LOSS OF LIFE WITH DEER AND DOGS: HOW TO PROTECT TRAVELERS AND ANIMALS ON ROADWAYS

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ABSTRACT

Animal-vehicle collisions (AVCs) are a growing problem in the United States, resulting in countless loss of animal life and considerable human injury and death every year, especially when it comes to motorcyclists. In addition to being a serious safety concern, these collisions can create trauma among all animal populations including: declining species, household pets, and livestock investments. Due to underreporting, collision data is often a gross underestimation of the actual impact of AVCs and often lacks key details such as the species of animals involved. This paper investigates both wild and domestic animal-vehicle collisions through statistical and spatial analysis of police-reported collision data in Texas.

51,522 animal-related crashes were reported in Texas from 2010 through 2016, averaging to 28 fatal crashes per year, 225 incapacitating crashes per year, 856 non-incapacitating crashes per year, at a total cost over $1.3 billion per year to Texas motorists – not including the value of lost animal lives. AVC reports jump twice a day: between 5 and 8 AM and between 6 PM and midnight. Motorists are also significantly more likely to collide with a wild animal during the months of October, November, and December. Wildlife-vehicle collisions (WVC) are 64% of total reports, events involving domestic animals (like dogs and cattle) are 31%, and the remaining 5% of animals are unspecified. Most AVCs occur at night in unlit locations, usually on rural roads with very low
traffic volumes. Motorcyclists bear high risks: while only 2.2% to 3.5% of reported AVCs each year in Texas, they comprise over half of all fatal and all injurious crashes.

Using ordinary least-squares (OLS) regression analysis across Texas’ n=254 counties, this work finds that less densely populated counties, marked as rural, and those with fewer vehicle-miles traveled (VMT) per capita but more lane-miles per capita, tend to experience the greatest number of AVCs per VMT.

Intervention options for the mitigation of animal-vehicle collisions are numerous and diverse. Lighting improvements and driver awareness of road conditions ahead are recommended. To reduce domestic-animal collisions, communities should establish a culture of spaying and neutering household pets and strays. Overpasses and culverts, along with wildlife fencing (which can steer animals to safe crossings), show promising results for both AVC reduction and habitat connectivity. Longer term, mobile reporting, by DOT employees, smartphone users, intelligent cameras and other devices, plus real-time information dissemination (tied to existing navigation apps) can enable safer driving along specific roadway sections as animals arrive.

BACKGROUND
Animal-vehicle collisions (AVCs) makeup 5% of all U.S-reported motor vehicle collisions every year and represent a growing problem (FHWA 2008). About 200 people – often motorcyclists – lose their lives on U.S roadways each year from collisions involving wild or domestic animals, and thousands more are seriously injured (Donaldson and Lafon 2008). In addition to being a serious safety concern for human travelers and their property, such collisions create trauma among animal populations and endanger dwindling species. A five-state study found that, in a single month, 15,000 reptiles and amphibians, 48,000 mammals, and 77,000 birds die due to collisions with vehicles (Havlick, 2014). Animals such as the endangered Texas ocelot number one threat to survival are AVCs (Haines et al. 2005). Many collisions also destroy household pets and livestock investments.

This research focuses on the centrally located state of Texas, the U.S.’s second largest state spatially (after Alaska) and with regards to population (after California). The Texas Department of Transportation is responsible for more centerline-miles of highway than any other U.S state (https://www.fhwa.dot.gov/policyinformation/statistics/2008/hm60.cfm), and the state’s landscape offers a wonderful diversity of wildlife, topography, and climate.

Following the literature review and numerical and spatial analysis of collision data, this paper offers further details on the state of animal-vehicle collisions in the state of Texas and suggests similar realities at a national or global context. Specifically, the following information clarifies and highlights at-risk persons, travel times, and locations and assesses the benefits of possible mitigation strategies.

Wildlife Impact
Millions of animals die every year in the U.S. as a result of animal-vehicle collisions (AVCs) (Donaldson and Lafon 2008). Most animal-vehicle collisions go unreported - with the exception of those involving large ungulates, such as deer, elk, and moose. In insurance claims, when a species of animal is named, the most commonly reported animal is deer. In fact, deer show up over 25 times more than the next animal, raccoons (NICB 2018). Smaller species, though they might not pose immediate threat of injury to a driver, also face great impacts from collisions. Turtle
populations including red-eared sliders and Missouri River Cooters suffer from AVCs, especially females as they travel to higher lands to lay their eggs (Steen and Gibbs 2004). These populations then become male dominated and cannot maintain reproductive sustainability. Endangered animals - like the Texas ocelot, an endangered species with less than 50 living individuals remaining (U.S Fish and Wildlife Service 2010), have populations that are especially vulnerable to vehicle collisions since even a few ocelot deaths have great impact on their potential for reproductive continuation. Further, carcass counts may be limited for endangered species, relative to more common species, and “bias mitigation measures based on small samples” (Neumann et al. 2012), resulting in inadequate protective measures for these species.

**Crash Under-reporting**

There were 51,522 animal-related crashes reported to authorities in Texas from 2010 through 2016. However, most property-damage-only crashes go unreported, and wildlife experts tend to find 5 to 10 wildlife carcasses for every reported wildlife crash (Donaldson and Lafon 2008, Olson et al., 2014). Even in documented cases, police reports often fail to specify the species of animal hit, which would be of obvious value in targeted mitigation strategies. Stewart (2015) finds that more than 50% of US deer-vehicle collisions nationwide go unreported.

**Crash Costs**

The FHWA’s (2008) best estimate of US AVC collision costs was $8.39 billion back in 2007 The economic costs of death and injuries arising from US AVCs exceed $1 billion per year (Donaldson and Lafon 2008). Approximately 26,000 AVCs each year (4 to 10% of the nation’s total) involve large animals and result in injuries to vehicle occupants (FHWA 2008).

Though motorist injuries may be relatively rare, “more than 90% of collisions with deer result in damage to the driver’s car or truck” (FHWA, 2008). State Farm Insurance Company (2015) estimates that 1 out of 169 US drivers had a claim from hitting a deer, moose or elk in 2015. The company’s analysis shows an average cost of $4,135 per claim involving a collision with one of these 3 animals, an increase of 6% from 2014. However, these estimates cannot paint a complete picture of AVC-related property damages, since many motorists do not file a claim with their insurance company (to avoid increased coverage costs in future years, for example).

A 2008 US Federal Highway Administration (FHWA) investigation identified “21 federally listed threatened or endangered animal species in the United States for which road mortality is among the major threats to the survival of the species.” While the survival of species is of clear significance to biodiversity on our planet and humanity as a whole, it is hard to ascribe an exact cost to losing an endangered animal. This ‘intrinsic value of a species’ is an under-researched topic. Economic value estimates for the Texas ocelot, for example, range from $50,000 to $5 million (Haines et al. 2007). Deaths of such animals can also become a liability risk as well as a public-perception hazard for transportation departments, since these animals are irreplaceable assets in a diverse ecosystem.

Other less easily quantifiable but very common consequences of most animal-vehicle collisions include traffic delays, diversions of law enforcement or emergency personnel and road maintenance crews. For example, deer carcass removal costs are estimated to be $30.50 per deer
Wildlife Crossing Mitigation

U.S. infrastructure project planning and delivery normally requires an environmental review process to avoid or at least mitigate detrimental project impacts on human and natural communities, as well as historic and cultural sites. For complex transportation projects, this process often is the most time-consuming part of project delivery (Evink, 2002; US GAO, 2003). Brown’s (2006) “Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects” report provides guidance and examples for streamlining environmental reviews while more effectively protecting natural resources and ecosystem processes (Brown, 2006). Planners and engineers applied these ideas to create the Integrated Transportation and Ecosystem Enhancements for Montana (ITEEM) process. Many measures can be taken to connect habitats and wildlife populations and increase motorist safety while lowering wildlife mortality. Iuell et al. (2005) summarized these measures into five categories:

- Wildlife overpasses
- Wildlife underpasses
- Specific measures: fencing, gates and escape ramps, signage, vehicle-animal detection systems, speed reduction, lighting and reflectors
- Habitat adaptation: manage habitat and right-of-way, intercept feeding
- Infrastructure adaptation: modify road infrastructure (curbs, drainage, gates, etc.) to better accommodate wildlife movement (e.g. increase width of road median).

Many U.S. states have been implementing some of these measures and other strategies. For example, Florida’s I-75 seeks to protect the endangered Florida Panther, North Carolina is building several wildlife underpasses on U.S. 64, and TxDOT budgeted $5 million for four wildlife crossings under Highway 100 (between Laguna Vista and Los Fresnos) to reduce ocelot deaths. States like Washington and Montana have recently pursued major crash-mitigation projects, with Montana providing more than 40 new wildlife crossings in the reconstruction of a 56-mile segment of US-93 (Jones et al. 2013). As of 2007, Texas had 10 major terrestrial wildlife crossings (Bissonette and Cramer 2008). The following data analyses help us understand where AVCs are high and investments may be most cost-effective.

DATA ANALYSIS

The AVCs analyzed here come from the TxDOT Crash Records Information System (CRIS), an online database containing crash data for the state of Texas submitted by law enforcement officers and available at https://cris.dot.state.tx.us. Almost all (with a few exception) of these AVCs are coded as ‘wild’ or ‘domestic’ animals involved. The data referenced here contains incidents from the years 2010 through 2016. The spatial and temporal accuracy of the data may vary by region and setting (e.g., under-reporting may be higher in rural contexts, at night, and for larger vehicles).

Using these 2010-2016 AVC data, with TxDOT's comprehensive crash costs (TxDOT Highway Safety Improvement Program Call, http://ftp.dot.state.tx.us/pub/txdot-info/trf/hsip/2018/program-call.pdf), the loss from reported AVCs is about $21 per Texan per year. 67% of this is attributable to wild-animal collisions, and 33% is attributable to domestic-animal collisions. Interestingly, though the domestic animals are often smaller (e.g., dogs rather than deer) and just one-third of all reported AVCs in Texas, the costs of these crashes is 44% of total costs, indicating higher crash severity for domestic animals. This may be due to their occurring in higher-population-density
settings (see Figure 9 vs 10), with more cars and trucks alongside when the collision occurs. Alternatively, it may be due to drivers swerving more dramatically to avoid harming someone's beloved pet.

**TABLE 1 CRIS Crash Cost Estimates (Texas AVCs, 2010-2016)**

<table>
<thead>
<tr>
<th>Crash Year</th>
<th>Contributing Factor</th>
<th>Killed</th>
<th>Incapacitating Injury</th>
<th>Non-Incapacitating Injury</th>
<th>Possible Injury</th>
<th>Not Injured</th>
<th>Unk.</th>
<th>Cost (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Animal - Domestic</td>
<td>9</td>
<td>43</td>
<td>194</td>
<td>214</td>
<td>1997</td>
<td>12</td>
<td>$279</td>
</tr>
<tr>
<td></td>
<td>Animal - Wild</td>
<td>6</td>
<td>52</td>
<td>173</td>
<td>185</td>
<td>3722</td>
<td>12</td>
<td>$289.5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>15</td>
<td>95</td>
<td>367</td>
<td>399</td>
<td>5719</td>
<td>24</td>
<td>$568.5</td>
</tr>
<tr>
<td>2011</td>
<td>Animal - Domestic</td>
<td>9</td>
<td>38</td>
<td>214</td>
<td>225</td>
<td>1936</td>
<td>14</td>
<td>$271.5</td>
</tr>
<tr>
<td></td>
<td>Animal - Wild</td>
<td>12</td>
<td>67</td>
<td>230</td>
<td>191</td>
<td>3981</td>
<td>14</td>
<td>$391.5</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>$0.5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>21</td>
<td>105</td>
<td>445</td>
<td>417</td>
<td>5918</td>
<td>28</td>
<td>$663.5</td>
</tr>
<tr>
<td>2012</td>
<td>Animal - Domestic</td>
<td>9</td>
<td>51</td>
<td>207</td>
<td>197</td>
<td>1943</td>
<td>18</td>
<td>$313.5</td>
</tr>
<tr>
<td></td>
<td>Animal - Wild</td>
<td>5</td>
<td>65</td>
<td>191</td>
<td>207</td>
<td>3828</td>
<td>20</td>
<td>$340.5</td>
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<td></td>
<td>Other</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>$0.5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>14</td>
<td>116</td>
<td>398</td>
<td>404</td>
<td>5772</td>
<td>38</td>
<td>$654</td>
</tr>
<tr>
<td>2013</td>
<td>Animal - Domestic</td>
<td>13</td>
<td>37</td>
<td>163</td>
<td>191</td>
<td>1781</td>
<td>11</td>
<td>$256.5</td>
</tr>
<tr>
<td></td>
<td>Animal - Wild</td>
<td>4</td>
<td>49</td>
<td>201</td>
<td>215</td>
<td>4108</td>
<td>16</td>
<td>$286</td>
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<td>Other</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>$0.5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>17</td>
<td>86</td>
<td>365</td>
<td>407</td>
<td>5891</td>
<td>27</td>
<td>$543</td>
</tr>
<tr>
<td>2014</td>
<td>Animal - Domestic</td>
<td>7</td>
<td>42</td>
<td>135</td>
<td>158</td>
<td>1668</td>
<td>19</td>
<td>$239</td>
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<tr>
<td></td>
<td>Animal - Wild</td>
<td>13</td>
<td>61</td>
<td>172</td>
<td>234</td>
<td>4115</td>
<td>22</td>
<td>$345</td>
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<td>Other</td>
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<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>$0.5</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>20</td>
<td>103</td>
<td>308</td>
<td>392</td>
<td>5784</td>
<td>41</td>
<td>$584.5</td>
</tr>
<tr>
<td>2015</td>
<td>Animal - Domestic</td>
<td>10</td>
<td>40</td>
<td>172</td>
<td>183</td>
<td>1761</td>
<td>12</td>
<td>$261</td>
</tr>
<tr>
<td></td>
<td>Animal - Wild</td>
<td>12</td>
<td>61</td>
<td>206</td>
<td>250</td>
<td>4610</td>
<td>23</td>
<td>$358.5</td>
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<tr>
<td></td>
<td>Total</td>
<td>22</td>
<td>101</td>
<td>378</td>
<td>433</td>
<td>6371</td>
<td>35</td>
<td>$619.5</td>
</tr>
<tr>
<td>2016</td>
<td>Animal - Domestic</td>
<td>5</td>
<td>46</td>
<td>181</td>
<td>181</td>
<td>1876</td>
<td>17</td>
<td>$269</td>
</tr>
<tr>
<td></td>
<td>Animal - Wild</td>
<td>10</td>
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<td>246</td>
<td>287</td>
<td>5131</td>
<td>44</td>
<td>$417</td>
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<tr>
<td></td>
<td>Other</td>
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<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$-</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>15</td>
<td>120</td>
<td>427</td>
<td>468</td>
<td>7008</td>
<td>61</td>
<td>$686</td>
</tr>
</tbody>
</table>

**Crash Time of Day**

As shown in Figures 1 and 2, AVCs peak twice a day: between 5 and 8 AM and from 6 PM to midnight, with heavy peaking at 6 or 6:30 am and 8 or 9 pm. When the times of day are adjusted (Figure 2) for daylight savings time shifts, the evening peak consolidates further (vs. Figure 1’s wide evening peak). Since travel or VMT demand does not peak at those same times of day or in quite the same way, AVC peaking implies that animal movement choices are key. Animal behavior is regularly based on the sun’s placement, while human behavior is dictated more often by clock time (for work and school start and end times, for example), as well as day of week (with Friday and Saturday nights often involving late-night socializing and the associated return travel).
Interestingly, domestic animals tend to experience more crashes earlier in the day than wild animals do (e.g., a 5 or 6 am peak).

FIGURE 1 Crash counts by time of day (30-min intervals, Texas AVCs, 2010-2016)

FIGURE 2 Crash counts by adjusted time of day (to eliminate daylight savings time effects, 30-min intervals, Texas AVCs, 2010-2016)

Time of Year
State Farm indicates that drivers are more than twice as likely to have a collision with a deer, elk, or moose during the months October, November, December (State Farm 2015). Texas AVC data delivers similar results, as shown in Figure 3.
Light Condition
Most AVCs occur at night in unlit locations. Unlike cars and trucks - with their headlights on, animals running across the road are unlit. Crash frequencies are also much higher in dark settings, as shown in Figure 4. Such settings can be especially problematic for smaller animals, such as turtles, armadillos, raccoons, possums, and the endangered Texas ocelot. It is difficult to know the rates of such incidents because crashes involving small animals are rarely detected by the involved motorists (unless they are riding a motorcycle, for example) and almost never reported. Swedish research (Neumann et al. 2015) notes how higher collision risk for moose is “largely due to low light and poor road surface conditions rather than to more animal road-crossings.”
Vehicle Type

Based on observations from the CRIS data shown in Figures 5 and 6, during the years 2010-2016 motorcycles comprised 2.2-3.5% of total reported AVCs, yet accounted for at least half of all fatal or injurious crashes. These animal-motorcycle collisions are especially deadly, as the driver has no physical protection between himself and the animal. Compared to other vehicle types, motorcycles see a large spike in AVCs on Saturdays and Sundays, likely due to those using motorcycles as recreational vehicles on the weekends.

![Figure 5: Number of crashes by vehicle type (Texas AVCs, 2010-2016)](#)

![Figure 6: Number of fatal or injurious crash reports by vehicle type (Texas AVCs, 2010-2016)](#)

Location and Density
51,522 collisions with wild animals were reported by Texas law enforcement between 2010-2016, including 254 human fatalities, 6,914 human injuries, and thousands more animal deaths. Most of these crashes happen on rural roads with very low traffic, as demonstrated in Figure 7.

**FIGURE 7** Crash counts by average annual daily traffic (Texas AVCs, 2010-2016)

From these coordinates, it is possible to develop a generic heat map based on the respective concentrations of the data points shown in Figure 8. A bright yellow spot indicates a very dense collection of data points whereas a light blue area suggests that crashes are fewer and farther
between. The heat maps for all animal vehicle collisions indicated that the San Antonio metropolitan area had the most concentrated AVCs. This is consistent with a 2018 report by the National Insurance Crime Bureau which stated that San Antonio and Austin, TX are the top 2 cities for animal loss claims across the whole U.S (NICB 2018).

FIGURE 9 Crash count hot spots for wild animals (Texas AVCs, 2010-2016)

Though collisions with domestic animals make up a smaller proportion of total reported crashes than collisions with wild animals and are researched less often, they are not to be discounted. Out of the 51,522 AVCs reported in the state of Texas between 2010-2016, 15,890 (31%) of these can be attributed to collisions with domestic animals and 32,920 (64%) with wild animals, as shown in Figures 9 and 10, where the rest were unspecified in the data.

FIGURE 10 Crash counts hot spots for domestic animals (Texas AVCs, 2010-2016)
As shown above, collisions with domestic animals seem to experience a high spike in the Rio Grande Valley region. This is possibly due to the unusually high number of stray animals in the region. According to Keely Lewis, board secretary for the Palm Valley Animal Center, the Valley has one of the highest populations of stray animals in the country. Christopher Gonzales, owner of Texas Pet Rescue, the only no-kill shelter in the city of McAllen, offered his perspective on the same issue in correspondence with Dr. Kara Kockelman. Gonzales suggests that many, if not most, residents of the Valley do not opt for rabies shots or microchips or will decline spaying and neutering services in favor of trying to turn a profit on the animal’s offspring. He also states that McAllen’s main roads are more residential than those in neighboring cities like Brownsville, making it more likely for runaway dogs to access the streets and cause crashes in that area. However, it is worth noting that according to national data, dogs make up only 3.5% of animal-related insurance claims.

**FIGURE 11** Crash counts by speed limit (Texas AVCs 2010-2016)
Regression Analysis
Using ordinary least-squares (OLS) regression across n=254 Texas counties, the following analysis highlights county attributes that are strong predictors of AVC crash rates (per VMT in each county). For further investigation, similar methods can be implemented at a link-based level, to identify problematic road segments.

Table 2 summarizes key statistics for the explanatory variables used in this analysis. Collision data were averaged over the 7-year data set (Texas AVCs 2010-2016 CRIS data).

**TABLE 2 Summary Statistics for Texas County Data**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVC/VMT</td>
<td>Animal-vehicle collisions per million annual VMT</td>
<td>1.17E-03</td>
<td>0.60</td>
<td>0.11</td>
<td>0.08</td>
</tr>
<tr>
<td>POP DENS</td>
<td>Population per square mile</td>
<td>2.6E-04</td>
<td>4.62</td>
<td>0.18</td>
<td>0.53</td>
</tr>
<tr>
<td>VMT/CAP</td>
<td>Average annual VMT per capita</td>
<td>498.53</td>
<td>312,372</td>
<td>18,948</td>
<td>33,402</td>
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<td>VEH/CAP</td>
<td>Vehicles registered per capita</td>
<td>0.04</td>
<td>8.81</td>
<td>1.21</td>
<td>0.78</td>
</tr>
<tr>
<td>LANEMI/CAP</td>
<td>Lane-miles per capita</td>
<td>4.59E-03</td>
<td>2.10</td>
<td>0.19</td>
<td>0.27</td>
</tr>
<tr>
<td>RAINFALL</td>
<td>Average annual rainfall (in inches)</td>
<td>9.10</td>
<td>60.57</td>
<td>31.39</td>
<td>11.93</td>
</tr>
<tr>
<td>ON SYSTEM</td>
<td>% VMT occurring on TxDOT managed-roadways</td>
<td>34.60</td>
<td>180.66</td>
<td>88.96</td>
<td>12.61</td>
</tr>
<tr>
<td>RURAL POP</td>
<td>Proportion of population that lives in rural areas</td>
<td>0.00E+00</td>
<td>2.53</td>
<td>0.063</td>
<td>0.24</td>
</tr>
<tr>
<td>JOBS DENS</td>
<td>Employees per acre</td>
<td>0.0069</td>
<td>1.00</td>
<td>0.56</td>
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</tr>
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</table>
TABLE 3 OLS Regression Results for Y = AVC per Million-VMT Prediction

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.08</td>
<td>0.04</td>
<td>2.26</td>
<td>0.02</td>
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<td>POP DENS</td>
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<td>0.03</td>
<td>-0.91</td>
<td>0.36</td>
<td>-0.18</td>
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<tr>
<td>VMT/CAP</td>
<td>-1.1E-06</td>
<td>1.7E-07</td>
<td>-6.66</td>
<td>1.7E-10</td>
<td>-0.45</td>
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<td>VEHICLES/CAP</td>
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<td>0.01</td>
<td>-1.40</td>
<td>0.16</td>
<td>-0.08</td>
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<tr>
<td>LANEMI/CAP</td>
<td>0.15</td>
<td>0.03</td>
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<td>6.7E-09</td>
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<td>RAINFALL</td>
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<td>0.95</td>
<td>0.34</td>
<td>+0.06</td>
</tr>
<tr>
<td>ON SYSTEM</td>
<td>-2.9E-04</td>
<td>3.9E-04</td>
<td>-0.75</td>
<td>0.45</td>
<td>-0.04</td>
</tr>
<tr>
<td>RURAL POP</td>
<td>0.09</td>
<td>0.02</td>
<td>4.60</td>
<td>6.8E-06</td>
<td>+0.33</td>
</tr>
<tr>
<td>JOBS DENS</td>
<td>0.01</td>
<td>0.07</td>
<td>0.16</td>
<td>0.87</td>
<td>+0.03</td>
</tr>
</tbody>
</table>

**Model Results**

A standardized coefficient (STD COEF) is a valuable way to compare the predictive strength of different explanatory variables. This coefficient refers to how many standard deviations the dependent variable (AVC/VMT) will change following a one-standard-deviation increase in the associated explanatory variable. When the percent of a county’s population that is rural rises, or the number of lane-miles per capita rises, the AVC rate rises (per VMT), everything else constant. Conversely, variables such as the % of VMT that occurs on-system have the opposite effect. This table indicates that overall, counties with less VMT/capita, more lane miles per capita and are less dense and more rural will experience the greatest number of crashes. Lane miles per capita are particularly concerning as wide-ranging animals will encounter many opportunities for road-crossings and subsequent collisions. This result supports preceding studies which have shown that higher road density leads to increased wildlife mortality rates in a non-linear manner due to an enhanced risk of collisions. (Frair et al., 2008 ref. in Neumann).

**INTERVENTION OPTIONS**

The options detailed here offer possible partial solutions and mitigation strategies that are most likely to reduce AVCs anywhere in the world. Long-term monitoring is necessary to ensure effectiveness of any mitigation for the area and to determine local species’ specific preferences for such devices.

**Wildlife Crossings**

A wildlife crossing structure refers to either a bridge or culvert constructed over or under a road, respectively, to allow for the safe crossing and promote habitat connectivity of wildlife species. At 2-10% of total construction costs, the cost of implementing crossings is relatively low when compared to the costs absorbed by DOTs and the public for retrofitting facilities, fixing/replacing damaged vehicles, and health care.

*Culverts*
A study in Utah regarding mule deer populations has indicated that culverts that are wider, higher, and shorter in length have the most success in passing animals through. Specifically, it was recommended that culverts be kept shorter than 120 feet in length.

**Bridges**

In the same study, it was found that bridge designs reduced AVC counts by 89-98%, though bridges do come with a high initial cost. It is much more economically viable to include these in initial constructions than it is to retrofit. For example, the project in Montana building more than 40 wildlife crossings in the reconstruction of a 56-mile segment of US-93 added only $9 million to the $133m project (Jones et al. 2013).

**Fencing**

Fencing alone can significantly decrease the number of animals accessing a roadway but can also have adverse consequences such as the disruption of habitat connectivity. Wildlife exclusion fencing in combination with crossing structures is widely regarded to be the most effective mitigation treatment. Several studies indicate that the presence of wildlife exclusion fencing enhances the effectiveness of crossing structures (Cramer 2013). However, a fence is only as effective as the infrastructure at its designated breaking points, often a simple cattle guard which has low efficacy in preventing deer from accessing the roadway (Cramer and Flower 2017).

**External Factors and Driver Attitudes**

There is evidence to suggest that driver attitudes and many other non-animal related conditions may have a large impact on crash density, as in the case of light condition. Therefore, solutions such as improved lighting or driver awareness of road conditions conducive to AVCs should be considered.

Unfortunately, there is some evidence to suggest that AVC rates’ correlation with lighting conditions may not have a cause-and-effect relationship. Though there have been a few studies conducted to analyze roadway lighting’s effect on AVCs, one of these studies reported no observable reduction of AVCs in the presence of new lighting. However, Sullivan et al. 2009 used a logistic regression model to find that night vision enhancement “may provide valuable assistance in helping drivers avoid animal-vehicle collisions.”

Both static and dynamic signage (warning signs that are initiated at the detection of an animal’s presence) can impact the mindset of drivers and encourage them both to be alert and to reduce speed, possibly preventing and certainly lessening the impact of a collision were it to occur (Sullivan 2009). In the case of domestic animal collisions, it is recommended that cities and states cultivate cultures where dogs are spayed and neutered rather than being raised as an investment. City animal control agents should have the appropriate resources delegated so that they can actively and effectively keep these animals off the road. Sharpshooting to reduce the abundance of deer populations has been considered (DeNicola et al. 2008) but has drawbacks including population impacts and public perception.

Looking to the future, some experts believe that the proliferation of sensing-enabled vehicles, which may be able to thoughtfully avoid or at least notify drivers of the presence of an obstacle, will greatly reduce the number of animal-vehicle collisions and may even result in a “rewilding”
of the predators that have been methodically killed off by animal-vehicle collisions over the last 100 years (Wollan 2018). Connected vehicles may also provide awareness of “hot spots for migrations of all animal types, even ones that will not harm cars or their occupants,” which may encourage a driver to reroute around that critical path for the day.

Improving Animal-Vehicle Collision Reporting
Mobile reporting, both from DOT employees and the average smartphone user, shows potential for increased frequency and specificity of WVC reporting. The Washington State Department of Transportation (WSDOT) and the South Dakota Department of Transportation (SDDOT) have both created mobile applications for employees to report carcasses upon spotting them. In Malaysia and Israel, government and non-profit organizations, respectively, are working with popular navigation app Waze to show WVC hotspots on their maps so that drivers may be alerted and consider slowing down as they approach these areas (Udasin 2017; Clean Malaysia 2018). WIRES, a wildlife rescue app based in Australia, claims to have rescued over 68,000 animals in 2014 with the help of mobile reporting from citizens (Inverell Times 2014). These promising applications demonstrate that ordinary citizens may be eager to download and utilize wildlife reporting apps.

Some researchers point to more detailed crash reports as simple strategy for fostering an environment of reliable data-gathering regarding AVC and its mitigation in the future. In the state of Nevada, officers reporting WVCs “have 14 species to select from a computer software pull down menu of species options, which includes wildlife and domestic animals” (Olson et al. 2014). Such detailed reporting provides transportation and wildlife departments with more accurate data to use in planning future mitigation strategies (Loftus-Otway et al. 2017).

Other Options
Many other mitigation strategies have been proposed, including but not limited to high-frequency ultrasound to deter animals from the roadway, dynamic signage during periods of high animal traffic, deer and livestock guards, and electric pavement installations (Cramer and Flower 2017).

CONCLUSIONS
Animal-vehicle collisions are a rising share of crash counts, but can be thoughtfully addressed by recognizing their specific locations, times of day, and months of year, as well as employing meaningful crossings, lighting, and/or real-time warnings. Best-practice projects, including infrastructure changes and behavioral strategies, are lowering such crash rates while raising driver awareness of AVCs. Communities and authorities throughout the world can address these issues by not only looking to infrastructure investments of the past but also to innovations of the future – including image processing on cameras, linked to smartphones and smarter cars and trucks – shifting crash reduction responsibilities to motorists. Intelligent investments, designs, and applications can save many lives and much property, while enabling longevity of endangered and near-endangered species around the world.

AUTHOR CONTRIBUTION STATEMENT
The authors confirm the contribution to the paper as follows: study conception and design: Wilkins, D. and Kockelman, K.; Data analysis and interpretation of results: Wilkins. D. and
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