I-64 in Albemarle County, where carcass removal records were documented as part of a separate study, the volume of carcass removals averaged 4 times higher than the DVCs from police crash reports from 2012 through 2016.* Along a shorter segment of I-64 in the I-64 Afton Mountain area, a VDOT safety evaluation had found DVCs to be the third most frequent type of crash in police crash reports, but the addition of deer carcass removal records showed the actual number of DVCs to be 8.5 times higher than those from police crash reports. An analysis of carcass removal records showed that DVCs were the most frequent type of collision, nearly 2 times higher than the next leading type of collision.

    — *In an analysis of the types of collisions on I-64 in Albemarle County from 2013 through 2016, deer carcass removal data indicated deer were the most frequent cause of collisions, causing 3 to 5 times more crashes than the next two most frequent collision types (i.e., rear end and colliding with a fixed object).* This was not apparent from police crash reports of DVCs.

    - *Insurance claims data, which are available as a statewide figure but do not provide location information, similarly illustrate the underrepresentation of DVCs in police crash reports.* DVCs in police crash reports represented 1 in 7.7, or 13%, of DVC insurance claims from 2012 through 2016.

- *From a cost estimate based in part on insurance claims data to calculate statewide DVC costs, DVCs were the fourth costliest collision type, averaging more than $533 million per year.* DVCs were 6 times costlier on average than what was indicated by police crash report data alone.

## CONCLUSIONS

- *DVCs represent a considerable safety hazard in Virginia, but the magnitude of this problem is not apparent from the data that are currently available to VDOT staff.* The volume of DVCs retrieved from police crash reports and VDOT databases was not reflected by the number of DVCs according to insurance claims, nor did it approximate the volume of data obtained by documenting carcass removals.

- *Carcass removal records, which are not systematically collected in the state, are the best representation of the DVC problem in Virginia.* In this study, the actual volume of DVCs in the areas evaluated was up to 8.5 times greater than what was documented in police crash reports and DVCs were the most frequent type of collision in many areas.

- *The underrepresentation of DVC volume understates the costs of these collisions in routine safety analyses.* Although other frequent collision types had a higher injury rate than DVCs, the high volume of DVCs placed them as the fourth costliest type of collision in Virginia from 2014 through 2016.

- *The underrepresentation of deer-related collisions and costs relative to other collision types creates missed opportunities for collision mitigation.* Improved data collection will provide states information upon which to base strategic decisions about countermeasures, which have been found to reduce large animal collisions by more than 80%.

- *Based on an evaluation of animal sightings and roadkill entries available through WAZE, a real-time crowdsourced navigation application with which VDOT has recently partnered, the WAZE data do not provide a reliable and useful source of AVC data.*

- *VDOT's HMMS project, whereby maintenance staff will be provided handheld devices for tracking road maintenance work orders, may provide an ideal opportunity for the systematic collection of carcass removal data.* The addition of a carcass removal element to the HMMS software would provide a high-quality DVC dataset if the element was routinely used by maintenance staff.

## RECOMMENDATIONS

1. *VTRC and the representative of VDOT's Traffic Engineering Division on the HMMS steering committee should work with the VDOT HMMS technical team to determine the system requirements, process, and timeline for the future addition of a carcass removal element to the HMMS software for the collection of deer and bear carcass removal data*.

2. *VTRC and VDOT's Traffic Engineering Division should provide the HMMS steering committee with the recommended next steps for field implementation of the carcass removal element.*

## BENEFITS AND IMPLEMENTATION

### Benefits

Safety is a high priority for DOTs, and deer movement across roadways presents a safety risk to drivers. A cost analysis in this study found DVCs to be the fourth costliest collision type, with costs to society of more than $533 million per year. A source of reliable DVC data would help VDOT efficiently use its resources through allocation of funds toward countermeasures in identified DVC problem areas. Thus, efforts as described in Recommendations 1 and 2 would further this cause.

*Implementing Recommendation 1* will provide the framework for a presentation to the HMMS committee on an organized and detailed path toward the adoption of a carcass removal element in HMMS.

*Implementing Recommendation 2* will increase the likelihood of a successful field implementation of a carcass removal element in HMMS.

### Implementation

*With regard to Recommendation 1,* a meeting was held in October 2017 with the VTRC researcher, VDOT's northwest regional operations director, and a VDOT safety engineer involved with HMMS development. The discussion focused on choosing the most efficient and effective means of adding a carcass removal element to the HMMS software once other prioritized HMMS components have been implemented. It was decided that the simplest and most efficient means to do this would be to include "deer removal" as a specific work order in the "Maintenance" module of HMMS. A second meeting was held in early December with the VTRC researcher, VDOT's northwest regional operations director, and the leader of the HMMS Maintenance module to discuss the importance and feasibility of including "deer removal" as a work order.

*With regard to Recommendation 2,* VTRC and VDOT's Traffic Engineering Division will provide the HMMS steering committee with the recommended next steps for field implementation of the carcass removal element by January 19, 2018.

## ACKNOWLEDGMENTS

The author is grateful for the support of Matthew Shiley, the VDOT champion of this project. Appreciation is also extended to other members of the technical review panel for their insightful review and suggestions: Mary Bennett, Michael Fitch, Ning Li, Cathy McGhee, John Miller, Amy O'Leary, and Kevin Wright. Thanks also go to Linda Evans for her valuable editorial assistance and Jim Gillespie for his helpful review of the cost analyses.

## REFERENCES

AASHTO. *AASHTO RAC Member Survey Results*. 2014. http://research.transportation.org/_layouts/15/AASHTORAC/RACSurveyResultDetail.aspx?SurveyID=255. Accessed April 19, 2017.

Best, A. Keeping Hoofs Off Hoods. *Planning,* Vol. 83, No. 3, 2017, pp. 12-19.

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.

Clevenger, A.P., and Huijser, M.P. *Wildlife Crossing Handbook: Design and Evaluation in North America.* FHWA-CFL/TD-11-003. Federal Highway Administration, Washington, DC, 2011.

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.

Conservation Northwest. Connecting Habitat for Wildlife. 2017. http://www.conservationnw.org/what-we-do/connectivity. Accessed April 26, 2017.

Desmond, J.C. *Displaying Death and Animating Life*. University of Chicago Press, Chicago, 2016.

Dodd, N.L., and Gagnon, J.W. *Preacher Canyon Wildlife Fence and Crosswalk Enhancement Project, State Route 260, Arizona*. Project JPA 04-088. Arizona Game and Fish Department, Research Branch, Phoenix, 2008.

Donaldson, B.M., and Lafon, N.W. *Testing an Integrated PDA-GPS System to Collect Standardized Animal Carcass Removal Data on Virginia Roadways.* VTRC 08-CR10. Virginia Transportation Research Council, Charlottesville, 2008.

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, 2016.

Druta, C., and Alden, A.S. *Evaluation of a Buried Cable Roadside Animal Detection System*. VTRC 15-R25. Virginia Transportation Research Council, Charlottesville, 2015.

Forman, R.T.T., Sperling, D., Bissonette, J., Clevenger, J.A.P., Cutshall, C., Dale, V., Fahrig, L., France, R., Goldman, C., Heanue, K., Jones, J., Swanson, F., Turrentine, T., and Winter, T.C. *Road Ecology: Science and Solutions*. Island Press, Washington, DC, 2003.

Fraser, S. *Wildlife-Vehicle Conflict Hotspots Along California Highways (2009-2015): Carcasses*. UC Davis Road Ecology Center, Davis, CA, 2016. https://roadecology.ucdavis.edu/files/content/projects/CROS_Hotspots_2016.pdf. Accessed June 2, 2017.

Herbel, S., Lorrie, L., and McGovern, C. *Highway Safety Improvement Program (HSIP) Manual*. FHWA-SA-09-029. Federal Highway Administration, Washington, DC, 2010.

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. Oregon Department of Transportation, Salem, 2006.

Huijser, M.P., Fuller, J., Wagner, M.E., Hardy, A., and Clevenger, A.P. *NCHRP Synthesis 370: Animal-Vehicle Collision Data Collection: A Synthesis of Highway Practice*. Transportation Research Board, Washington, DC, 2007.

Huijser, M.P., McGowen, P., Fuller, J., Hardy, A., Kociolek, A., Clevenger, A.P., Smith, D., and Ament, R. Wildlife-Vehicle Collision Reduction Study: Report to Congress. FHWA-HRT-08-034. Federal Highway Administration, Washington, DC, 2008.

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, No. 2, 2009.

Huijser, M.P., Kociolek, A.V., Allen, T.D.H., McGowen, P., Cramer, P.C., and Venner, M. *Construction Guidelines for Wildlife Fencing and Associated Escape and Lateral Access Control Measures.* 2015. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(84)_FR.pdf. Accessed April 26, 2017.

International Union for Conservation of Nature. Connectivity Conservation. 2017. https://www.iucn.org/theme/protected-areas/wcpa/what-we-do/connectivity-conservation. Accessed April 24, 2017.

Jacobsen, M. 'Roadkill App' Paints Clearer Picture of Wildlife-Vehicle Collisions. *Desert News,* Utah. 2014. http://www.deseretnews.com/article/865607995/Roadkill-app-paints-clearer-picture-of-wildlife-vehicle-collisions.html. Accessed April 21, 2017.

Landscape Conservation Cooperative Network. Conservation Issue: Transportation. n.d. https://lccnetwork.org/issue/transportation. Accessed April 26, 2017.

Lopez, G. You Are Way More Likely to Be Killed by Deer Than Sharks, Bears, and Gators Combined. *Vox,* September 24, 2016. https://www.vox.com/2016/9/24/13032272/killer-animals-deer-sharks-bears. Accessed May 3, 2017.

M. Davis and Company, Inc. *National Telephone Survey of Reported and Unreported Motor Vehicle Crashes*. DOT HS 812 183. National Highway Traffic Safety Administration, Washington, DC, 2015.

Maine Audubon. Wildlife Road Watch. n.d. http://www.wildlifecrossing.net/maine/. Accessed April 21, 2017.

Olson, D.D., Bissonette, J.A., Cramer, P.C., Green, A.D., Davis, S.T., Jackson, P.J., and Coster, D.C. Monitoring Wildlife-Vehicle Collisions in the Information Age: How Smartphones Can Improve Data Collection. *PLoS One,* Vol. 9, No. 6, 2014. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4045807/. Accessed June 12, 2017.

Raynor, J. *The Causal Impact of Increased Deer Abundance on Vehicle Collisions*. Master's Thesis. University of Wisconsin, Madison, 2016.

Romin, L.A., and Bissonette, J.A. Deer-Vehicle Collisions: Status of State Monitoring Activities and Mitigation Efforts. *Wildlife Society Bulletin,* Vol. 24, No. 2, 1996, pp. 276-283.

Sharif, H.A. Incorporating Wildlife Crossings Into TxDOT's Project Development Design and Operations Processes. *Research in Progress.* Transportation Research Board, 2016. https://rip.trb.org/view/1455577. Accessed June 12, 2017.

Slater, F.M. An Assessment of Wildlife Road Casualties—The Potential Discrepancy Between Numbers Counted and Numbers Killed. *Web Ecology*, Vol. 3, 2002, pp. 33-42.

Smith, C. Idaho and WMI Cooperate to Reduce Wildlife-Vehicle Collisions and Improve Wildlife Connectivity. *Outdoor News Bulletin,* Vol. 71, No. 4, 2017.

Staying Connected Initiative. Staying Connected. 2017. http://stayingconnectedinitiative.org/. Accessed April 36, 2017.

The Louis Berger Group, Inc. *NCHRP Project 25-25 Task 68: Implementing Measures to Reduce Highway Impacts on Habitat Fragmentation.* 2011. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(68)_FR.pdf. Accessed April 17, 2017.