CORRIDORS AND DEER-VEHICLE COLLISIONS ALONG MISSOURI INTERSTATE HIGHWAYS

A Thesis

presented to

the Faculty of the Graduate School

at the University of Missouri- Columbia

In Partial Fulfillment

of the Requirements for the Degree in

Master of Science

by

SHIKHA ACHARYA

Dr. Mark Morgan, Thesis Supervisor

December 2022

The undersigned, appointed by the dean of the Graduate School,

have examined the thesis entitled

CORRIDORS AND DEER-VEHICLE COLLISIONS ALONG MISSOURI INTERSTATE HIGHWAYS

presented by Shikha Acharya,

a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

Associate Professor Mark Morgan

Assistant Professor Shuangyu Xu

Professor Mark Palmer

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my advisor, Dr. Mark Morgan, who made this work possible. His invaluable patience, moral support, and feedback carried me through all the stages of writing this report. Thank you for your constant encouragement, enthusiasm, and guidance throughout this journey.

I could not have undertaken this journey without my thesis committee members, Dr. Shuangyu Xu and Dr. Mark Palmer, who generously provided their encouragement, knowledge, and expertise. I also would like to give a special thanks to Tara L. Bose and Loretta Mitchell, from Missouri State Highway Patrol, for providing us with the dataset for our study, and also for their timely response with additional information and clarification when needed.

I am grateful to my family, especially my parents, for their continuous love and support. Your belief in me has kept my spirits and motivation high during this process. I would also like to thank my friends, for the emotional support through the highs and lows, and for providing the comfort of a home away from home.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABSTRACT

A total of 3,639 deer-vehicle collisions (DVCs) were reported on Missouri roadways in 2020, resulting in 348 injuries and 5 deaths. Missouri is ranked 15th nationwide for this type of accident. Of the DVCs, 490 occurred along 1,200 miles of urban and rural interstates in Missouri (I-29, I-35, I-44, I-49, I-55, I-57, I-64, I-70, I-155, I-170, I-255, I-270, I-435, and I-470). Despite the small number of DVCs on interstates (<15%), these sites are high-speed impacts, averaging $6,717 per crash. This study investigated DVCs on interstate highways using secondary data obtained from the Missouri State Highway Patrol. Each pair of longitude and latitude coordinates was uploaded into Google Maps and observed on a 200-foot scale view. Aerial photography and street-side images were used to examine the possible influence of land use characteristics and corridors adjacent to each location. Of the 490 DVC sites examined, 449 (91.6%) were near a natural (47%) or cultural (31%) corridor, and sometimes both (22%). Natural corridors consisted mostly of vegetation (65.7%), water (31.8%), and dry creeks (2.5%), whereas cultural corridors were secondary roads (36.1%), fence rows (22.6%), public utilities (22.2%) and overpasses (19%). Results showed that the distance from the nearest corridor to the collision point was about 350 feet, reinforcing the importance of landscape connectivity. These findings, when combined with other studies, can be useful to warn motorists at certain times (dawn/dusk) and seasons (fall/winter) at specific locations (hotspots) along Missouri interstates when the risk of a collision with deer is greatest. St. Louis and Kansas City had the most concentrated DVC sites statewide, drawing attention to urban deer and city drivers.

INTRODUCTION

According to the Missouri Department of Transportation (MODOT), there were 3,639 deer-vehicle collisions (DVCs) on Missouri roadways in 2020, resulting in 348 injuries and five deaths. Missouri drivers have a 1 in 74 chance of striking a deer, an event that happens every 2.4 hours, statewide (MODOT, 2022). As a result, Missouri is ranked 15th in the nation for DVCs (State Farm Insurance, 2020). Of these crashes, 490 occurred along interstate highways (13.4% of total collisions and 44% of total crashes involving personal injury) (Missouri State Highway Patrol, 2020). Although interstates are twice as safe as other roads, they have a greater risk of bodily injury and property damage that often results from high-speed collisions (The Road Information Program (TRIP), 2006). By 2026, it is predicted that interstate highway traffic would increase by 40 percent in Missouri (TRIP, 2006).

Missouri is home to about 1.4 million white-tailed deer (*Odocoileus virginianus*) (Pierce et al., 2011). During the early 1900s, however, the state's deer population was only about 400, mostly because of unregulated hunting and habitat loss (Flinn et al., 2012). Today, deer are a popular game species found in all 114 counties in Missouri (Pierce et al., 2015). Improved habitat management practices have resulted in improved reproduction, hence more deer than ever before (Pierce et al., 2011). Aside from humans, deer have no natural predators except for black bears and mountain lions. Hunting is the primary cause of deer mortality statewide and a leading factor in regulating their abundance (Pierce et al., 2011). Missouri hunters harvest approximately 300,000 deer each year, accounting for 40 to 70 percent of the antlered bucks and up to 25 percent of the does (Pierce et al., 2011). If hunting was eliminated and reproduction stayed the same, the deer population would quadruple in about 10 years (Flinn et al., 2012).

The Missouri Department of Conservation (MDC), founded in 1937, is the primary agency responsible for managing the deer population statewide. Intensive wildlife management practices have made Missouri a leader in natural resources, with support from the Conservation Federation of Missouri. Although the amount of public land in Missouri is only 7% (3.1 million acres), this acreage provides abundant habitat to support a large deer population, even in urban areas (Hansen & Beringer, 1997). The statewide deer management goal is focused largely on stabilizing deer numbers through increased antlerless harvest (MDC, 2020).

MDC manages the deer population at levels high enough for public enjoyment and benefit, yet low enough to maintain a healthy herd, thus preventing problems caused by overcrowding (Pierce et al., 2011). Deer management techniques include annual harvesting by hunters, transplanting live-trapped deer to stock new ranges, preventing illegal kills, and sterilization (MDC, n.d.). Population assessment and management strategies include ways to minimize deer-human conflict by promoting awareness of potential impacts (MDC, n.d.). Although the number of hunters nationwide is declining, deer hunting in Missouri has remained steady due to recruitment, retention, and re-activation efforts ("Hunters Number", 2018).

Deer are abundant in areas where lightning fires and other disturbances have created openings in the forest canopy (Pierce et al., 2011). Deer often live in timbered areas, particularly at the edges of clearings, where they can find a variety of food (MDC, n.d.). Oak mast, grain (mostly corn), and fruits are staple deer food in Missouri (Korschgen, 1962). Landscapes that feature several habitats, such as forests, old fields, and croplands can maintain deer densities at higher levels compared with monocultures (Piccolo et al., 2000). Land-use patterns and habitat composition have a large effect on deer herds and their movements because management strategies can influence the availability of food and cover (Mormann et al., 2022). Common land use practices in Missouri include agriculture, timber, pasture, and livestock production which can be categorized into three generic habitat types: woodlands, grasslands, and croplands

(Mormann et al., 2022). For these and other reasons, Missouri is ideally suited for deer to thrive.

Landscape fragmentation often results in asymmetrical conflict with animals. Although roads and highways provide numerous transportation benefits for people, this form of development comes at a high cost to wildlife (Smith et al., 1999). Highway construction often leads to degradation and/or loss of natural settings and limited access to vital habitats (Jackson, 1999). Roads and railways often create fragmented habitats, resulting in barriers that impede animal movement and migration patterns, thus increasing the mortality of species that attempt to cross over (Jackson, 2000; Smith et al., 1999). The movement of animals through the landscape should be managed over time to ensure ecosystem integrity (Jackson, 2000).

Many studies have shown that wildlife mortality from vehicular collision is a result of landscape conditions (Farrell & Tappe, 2007; Keken et al., 2019; McKee & Cochran, 2012). Features such as vegetation, water, wetlands, and some forms of development can influence the occurrence of DVCs (Christie & Nason, 2003). For example, there is a correlation between migration corridors and DVCs (Coe et al., 2015). Landscape connectivity is undermined when road projects interfere with wildlife habitat (Donaldson, 2006). Corridors allow for the safe passage of animals in addition to providing areas for feeding and breeding (Douglas & Sadler, 2010). Ecological corridors are linear habitats that differ from the surrounding landscape matrix and play an important role in connecting isolated areas (Anderson & Jenkins, 2006). Efforts to mitigate DVC risk should focus on places where roadways and corridors intersect (Donaldson, 2006). Corridors and their influence on DVCs have been studied previously. Examples include remnant tree lines left from original forests (Forman & Godron, 1981), secondary roads with residual vegetation (Lentini et al., 2012), linear infrastructures without vehicular movement (van der Ree et al., 2015), drainage areas (Gunson et al., 2011), level terrain (Gunson et al., 2011), topographic features such as ridges and riparian corridors (Litvaitis & Tash, 2008), and public utilities such as electric lines, and pipelines (Primack 2006).

White-tailed deer are involved in more vehicle collisions than any other species of cervid (VerCauteren et al., 2006). Collision with deer is a significant cause of motor accidents in North America (Abeyrathna & Langen, 2021). The corridor-collision relationship is promising because deer movement depends on forested areas (Pagany, 2020), in addition to sources of food and water (Ng et al., 2008; Clevenger et al., 2015). Although the influence of corridors at collision sites has been studied elsewhere, no research of this type has been conducted in Missouri. Considering the risk of DVCs in Missouri is quite large due to herd size, the number of drivers, and the total mileage of interstates, understanding the importance of corridors is long overdue.

OBJECTIVES OF THE STUDY

This study will identify and describe the importance of corridors associated with DVC sites on Missouri interstates. In doing so, it will: a) determine the number of DVCs; b) analyze landscape features associated with each location; c) measure the distance of corridors from DVC sites, and d) identify ideal attributes that lead to DVCs. Managerial implications for transportation officials will be discussed, as needed.

LITERATURE REVIEW

Wildlife-Vehicle Collisions

Wildlife vehicle collisions (WVCs) on roadways are a significant socio-economic issue that causes a loss of animals, puts humans in danger, and results in costly repairs (Bruinderink & Hazebroek, 1996; Gunson et al., 2011). For example, about 200 human deaths, and 26,000 injuries are from the 1 - 2 million WVCs which occur in the United States each year, resulting in approximately $8 billion in property damage and other costs (State Farm Insurance, 2022). According to State Farm Insurance, there is a 1 in 115 chance of collision with an animal for U.S. drivers. The costs and impacts of WVCs will continue to worsen globally since traffic volume is expected to double by 2050 worldwide and increase five-fold in developing countries (van der Ree et al., 2015).

Wildlife vehicle collisions have financial implications for law enforcement and transportation agencies, such as direct costs associated with investigation and traffic control following a collision, carcass removal, and disposal, and infrastructure repair, if needed (Huijser et al., 2017). Public agencies may also incur some indirect losses based on the monetary value of the animal itself, as defined by lost opportunity costs associated with hunting, license fees, or wildlife viewing (Huijser et al., 2017). The severity of injuries from collisions depends upon the species involved (Haikonen & Summala, 2001). Costs increase significantly if larger animals, such as bears, elk, or moose, are involved in the accident (U.S. Department of Transportation (DoT), 2008). Since WVCs are expensive, understanding the nature and location of collisions (Bissonette et al., 2008; Huijser et al., 2009; Rowden, Steinhardt & Sheehan, 2008) is an important first step in reducing them (Rendall et al., 2021).

The pattern of WVCs is influenced by environmental and socio-demographic factors (Ha & Shilling, 2018). Transportation infrastructure often undermines ecological processes by restricting wildlife movement, disrupting gene flow, and changing metapopulation dynamics (Jackson, 2000). Therefore, wildlife survival is significantly affected by roads and road construction (Douglas & Sadler, 2010). Interstate and federal highways have the highest numbers of WVCs per km of road (Chen & Wu, 2014). With the land cover data from 2000, it was estimated that transportation infrastructure and residential land use have reduced the area of forested patches in the Western U.S. by 4.5% (20,000 km^2), and continued residential land expansion by 2030 will likely reduce forested patches by another 1.2%, thus shrinking wildlife habitat even more (Theobald et al., 2011).

A change in perspective is needed to mitigate WVCs: "it is not the animal that crosses the road but the road that crosses the forest" (Seiler & Bhardwaj, 2020). Collisions with wildlife occur when roads bisect habitat (Gunson et al., 2011) since construction and development often create isolated patches, otherwise known as fragmentation (DeStefano, 2009). Highways built through wildlife habitats reduce landscape connectivity, thereby altering patterns of animal movement, including migration (Davidson, 2003).

Some animals are drawn to roadside locations due to the presence of forage, proximity to water resources, or accumulation of salt (Litvaitis & Tash, 2008). Animals that avoid roadways have low rates of mortality due to WVC because they rarely attempt to cross, yet the barrier to movement effects may be high, potentially sub-dividing the population into smaller units (van der Ree et al., 2015). Migratory species are at greater risk of vehicle collisions because they use multiple habitats and a wide range of resources throughout their journey (Bolger et al. 2008). Completion of this cycle is threatened by habitat destruction, exploitation, changes in migration routes, lack of food sources, changes in nesting and breeding habits, diseases, and climate change (Primack, 2006). Identifying and maintaining the corridors is significant to maintain wildlife populations throughout their range to avoid bottlenecks (Sawyer et al., 2005). Wildlife habitats and migration corridors should be considered during road planning to minimize such collisions (Chen & Wu, 2014).

Deer-Vehicle Collisions

There are about 36 million deer in the U.S. (Wildlife Informer, 2022). In some states, about 90% of automobile collisions with wildlife involve deer (US DoT, 2008). Given their relative abundance and size, deer are a critical safety risk to humans (Blackwell et al., 2014). Collisions with deer increase as the number of animals and vehicles increase (Hedlund et al., 2004), which explains the high mortality rate of suburban deer (Etter et al., 2002).

Deer-vehicle collisions are the single largest category of human and vehicle costs (US DoT, 2008). According to the National Highway Safety Administration, there are about 1.5 million DVCs in the U.S. each year, resulting in $1 billion in automobile damages. Approximately 175-200 human deaths and 10,000 injuries are caused by DVCs annually (State Farm Insurance, 2020). There were an estimated 1.5 million deer claims industry-wide from July 1, 2019, to June 30, 2020, and 185 deaths from DVCs in 2019 (State Farm Insurance, 2020). The average cost per DVC is about $6,617, including $2,622 in vehicle repair costs, $2,702 human injuries, $1,002 human fatalities, $125 in towing and law enforcement services, $116 hunting value of the animal, and $50 carcass removal and disposal (Huijser et al., 2009). The economic value of deer ranges from $23 million to nearly $1 billion annually (Schwabe & Schuhmann, 2002). Shilling and Waetjen (2015) identified hotspots along ~7,900 km of highways and found that the annual cost of collisions near frequent DVC sites ranged from $0 to > $30,000/km.

Factors causing DVCs

Deer vehicle collisions are associated with habitat attributes (features that are attractive to deer) and roadway attributes (factors that increase the risk of collision with a deer) (Found & Boyce, 2011). Historically, conflicting goals of state wildlife agencies (protecting wildlife populations) and those of transportation departments (developing and improving transportation systems) have resulted in increased human-wildlife conflicts, most notably, DVCs (Sullivan & Messmer, 2003). Despite perceived threats to human and animal welfare, there is a poor understanding of DVCs (Ha & Shilling, 2018). The likelihood of encountering deer on the roadways, DVCs, as well as injury-severity level resulting from DVCs, are dependent on factors such as roadways, environment, weather-specific characteristics, spatial-temporal and collision information, and driver and vehicle-specific attributes (Ahmed et al., 2021). The DVC literature can be classified into deer-specific causes, temporal factors, and spatial conditions.

Deer specific causes

Habitat type and structure are some primary reasons for DVCs (Schwabe et al., 2000; Gonser et al., 2009). The probability of colliding with a deer is much higher when driving through their habitat (Lao et al., 2011). The basic habitat requirements of deer include food, cover, water, and space for survival and reproduction (Fulbright & Ortega-Santos, 2013). Deer are large herbivores that consume a variety of plant leaves, stems, flowers, fruits, and seeds, not necessarily the entire plant (Fulbright & Ortega-Santos, 2013). They browse on tree seedlings, shrubs, and climbers that are reachable from the ground and create a browse line with an open understorey (Gill & Beardall, 2001).

Many DVC sites are associated with landscapes having edge habitats (transitions from cover to open areas) and riparian zones (Huijser et al., 2017). Deer prefer areas with a mix of woods and fields or grassland and shrubs that provide a variety of food, shelter, habitat components, and an abundance of edge (Hiller, 1996). Deer crossing is common when cornfields were present on one side of the roadway with forest cover on the other (Waring et al., 1991). The abundance of deer is associated with an adequate supply of food and brushy cover, mostly a mosaic of different habitat types (Pierce et al., 2011). The presence of woodlands relative to cropland can result in increased DVC risks (Ng et al., 2008) since the presence of these conditions can influence deer abundance, often near public lands (Finder et al., 1999).

Although the presence of habitat is one of the main factors for DVCs (Lao et al., 2011), collision risks also depend on the behavioral patterns of deer (von Hoermann et al., 2020). The risk of collision is elevated by deer movements in space and time (Laliberté & St-Laurent, 2020). The locomotory behavior and pattern of deer can determine specific sites where collisions are likely to occur (Kušta et al., 2017). For example, feeding is the pre-dominant roadside behavior of the deer (Waring et al., 1991). Therefore, it is plausible that highway crossings are a way for deer to move from one feeding site to another one (Waring et al., 1991). Deer movements are usually classified as dispersal, immigration, or emigration, typically involving yearling bucks that are leaving the area where they were born to establish a home range elsewhere (Flinn et al., 2012). Deer movement is associated with the level of human activity (Root et al., 1988), a factor that can also determine DVC sites (Rodríguez-Morales et al., 2013).

The size of the deer herd will also determine the number of collisions (McCance, et al., 2015; Schwabe et al., 2000). Herd density was one of the significant predictors of DVCs in Illinois at the county level (Finder, 1998). A study conducted in Alabama showed that a deer population density (≥31/km^2) increased the odds of DVCs (Hussain et al., 2007). Hunting and predation were the primary sources of mortality for rural Midwestern deer (Etter et al., 2002). High deer densities are caused by a lack of predators and/or high plant productivity, in addition to deer management goals set by stakeholders that rely on cultural values, rather than biological information (Ahmed et al., 2021). Based on the number of DVCs in Alabama, the annual deer harvest (i.e., 300,000 to 500,000 per year) in comparison to the statewide population (around 1.75 million) was not sufficient for reducing the risk of collision (Chen & Wu, 2014). The likelihood of DVCs intensifies as density increases (Hothorn et al., 2015; Hussain et al., 2007; Mayer et al., 2021), especially in urban areas (Honda, et al., 2018) which sometimes have high populations of deer (McCance, et al., 2015).

Temporal factors

The temporal activity pattern of deer is one of the important causes of DVCs (Laliberté & St-Laurent, 2020; Meisingset, et al., 2014; Pagany, 2020; Steiner et al., 2014). Collisions are determined by deer-related activities based on habits and patterns (Hothorn et al., 2015). One study using three scales of temporal analysis (daily, weekly, and seasonal) revealed that DVCs were related to life cycle and human activities (Rodríguez-Morales et al., 2013).

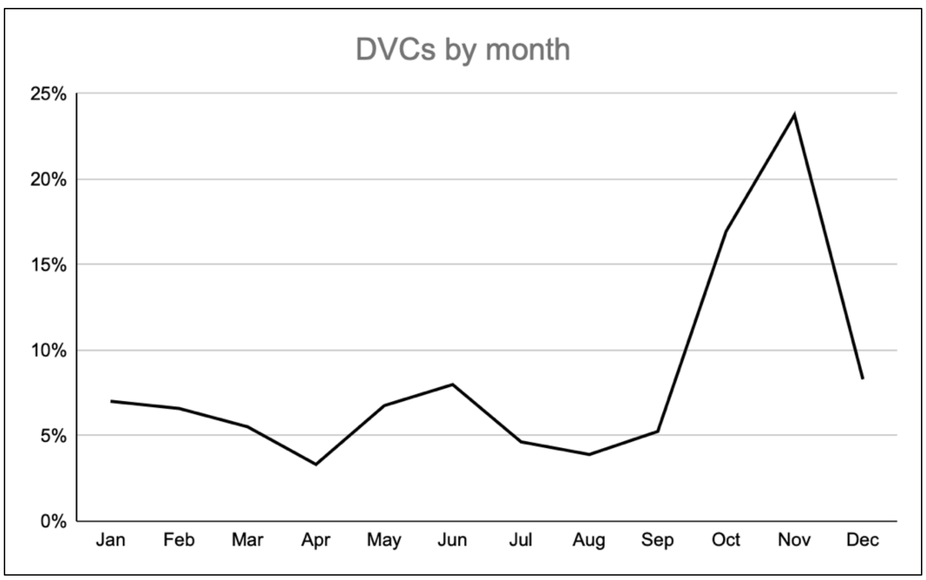
Deer are most active during the breeding season (Ahmed et al., 2021), which also coincides with the hunting season (Steiner et al., 2014). A strong relationship was found between DVCs and the peak rut (Stickles et al., 2015), suggesting that deer movement is highest during fall/winter (Allen & McCullough, 1976; Feldhamer et al., 1986; Gleason & Jenks, 1993; Meisingset et al., 2014; Sudharsan et al., 2006). The months that U.S. drivers are most likely to collide with large animals (typically deer) are October, November, and December (State Farm Insurance, 2022).

Hour of the day also influences DVCs (Schwabe et al., 2000) since deer are most active at sunrise and sunset (Bíl et al., 2017; Bruinderink & Hazebroek, 1996; Kušta et al., 2017; Mayer et al., 2021; Steiner et al., 2014). Although DVCs can occur within 1-2 hours before and after dawn/dusk, (Bíl et al, 2017; Hothorn et al., 2015), the peak seems to occur 1 hour after sunset (Haikonen & Summala, 2001). In the study by Waring et al., (1991), deer roadside activity was highest between 17:00 and 07:00. Other researchers (Huijser et al., 2017) have found similar results: DVCs were more frequent during early mornings (5–9 a.m.) and evenings (4 p.m.–12 a.m.).

Although deer strikes can occur at any time of the day, the most frequent times in Missouri were from 6:00-6:69 PM (9.81%) and 6:00-7:00 AM (8.74%) (Missouri State Highway Patrol, 2021). Collisions with deer were almost equal throughout the week with a slight increase on Saturdays (15.36%) and Sundays (14.81%). Most of the DVCs occurred during clear weather conditions (68.13%), followed by cloudy (21.78%), and rainy (4.98%) conditions. Based on five years' worth of data, 36% of auto claims filed by farmers due to animal-related accidents occurred between September-November (State Farm Insurance, 2019). According to the Missouri State Highway Patrol, nearly half (49.01%) of DVCs in 2020 occurred during October (16.95%), November (23.74%), and December (8.32%). The rest of the collisions (50.99%) were spread out over the other nine months. Most DVCs in Missouri occurred at dawn and dusk during October and November, with the largest number taking place in November (MODOT, n.d.).

Figure 1

DVCs by month of the year



Source: Missouri State Highway Patrol (2020)

Spatial factors

Vehicular collisions with deer are not random occurrences (Finder et al., 1999; Sudharsan et al., 2009), even though many people think otherwise. Gonser et al. (2009) used nearest neighbor analysis, chi-square test, and a landscape metric to examine the spatial relationship of DVCs in western Indiana and found that DVCs were dependent on land cover attributes such as habitat type and structure. Similarly, landscape factors evaluated using the nearest-neighbor and discriminant analysis in Southern Mississippi also found that they were a non-random spatial phenomenon (McKee & Cochran, 2012). Collision patterns are based on landscape elements usually followed in regular movements (Donaldson, 2006; Hussain et al. 2007) through different habitat types (Danielson & Hubbard, 1998). Deer movement occurs at various levels, ranging from large-scale such as dispersal and migration to small-scale, within home ranges and among habitat types (Webb et al., 2009).

Spatial differences are some of the most important factors that influence DVCs (Meisingset, et al., 2014). Spatial heterogeneity in the distribution of DVCs can be caused by attributes such as land-use patterns, population density, vehicle density, deer density, and wildlife management strategies such as hunting license sales, and hunting bag limits (Hussain et al., 2007).

Spatial conditions such as vegetation composition and structure can affect deer density which will influence the risk of collisions with vehicles (Shi et al., 2006). Understanding spatial patterns of urban deer will increase the predictive abilities of wildlife managers (Piccolo, 2000). Many DVCs are context-specific, resulting from interactions between large and local, biophysical processes (Clevenger et al., 2015). Spatial factors that influence DVCs can be subdivided into road and traffic conditions, landscape conditions, and corridors.

Road and traffic conditions

Unlike in the past, roads do not tend to follow natural landscape contours that run parallel or adjacent to rivers and streams but instead have taken on a more functional role of efficient transportation (Clevenger & Huijser, 2011). In doing so, road construction has disrupted wildlife movement and distribution patterns across the environment (Clevenger & Huijser, 2011; Litvaitis & Tash, 2008). DVCs are likely to occur when roads are close to (or running through) significant areas of woodland / forest (Nelli et al., 2018). Road location has a direct impact on the number of DVCs (Donaldson, 2006). For example, road sinuosity has a positive influence on DVCs (Laliberté & St-Laurent, 2020). Curvy roads with steeper slopes decrease driver visibility (Jensen et al., 2014; Donaldson, 2006), leading to more accidents. According to the Missouri State Highway Patrol, a majority of DVCs in 2020 occurred on level roads (63.40%), while the number of uphill and downhill gradients was relatively low (16.9% for each).

Factors that increase the time required by deer to cross a highway can influence the frequency of collisions (Clevenger et al., 2015), such as street width (Bartonička, et al., 2018; Pagany, 2020), the number of lanes (Donaldson, 2006; Hubbard et al., 2000), and so forth. Although barriers that separate lanes of traffic moving in opposite directions on multi-lane highways decrease automobile collisions, they can also impede wildlife movements, thereby increasing the risk of collisions (Clevenger & Kociolek, 2013). Animals are likely to feel trapped against concrete dividers while searching for places to cross over (Clevenger & Kociolek, 2013), resulting in panic. Rock cuts along some highways could produce a similar response. The higher the number of lanes, the greater the likelihood of a collision since it keeps deer in the danger zone for a longer time, likely experiencing more traffic trauma (Hubbard et al., 2000).

The impacts of road projects on wildlife movement and collisions with vehicles can be predicted by variables such as traffic intensity and vehicle speed (Donaldson, 2006). Vehicular collisions with deer increased with speed (Meisingset et al., 2014), as shown by a study in Canada (Ng et al., 2008). The risk of a DVC was higher on high and medium-speed roads in Southeast Michigan than on lower-speed roads (Sudharsan et al., 2009). This study compared rural and urban roads and roads with a traffic volume of more than 120 vehicles per hour. In addition to speed limits, DVCs were also dependent on traffic conditions (Clevenger et al., 2015; Schwabe et al., 2000). Collisions with deer occur mostly at intermediate traffic density (Mayer et al., 2021). Traffic volume was one of the significant predictors of DVCs in Illinois (Finder, 1998). Greater speed limits and traffic volume, especially in deer-feeding areas, increased the risk of DVCs (Clevenger et al., 2015; Hussain et al., 2007). In an urban setting, Farrell and Tappe (2007) found that the risk of DVCs increased with high road densities, human population densities, and daily traffic averages.

Few studies, however, claim that traffic volume alone accounts for DVCs. Bissonette and Kassar (2008) studied the effects of traffic volume and vehicle speed on DVCs in Utah and discovered no relationship between annual average daily traffic flow (AADT) and posted speed limit (PSL) with DVCs. Increased traffic volume may not increase DVCs because deer tend to avoid crossing roads at times of peak traffic (Kušta et al., 2017). One study showed that high road densities were associated with decreased DVCs (Ng et al., 2008). Reduced traffic volume during the COVID-19 pandemic led to more animal collisions; suggesting that road usage offsets the effect of reduced traffic volume (Abraham & Mumma, 2021). On an aggregate level, traffic volume and DVCs can be linear, but locally this relationship is influenced by wildlife behavior, road characteristics, and temporal and landscape factors (Donaldson, 2006).

Landscape conditions

Most studies have focused on site-specific factors that influence DVCs, but relatively few of them have discussed the broader impact of landscape features (Farrell & Tappe, 2007). Deer populations are influenced heavily by land-use practices and habitat management practices (Epps et al., 2005). Landscape patterns and features adjacent to highways influence DVC occurrence (Coe, 2015; Finder et al.,1999; Hussain et al., 2007; Keken et al., 2019). Landcover heterogeneity was found to be positively associated with the likelihood of DVCs based on landscape-based frequency models (Found & Boyce, 2011). For example, DVCs were more common where the roadside vegetation was both denser and more diverse (Found & Boyce, 2011). The edge effect is one of the prominent landscape features associated with high productivity and enhanced biodiversity (Leopold, 1933) that can influence animal movement and DVCs patterns. The migration pathways of deer can be modified over time by changes in landscape conditions (Seidler et al. 2014). Understanding the distribution and presence of habitat within landscapes is important for identifying DVC patterns (Ng et al., 2008).

Landscape variables were useful in predicting collisions with white-tailed deer in Europe (Gunson et al. 2011). Roadside strips provide the majority of wildlife habitat in highly modified landscapes (van der Ree et al., 2015). Wildlife movements restricted across the landscape tend to increase the number of DVCs (Bissonette & Rosa, 2012). Finder et al. (1999) studied landscape features such as topography and highway construction variables using remote sensing and showed that the risk of collision increased with greater landscape diversity and proximity to nearby forest patches. Collisions with deer were more frequent in heterogeneous landscapes where farmland and other non-forested vegetation were located closer to larger tracts of forest (Found & Boyce, 2011).

The proportion of mature coniferous stands (Laliberté & St-Laurent, 2020), grasslands cover types (McCance et al., 2015), and topography (Laliberté & St-Laurent, 2020; Pagany, 2020), influenced DVCs. Deer-vehicle collisions were more common in forested areas, grasslands, and agricultural areas (McKee & Cochran, 2012) and intensified with greater forest cover (Mayer et al., 2021). Forest fragmentation increases the density of DVCs (Saint-Andrieux et al., 2020). Distance to forest cover can be an important predictor of high DVC occurrence

(Finder et al., 1999). A lack of nearby cover could influence deer to take more risks when crossing roadways (Liu et al., 2018). Aside from forest cover and distance to pasture, the ruggedness of the terrain also increased DVCs (Meisingset, et al., 2014).

In urban settings, landscapes with few buildings and large public properties influence DVCs (Nielsen et al., 2003). Preserved green spaces in suburban areas can act as wildlife corridors (Houck, 1990). Corridors that encourage deer to thrive in them instead of simply moving through are vital in suburban environments (Gorham & Porter, 2011). A combination of suburban areas and broadleaved forests were associated with an increased frequency of DVCs (Nelli et al., 2018). City and county parks and residential areas in wooded habitats often act as refuges for deer to escape hunting pressure. However, the presence of such lands within the 0.8 km radius increased the probability of DVCs (Finder et al., 1999).

Corridors

Corridors are one of the best, and possibly only, management tools to maintain biodiversity at large scales (Gregory et al., 2021). They can be categorized as lines, strips, streams, and networks that provide habitat and breeding sites for animals who use these areas (Forman & Godron, 1981). Linear corridors are narrow paths, roads, hedgerows, property boundaries, drainage ditches, or irrigation channels. Strip corridors are wider, consisting of habitat patches in which species can migrate or live within. Stream corridors represent flowing bodies of water. Network corridors are formed through the intersection of loops. Corridors provide habitat and breeding sites for species but can be dominated by human activities (Forman & Godron, 1981). Corridors might not be of the same habitat type as the patches they connect to or even consist of native species (Lidicker, 1999).

Roads can function as corridors because they link animal populations in isolated patch habitats (Clevenger & Huijser, 2011). Abandoned roadbeds received the highest crossing utilization by deer (Waring et al., 1991). Deer prefer edge habitats along woodlands and fields within a corridor (Donaldson, 2006). Forest edges were also used for frequent travel (Bartonička, et al., 2018). Distance from forests or linear vegetation can be used to estimate collision locations (Bartonička, et al., 2018).

Corridors can occur in the floodplains of streams and rivers in addition to riparian zones associated with surface waters (Gregory et al., 2021). Riparian corridors are frequently used by deer for moving to and from desirable feeding, bedding, and refuge locations (Dusek et al., 1988). When riparian corridors cross road segments, they impact deer movement patterns and influence DVC locations (Dusek et al., 1988; Finder et al., 1999). Distance to the nearest river can be useful to predict DVC occurrences (Bartonička, et al., 2018; Danielson & Hubbard, 1998). Clevenger et al., (2015) found that the distance of streams from the collision site was less than 120 meters. Topographic corridors adjacent to roads can affect deer movements (Carbaugh et al., 1975; Laliberté & St-Laurent, 2020; Peek & Bellis, 1969) and collisions with vehicles (Laliberté & St-Laurent, 2020). Since deer feed on grasses planted on hills and valleys adjacent to highways, local topography can funnel deer into certain areas (Finder et al., 1999).

Deer-vehicle collisions are likely to occur when corridors intersect with roads (Donaldson & Weber, 2006; Romin, 1994), especially during seasonal movements and migrations (Nixon et al., 1991). Corridors maximize biological connectivity (Forman & Godron, 1986), and their functionality depends upon their width and length (Newmark, 1993). The risk of collision rises with an increase in the corridor’s width (Dusek et al., 1988). Corridors maintain continuity and flow between patches of chaparral and other habitats, thus mitigating some of the deleterious effects of fragmentation (Forman & Godron, 1986). However, corridors are affected by the impacts of linear features such as roads, canals, security fences, and power transmission lines (Gregory et al., 2021). Interference from corridors during road construction or lack of effective mitigation measures to minimize the impacts on corridors increases the risk of collisions in roadways (Donaldson & Weber, 2006).

Bridges indicate the presence of corridors that are fragmented by roads (Hubbard et al., 2000; Hussain, et al. 2007). Deer frequently travel along waterways and many bridges allow enough space for them to pass underneath (Donaldson, 2006). Bridges are often the best predictors of high-density DVC sites because they indicate the presence of riparian corridor habitat, which funnel animals along specific paths (Haddad & Baum 1999; Hubbard et al., 2000), even into roadways. Bridges can also signal edge habitat, providing deer with optimal browse conditions (Haddad & Baum, 1999). However, bridges without dry passageways force deer over the road, increasing the risk of collision with vehicles (Donaldson, 2006). The presence of gullies near roads can be useful for predicting DVC sites since they also increase the chance of collision (Donaldson, 2006; Finder et al., 1999).

Migration corridors including feeding and breeding sites are considered high-risk DVC areas (Sullivan et al., 2004). Mitigation strategies should focus on maintaining deer migration corridors in the face of increasing traffic and development (Coe et al., 2015; Sullivan et al., 2004). Information on deer habitat and migration routes can assist in roadway planning (Donaldson, 2006). Corridor analyses, which include the identification of natural passageways necessary to support the movement and reproductive needs of wildlife populations, are conducted frequently (Donaldson & Weber, 2006). Although linear infrastructure such as power lines, pipelines, and roads cause habitat fragmentation, deer also use these cultural corridors as transportation routes which can lead to highways (Donaldson & Weber, 2006). The possible influence of cultural corridors, including overpasses, has been under-studied.

Generally speaking, it is impractical to extend entire highways or railways for wildlife movement, therefore, it is important to identify “Connectivity Zones” (Jackson, 2000). Connectivity zones are areas designated as important travel corridors or connections between significant habitats (Jackson & Griffin, 1998). Since measures to mitigate the impact of transportation on wildlife movement can be expensive, officials should focus on areas that have the highest potential for collision (Jackson & Griffin, 1998). Hotspots are created along sections of roadways where there are disproportionately more collisions between wildlife and vehicles due to animal activity clusters (Litvaitis & Tash, 2008). Predicting the hotspot location for mitigation measures increases wildlife survival and road safety (Malo, et al., 2004).

Strategies to reduce DVCs

Since DVCs cause pain and suffering to humans and animals, traffic safety issues, and financial loss, they should be addressed by proper landscape planning and road management (Hegland & Hamre, 2018). Increased numbers of DVCs create new biological and socioeconomic consequences each year (Sullivan & Messmer, 2003). Mitigation is less likely to solve problems if it only accounts for traffic issues and disregards wildlife (Bissonette & Rosa, 2012). Mitigation of DVCs should be part of a broader strategy that balances the needs of humans and wildlife, which are frequently in competition (Hedlund et al., 2004). When DVCs are reduced, property damage as well as human and deer mortality decreases (Schwabe et al., 2000), producing positive net economic gains and increasing driver safety (Bissonette et al., 2008).

Accident-specific information (such as road design, adjacent topography, and nature of roadside vegetation), supplemented by onsite information, along with wildlife management strategies can be successful in mitigating DVCs (Hussain, et al. 2007). Improving the consistency and precision of data collection helps to identify and prioritize road sections that need attention (Huijser et al., 2017). Different methods are used to mitigate DVCs, but with insufficient science and limited evaluation (Hedlund et al., 2004). Multiple studies have introduced, evaluated, and recommended different strategies to reduce DVCs which can be broadly categorized as reducing the deer population, modifying deer behavior, and driver behavior (Hedlund et al., 2004).

Reducing deer population

Proactive habitat management programs to stabilize deer populations can minimize vehicular collisions (Nielsen et al., 2003). Understanding wildlife biology and ecology is essential for effective deer management (Pierce et al., 2011). To manage locally abundant deer, biologists should address density issues (Lopez, 2003). Deer-vehicle collisions can account for a significant portion of non-hunting mortality, especially in urban and suburban regions (Flinn et al., 2012). However, methods to control urban deer have not been successful (Honda et al., 2018).

A herd reduction strategy should be part of a larger wildlife management plan that balances the costs and benefits of maintaining wildlife populations (Hedlund et al., 2004). Missouri has reported an increasing trend in statewide deer harvest over the last 8 years, with a total deer harvest of 293,670 for the year 2021-2022 of which 143,049 were antlered deer, 26,599 were button bucks and 124,022 were does (MDC, 2022). According to MDC, for successful deer population management, 30% of the doe population must be harvested. Lethal control measures usually can have long-term benefits (MDC, 2022).

Population control mechanisms such as hunting can be controversial but are effective in reducing DVCs on roadways (DeNicola & Williams, 2008; McKee & Cochran Jr, 2012; Schwabe et al., 2000). Hunting license sales (Ahmed et al., 2021), high bag limits (Hussain et al. 2007; Ng et al., 2008), recruitment of local hunters (Hussain et al. 2007), and incentives for nonresident hunters (Hussain et al. 2007) are ways to decrease the frequency of DVCs on roadways. The absence of hunting in urban areas often results in excessive deer which also increases the risk of

DVCs (Hansen & Beringer, 1997). Sharpshooting can be an effective tool for controlling the deer population when other methods (i.e., traditional harvest) is not feasible (Kilgo et al., 2020). Archery hunts can be encouraged in high-risk corridors in urban areas (Indiana Department of Natural Resources, 2018).

Non-lethal ways to reduce the deer herd include immunocontraceptive vaccination of females, a strategy that can reduce DVC frequency (Rutberg, & Naugle, 2008). Relocation (within home range) is not viable for deer population control since it increases the potential spread of disease, stress on the animal, high costs, and lack of suitable placement sites (MDC, n.d.). Translocation (outside the home range) is an expensive procedure to control urban deer, costing nearly $400 per animal (Beringer et al., 2002). The major causes of mortality among translocated deer in Town and Country, Missouri were roadkill (68%), followed by hunting (12%), unknown causes (8%), fences (8%), and wounding from hunting (4%) (Beringer et al., 2002).

Compared to direct management of deer populations, habitat modification is less costly and less controversial in addressing problems related to the overabundance of suburban deer (Gorham & Porter, 2011; Litvaitis & Tash, 2008). Landscape management, especially near transportation infrastructure, can decrease the risk of DVCs (Keken et al., 2019). Habitat management along roadways (e.g., roadside vegetation reduction, including the highway medians (Rea, 2003)), can also be a promising method to decrease the number of deer (Jaren et al., 1991). Decreasing the number of fields and the distribution of tree canopy across the landscape were associated with decreased deer densities (Gorham & Porter, 2011). Habitat suitability can be decreased by reducing landscape diversity (Nielsen et al., 2003). In the suburbs where food is abundant, the availability of cover throughout the landscape affects deer density (Gorham & Porter, 2011). Vehicle collisions involving deer can be minimized by reducing forest cover and shrubby areas on public lands near roads (Nielsen et al., 2003).

Deer behavior modification

Approaches that modify deer behavior and movement patterns could reduce DVCs (Romin & Bissonette, 1996). Controlling animal movement is easier than changing the behavior of motorists when reducing DVC risk (Laliberté & St-Laurent, 2020). Mitigation measures aimed at increasing the safe passage of animals across roadways are some of the most effective strategies (Clevenger et al., 2015). Designing effective highway structures that allow deer to cross at specific, well-marked crossing points, where motorists can anticipate them along the highways can reduce collisions (Lehnert & Bissonette, 1997). For example, a barrier wildlife crossing plan was implemented in McDonald County, Missouri using special median openings at 14 locations along a five-mile section of I-49 that allowed wildlife to cross over without becoming trapped on the highway (MODOT, n.d.). Animal movement can be facilitated by implementing other suitable measures such as underpasses (Jackson, 2000; Litvaitis & Tash, 2008), overpasses (Jackson, 2000), viaducts (Jackson, 2000), and fencing (Litvaitis & Tash, 2008). These options are effective but expensive.

Fencing is a good DVC reduction strategy (Clevenger et al., 2001; Sullivan & Messmer, 2003). However, for fencing to be effective, several factors must be considered, such as height, quality, maintenance, and length (Danielson & Hubbard, 1998). Fences must be well-designed and well-maintained to be sustainable and can be combined with underpasses (McCollister & Van Manen, 2010), overpasses (Hedlund et al., 2004), or a combination of both (Hedlund et al., 2004), escape ramps (Bissonette & Rosa, 2012), deer guards (Braden, 2008), deer exclusion-grate system (Peterson, 2003), and crosswalks (Danielson & Hubbard, 1998). A study along an Interstate highway in Minnesota found that DVCs were reduced by a 2.4-m fence with one-way gates (Ludwig & Bremicker, 1983).

Other studies suggest that even the best fencing will not prevent deer from entering (Hedlund et al., 2004), but can funnel them toward the road crossing points (Malo et al., 2004). Fencing only creates barrier effects – a direct impediment to the movement of many species which might affect the dispersal and gene flow of the deer population (Epps et al., 2005). It can have significant ecological consequences if historical migration patterns are disrupted (Sullivan et al., 2004). Animals are quick to utilize openings in fences, therefore they must be inspected and repaired frequently (Foster and Humphrey, 1995). Although repair is inexpensive and effective, fencing can be too costly to erect and maintain over long distances (Bashore et al., 1985; Hedlund et al., 2004).

Deer are most likely to cross roads that are concealed by a cover (DeVault et al., 2020) such as vegetation (Meisingset et al., 2014), thus increasing the risk of collision by vehicles. During highway planning and construction, roads should be placed away from woodlots where deer feed frequently (Finder, 1999). Planning new roads in open landscapes (Hegland & Hamre, 2018) is one strategy to minimize the risk of collision (Meisingset et al., 2014). Road edge clearance also reduces the possibility of collisions, especially during winter, within dense forest habitats close to pastures because these stretches have the highest risk of DVCs (Meisingset, et al., 2014).

Year-round forage, including favorite food sources along highways, should not act as an inducement for deer to cross roads (Waring et al., 1991). Intercept feeding combined with alternate methods such as fencing kept deer away from the roadside and reduced the DVCs by < 50% (Wood & Wolfe, 1988). However, this is a costly approach and also can make deer dependent on supplemental food (Wood & Wolfe, 1988). Vehicle collisions with deer were clustered in areas where food was provided; therefore, feeding bans can help, especially in urban areas (McCance et al., 2015). Odor repellents, which contain predator odors, kept deer away from the road temporarily, and also had an overall lower number of collisions in the treated road sections (Bíl et al., 2018). Salt accumulation can also attract deer to roadsides, so alternatives should be considered (Leblond et al., 2007). In Missouri, about 144,000 tons of salt are used on roadways each winter, sprayed with brine and calcium chloride (MODOT, n.d.).

Understanding deer response to the vehicle was found to be helpful (Pfeiffer et al., 2020). The use of a vehicle-based lighting system increased the flight-initiation distance (FID) of white-tailed deer by enhancing their ability to detect an approaching vehicle at night (Blackwell & Seamans, 2009). However, most techniques for changing deer behavior in response to the vehicle (e.g., deer whistles, flagging, and deer reflectors) are ineffective because they do not elicit a flight response (Mastro et al., 2008).

Warning reflectors were unsuccessful in changing deer behavior to prevent collisions (Brieger et al., 2017; D' Angelo et al., 2006; Romin & Dalton, 1992) due to animal habituation as well as technical limitations, such as limited angle and intensity of the reflection (Ujvari et al., 1998). Evidence from controlled experiments showed that deer flagging signs were ineffective (Hedlund et al., 2004). Whistles mounted on cars were not effective in changing deer behavior in such a way that would prevent collisions (Sullivan & Messmer, 2003; Valitzski, 2009). Mirrors used to reflect the headlights of oncoming vehicles to "freeze" the deer on the roadsides were also ineffective (Danielson & Hubbard, 1998; Gilbert, 1982; Sullivan & Messmer, 2003).

Modifying driver's behavior

Altering driver behavior can reduce vehicle collisions with wildlife (Grace et al., 2015; Huijser & McGowen, 2003; Seiler & Helldin, 2006). A study in Southern Michigan to understand the nature of drivers involved in DVCs found that they were more likely to be males, drive more often, knowledgeable about DVCs, and likely to want a decrease in the deer population (Marcoux & Riley, 2010). These drivers perceived DVC as a serious issue and were willing to make a modest change in their behavior by slowing their vehicle in response to a deer-crossing sign, however, they were not willing to take special driver's education courses or eliminate driving at peak hours (Marcoux & Riley, 2010). In 2020, nearly 60% of U.S. drivers involved in DVCs were male (State Highway Patrol, 2020). However, in the study by Ahmed et al., (2021), female drivers were more likely to hit a deer. According to Marcoux and Riley (2010), drivers believed that DVCs were random events, resulting in a laissez-faire attitude toward this type of collision. Although drivers cannot prevent animals from crossing the road, they can exercise caution before such encounters occur (MODOT, n.d.). Strategies to influence driver behavior can be categorized as improving the visibility of drivers, increasing awareness of deer and the possibility of DVCs, and reducing driving speeds to increase the reaction time (Hedlund et al., 2004).

Improving driver visibility reduces DVCs (Waring et al., 1991). For example, woodlands and gullies adjacent to the road obstruct the visibility of motorists (Donaldson, 2006; Finder et al., 1999). Reduction of forest cover and shrubby areas on land near roadsides will enhance visibility for drivers (Nielsen et al., 2003). Most collisions occur during low-light conditions, so frontal vehicle illumination is important (DeVault et al., 2020). The use of high-beam headlamps and minimizing roadside reflectors, signs, and other bright objects that distract motorists can reduce the frequency of DVCs, especially at dawn and dusk (Mastro et al., 2010). Road lighting improves driver vision but can be expensive in many situations (Hedlund et al., 2004).

Driver awareness programs or driving schools can offer some practical information for preventing deer collisions (Steiner et al., 2014). Drivers can change their behavior when informed of the risks of DVCs under various landscape characteristics, thus increasing awareness

(Sudharsan et al., 2009). Informing motorists that DVCs are not random events can enable drivers to recognize several factors associated with DVCs which may help them identify areas of greatest risk, resulting in safer driving behavior (Marcoux & Riley, 2010). For example, drivers should be told to hold their course when facing a deer on the highway, rather than swerving at high speeds to avoid striking it (State Farm Insurance, 2020).

Public awareness campaigns and news stories during the peak DVC seasons can be beneficial (Hedlund et al., 2004). Campaigns to inform drivers of costly repairs and medical bills resulting from DVCs might be effective (Marcoux & Riley, 2010). However, adherence to laws and their enforcement is one of the best modification strategies (Williams, 1994). Another idea is to focus on hunter activity before or around peak DVC times and months during the hunting season (Steiner et al., 2014). This topic is addressed in hunter education classes (MDC, n.d.). Furthermore, information on seasonal collision data enables roadway workers to place proper signage for improving the visual awareness of drivers (MDC, n.d.).

DVCs are more common on the outskirts of cities, where deer are numerous and speed limits are high (Ng et al., 2008). Lowering speed limits during peak seasons can reduce DVC rates and improve road safety (Meisingset et al., 2014; Shilling & Waetjen, 2015; Waring et al., 1991), particularly in areas with high deer density (i.e., interchanges) and non-forested vegetation near roads (Ng et al., 2008). Reduced speed limits may be effective in areas with high amounts of non-forested green space and low road density (Ng et al., 2008). Speeding is a significant contributor to collisions on roadways (MODOT, n.d.); slower drivers are more likely to see a deer and avoid it (Ng et al., 2008). Ineffective responses will increase with the speed limit, going up significantly when it is greater than 50 mph (Lao et al., 2011). For this reason, vehicles are more likely to collide with deer on roads with speed limits above 55 mph (Ahmed et al., 2021). However, lower speed limits do not always imply lower travel speeds (Transportation Research

Board, 1998). Unless speed limits are enforced, they are unlikely to have a significant, if any, impact on travel speeds (Hedlund et al., 2004).

In addition to posting advisory speed limits, drivers can reduce their risk of DVCs by remaining alert for deer intrusions on the roadways during the most critical times of the day (Haikonen & Summala, 2001). Spatial-temporal warning systems on maps can be a cheap mitigation strategy to lower the risk of DVCs as compared to classic warning systems (Hothorn et al., 2015; Mayer et al., 2021). They can warn drivers about DVC risk and also prevent habituation because the warnings are based on landscape conditions, traffic, and speed (Nelli et al., 2018). Animal-detection driver warning systems do not reduce the barrier effect of highways and traffic (Huijser, et al., 2015), however, they are likely to reduce driver speed and increase awareness (Donaldson, 2006). Further study on the effectiveness of warning systems is needed (Huijser, 2007).

Road signs are the cheapest and most commonly used deterrents (Bond & Jones, 2013) which can be located anywhere without terrain obstructions (Found & Boyce, 2011). They must be reliable if they are used with other mitigation measures (Huijser, et al., 2015). Signs can be categorized into five groups: 1) caution; 2) enhanced caution; 3) temporary; 4) dynamic messages; and 5) animal-activated warning systems (Mastro et al., 2008).

Caution signs are frequently used. They are standard signs that feature a black deer in the center on a yellow background, posted in areas where road crossings are common (Department of Motor Vehicles, 2019). The sign conveys a message to slow down and be alert, watch for deer and other animals crossing the road, be particularly cautious during twilight and nighttime hours, and be ready to stop (Department of Motor Vehicles, 2019). However, these signs are not effective in reducing the impacts of DVCs and increasing motorist safety (Huijser et al., 2009).

Enhanced caution signs are designed to increase driver attention, i.e., words or deer silhouettes illuminated with neon tubing (Mastro et al., 2008). The effectiveness of these signs is unknown which suggests a minimal or non-existent change in driver behavior (Bond & Jones, 2013). Permanent caution signs have standard messages and are positioned at fixed locations during every season (Hedlund et al., 2004). Driver's memory and recall of warning signs are poor (Fisher, 1992). If signage is present throughout the year, habituation is likely to occur, suggesting that the messages are not retained (Gordon et al., 2004).

Temporary signs placed in high-risk areas during peak times i.e., seasonal migration periods (Sullivan et al., 2004), provide the most effective means of altering motorist behavior, thus reducing DVCs (Hindelang et al. 1999). Warning signs that are place and time specific are more effective in reducing collisions (Huijser et al., 2015). Temporary active message signs were found to have a more significant impact on average speed than messages on permanent signs (traditional / passive) (Hardy et al., 2006). This strategy is more efficient than stationary warning signs because it is more realistic and flexible for advertising certain risk times and areas i.e., it would only warn drivers when there is a high potential of DVCs (Mayer et al., 2021). The risk of DVCs shows a considerable temporal variation (Meisingset et al., 2014), therefore the timing of placement is critical (Hedlund et al., 2004). Temporary road signs for times of high collision risk (for example, dawn and dusk, from October to December) can result in less driver habituation (Laliberté & St-Laurent, 2020). There is a wide range in the effectiveness of temporal warning signs (Huijser, et al., 2015). However, there have not been enough studies to confirm the effectiveness of temporary signs for increasing driver awareness, reducing driver speed, and reducing DVCs, although they could be effective in some situations (Hedlund et al., 2004).

Dynamic message signs are either permanent or portable electronic panels with a black background and amber lettering (Mastro et al., 2008). In the study by Bond and Jones (2013), drivers were more likely to respond to a warning sign that displayed the most recent number of animals killed on the road during a specific period. Such data provide direct evidence that wildlife-vehicle collisions occur on a regular basis in that area, particularly where the bodies of road-killed animals are removed. Portable dynamic signs yielded greater speed reduction than permanent ones (Hardy et al. 2006).

Animal-activated warning systems flash warning signs to alert drivers when wildlife is detected on the roadside (Litvaitis & Tash, 2008; Mastro et al., 2008). These temporary active signs only become lighted when deer are detected near the roadside (Hedlund et al., 2004). Bond and Jones (2013) found that warning signs with designs that include animal-activated and vehicle-speed-activated warnings were desirable among drivers. They are intended to reduce the rate and severity of collisions, without creating a barrier effect on roads and traffic (Huijser, et al., 2015).

A 50% reduction in DVCs was observed when temporary warning signs with reflective flags and solar-powered flashing amber lights, were erected near corridors used by deer during seasonal migration (Sullivan et al., 2004). A 70% reduction in DVCs was noted in a pilot study in Utah using temporary flashing signs during seasonal migrations (Messmer et al., 1999). Temporary blinking signs during critical periods were also useful (Laliberté & St-Laurent, 2020). While both temporary passive and active signs have potential in certain situations, more research is required to assess long-term driver response patterns and enhance deer detection technology for active signs (Hedlund et al., 2004).

Road signs are most effective if drivers reduce their speed (Romin & Bissonette, 1996). Although reducing the speed limit may be undesirable among drivers, it might work for short times or at high-risk sites (Hedlund et al., 2004). Deer warning signs combined with speed limit reductions can be useful in certain areas with high deer populations or migration routes

(Hedlund et al., 2004; Mayer et al., 2021). Additionally, knowledge of high-risk periods can reduce DVCs by informing drivers through road-crossing signs, along with variable speed limits (Haikonen & Summala, 2001).

Despite a common misconception that standard deer-crossing signs may be ineffective, signage targeting hotspots significantly reduced DVCs (Found & Boyce, 2011). Rather than frequent signage, placing them at hotspots can be more strategic (Bond & Jones, 2013). Warning signs at collision hotspots can increase driver awareness over a short distance (Collinson et al., 2019). Biologists can identify the beginning and end of migration periods to guide the placement and activation of signs (Sullivan et al., 2004). The use of temporary deer-crossing signs within dense forest habitats with varying topography in the vicinity of pastures can be effective (Meisingset et al., 2014). DVCs declined significantly at hotspots with warning signs, compared to those without any signs (Found & Boyce, 2011). Wrongly placed road signs are commonplace (70% of the time), however, vehicle collisions decreased by 50% after adding additional signs at hotspots when combined with a public awareness campaign (Rea, 2012). Identifying collision hotspots is significant for reducing deer-vehicle collisions (Litvaitis & Tash, 2008).

In sum, instead of waiting until multiple accidents occur at a location before designating it as a DVC hotspot, corridors along roadways should be proactively analyzed to determine ideal collision sites (Finder et al., 1999). Corridors reveal frequent patterns of animal movement as the risk of collision increases when roadways intersect with corridors (Donaldson, 2006). In general, collision hotspots are road segments that cross natural and / or cultural corridors, frequently used by deer (Sullivan et al., 2004). The association of DVCs to corridors can be helpful for transportation officials to help them locate appropriate sites for installing temporary flashing signs and speed limit reductions during the months when deer are most active, thus preventing collisions (Finder et al., 1999). The goal of this study is to describe the role of corridors using landscape attributes to identify locations that have the highest DVC potential and to mitigate this occurrence along Missouri interstates.

METHODS

Study Area

Missouri is the 28th most densely populated state in the nation (87.1 people per square mile), despite being ranked 18th in population (6.14 million people) and 21st in land area (69,704 square miles) (World Population Review, 2022). The statewide population has increased by 47 percent (4.2 million to 6.1 million) since 1956, the year when funds for the Interstate system were approved (TRIP, 2021). Missouri has 4.3 million licensed drivers and 5.5 million registered vehicles as of 2022 (MODOT, 2022). According to the Road Information Program, the number of vehicles in Missouri has increased nearly four times, from about 1.5 million in 1956 to 5.5 million in 2021.

Kansas City and St. Louis are the two largest cities in Missouri. Kansas City is the largest metropolitan area in the state with 5,08,415 residents as of 2022 (U.S. Census Bureau, 2022). It spans over 319 miles and has a population density of 1,644 people per square mile. It is the 35th largest city in the United States (World Population Review, 2022). The potential driver population of Kansas City is about 366,059 (U.S. Census Bureau, 2022). St. Louis is the second largest city in Missouri and 72nd in the United States. It spans over 66 miles and has a population density of 4,827 people per square mile (World Population Review, 2022). St. Louis has a total population of 293,310 and 222,916 potential drivers (U.S. Census Bureau, 2022).

The seventh-largest state highway system in the country, with 33,890 miles of highways and more than 10,000 bridges, is maintained by the Missouri Department of Transportation (MODOT) (MODOT, n.d.). The agency ranks 5th nationally in interstate coverage (MODOT, n.d.,).

After President Eisenhower signed the Federal-Aid Highway Act of 1956 on June 29, 1956, Missouri was the first state to receive an interstate construction contract (TRIP, 2006). Sections of I-70 in Missouri and Kansas was the first interstate in the U.S. Only 2% of Missouri's roads are interstates, but they account for 26% of all automobile travel in the state (TRIP, 2021). The increased number of vehicles has surpassed the carrying capacity of Missouri interstate highways, thus resulting in traffic congestion (TRIP, 2021). For example, almost 50% of Missouri urban interstates are congested (TRIP, 2021).

The primary Missouri interstates are: I-66, I-44, I-70, I-55, I-49, I-29, I-35, I-64, I-57, and I-72, followed by the secondary ones: I-435, I-270, I-244, I-470, I-144, I-229, I-170, I-155, I-755, I-255, I-635, and I-670. I-44 is the longest interstate which covers 293.18 miles, followed by I-70 with 250.06 miles, and I-55 with 210.45 miles. I-670 is the shortest interstate, only 2.32 miles.

Table 1

List of Interstate Highways, their distance, and relative percentage

Interstate	Distance (miles)	Relative Percent
Primary Interstates		
I-44	293.18	20.42
I-70	250.06	17.42
I-55	210.45	14.66
I-49	178.72	12.45
I-29	128.58	8.96
I-35	114.45	7.97
I-64	40.82	2.84
I-57	22.06	1.54
I-72	2.06	0.14
Auxiliary Interstates		

I-435	55.18	3.84
I-270	35.50	2.47
I-244	21.05	1.47
I-470	17.08	1.19
I-144	15.4	1.07
I-229	15.02	1.05
I-170	11.26	0.78
I-155	10.83	0.75
I-755	4	0.28
I-255	3.98	0.28
I-635	3.77	0.26
I-670	2.32	0.16
Total	1435.77	100%

Source: Missouri Department of Transportation (2012)

Missouri's Interstate Highway System saves time and lives, in addition to playing a significant role in economic development (TRIP, 2021). Missouri's Interstate highways are the most important connection in the state's economy and offer greater traffic safety than other roads (TRIP, 2006). Separation from neighboring roads, rail lines, a minimum of four lanes, gentler curves, paved shoulders, median barriers, and rumble strips to alert drivers if they veer off the road are all features that make interstates safe (TRIP, 2006). According to an estimate based on the number of additional fatalities that may have occurred if that traffic had been carried by non-interstate routes, the interstates in Missouri prevented 137 deaths in 2019 (TRIP, 2021).

Unfortunately, interstates are also the locations where most auto and truck accidents occur (MODOT, n.d.). The fatality rate per 100 million vehicle miles traveled on Missouri's Interstate system in 2019 was 0.69 (TRIP, 2021). Interstate 70 is ranked in the top 10 deadliest interstates nationwide with 134 deaths in 2020 (National Highway Traffic Safety Administration

(NHTSA), 2020). Interstate 270 has sections with the most fatal crashes in Missouri (NHTSA, 2020). Based on the data from the years 2004 - 2008, I-64, I-70, I-44, and I-55 were the deadliest interstate highways in Missouri (U.S. DoT, 2008).

Source of data

The Statewide Traffic Accident Records System (STARS) was established using funds from the National Highway Traffic Safety Administration to provide timely and accurate crash data to federal, state, and local users for supporting operational and managerial functions of traffic safety. The Missouri State Highway Patrol uses the STARS traffic crash reporting system. The dataset contains information collected by highway patrol officers after the investigation of an accident resulting in personal injury or death or property damage that exceeds five hundred dollars. The data was in 3 comma-delimited files, each with a different record level: crash level, vehicle level, and individual level. Not all the collisions represent unique locations since some of the sites were repeated and some intersections experienced > 1 crash. Each report contains valuable information such as coordinates of crash type, accident site, roadways, direction, date of the accident, and so forth.

Content of data

The datasets included roadway, environment, and weather-specific information, spatial and temporal characteristics, as well as animal, vehicle, and driver-specific characteristics. The roadway-specific information consists of classification (interstate, state highway, local), highway number, road alignment (straight or curved), speed limit, traffic way type, route direction, intersection type and direction, number of lanes, road profile (uphill, downhill or level), and road surface (concrete, asphalt, brick, gravel, sand or multi-surface). Environment and weather-specific information consisted of roadway surface conditions (dry, wet, snow, ice, standing water or moving water), light conditions (daylight, dark-lighted, dark-unlighted, or dark-unknown lighting), and weather conditions (clear, cloudy, rain, snow, sleet, freezing, fog, and crosswind).

Spatial-temporal characteristics include information on the month, day of the week, and time of day of the incident, county, municipality, district, street, where the incident occurred, and rural or urban zone characteristics. The dataset also included information on animal collisions (deer, farm animals, dogs, or others). Vehicle-specific information included the number of vehicles involved in the crash, the state that issued the vehicle license, license year, type, make, model, model year, color, usage type, and insurance. Driver-specific information consisted of the age and gender of the driver, driver's license state and class, injury level, state of alcohol use, and potential distraction. The crash-specific characteristics included information on restraint use, airbag deployment, and vehicle overturning.

Deer-vehicle collision data for 2020 was obtained free of charge from the MSHP. The agency also sent collision data from 2010-2019 which included DVCs. This data was used to calculate the total number of DVCs for each year to determine if COVID-19 had an impact on the number of collisions in 2020.

Protocol

Spatial analysis was used to examine each DVC site on Missouri interstates in 2020. Spatial analysis is a useful tool for guiding present and future research in DVCs (Miller, 2004). The longitude and latitude coordinates for the collision sites were uploaded into Google Maps and observed on a 200-foot scale (aerial view). Two coders were involved in the analysis.

The nearest corridor to the DVC site was selected using a 3-part designation: natural, cultural, or a combination of both. Natural corridors consisted of dry creeks, flowing water, standing water, and vegetation. Dry creek beds were gullies or trenches that crossed underneath the interstates. Flowing water was recorded as creeks, streams, or rivers, usually surrounded by vegetation. Standing water was nearby ponds or lakes on either side of the road, often connected to the interstates via secondary roads or vegetation. Vegetation was tree lines or forest patches.

Cultural corridors were overpasses, public utilities, fencerows, or secondary roads. Overpasses were structures that crossed over interstates, different than bridges. Public utilities were powerlines that crossed overhead. Fencerows were narrow, linear strips of overgrown vegetation that sub-divided croplands, usually indicating property boundaries. Secondary roads were parallel or perpendicular to interstates, but not leading to them (entrance or exit ramps). Combination corridors consisted of natural and cultural features, often including vegetation.

Corridors were recorded as closed or open. Closed meant low light penetration, often containing dense vegetation (i.e., dense fencerows or forest patches). Open corridors (high visibility) included public utility lines and some examples of flowing water. If the corridor was present on both sides of the interstate, it was considered full. If only on one side, it was noted as half. DVC sites were recorded as occurring on the corridor side of the interstate or the opposite side. The frequency and percentages of each corridor were measured to identify the most common type. Distance from the collision site to the nearest corridor was measured using an imaginary line that was drawn across the road. The satellite view on a 1:240 scale was used to determine the presence of a corridor and to measure the distance.

Street-side images were viewed to determine the possible influence of land use characteristics and topographic features (i.e., cover type, median width, presence of guard rails, slopes, and so forth), adjacent to each collision site. Shrubs, trees, grass, or combination cover type was recorded on each side of the road and in the median. Medians, also known as highway dividers, are longitudinal safety devices separating opposing lanes of traffic for redirecting vehicles that strike either side of the barrier (America Association of State Highway and Transportation Officials (AASHTO), 2006). Medians were also recorded based on their width - standard, wide, and none. Most of the standard-width medians contained grass only, however, the wider medians had more vegetation, such as trees between the lanes of traffic. Medians with no width were simply concrete barriers. These were common in urban areas whereas metal beam and cable barriers were common in rural areas (AASHTO, 2006).

Guardrails were traffic barriers designed to keep vehicles on the roadway, preventing them from colliding with obstacles such as trees, bridges, buildings, and so forth. Guardrails were observed on both sides of the road and sometimes in the median. Other landscape variables associated with DVCs were road profile (i.e., flat/level, slope, or rock-cut). Flat/level roads were even surfaces without projections or depressions. Slope, in this study, referred to areas that had an incline (uphill) or decline (downhill) from the roadbed, consistent with local topography. Rock cuts were exposed profiles through hilly terrain.

Data analysis

Information for each crash site was recorded in MS excel and later uploaded into Statistical Package for the Social Sciences (SPSS). A descriptive analysis of each variable was performed and shown in tables and figures. Geographic Information System (GIS) was used to create a map for viewing the distribution of collision sites, thus identifying hotspot areas.

RESULTS

Deer-Vehicle Collision

According to the Missouri State Highway Patrol, a total of 3,639 DVCs was recorded on Missouri roads in 2020. Of that number, 490 crashes occurred on nearly 1,500 miles of Missouri interstates, including those in urban and rural areas (I-29, I-35, I-44, I-49, I-55, I-57, I-64, I-70, I-

155, I-170, I-255, I-270, I-435, and I-470). The total number and percent of collisions were calculated (see Table 2), in addition to collisions per mile for each interstate.

Table 2

Number and percentage of collision and collision per mile in Missouri interstates

Interstate	No. of Collisions	% of collision	Collision per mile	Rank
I-44	96	19.60	.3274	11
I-70	82	16.73	.3279	10
I-55	72	14.70	.3421	7
I-29	64	13.06	.4977	5
I-49	60	12.24	.3357	8
I-35	36	7.35	.3145	12
I-435	22	4.49	.3986	6
I-270	19	3.88	.5352	3
I-470	12	2.45	.7025	2
I-64	11	2.24	.2695	13
I-229	5	1.02	.3329	9
I-57	4	0.82	.1813	14
I-635	3	0.61	.7958	1
I-255	2	0.41	.5025	4
I-155	1	0.20	.0923	15
US-50	1	0.20		*
Total	490	100%		

*(*Note: Highway 50 is a US federal highway that was misidentified as interstate in the original data.)*

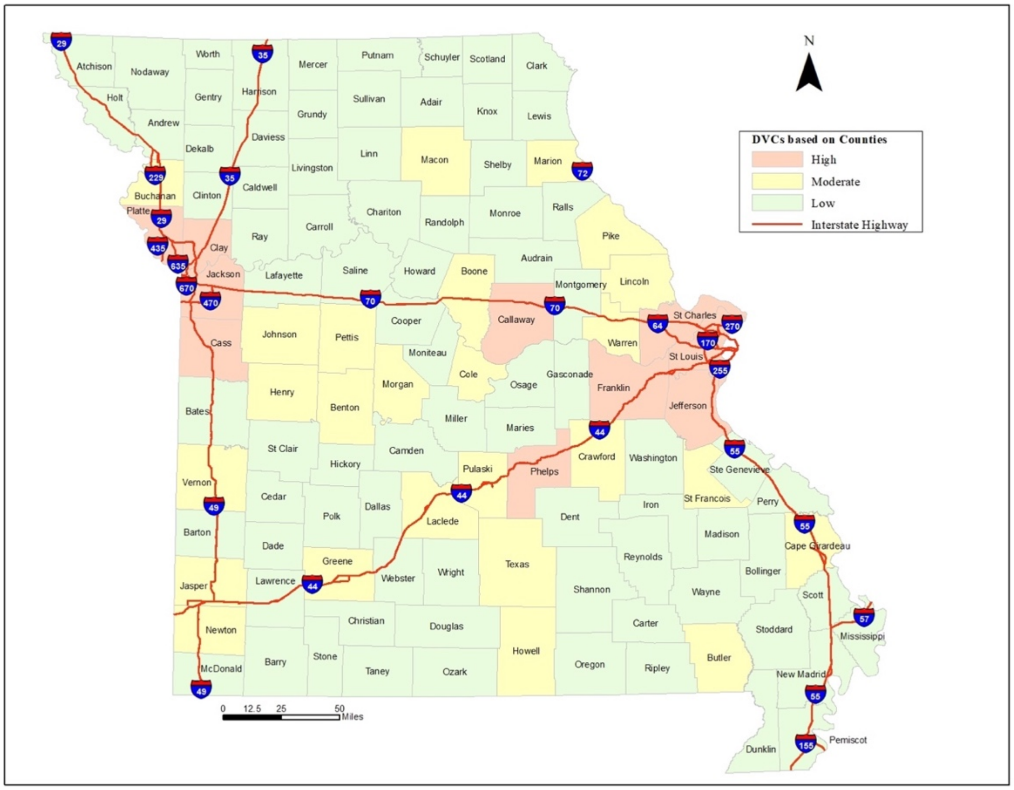
The highest number of collisions statewide occurred on I-44 (19.60%, *n* = 96), followed by I-70 (16.73%, *n*= 82), I-55 (14.70%, *n* = 72), I-29 (13.06%, *n* = 64), and I-49 (12.24%, *n* = 60). Yet, I-635 had the highest rate of collisions per mile (0.80), followed by I-470 (0.70), I-270 (0.54), I-255 (0.50), and I-29 (0.50). Deer collisions per mile were highest for interstates in or near St. Louis and Kansas City than those in rural areas, clearly showing the impact among urban drivers.

Actual DVC sites

Of the statewide DVCs in 2020, only about 30% (29.8%) occurred in metropolitan areas (MSHP, 2020). Although urban DVCs are under-represented in the total, the top ten counties in Missouri were: St. Louis (6.13%), Jefferson (5.30%), Jackson (3.30%), Platte (2.64%), Clay (2.58%), Callaway (2.45%), Phelps (2.42%), St. Charles (2.34%), Franklin (2.23%), and Cass (2.03%) (MSHP, 2020). Each of these, except for Callaway and Phelps, is in or adjacent to a major metropolitan area (MSHP, 2020). According to this data, St. Louis had 16% of the DVCs, statewide, whereas Kansas City had almost 11% (10.55%).

Figure 2

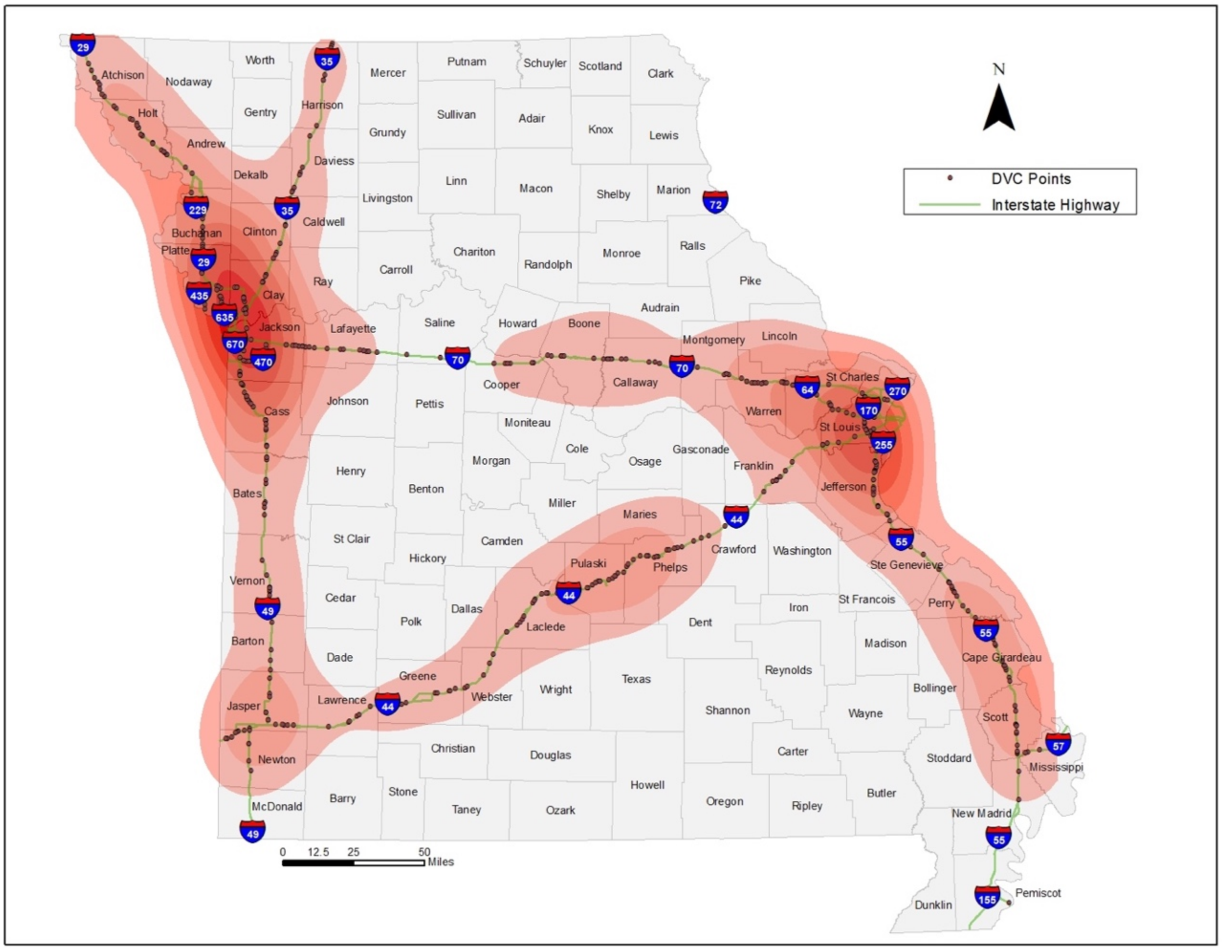
Counties of Missouri representing DVCs concentration



Collision sites were uploaded into ArcGIS for conducting a statewide hotspot analysis. This procedure identified portions of interstates in Missouri having the highest and lowest concentrations of DVCs in 2020. As before, most of the collisions occurred in St. Louis and Kansas City, showing the prevalence of deer and drivers in urban areas. Both of these metropolitan locations revealed a concentric pattern of DVCs, from downtown (city center), extending for about 60-65 miles, fully covering the suburbs. The map also showed areas of less concern, at least on the interstates. These included rural areas, such as portions of Mid-Missouri and the Bootheel.

Figure 3

Hotspot map of DVCs in Missouri



Landscape Features and Attributes

Aside from the urban-to-rural gradient, DVCs can be influenced by the surrounding landscape and road conditions. Landscape attributes and highway features around DVCs such as the type of cover, the slope of the road, the presence of a median, the median width, and the presence of guard rails were examined to determine if these characteristics increased or decreased the risk of DVCs.

Table 3

Frequency and percent of landscape features and road attributes at DVC sites

Features & Attributes		N (%)
Same side cover	No Vegetation	6 (0.8)
	Grass	252 (31.5)
	Shrubs	184 (23)
	Trees	357 (44.7)
Opposite side cover	No Vegetation	6 (0.8)
	Grass	238 (30)
	Shrubs	189 (23.8)
	Trees	361 (45.5)
Median cover	No Vegetation	65 (14.2)
	Grass	372 (81.4)
	Shrubs	6 (1.3)
	Trees	14 (3.1)
Median width	Standard	349 (77.7)
	Wide	40 (8.9)
	None	60 (13.4)
Presence of Guard Rail	Median	317 (91.4)
	Same side	128 (36.9)
	Opposite Side	129 (37.2)
Same side slope	Flat/Level	193 (43)
	Decline from roadbed	58 (12.9)
	Incline from roadbed	177 (39.4)
	Rock Cut	21 (4.7)
Opposite side slope	Flat/Level	206 (45.9)
	Decline from roadbed	60 (13.4)
	Incline from roadbed	160 (35.6)
	Rock Cut	23 (5.1)

Cover adjacent to collision sites mostly consisted of trees (44.7%), followed by grass (31.5%), shrubs (23%), and no vegetation (0.8%). On the opposite side of the road from the collision, trees (45.5%) were dominant, followed by grass (30%), shrubs (23.8%), and no vegetation (0.8%). Most of the medians were grassy (81.4%), whereas 14.2% of the sites had little to no vegetation in the median. Most of the medians were standard-sized (77.7%), but some of the collision sites (13.4%) had no median width (concrete barriers), while others were wide (8.9%), containing trees (3.1%) and/or shrubs (1.3%). Nearly 100% (91.4%) of the medians had guard rails. About 37% of the sites (36.9%) had guard rails on the collision side and 37.2% had them on the opposite side of the road. The majority of slopes (43%) on the same side of the collision were flat, followed by inclining slopes (39.4%), and declining slopes (13%). On the opposite side of the collision, the majority of slopes were flat (46%), followed by an inclining slope (35.6%), and lastly a declining slope (13.4%). Few roads had rock cuts on both sides (5%). Among the landscape variables, corridors were examined to see if a prominent factor emerged.

Table 4

Frequency and percentages of corridor variables at DVCs sites

Characteristics	Variables	N (%)
Type	Natural	212 (47.2)
	Cultural	139 (31.0)
	Combination	98 (21.8)
Natural	Dry Creek	11 (2.5)
	Flowing Water	46 (10.3)
	Standing Water	96 (21.5)
	Vegetation	293 (65.7)
Cultural	Overpass	48 (19)
	Public Utilities	56 (22.2)

	Fencerow	57 (22.6)
	Secondary Road	91 (36.1)
Visibility	Open	214 (47.7)
	Closed	235 (52.3)
Location	Both sides	275 (61.2)
	Collision side only	103 (22.9)
	Opposite side only	71 (15.8)

Of the 490 DVC sites examined, 91.6% (*n* = 449) of them occurred near corridors. Natural corridors were observed most frequently (47.2%, *n* = 212), and cultural ones were next (31%, *n* = 139), followed by a combination of natural and cultural (21.8%, *n* = 98). Natural corridors consisted mostly of vegetation (65.7%, *n* = 293), standing water (21.5%, *n* = 96), flowing water (10.3%, *n* = 46), and dry creek beds (2.5%, *n* = 11). Cultural corridors consisted of secondary roads (36.1%, *n* = 91), fencerows (36.1%, *n* = 57), public utilities (22.2%, *n* = 56), and overpasses (19%, *n* = 48). Corridors were either open (47.7%, *n* = 214) or closed (52.3%, *n* = 235). They were on both sides of the interstate (61.2%, *n* = 275), on the collision side (22.9%, *n* = 103), or on the opposite side (15.8%, *n* = 71).

Most of the natural corridors were closed (mostly dark), consisting of dense vegetation, whereas cultural corridors were open (highly visible). Table 4 provides more detail about the corridor arrangement. The most common pattern was closed / natural corridors (39.42%, *n* = 177), followed by open/cultural corridors (27.84%, *n* = 125), and lastly an open / combination corridor (12.03%, *n* = 54). Closed cultural corridors (3.12%, *n* = 14) and open natural corridors (7.80%, *n* = 35) were infrequent.

Table 5

Frequency and percentages of open and closed corridors that are natural, cultural, and combination

Type of Corridors	Natural	Cultural	Combination	Total
Open	35 (7.80%)	125 (27.84%)	54 (12.03%)	214 (47.66%)
Closed	177 (39.42%)	14 (3.12%)	44 (9.80%)	235 (52.34%)
Total	212 (47.22%)	139 (30.96%)	98 (21.83%)	449 (100%)

Corridor - Collision Distance

Distance from the DVC site to the nearest corridor is shown in Table 5. If more than one corridor was present at the collision site, the nearest one was selected. Corridor distance was recorded and an average was calculated for each DVC site. The average distance was (M = 107, SD = 95.13) (~ 350 feet).

Table 6

The average distance of corridors from the deer-vehicle collision location

	N	Minimum	Maximum	Mean Distance (M)	Std. Deviation
Distance	449	2.61	601.31	107.02	95.13

Distances from collision sites to the nearest natural, cultural, and combination corridors were also calculated (Table 6). Combination corridors were nearest to the collision sites (M = 95.3 meters, SD = 79.93), followed by cultural corridors (M = 97.29 meters, SD = 86.90), and natural corridors (M = 118.8 meters, SD = 105.22).

Table 7

Distance of corridors from the collision sites

Corridors	N	Mean Distance (M)	Std. Deviation
Natural	212	118.80	105.22
Cultural	139	97.29	86.90
Combination	98	95.33	79.93

The average distance was also calculated for each specific corridor type (Table 7). Collisions with deer were nearby overpasses (M = 82.49, SD = 77.9), followed by secondary roads (M = 88.88, SD = 77.9), and standing water (M = 96.1, SD = 85.2). Corridors that were farthest away from collision sites were dry creeks (M = 181.73, SD = 139.9), flowing water (M =119.70, SD = 106.1), and vegetation (M =108.59, SD = 97.0).

Table 8

Distance of each corridor type from the collision sites

		N	Mean Distance (M)	Std. Deviation
Natural	Dry Creek	11	181.73	139.9
	Flowing Water	46	119.70	106.1
	Standing Water	96	96.10	85.2
	Vegetation	293	108.59	97.0
Cultural	Overpass	48	82.49	77.9
	Public Utilities	56	102.53	86.6
	Fencerow	57	106.07	92.5
	Secondary Roads	91	88.88	77.9

Corridor Features

<u>Natural Corridors</u>

Figure 4

Riparian corridor in I-44 (Lat: 37.76042, Long: -92.51872)

Figure 5

Vegetation corridor on both sides of I-55 (Lat: 37.00077, Long: -89.53507)

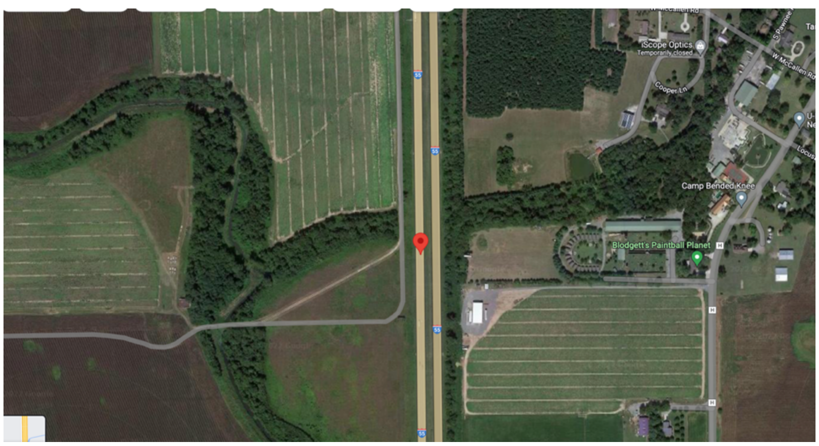
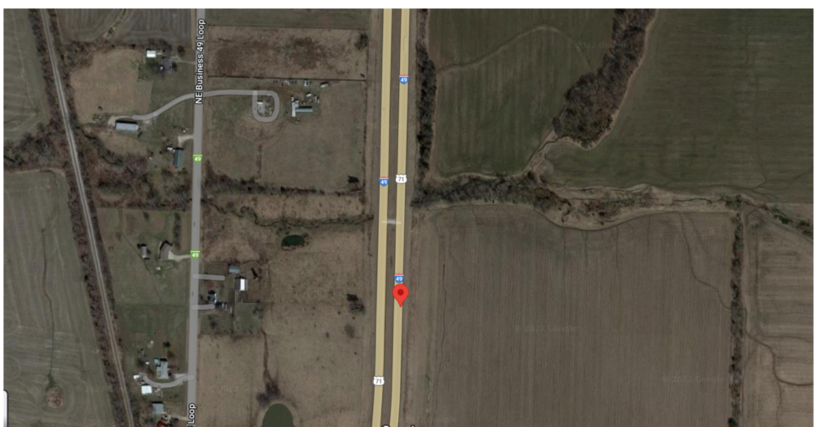


Figure 6

Strip vegetation corridor on the collision side of I-35 (Lat: 39.80311, Long: -94.19901)

Figure 7

Dry creek on I-49 (Lat: 38.31333, Long: -94.34356)



<u>Cultural Corridors</u>

Figure 8

Secondary road on I-270 (Lat: 38.93812, Long: -94.48777)

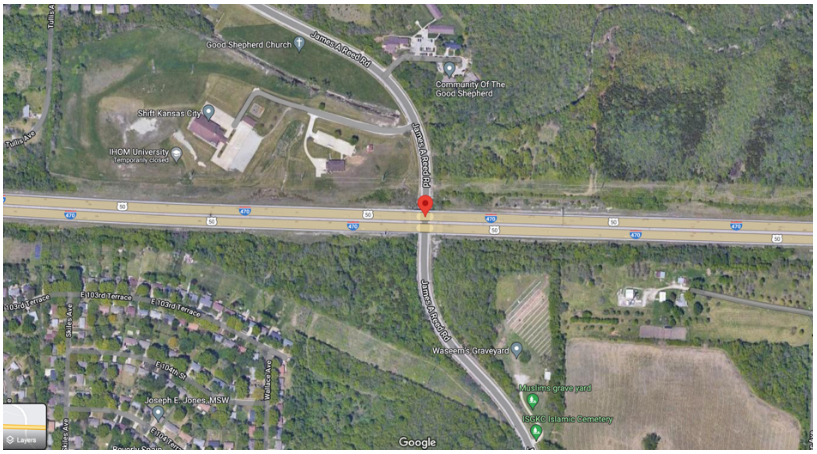


Figure 9

Powerlines on I-44 (Lat: 37.00582, Long: -94.56955)

Figure 10

Overpass with a creek nearby on I-29 (Lat: 39.51597, Long: -94.78692)

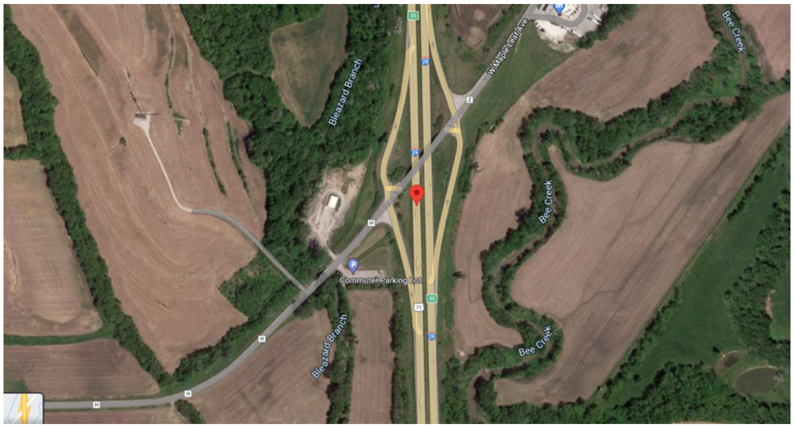


Figure 11

Fence row on the collision side of I-55 (Lat: 37.48663, Long: -89.66755)

<u>Combination corridor</u>

Figure 12

Water creek, vegetation, and secondary road corridor on I-55. Shows the funneling effect of roads/cars. (Lat: 38.34752, Long: -90.39597)

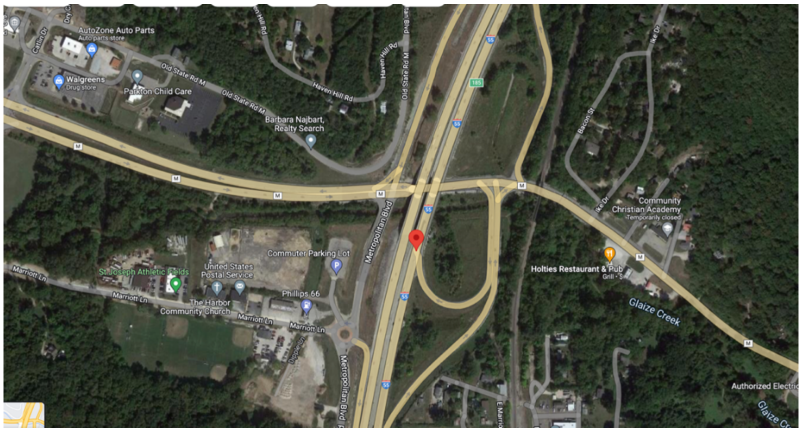


Figure 13

Heavily traveled roads in an urban area with no vegetation on I-270. (Lat: 38.60362, Long: -90.45078)

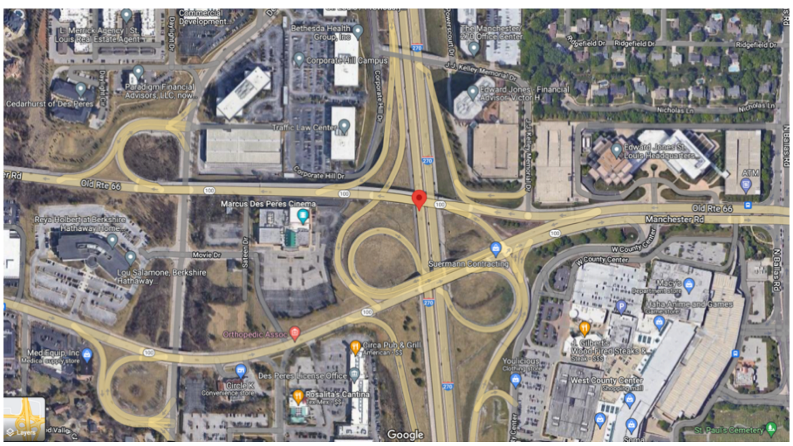


Figure 14

Wide median with vegetation on I-44. (Lat: 38.31495, Long: -91.0537)

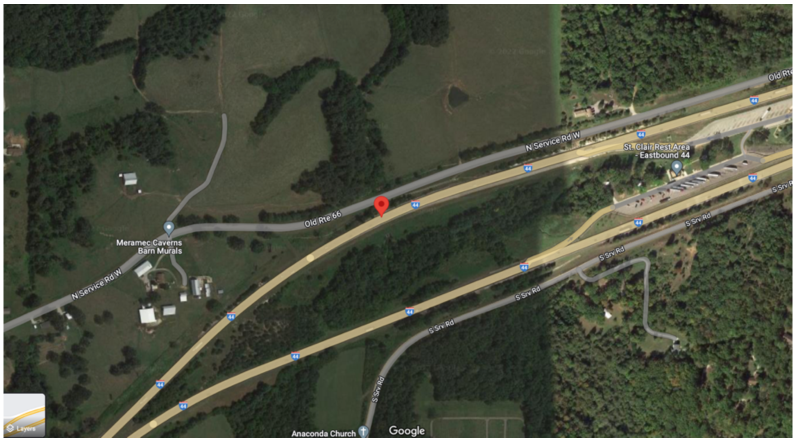


Figure 15

Rock Cut on the same side of collision in I-55. (Lat: 38.2636, Long: -90.40272)

DISCUSSION

In 2020, there were 3,639 DVCs statewide, yet the average number of reported crashes over the previous decade (2010-2019) was 3,818. A decline of 158 DVCs from the 10-year average was likely due to fewer drivers during the pandemic. A study conducted in Spain also reported a decrease in wildlife-vehicle collisions due to the COVID-19 lockdown, likely due to traffic reduction (García-Martínez-de-Albéniz, 2022). Basak et al. (2022) found that in Poland, due to the pandemic, WVCs decreased in suburban areas, but not in the urban areas despite a significant reduction in traffic volume. However, according to State Farm Insurance (2022), approximately 2.1 million animals were killed due to vehicle collisions on U.S. roadways between July 2020 and June 2021, an increase of 7.2% compared to the previous year. Similarly, Abraham and Mumma (2021) found that although the number of WVCs in the U.S. declined at the start of the pandemic, it increased as the pandemic progressed, ultimately exceeding the previous year's collision number, suggesting that road usage can offset the effect of reduced traffic volume. DVCs are increasing in Missouri, not getting better. In 2022, Missouri was ranked as the 14th most likely state to incur a DVC, up from the 15th position in 2021 (State Farm Insurance, 2021).

Results from this study are consistent with the findings of others, mainly that DVCs are non-random phenomena that are dependent on spatial factors (Finder, 1999; Gonser et al., 2009; Sudharsan et al., 2009;). By using ArcGIS, a hotspot map was created to identify the concentration of DVCs along Missouri interstates. Collisions were most prevalent in urban areas. St. Louis had a greater number of DVCs than Kansas City, despite having a smaller population. This may be due to the density of drivers (about 4 times greater in St. Louis than in Kansas City). Other studies have shown that DVCs are common in urban areas (Finder et al., 1999; Found & Boyce, 2011; Ng et al., 2008; Nielsen et al., 2003). In their study of animal-vehicle collisions in Alabama, Chen and Wu et al., (2014) found that counties in metropolitan areas had a high number of deer collisions. In contrast, the findings by Ahmed et al. (2021) and Lao et al. (2011) showed that DVCs were more likely to occur in rural locations. However, the patterns of DVCs are far more complex than simply classifying them along an urban-rural gradient. Most studies on urban DVCs had landscape features as the most significant factors contributing to increased risks.

Our study suggests that landscape conditions influence DVCs. This confirms the findings of Clevenger et al. (2015) who thought that large and local-scales landscape factors contribute to DVCs occurrence. Malo et al. (2004) used logistic regression to examine the relationship between collision frequency and landscape features. In the present study, road segments with high DVC rates were associated with patterns such as high forest cover, low crop cover, few buildings, and greater habitat diversity. We analyzed landscape conditions such as adjacent cover, road slope, median width, and guard rails near the DVCs site, using satellite and aerial images. The most ideal condition for DVCs in our study was forest cover on both sides of the interstate, sometimes with flowing water. High forest cover along the roadsides has been linked to increased DVCs (Finder et al., 1999; Laliberté & St-Laurent, 2020; Malo et al., 2004; Mayer et al., 2021). One study showed that DVC occurrence was about 50% lower when there was no forest cover on the roadside (Hegland & Hamre, 2018). McCane et al. (2015) found that most collisions with deer occurred adjacent to grassland cover types. Hussain et al. (2007) and Meisingset et al. (2014) mentioned that land-use patterns can affect DVCs distribution with the risk being higher in road segments close to pastures.

Ahmed et al. (2021) emphasized the potential influence of roadside barriers or medians in DVCs. In our study, almost all the DVCs sites had guard rails in/near the median, and around 40% of the sites had guard rails on either side of the road. In the study by Mayer et al. (2021), less than 2% of the roads had guardrails. They found no evidence to suggest the presence of road barriers reduced the probability of DVCs. In Malo et al., (2004), typical DVC sites had no guard rails, since they found that animals avoided such barriers for crossing. Our study found that DVCs sites were associated with standard-sized medians, compared to a wide or concrete barrier median. However, we did not find this result in any other studies for comparison.

Based on our results, flat/level roads were ideal for DVCs, followed by an incline (up from the roadbed). In the study by Gunson et al. (2011), collisions were less likely to occur when a road bisected a steep slope and was highest when roads went through level terrain. This suggests that deer feel more comfortable walking downhill or on flat ground. In contrast, few DVC sites on either side of the road were associated with declining slopes (26.3%), suggesting that deer are less likely to walk uphill and be involved in a vehicle collision on the interstate. Finder et al. (1999) thought that slope can influence collision sites if associated with gullies. Gullies lead to visual obstruction due to the unevenness of topography, thus causing a collision.

Finder (1998) used aerial photographs and topographic maps to identify and measure landscape variables that are within a 0.8 km radius of the DVCs road segment. The study found that landscape features such as land cover, topography, field edges, corridors, residences, buildings, water, distance to an urban area, road curvature, and public recreational land, around the collision side, can contribute to the increased risk of DVCs. Malo et al. (2004) used GIS to analyze the habitat features within a circular area of a 1000m radius of collision sites, based on a 1:50 000 digital forest cover map. Gonser et al. (2009) studied landscape variables within the buffer zones of 250, 500, 1000, and 1500 meters to understand the influence of spatial conditions in western Indiana. Landscape-based models by Found and Boyce (2011) showed that DVCs were more likely to occur in heterogeneous landscapes.

According to Meisingset et al. (2014), the most important predictor of DVCs risk was the distance to forest cover. Although deer typically feed on grasses and other herbaceous vegetation, Finder et al. (1999) suggested that they remain in nearby wooded cover when foraging or moving between areas, hence the distance to forest cover was important to understand deer movement. In our study, the collision distance to vegetation was only 109 meters, much closer than Bartonička, et al. (2018) who measured it to be less than 350 meters. McCance et al. (2015) reported the mean distance of DVCs to deer feeding sites was 289.85 meters. Distance to water is an important predictor of DVCs according to Clevenger et al., (2015). The measured distance of the collision site from the stream was less than 120 meters, which is similar to our results (the distance to standing and flowing water was 96 and 110 meters, respectively; both less than 120 meters).

Coe et al. (2015) was the first to link animal migration corridors with DVCs in western North America. They studied mule migration in South-Central Oregon for six years and concluded that migration corridors were the strongest predictor of DVCs, compared to other biophysical attributes. Bartonicka et al. (2018) explained that animal-vehicle collisions tend to aggregate into clusters due to the presence of corridors such as streams and forest edges. Gunson et al. (2011) conducted a content analysis of studies that used generalized linear models to determine the influence of explanatory predictors on DVCs. They found that roads that cut through drainage areas had the highest risk of collisions. In our study, only 3% of corridors were drainage (dry creeks).

Corridors were the most prominent landscape feature affecting DVCs in Missouri. Although most studies consider corridors as full (extending on both sides of the road) by default; our study found that 40% of corridors were half (present on only one side of the road). Half corridors have not been reported elsewhere. Davenport and Davenport (2006) found that environmental factors such as natural corridors and fragmentation were important predictors of DVC sites. Our findings are consistent with Finder (1998) who showed that riparian corridors influence deer movement patterns. Riparian corridors regulated deer density distribution in a study by Dusek et al. (1988). Litvaitis and Tash (2008) mentioned that riparian corridors can funnel animal movements toward a particular segment of the road and increase the risk of collision with vehicles. According to Hubbard et al. (2000) travel corridors such as bridges, which are often associated with water sources, can increase the risk of DVCs.

Our study observed that the distance of corridors from the collision site was a significant predictor of DVCs risk. By using satellite images, we measured the average distance of corridors to the collision site as 107.02 meters, which reinforces their significance to DVC sites. Natural corridors have been studied extensively in relation to DVCs. However, our study is unique because we found that cultural corridors were also an important variable for predicting DVCs. Although cultural corridors such as power lines, pipelines, railroads, and roads have been studied, they were mostly considered as factors that lead to habitat fragmentation (Donaldson & Weber, 2006), not as something that might influence deer behavior. Primack (2006) studied the possibility of public utilities such as railroads, electric lines, and pipelines used as travel corridors. Our study found that about 25% of cultural corridors were transmission lines (an average distance of 102.53 meters from collision sites). Half of the DVC sites (50%) were either cultural or a combination of both natural and cultural corridors. The average distance of cultural corridors from the collision point was 97.29 meters, which is closer than natural corridors (average distance of 118.80 meters). This finding suggests that cultural corridors might be a greater risk of DVCs than natural corridors.

Lentini et al. (2011) found that secondary roads with linear remnants of vegetation were used as travel corridors by certain species, and have the potential to influence DVCs. In our study, around 40% of the cultural corridors were secondary roads which were about 91 meters, on average, from the collision site. In the study by van der Rea et al. (2015), cleared roadways were used as travel corridors within a highly fragmented landscape. The presence of a national road was a potential factor for animal-vehicle collision in the study by Bartonička et al., (2018). Finder (1998) found hedgerows as one of the landscape variables influencing DVCs. Our study found that 23% of cultural corridors were fencerows with an average distance of 106 meters from the DVC.

However, overpasses were the most unique cultural corridor. It is possible that deer use overpasses as sight lines. Although overpasses were only 20% of the total, their average distance to the collision site was only 83 meters. No other literature has mentioned the potential influence of overpasses in DVCs. In fact, we did not find any literature that studied DVCs in relation to cultural corridors; opening possibilities for future studies.

Finally, we suggest that both natural and cultural corridors should be prioritized while designing and implementing temporal DVCs mitigation strategies on highway interstates. Malo et al. (2004) found that more than 70% of collisions in their study area occurred in less than 8% of the roadways, emphasizing the need to focus on hotspot areas for DVCs mitigation strategies. Similarly, Coe et al. (2015) made a strong argument for the use of migration corridor data for selecting sites for wildlife passage structures. Liu et al. (2018) suggested that focusing on hotspot road segments (i.e., the presence of corridors) is most effective in mitigating DVCs.

LIMITATIONS OF THE STUDY

DVCs are under-reported if the estimated damage is less than $500 or the motorist is uninsured. In fact, some sources indicate that only half of DVCs are reported (Deer Crash, 2008). Not all drivers report animal collisions and not all law enforcement officers have the resources to collect such information. Many animals that are injured simply leave the roadway before they die and are never found. Drivers who swerve to avoid deer often collide with something else which might not be recorded as a DVC. Therefore, inconsistent and/or inaccurate reporting of DVCs can be a limitation in our dataset.

Our study results are somewhat subjective, i.e., identifying the nearest corridors and coding the adjacent surroundings. To minimize this issue, each collision site was cross-checked among two coders; however, it was not possible to eliminate all sources of error. For consistency, the default 200-foot scale (satellite view) in Google Maps was used to identify corridors and measure distances. Some corridors and landscape attributes could have been overlooked using this scale resolution. The latest Missouri State Highway Patrol dataset (2020) was used for analysis which coincided with the COVID-19 pandemic. Although the total number of collisions compared favorably with previous years, the pandemic likely affected traffic volume and the nature of collisions.

CONCLUSION

Habitat fragmentation due to road construction and development results in injury or death to countless animals in Missouri each year. Solutions are needed to reduce the number of vehicular collisions with deer along interstates, especially in urban areas. Corridors are vital for understanding large animal behavior and movement near interstates and can be useful for predicting the risk of DVCs. This study analyzed natural and cultural corridors, both full and partial, as an explanation for DVCs along Missouri interstates. The relatively short distance from corridors to DVCs only reinforces their potential influence. Although natural corridors are more obvious, our study also highlights cultural corridors as an unexplored, but potentially important factor associated with DVCs. From our analysis, we developed a short list of landscape features that can be useful for describing ideal (hotspot) DVC sites, either in urban or rural areas. These attributes include:

- Tree cover on both sides of the road
- Riparian zones (creeks, streams, and rivers)
- Flat/level surfaces adjacent to interstates, followed by inclining slopes

- The presence of secondary roads, overpasses, public utilities, & fencerows

This study has the potential to reduce DVCs in Missouri by addressing persistent questions such as “where, when, why, and what” that remain unanswered. Identification of natural and cultural corridors might be useful to prioritize certain segments of Missouri interstates. For example, targeting areas that contain linear dense forests on both sides of the interstate, especially riparian crossings. Similar to the management practices in Indiana, corridors can be “deer reduction zones” where hunting is encouraged, but only in certain areas (Indiana Department of Natural Resources, 2018). For example, focusing on high risks corridors, especially in urban areas. Although these zones may not be as appealing to hunters as compared to other locations, they could be ideal for archers.

Our strategy also involves an early warning system for motorists, but only during specific times and seasons of the year. The risk for DVCs is highest during peak movement (fall and early winter) and time (dawn and dusk). Temporary flashing road signs could be moved into place for alerting drivers of the increased probability of deer, but only at select natural/cultural corridors. These would include both urban and rural settings, thereby reducing the risk of collision and its consequences. Temporary flashing signs could be placed along the interstate, on both sides of the corridor, well in advance to ensure that motorists have sufficient time to slow down. Creative messaging should be used to warn motorists, such as already done by MODOT. Some examples might include:

- The buck stops here!
- Show-Me deer, right here!
- Tis the season, deer are near!
- Deer are here and near! Slow down!

- Slow down & fear no deer!
- Oh deer, watch out!
- Deer in your headlights!
- Deer, a 4-letter word!
- Nearly 500 deer collisions yearly

This simple solution is an inexpensive and practical way to reduce deer roadkill on Missouri interstates. Information on corridors could be valuable to highway safety personnel, urban planners, engineers, wildlife managers, and others who are concerned with mitigating DVCs. Avoiding corridors and high connectivity zones during the planning and designing stage of highways can also reduce DVC risks.

FUTURE RESEARCH

Consistent data collection of DVCs will give a lead to better strategies for predicting DVCs. Our study focused on a single year of collision; future studies can analyze collisions over multiple years and compare the results to find patterns in collisions. Similar methodologies can be used to understand the correlation between corridors and collisions by transferring it to other countries and geographical regions. The effectiveness of temporary flashing signs and electronic message boards on 'hotspot' areas should be evaluated under field conditions. The response of drivers and their effect on collisions can also be assessed.

Cultural corridors should be incorporated into future work, especially those that have not been studied yet (i.e., overpasses). Assessment of corridors should be a compulsory part of the environmental impact assessments. Additional variables such as detailed traffic intensity, surrounding relief and land use, and dynamic socio-economic parameters can also be considered in the DVCs study. Consistency of research results can direct wildlife managers and transportation officials to the best practices for minimizing DVCs.

REFERENCES

Abeyrathna, W. A. N. U., & Langen, T. A. (2021). Effect of daylight-saving time clock shifts on white-tailed deer-vehicle collision rates. *Journal of environmental management, 292, 112774.*

Abraham, J. O., & Mumma, M. A. (2021). Elevated wildlife-vehicle collision rates during the COVID-19 pandemic. *Scientific reports*, *11*(1), 1-10.

Ahmed, S. S., Cohen, J., & Anastasopoulos, P. C. (2021). A correlated random parameter with heterogeneity in means approach of deer-vehicle collisions and resulting injury-severities. *Analytic methods in accident research*, *30*, 100160.

Allen, R. E., & McCullough, D. R. (1976). Deer-car accidents in southern Michigan. *The Journal of Wildlife Management*, 317-325.

America Association of State Highway and Transportation Officials (AASHTO). (2006). *Roadside design guide* (3rd ed.). American Association of State Highway and Transportation Officials.

Anderson A.B., & Jenkins C.N. (2006). Applying Nature's Design. Corridors as a Strategy for Biodiversity Conservation. Columbia University Press, New York, 231 pp.

Bartonička, T., Andrášik, R., Duľa, M., Sedoník, J., & Bíl, M. (2018). Identification of local factors causing clustering of animal-vehicle collisions. *The Journal of Wildlife Management*, *82*(5), 940-947.

Basak, S. M., O'Mahony, D. T., Lesiak, M., Basak, A. K., Ziółkowska, E., Kaim, D., ... & Wierzbowska, I. A. (2022). Animal-vehicle collisions during the COVID-19 lockdown in early 2020 in the Krakow metropolitan region, Poland. *Scientific reports*, *12*(1), 1-14.

Bashore, T. L., Tzilkowski, W. M., & Bellis, E. D. (1985). Analysis of deer-vehicle collision sites in Pennsylvania. *The Journal of Wildlife Management*, 769-774.

Beringer, J., Hansen, L. P., Demand, J. A., Sartwell, J., Wallendorf, M., & Mange, R. (2002). Efficacy of translocation to control urban deer in Missouri: costs, efficiency, and outcome. *Wildlife Society Bulletin*, 767-774.

Bíl, M., Andrášik, R., Bartonička, T., Křivánková, Z., & Sedoník, J. (2018). An evaluation of odor repellent effectiveness in prevention of wildlife-vehicle collisions. *Journal of environmental management*, *205*, 209-214.

Bíl, M., Kubeček, J., Sedoník, J., & Andrášik, R. (2017). Srazenazver. CZ: A system for evidence of animal-vehicle collisions along transportation networks. *Biological Conservation*, *213*, 167-174.

Bissonette, J. A., & Kassar, C. A. (2008). Locations of deer-vehicle collisions are unrelated to traffic volume or posted speed limit. *Human-Wildlife Conflicts*, *2*(1), 122-130.

Bissonette, J. A., Kassar, C. A., & Cook, L. J. (2008). Assessment of costs associated with deer-vehicle collisions: human death and injury, vehicle damage, and deer loss. *Human-Wildlife Conflicts*, *2*(1), 17-27.

Bissonette, J. A., & Rosa, S. (2012). An evaluation of a mitigation strategy for deer-vehicle collisions. *Wildlife Biology*, *18*(4), 414-423.

Blackwell, B. F., & Seamans, T. W. (2009). Enhancing the perceived threat of vehicle approach to deer. *The Journal of Wildlife Management*, *73*(1), 128-135.

Blackwell, B. F., Seamans, T. W., & DeVault, T. L. (2014). White-tailed deer response to vehicle approach: evidence of unclear and present danger. *PloS one*, *9*(10), e109988.

Bolger, D. T., W. D. Newmark, T. A. Morrison, and D. F. Doak (2008). The need for integrative approaches to understand and conserve migratory ungulates. *Ecology Letters* 11:63–77.

Bond, A. R., & Jones, D. N. (2013). Wildlife warning signs: public assessment of components, placement, and designs to optimize driver response. *Animals*, *3*(4), 1142-1161.

Braden, A. W., Lopez, R. R., Roberts, C. W., Silvy, N. J., Owen, C. B., & Frank, P. A. (2008). Florida Key deer *Odocoileus virginianus clavium* underpass use and movements along a highway corridor. *Wildlife Biology*, *14*(1), 155-163.

Brieger, F., Hagen, R., Kröschel, M., Hartig, F., Petersen, I., Ortmann, S., & Suchant, R. (2017). Do roe deer react to wildlife warning reflectors? A test combining a controlled experiment with field observations. *European Journal of Wildlife Research*, *63*(5), 1-11.

Bruinderink, G. G., & Hazebroek, E. (1996). Ungulate traffic collisions in Europe. *Conservation biology*, *10*(4), 1059-1067.

Carbaugh, B., Vaughan, J. P., Bellis, E. D., & Graves, H. B. (1975). Distribution and activity of white-tailed deer along an interstate highway. *The Journal of Wildlife Management*, 570-581.

Chen, X., & Wu, S. (2014). Examining patterns of animal-vehicle collisions in Alabama, USA. *Human-Wildlife Interactions*, *8*(2), 235-244.

Christie, J. S., & Nason, S. (2003). Analysis of vehicle collisions with moose and deer on New Brunswick arterial highways. In *The 31st Annual Conference of the Canadian Society for Civil Engineering, Moncton, New Brunswick. 11p* (pp. 652-661).

Clevenger, A. P., Barrueto, M., Gunson, K. E., Caryl, F. M., & Ford, A. T. (2015). Context-dependent effects on spatial variation in deer-vehicle collision. *Ecosphere*, *6*(4), 1-20.

Clevenger, A. P., Chruszcz, B., & Gunson, K. E. (2001). Highway mitigation fencing reduces wildlife-vehicle collisions. *Wildlife society bulletin*, 646-653.

Clevenger, A. P., & Huijser, M. P. (2011). *Wildlife crossing structure handbook: design and evaluation in North America* (No. FHWA-CFL-TD-11-003). United States. Federal Highway Administration. Central Federal Lands Highway Division

Clevenger, A. P., & Kociolek, A. V. (2013). Potential impacts of highway median barriers on wildlife: State of the practice and gap analysis. *Environmental management*, *52*(5), 1299-1312.

Coe, P. K., Nielson, R. M., Jackson, D. H., Cupples, J. B., Seidel, N. E., Johnson, B. K., ... & Speten, D. A. (2015). Identifying migration corridors of mule deer threatened by highway development. *Wildlife Society Bulletin*, *39*(2), 256-267.

Collinson, W. J., Marneweck, C., & Davies-Mostert, H. T. (2019). Protecting the protected: reducing wildlife roadkill in protected areas. *Animal Conservation*, *22*(4), 396-403.

Compton, B. B., Mackie, R. J., & Dusek, G. L. (1988). Factors influencing the distribution of white-tailed deer in riparian habitats. *The Journal of Wildlife Management*, 544-548.

D'Angelo, G. J., D'Angelo, J. G., Gallagher, G. R., Osborn, D. A., Miller, K. V., & Warren, R. J. (2006). Evaluation of wildlife warning reflectors for altering white-tailed deer behavior along roadways. *Wildlife Society Bulletin*, *34*(4), 1175-1183.

Danielson, B. J., & Hubbard, M. W. (1998). A literature review for assessing the status of current methods of reducing deer-vehicle collisions. *Iowa, The Task Force on Animal Vehicle Collisions, the Iowa Department of Transportation, and the Iowa Department of Natural Resources*.

Davenport, J., & Davenport, J. L. (2006). The ecology of transportation: managing mobility for the environment, series: Environmental pollution. Springer, Dordrecht, Netherlands.

Davidson, D. K. (2003). Innovative partnerships that address highway impacts to wildlife habitat connectivity in the Northern Rockies.

Deer Crash (2008). Countermeasures toolbox. Deer-Vehicle Crash Information Clearinghouse. Madison, WI: University of Wisconsin. http://www.DeerCrash.com. Accessed August 14, 2022.

DeNicola, A. J., & Williams, S. C. (2008). Sharpshooting suburban white-tailed deer reduces deer-vehicle collisions. *Human-Wildlife Conflicts*, *2*(1), 28-33.

Department of Motor Vehicles (2022). *Deer Crossing Sign-Meaning.* https://dmv-permit-test.com/road-signs/deer-crossing-sign.

DeStefano, S. (2009). Wildlife corridors and developed landscapes. In *The Planner's Guide to Natural Resource Conservation:* (pp. 85-102). Springer, New York, NY.

DeVault, T. L., Seamans, T. W., & Blackwell, B. F. (2020). Frontal vehicle illumination via rear-facing lighting reduces potential for collisions with white-tailed deer. *Ecosphere*, *11*(7), e03187.

Donaldson, B. M. (2006). *A toolkit of measures for reducing animal-vehicle collisions* (No. FHWA/VTRC 07-R13). Virginia Transportation Research Council.

Donaldson, B.M., and Weber, J.T. (2006). Use of a GIS-Based Model of Habitat Cores and Landscape Corridors for Transportation Project Planning and Environmental Scoping by the Virginia Department of Transportation. VTRC 07-R14. Virginia Transportation Research Council, Charlottesville.

Douglas, I., & Sadler, J. P. (2010). Urban wildlife corridors. *The Routledge Handbook of Urban Ecology*, 274.

Epps, C. W., Palsbøll, P. J., Wehausen, J. D., Roderick, G. K., Ramey, R. R., & McCullough, D. R. (2005). Highways block gene flow and cause a rapid decline in genetic diversity of desert bighorn sheep. *Ecology letters*, *8*(10), 1029-1038.

Etter, D. R., Hollis, K. M., Van Deelen, T. R., Ludwig, D. R., Chelsvig, J. E., Anchor, C. L., & Warner, R. E. (2002). Survival and movements of white-tailed deer in suburban Chicago, Illinois. *The Journal of Wildlife Management*, 500-510.

Farrell, M. C., & Tappe, P. A. (2007). County-level factors contributing to deer-vehicle collisions in Arkansas. *The Journal of Wildlife Management*, *71*(8), 2727-2731.

Feldhamer, G. A., Gates, J. E., Harman, D. M., Loranger, A. J., & Dixon, K. R. (1986). Effects of interstate highway fencing on white-tailed deer activity. *The Journal of Wildlife Management*, 497-503.

Finder, R. A. (1998). *Relationships between landscape patterns and white-tailed deer/vehicle accidents* (Doctoral dissertation, Southern Illinois University at Carbondale).

Finder, R. A., Roseberry, J. L., & Woolf, A. (1999). Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. *Landscape and Urban Planning*, *44*(2-3), 77-85.

Fisher, J. (1992). Testing the effect of road traffic signs' informational value on driver behavior. *Hum. Factors* 34, 231– 237.

Flinn, E., Pierce, R. A., & Sumners, J. (2012). Estimating deer populations on your property: population dynamics (2012).

Forman, R. T., & Godron, M. (1981). Patches and structural components for a landscape ecology. *BioScience*, *31*(10), 733-740.

Foster, M. L., & Humphrey, S. R. (1995). Use of highway underpasses by Florida panthers and other wildlife. *Wildlife Society Bulletin*, 95-100.

Found, R., & Boyce, M. S. (2011). Predicting deer-vehicle collisions in an urban area. *Journal of environmental management*, *92*(10), 2486-2493.

Found, R., & Boyce, M. S. (2011). Warning signs mitigate deer-vehicle collisions in an urban area. *Wildlife Society Bulletin*, *35*(3), 291-295.

Fulbright, T. E., & Ortega-Santos, J. A. (2013). *White-tailed deer habitat: ecology and management on rangelands*. Texas A&M University Press

García-Martínez-de-Albéniz, Í., Ruiz-de-Villa, J. A., & Rodriguez-Hernandez, J. (2022). Impact of COVID-19 Lockdown on Wildlife-Vehicle Collisions in NW of Spain. *Sustainability*, *14*(8), 4849.

Gilbert, J. R. (1982). *Evaluation of deer mirrors for reducing deer-vehicle collisions* (No. FHWA/RD-82/061). United States. Federal Highway Administration.

Gill, R. M. A., & Beardall, V. (2001). The impact of deer on woodlands: the effects of browsing and seed dispersal on vegetation structure and composition. *Forestry: An International Journal of Forest Research*, *74*(3), 209-218

Gleason, J. S., & Jenks, J. A. (1993). Factors influencing deer/vehicle mortality in east central South Dakota. *Prairie Naturalist*, *25*, 281-281.

Gonser, R. A., Jensen, R. R., & Wolf, S. E. (2009). The spatial ecology of deer-vehicle collisions. *Applied Geography*, *29*(4), 527-532.

Gordon, K.M., McKinstry, M.C. & Anderson, S.H. (2004). Motorist response to a deer-sensing warning system. *Wildlife Society Bulletin,* 32, 565– 573.

Gorham, D. A., & Porter, W. F. (2011). Examining the potential of community design to limit human conflict with white-tailed deer. *Wildlife Society Bulletin*, *35*(3), 201-208.

Grace, M.K., Smith, D.J. & Noss, R.F. (2015). Testing alternative designs for a roadside animal detection system using a driving simulator. In: Seiler A, Helldin J-O (Eds) *Proceedings of IENE 2014 International Conference on Ecology and Transportation,* Malmö, Sweden. Nature Conservation 11, 61–77.

Gregory, A., Spence, E., Beier, P., & Garding, E. (2021). Toward best management practices for ecological corridors. *Land*, *10*(2), 140.

Gunson, K. E., Mountrakis, G., & Quackenbush, L. J. (2011). Spatial wildlife-vehicle collision models: A review of current work and its application to transportation mitigation projects. *Journal of environmental management*, *92*(4), 1074-1082.

Ha, H., & Shilling, F. (2018). Modeling potential wildlife-vehicle collisions (WVC) locations using environmental factors and human population density: a case-study from 3 state highways in Central California. *Ecological Informatics*, *43*, 212-221.

Haddad, N. M., & Baum, K. A. (1999). An experimental test of corridor effects on butterfly densities. *Ecological Applications*, *9*(2), 623-633.

Haikonen, H., & Summala, H. (2001). Deer-vehicle crashes: extensive peak at 1 hour after sunset. *American journal of preventive medicine*, *21*(3), 209-213.\

Hansen, L., & Beringer, J. (1997). Managed hunts to control white-tailed deer populations on urban public areas in Missouri. *Wildlife Society Bulletin*, 484-487.

Hardy, A., Lee, S., & Al-Kaisy, A. F. (2006). Effectiveness of animal advisory messages on dynamic message signs as a speed reduction tool: Case study in rural Montana. *Transportation Research Record*, *1973*(1), 64-72.

Hedlund, J. H., Curtis, P. D., Curtis, G., & Williams, A. F. (2004). Methods to reduce traffic crashes involving deer: what works and what does not. *Traffic injury prevention*, *5*(2), 122-131.

Hegland, S. J., & Hamre, L. N. (2018). Scale-dependent effects of landscape composition and configuration on deer-vehicle collisions and their relevance to mitigation and planning options. *Landscape and Urban Planning*, *169*, 178-184.

Hiller, I. (1996). *The white-tailed deer*. Texas A and M University Press.

Hindelang, M., Premo, D., Rogers, E., & Premo, K. (1999). Addressing deer-vehicle accidents with an ecological landscape GIS approach. In Third International Conference on Wildlife Ecology and Transportation Florida Department of Transportation, US Department of Transportation, US Forest Service, Defenders of Wildlife.

Honda, T., Iijima, H., Tsuboi, J., & Uchida, K. (2018). A review of urban wildlife management from the animal personality perspective: the case of urban deer. *Science of the total environment*, *644*, 576-582.

Hothorn, T., Müller, J., Held, L., Möst, L., & Mysterud, A. (2015). Temporal patterns of deer-vehicle collisions consistent with deer activity pattern and density increase but not general accident risk. *Accident Analysis & Prevention*, *81*, 143-152.

Houck MC. (1990). Metropolitan wildlife refuge system: A strategy for regional natural resource planning, in Wildlife Conservation in Metropolitan Environments, Ed. L. W. Adams, D. L. Leedy, National Institute for Urban Wildlife, Columbia, MD, pp. 225–229.

Hubbard, M. W., Danielson, B. J., and Schmitz, R. A. (2000). Factors Influencing the Location of Deer Vehicle Accidents in Iowa. Journal of Wildlife Management 64:707-713.

Huijser, M. P., Duffield, J. W., Clevenger, A. P., Ament, R. J., & McGowen, P. T. (2009). 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*, *14*(2).

Huijser, M. P., Kociolek, A. V., McGowen, P. T., Ament, R., Hardy, A., & Clevenger, A. P. (2007). Wildlife-vehicle collision and crossing mitigation measures: a toolbox for the Montana Department of Transportation.

Huijser, M.P. & McGowen, P.T. (2003). Overview of animal detection and animal warning systems in North America and Europe. In: Irwin CL, Garrett P, McDermott KC (Eds) Proceedings of the International Conference on Ecology & Transportation (ICOET).

Center for Transportation and the Environment, North Carolina State University, Raleigh, 368–382.

Huijser, M. P., McGowan, P., Hardy, A., Kociolek, A., Clevenger, A. P., Smith, D., & Ament, R. (2017). Wildlife-vehicle collision reduction study: report to congress.

Huijser, M. P., Mosler-Berger, C., Olsson, M., & Strein, M. (2015). Wildlife warning signs and animal detection systems aimed at reducing wildlife-vehicle collisions. *Handbook of road ecology*, 198-212.

Hunter numbers decline nationwide, Missouri numbers hold steady. (2018, November 16). KY3: The place to be. Retrieved September 25, 2022, from https://www.ky3.com/content/news/Hunter-numbers-decline-nationwide-Mo-numbers-hold-steady--500705461.html

Hussain, A., Armstrong, J. B., Brown, D. B., & Hogland, J. (2007). Land-use pattern, urbanization, and deer–vehicle collisions in Alabama. *Human-Wildlife Conflicts*, *1*(1), 89-96.

Indiana Department of Natural Resources (2018, September 18). Deer Reduction Zone Corridors Explained [Video]. YouTube. https://www.youtube.com/watch?v=qPBbrVEnPE4

Jackson, S. D. (1999). Overview of transportation related wildlife problems. In Third International Conference on Wildlife Ecology and Transportation, Florida Department of Transportation, US Department of Transportation, US Forest Service, Defenders of Wildlife.

Jackson, S. D. (2000). Overview of transportation impacts on wildlife movement and populations. *Wildlife and highways: seeking solutions to an ecological and socio-economic dilemma. The Wildlife Society*, 7-20.

Jackson, S. D., & Griffin, C. R. (1998). Toward a practical strategy for mitigating highway impacts on wildlife. In International Conference on Wildlife Ecology and Transportation (ICOWET 1998) Florida Department of Transportation, US Department of Transportation, US Forest Service, Defenders of Wildlife.

Jaren, V., Andersen, R., Ulleberg, M., Pedersen, P. H., & Wiseth, B. (1991). Moose-train collisions: the effects of vegetation removal with a cost-benefit analysis. *Alces: A Journal Devoted to the Biology and Management of Moose*, *27*, 93-99.

Jensen, R. R., Gonser, R. A., & Joyner, C. (2014). Landscape factors that contribute to animal–vehicle collisions in two northern Utah canyons. *Applied Geography*, *50*, 74-79.

Keken, Z., Sedoník, J., Kušta, T., Andrášik, R., & Bíl, M. (2019). Roadside vegetation influences clustering of ungulate vehicle collisions. *Transportation research part D: transport and environment*, *73*, 381-390.

Kilgo, J. C., Blake, J. I., Grazia, T. E., Horcher, A., Larsen, M., Mims, T., & Zarnoch, S. J. (2020). Use of roadside deer removal to reduce deer–vehicle collisions. *Human–Wildlife Interactions*, *14*(1), 13.

Korschgen, L. J. (1962). Foods of Missouri deer, with some management implications. *The Journal of Wildlife Management*, *26*(2), 164-172.

Kušta, T., Keken, Z., Ježek, M., Holá, M., & Šmíd, P. (2017). The effect of traffic intensity and animal activity on probability of ungulate-vehicle collisions in the Czech Republic. *Safety science*, *91*, 105-113.

Laliberté, J., & St-Laurent, M. H. (2020). In the wrong place at the wrong time: Moose and deer movement patterns influence wildlife-vehicle collision risk. *Accident Analysis & Prevention*, *135*, 105365.

Lao, Y., Zhang, G., Wu, Y. J., & Wang, Y. (2011). Modeling animal–vehicle collisions considering animal–vehicle interactions. *Accident Analysis & Prevention*, *43*(6), 1991-1998.

Leblond, M., Dussault, C., Ouellet, J. P., Poulin, M., Courtois, R., & Fortin, J. (2007). Management of roadside salt pools to reduce moose-vehicle collisions. *The Journal of Wildlife Management*, *71*(7), 2304-2310.

Lehnert, M. E., & Bissonette, J. A. (1997). Effectiveness of highway crosswalk structures at reducing deer-vehicle collisions. *Wildlife Society Bulletin*, 809-818.

Lentini, P. E., Martin, T. G., Gibbons, P., Fischer, J., & Cunningham, S. A. (2012). Supporting wild pollinators in a temperate agricultural landscape: Maintaining mosaics of natural features and production. *Biological Conservation*, *149*(1), 84-92

Leopold, A. (1933). Game management. Chas. Scribner's Sons, New York.

Lidicker, W.Z. (1999). Responses of mammals to habitat edges: an overview. *Landscape Ecology* 14, 333–343.

Litvaitis, J. A., & Tash, J. P. (2008). An approach toward understanding wildlife-vehicle collisions. *Environmental management*, *42*(4), 688-697.

Liu, Y., Nieuwenhuis, M., & McCullagh, A. (2018). The effect of roadside land-use on the occurrence of deer vehicle collisions. *Irish Forestry*, *75*(1&2), 8-25.

Lopez, R. R., Vieira, M. E., Silvy, N. J., Frank, P. A., Whisenant, S. W., & Jones, D. A. (2003). Survival, mortality, and life expectancy of Florida Key deer. *The Journal of wildlife management*, 34-45.

Ludwig, J., & Bremicker, T. (1983). Evaluation of 2. 4-m fences and one-way gates for reducing deer-vehicle collisions in Minnesota. *Transportation Research Record*, *913*, 19-22.

Malo, J. E., Suárez, F., & Díez, A. (2004). Can we mitigate animal–vehicle accidents using predictive models? *Journal of applied ecology*, *41*(4), 701-710.

Marcoux, A., & Riley, S. J. (2010). Driver knowledge, beliefs, and attitudes about deer–vehicle collisions in southern Michigan. *Human-Wildlife Interactions*, *4*(1), 47-55.

Mastro, L. L., Conover, M. R., & Frey, S. N. (2008). Deer–vehicle collision prevention techniques. *Human-Wildlife Conflicts*, *2*(1), 80-92.

Mastro, L. L., Conover, M. R., & Frey, S. N. (2010). Factors influencing a motorist's ability to detect deer at night. *Landscape and Urban Planning*, *94*(3-4), 250-254.

Mayer, M., Nielsen, J. C., Elmeros, M., & Sunde, P. (2021). Understanding spatio-temporal patterns of deer-vehicle collisions to improve roadkill mitigation. *Journal of environmental management*, *295*, 113148.

McCance, E. C., Baydack, R. K., Walker, D. J., & Leask, D. N. (2015). Spatial and temporal analysis of factors associated with urban deer–vehicle collisions. *Human–Wildlife Interactions*, *9*(1), 12.

McCollister, M. F., & Van Manen, F. T. (2010). Effectiveness of wildlife underpasses and fencing to reduce wildlife-vehicle collisions. *The Journal of Wildlife Management*, *74*(8), 1722-1731.

McKee, J. J., & Cochran Jr, D. M. (2012). The role of landscape in the distribution of deer-vehicle collisions in south Mississippi. *southeastern geographer*, *52*(3), 327-340.

Meisingset, E. L., Loe, L. E., Brekkum, Ø., & Mysterud, A. (2014). Targeting mitigation efforts: The role of speed limit and road edge clearance for deer–vehicle collisions. *The Journal of wildlife management*, *78*(4), 679-688.

Messmer, T. A., Hendricks, C. W., & Klimack, P.W., (1999). The effect of temporary signing on reducing deer-vehicle collisions during seasonal mule deer migrations. Jack H. Berry-man Institute, Final Project Report, Utah State University, Logan, USA.

Miller, H. J. (2004). Tobler's first law and spatial analysis. Annals of the Association of American Geographers, 94, 284–289.

Missouri Department of Conservation (n.d.,). *Deer Management.* https://mdc.mo.gov/your-property/improve-your-property/wildlife-management/deer-management. (Retrieved November 25, 2022).

Missouri Department of Conservation (2020). *Missouri Deer Season Summary & Population Status Report.* https://mdc.mo.gov/sites/default/files/2021-09/2020_Deer_Population_Status_Report_0.pdf

Missouri Department of Transportation. (2021, October 6). *Watch for wildlife movement on state roads.* https://www.modot.org/node/24368

Missouri Department of Transportation. (2022, October 5). *Roadkill increases as nights grow cooler.* https://www.modot.org/node/27169

Missouri State Highway Patrol, (2020). *Missouri Traffic Crashes.* *https://www.mshp.dps.missouri.gov/MSHPWeb/SAC/pdf/2020E.pdf*

Missouri State Highway Patrol, (2021). Missouri Traffic Safety Compendium. https://apps.mshp.dps.mo.gov/MSHPWeb/SAC/Compendium/TrafficCompendium.html (Retrieved September 15, 2022).

Mormann, B., Pierce, R. A., & Flinn, E. (2022). Managing for white-tailed deer in Missouri: setting and accomplishing management goals.

National Highway Traffic Safety Administration (NHTSA). (2020). *Overview of Motor Vehicle Crashes in 2020.* https://crashstats.nhtsa.dot.gov/Api/Public/Publication/813266

Nelli, L., Langbein, J., Watson, P., & Putman, R. (2018). Mapping risk: Quantifying and predicting the risk of deer-vehicle collisions on major roads in England. *Mammalian Biology*, *91*(1), 71-78.

Newmark, W. D. (1993). The role and design of wildlife corridors with examples from Tanzania. *Ambio*, 500-504.

Ng, J. W., Nielsen, C., & St. Clair, C. C. (2008). Landscape and traffic factors influencing deer–vehicle collisions in an urban enviroment. *Human-Wildlife Conflicts*, *2*(1), 34-47.

Nielsen, C. K., Anderson, R. G., & Grund, M. D. (2003). Landscape influences on deer-vehicle accident areas in an urban environment. *The Journal of wildlife management*, 46-51.

Nixon, C. M., Hansen, L. P., Brewer, P. A., & Chelsvig, J. E. (1991). Ecology of white-tailed deer in an intensively farmed region of Illinois. *Wildlife monographs*, 3-77.

Pagany, R. (2020). Wildlife-vehicle collisions-Influencing factors, data collection and research methods. *Biological Conservation*, *251*, 108758.

Peek, F. W., & Bellis, E. D. (1969). Deer movements and behavior along an interstate highway. *Highway Research News*, (36), 36-42.

Peterson, M. N., Lopez, R. R., Silvy, N. J., Owen, C. B., Frank, P. A., & Braden, A. W. (2003). Evaluation of deer-exclusion grates in urban areas. *Wildlife Society Bulletin*, 1198-1204.

Pfeiffer, M. B., Iglay, R. B., Seamans, T. W., Blackwell, B. F., & DeVault, T. L. (2020). Deciphering interactions between white-tailed deer and approaching vehicles. *Transportation Research Part D: Transport and Environment*, *79*, 102251.

Piccolo, B. P., Hollis, K. M., Warner, R. E., Van Deelen, T. R., Etter, D. R., & Anchor, C. (2000). Variation of white-tailed deer home ranges in fragmented urban habitats around Chicago, Illinois.

Pierce, R. A., Sumners, J. A., & Flynn, E. (2011). Ecology and management of white-tailed deer in Missouri (2011).

Pierce, R. A., Sumners, J., & Flynn, E. (2015). Implementing quality deer management on your property (2015).

Primack, R. B. (2006). *Essentials of conservation biology* (Vol. 23). Sunderland: Sinauer Associates.

Rea, R. V. (2003). Modifying roadside vegetation management practices to reduce vehicular collisions with moose *Alces alces*. *Wildlife Biology*, *9*(2), 81-91.

Rea, R. V. (2012). Road Safety implications of moose inhabiting an urban-rural interface. *Urban Habitats*, *7*, 8pp.

Rendall, A. R., Webb, V., Sutherland, D. R., White, J. G., Renwick, L., & Cooke, R. (2021). Where wildlife and traffic collide: Roadkill rates change through time in a wildlife-tourism hotspot. *Global Ecology and Conservation*, *27*, e01530.

Rodríguez-Morales, B., Díaz-Varela, E. R., & Marey-Pérez, M. F. (2013). Spatiotemporal analysis of vehicle collisions involving wild boar and roe deer in NW Spain. *Accident Analysis & Prevention*, *60*, 121-133.

Romin, L. A. (1994). Factors associated with the highway mortality of mule deer at Jordanelle Reservoir, Utah.

Romin, L. A., & Bissonette, J. A. (1996). Deer: vehicle collisions: status of state monitoring activities and mitigation efforts. *Wildlife Society Bulletin*, 276-283.

Romin, L. A., & Dalton, L. B. (1992). Lack of response by mule deer to wildlife warning whistles. *Wildlife Society Bulletin (1973-2006)*, *20*(4), 382-384.

Root, B. G., Fritzell, E. K., & Giessman, N. F. (1988). Effects of intensive hunting on white-tailed deer movement. *Wildlife Society Bulletin (1973-2006)*, *16*(2), 145-151.

Rowden, P., Steinhardt, D., & Sheehan, M. (2008). Road crashes involving animals in Australia. *Accident Analysis & Prevention*, *40*(6), 1865-1871.

Rutberg, A. T., & Naugle, R. E. (2008). Deer–vehicle collision trends at a suburban immunocontraception site. *Human-Wildlife Conflicts*, *2*(1), 60-67.

Saint-Andrieux, C., Calenge, C., & Bonenfant, C. (2020). Comparison of environmental, biological and anthropogenic causes of wildlife–vehicle collisions among three large herbivore species. *Population Ecology*, *62*(1), 64-79.

Sawyer, H., Lindzey, F., & McWhirter, D. (2005). Mule deer and pronghorn migration in western Wyoming. *Wildlife Society Bulletin*, *33*(4), 1266-1273.

Schwabe, K. A., & Schuhmann, P. W. (2002). Deer-vehicle collisions and deer value: an analysis of competing literatures. *Wildlife Society Bulletin*, 609-615.

Schwabe, K. A., Schuhmann, P. W., Tonkovich, M. J., & Wu, E. (2000). An analysis of deer-vehicle collisions: the case of Ohio.

Seidler, R. G., Long, R. A., Berger, J., Bergen, S. and Beckman, J.P. (2014). Identifying impediments to long-distance mammal migrations. Conservation Biology 29:99–109.

Seiler, A., & Bhardwaj, M. (2020). Wildlife and traffic: an inevitable but not unsolvable problem? In *Problematic Wildlife II* (pp. 171-190). Springer, Cham.

Seiler, A. & Helldin, J.O. (2006). Mortality in wildlife due to transportation. In *The ecology of transportation: managing mobility for the environment*: pp. 165– 189. J. Davenport, J.L. Davenport (Eds). Dordrecht: Springer.

Shilling, F. M., & Waetjen, D. P. (2015). Wildlife-vehicle collision hotspots at US highway extents: scale and data source effects. *Nature Conservation*, *11*, 41-60.

Shi, H., Laurent, E. J., LeBouton, J., Racevskis, L., Hall, K. R., Donovan, M., ... & Liu, J. (2006). Local spatial modeling of white-tailed deer distribution. *Ecological Modelling*, *190*(1-2), 171-189.

Smith, D. J., Harris, L. D., & Mazzotti, F. J. (1999). Highway-wildlife relationships (Development of a decision-based wildlife underpass road project prioritization model on GIS with statewide application)

State Farm Mutual Automobile Insurance Company (2018). *Deer damage can be costly*. https://www.statefarm.com/simple-insights/auto-and-vehicles/deer-damage- can-be-costly.

State Farm Mutual Automobile Insurance Company (2019). *Look OUT! Deer Damage can be Costly!* https://newsroom.statefarm.com/state-farm-releases-2016-deer-collision-data/

State Farm Mutual Automobile Insurance Company (2020). *Don't Veer for Deer.* https://newsroom.statefarm.com/animal-collision/

State Farm Mutual Automobile Insurance Company (2022). *Where are Animal (Deer) Collisions Most Likely?* https://www.statefarm.com/simple-insights/auto-and-vehicles/how-likely-are-you-to-have-an-animal-collision

Steiner, W., Leisch, F., & Hackländer, K. (2014). A review on the temporal pattern of deer–vehicle accidents: Impact of seasonal, diurnal and lunar effects in cervids. *Accident Analysis & Prevention*, *66*, 168-181.

Stickles, J. H., Stone, D. B., Evans, C. S., Miller, K. V., Warren, R. J., Osborn, D. A., & Killmaster, C. H. (2015). Using deer-vehicle collisions to map white-tailed deer breeding activity in Georgia. *J SEAFWA*, *2*, 202-207.

Sudharsan, K., Riley, S. J., & Campa Iii, H. (2009). Relative risks of deer–vehicle collisions along road types in southeast Michigan. *Human dimensions of wildlife*, *14*(5), 341-352.

Sudharsan, K., Riley, S. J., & Winterstein, S. R. (2006). Relationship of autumn hunting season to the frequency of deer-vehicle collisions in Michigan. *The Journal of wildlife management*, 1161-1164.

Sullivan, T. L., & Messmer, T. A. (2003). Perceptions of deer-vehicle collision management by state wildlife agency and department of transportation administrators. *Wildlife Society Bulletin*, 163-173.

Sullivan, T. L., Williams, A. F., Messmer, T. A., Hellinga, L. A., & Kyrychenko, S. Y. (2004). Effectiveness of temporary warning signs in reducing deer-vehicle collisions during mule deer migrations. *Wildlife Society Bulletin*, *32*(3), 907-915.

The Road Information Program (TRIP) (2006). The Interstate Highway System in Missouri: Saving Lives, Time and Money. *A report on the condition, impact, use and future needs of Missouri's Interstate highway system,* Washington, DC.

The Road Information Program (TRIP) (2021). Restoring Missouri's Interstate Highway System: *Meeting Missouri's Transportation Needs with a Reliable, Safe & Well-Maintained National Highway Network,* Washington, DC.

Theobald, D. M., Crooks, K. R., & Norman, J. B. (2011). Assessing effects of land use on landscape connectivity: loss and fragmentation of western US forests. *Ecological Applications*, *21*(7), 2445-2458.

Transportation Research Board (1998). *Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits*, Special Report 254, Transportation Research Board, Washington, DC.

Ujvari, M., Baagøe, H. J., & Madsen, A. B. (1998). Effectiveness of wildlife warning reflectors in reducing deer-vehicle collisions: a behavioral study. *The Journal of wildlife management*, 1094-1099.

United States Census Bureau, (2022). *QuickFacts. https://www.census.gov/quickfacts/kansascitycitymissouri*

United States Department of Transportation. (2008, August). *Wildlife-Vehicle Collision Reduction Study: Report to Congress.* https://www.fhwa.dot.gov/publications/research/safety/08034/exec.cfm

United States Department of Transportation. (2022, January). *National Roadway Safety Strategy.* https://www.transportation.gov/sites/dot.gov/files/2022-02/USDOT-National-Roadway-Safety-Strategy.pdf

Valitzski, S. A., D'Angelo, G. J., Gallagher, G. R., Osborn, D. A., Miller, K. V., & Warren, R. J. (2009). Deer responses to sounds from a vehicle-mounted sound-production system. *The Journal of wildlife management*, *73*(7), 1072-1076.

van der Ree, R., Smith, D. J., & Grilo, C. (2015). The ecological effects of linear infrastructure and traffic: challenges and opportunities of rapid global growth. *Handbook of road ecology*, 1-9.

VerCauteren, K. C., Lavelle, M. J., & Hygnstrom, S. (2006). From the field: fences and deer-damage management: a review of designs and efficacy. *Wildlife Society Bulletin*, *34*(1), 191-200.

von Hoermann, C., Pagany, R., Kirchner, K., Dorner, W., Heurich, M., & Storch, I. (2020). Predicting the Risk of Deer-vehicle Collisions by Inferring Rules Learnt from Deer Experience and Movement Patterns in the Vicinity of Roads. In *2020 10th International Conference on Advanced Computer Information Technologies (ACIT)* (pp. 368-373). IEEE.

Waring, G. H., Griffis, J. L., & Vaughn, M. E. (1991). White-tailed deer roadside behavior, wildlife warning reflectors, and highway mortality. *Applied Animal Behaviour Science*, *29*(1-4), 215-223.

Webb, S. L., Riffell, S. K., Gee, K. L., & Demarais, S. (2009). Using fractal analyses to characterize movement paths of white-tailed deer and response to spatial scale. *Journal of Mammalogy*, *90*(5), 1210-1217.

Wildlife Informer. (2022, January). *Deer Population by State (Estimates and Info).* https://wildlifeinformer.com/deer-population-by-state/

Williams, A. F. (1994). The contribution of education and public information to reducing alcohol-impaired driving. Alcohol, Drugs, and Driving 10:197–205.

Wood, P., & Wolfe, M. L. (1988). Intercept feeding as a means of reducing deer-vehicle collisions. *Wildlife Society Bulletin (1973-2006)*, *16*(4), 376-380.
Abraham, J. O., & Mumma, M. A. (2021). Elevated wildlife-vehicle collision rates during the COVID-19 pandemic. *Scientific reports*, *11*(1), 1-10.

World Population Review. (2022). *Missouri Population 2022*. https://worldpopulationreview.com/states/missouri-population

APPENDIX 1: Variable Checklist

Satellite view

Crash ID_________

Corridor? □ No □ Yes

If YES, type? □ Open □ Closed

If YES, Location? □ Both sides □ Collision side only □ Opposite side only

If YES, type? □ Natural □ Cultural □ Combination

Natural □ Dry creek □ Flowing water □ Standing water □ Vegetation

Cultural □ Overpass □ Public Utilities □ Fence-row □ Secondary Road

Distance? feet: ________ meters: ___________

Street view

Adjacent Cover: Same Side □ No vegetation □ Grass □ Shrubs □ Trees

Adjacent Cover: Median □ No vegetation □ Grass □ Shrubs □ Trees

Adjacent Cover: Opposite side □ No vegetation □ Grass □ Shrubs □ Trees

Median Width □ Standard □ Wide □ None

Cable/Guard Rail: Median □ No □ Yes

Guard Rail: Same Side □ No □ Yes

Guard Rail: Opposite Side □ No □ Yes

Adjacent Slope: **Same Side** □ Flat / level □ Decline (from road bed) □ Incline (from road bed) □ Rock cut

Adjacent Slope: Opposite Side □ Flat / level □ Decline (from road bed) □ Incline (from road bed) □ Rock cut