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Q1 # Improvement of the performance of animal crossing warning signs

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ABSTRACT

Introduction: Animal–vehicle collisions (AVCs) can result in serious injury and death to drivers, animals' death, and significant economic costs. However, the cost effectiveness of the majority of AVC mitigation measures is a significant issue. *Method*: A mobile-based data collection effort was deployed to measure signs under the Utah Department of Transportation's (UDOT) jurisdiction. The crash data were obtained from the UDOT risk management database. ArcGIS was employed to link these two data sets and extract animal-related crashes and signs. An algorithm was developed to process the data and identify AVCs that occurred within sign recognition distance. Kernel density estimation (KDE) technique was applied to identify potential crash hotspots. *Results:* Only 2% of AVCs occurred within the recognition distance of animal crossing signs. Almost 58% of animal-related crashes took place on the Interstate and U.S. highways, wherein only 30% of animal crossing signs were installed. State routes with a higher average number of signs experienced a lower number of AVCs per mile. The differences between AVCs that occurred within versus outside of sign recognition distance were not statistically significant regarding crash severity, time of crash, weather condition, driver age, vehicle speed, and type of animal. It is more likely that drivers become accustomed to deer crossing signs than cow signs. *Conclusions*: Based on the historical crash data and landscape structure, with attention given to the low cost safety improvement methods, a combination of different types of AVC mitigation measures can be developed to reduce the number of animal-related crashes. After an in-depth analysis of AVC data, warning traffic signs, coupled with other low cost mitigation countermeasures can be successfully placed in areas with higher priority or in critical areas. *Practical applications*: The findings of this study assist transportation agencies in developing more efficient mitigation measures against AVCs.

1. Introduction

With particular concern for fatal and serious injury crashes, transportation agencies continually make efforts to design safety improvements that will mitigate vehicular crashes (Baratian-Ghorghi, Zhou, Jalayer, & Pour-Rouholamin, 2015; Pour-Rouholamin & Zhou, 2016). Animal–vehicle collisions (AVCs) are a serious concern since they can lead to the death of animals and serious injury and death to drivers (Bissonette, Kassar, & Cook, 2008). Also, AVCs result in increased economic costs to the individuals and agencies (Rodríguez-Morales, Díaz-Varela, & Marey-Pérez, 2013). In the state of Utah, a total cost of $778 million dollars based on vehicle damage and injury only was estimated over a 14-year study period, 1992–2005 (West, 2008). After considering the expenses for carcass removal, the cost of delay to the road users, and the value of dead animals, the estimated cost would even increase. However, a survey conducted across the United States and Canada (Clevenger & Kociolek, 2006) concluded that the most of the transportation agencies rarely consider AVCs mitigation strategies when planning or constructing the roadways. For example, the installation of median barriers for traffic safety improvement interrupts cross-highway movements of wildlife habitat. A variety of countermeasures and policies have been extensively implemented by agencies to reduce AVCs. Examples of these measures include: using swareflex warning reflectors, construction or changing underpasses or overpasses for animals, animal-proof fencing with wildlife escape ramps, increasing public awareness (specifically in peak AVC seasons), jersey barriers, setting lower speed limits, changing road slope steepness, improving lighting condition, installing animal detection systems, and even altering the animals' habitat (Hedlund, Curtis, Curtis, & Williams, 2004; Huijser, McGowen, Fuller, Hardy, & Kociolek, 2007). Challenges emerged when the implementation of the majority of animal related crash prevention measures was very costly. Also, the effectiveness of these expensive methods has been questioned. For example, McCollister and Manen (2010) discussed that, except deer, continuous fencing would not be adequate for many other species.

As a low-cost safety improvement, installing animal crossing warning traffic signs on the roadways has been, by far, the most selected

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countermeasure by transportation agencies (Haikonen & Summala, 2001; West, 2008). The goal of installing animal crossing warning signs is to increase driver awareness and advise them to be careful (Krisp & Durot, 2007). Generally speaking, of all transportation infrastructures, traffic signs are the most common visual aids that provide safer traffic environments through regulating or warning drivers (Ellis, Houten, & Kim, 2007; Romano, Voas, & Tippetts, 2006; Strawderman, Rahman, Huang, & Nandi, 2015). Transportation agencies spend millions of dollars to place new traffic signs or maintain their available sign inventory. However, the widespread placement of animal-related traffic signs may lead to a lack of attention to signs (Krisp & Durot, 2007). Previously, little research has been undertaken to evaluate the effects of installation of animal related warning signs on animal–vehicle collisions. Although there are very few definitive field studies conducted to assess the impacts of animal crossing warning signs, many agencies are unsure about the effectiveness of signs (Huijser et al., 2007). According to Huijser et al. (2007), "There is no single, low-cost solution for AVCs that can or should be applied everywhere." Thus, to address the issue of AVCs, agencies should collect detailed and accurate data, conduct in-depth data analysis, and design and develop mitigation strategies. This study aims to bridge this gap. This paper assesses the impacts of traffic sign placement on the rate of AVCs. Additionally, the attributes of AVCs occurred within or outside of traffic sign recognition distance are compared, and the effects of traffic sign type and visual condition on the animal-related crashes are discussed. Based on our findings, we propose a time and location specific data-based policy that could lead to more efficient mitigation strategies against AVCs. The proposed plan relies on combining different types of countermeasures. To accomplish the goal of the study, we linked a large scale traffic sign and crash data in the state of Utah. This paper describes the previous research regarding AVCs mitigation and discusses data sets. Then, the algorithm developed to process data is provided, and the results of data analysis are presented. Finally, the key conclusions of the study and recommendations for agencies are presented.

2. Background

A variety of factors associated with drivers, animals, vehicles, and the roadway contribute to the elevated risk of AVCs (Lao, Wu, Corey, & Wang, 2011). Previous studies showed that AVCs are not randomly distributed and the locations of AVCs are predictable (Gonser, Jensen, & Wolf, 2009). Thus, it is important to identify the contributing factors to the occurrence of animal–vehicle collisions and design countermeasures against collisions. Conn, Annest, and Dellinger (2004) discussed the importance of providing drivers with more reaction time to a potentially dangerous situation or keeping animals from entering the roadway in mitigating AVCs. Landscape structure (e.g., proximity to water or vicinity to highly productive vegetation), is a significant indicator of AVC occurrence (Found & Boyce, 2011). Animal population density is a factor contributing to AVCs (Gkritza, Baird, & Hans, 2010). Also, the time of day and day of the week are important to the rate of AVCs. At the period of animals' highest peak of activity, the likelihood of AVCs is increases. During the breeding season, an increase in the number of AVCs is also expected (Hedlund et al., 2004). Thus, the season is another important factor. A study discussed the association between speed limit and the risk of AVCS in darkness (Sullivan, 2011). The consequences of animal-related injuries among agricultural households were quantified by (Erkal, Gerberich, Ryan, Renier, & Alexander, 2008). A study discussed that traffic volume and vehicle speeds are not highly correlated with AVCs though (Gonser et al., 2009), while the other identified them as significant factors (Found & Boyce, 2011). A spatiotemporal analysis of animal-related crashes was conducted by (Rodríguez-Morales et al., 2013).

Previously, some studies examined the safety effects of traffic sign placement. Retting, Weinstein, and Solomon (2003) and Romano et al. (2006) analyzed the crashes that occur at stop signs. A study showed violating speed limits is a significant cause of vehicular crashes, and assessed the impacts of using dynamic speed signs on such crashes (Ardeshiri & Jeihani, 2014). Also, Wu et al. (2016) quantified the effects of chevrons on the performance of drivers. The Chevron Alignment (W1-8) warning sign is a vertical rectangle that is used to improve driver performance on horizontal curves with different roadway geometries. Chevrons can be effective in reducing crashes, in particular, run-off-road crashes in curves (Zhao, Wu, Rong, & Ma, 2015). Schattler, Gulla, Wallenfang, Burdett, and Lund (2015) evaluated the effects of the placement of supplemental signs with text "Left Turn Yield on Flashing Yellow Arrow" when implementing the flashing yellow arrow signals. Their results showed great reductions in the number of crashes when the supplemental signs were present. Another study concluded that a combination of traffic signs with written text and flashing lights is very effective on speed reduction in school zones (Gregory, Irwin, Faulks, & Chekaluk, 2016). Installing a specific worded sign ("Begin Slowing Here") where a highway entered an urban area significantly reduced vehicle speeds (Van Houten & Van Huten, 1987). A driving simulator study concluded that installing wildlife warning sign and radio message to reduce vehicle speed are the most effective countermeasures against AVCs (Jägerbrand & Antonson, 2016). Al-Ghamdi and AlGadhi (2004) concluded that the installation of camel crossing warning signs could lead to the speed reduction of drivers on rural roads. Hedlund et al. (2004) stated that passive warning signs appear ineffective due to the lack of studies proving their effectiveness. West (2008) stated that drivers tend to become accustomed to animal-related signs so that signs can be mostly ineffective. A before and after study was conducted by Meyer (2006) to evaluate the effectiveness of deer warning signs to reduce deer-vehicle collisions. At the completion of the study, the results of data analysis did not prove that deer-crossing warning signs are ineffective. However, the research regarding the impacts of animal crossing warning signs on animal-related crashes is not well developed.

3. Study area

We conducted our study in the state of Utah. According to the U.S. Census Bureau data, with an overall population of almost 3,000,000 people, Utah is not a high-density state. Of all the United States, Utah is ranked 41st, with an average population density of 33.31 persons per square mile, while the national average population density is 95.66. Fig. 1(a) shows Utah's population density by county. Approximately 37% of Utah's inhabitants reside in the most populous county, Salt Lake. Rich, Piute, Wayne, and Daggett counties have less than 5000 residents. Utah's largest county is San Juan with an area of almost 7800 mi^2 (Khalilikhah, Heaslip, & Hancock, 2016). Utah's landscape is very diverse with different land cover types (Fig. 1(b)). We obtained land cover classification data from the National Land Cover Database (NLCD, 2011). Forest and shrubland dominated by trees Q5 are major land covers in Utah that provide wild and domestic animals with nutritious food sources. Focusing on the developed areas, open space and low-intensity areas (most commonly include single-family housing units) account for the majority of the total cover in Utah.

3.1. Traffic sign data

In 2012, the Utah Department of Transportation (UDOT) conducted a mobile-based data collection effort to measure traffic signs on roadways along interstates and state routes. The data collection was carried out by an instrumented vehicle driven at freeway speeds. The vehicle was equipped with a LiDAR sensor, laser systems, a position orientation system, and imaging technologies to automatically take high-resolution detailed photos from traffic signs. Khalilikhah, Heaslip, and Song (2015) details traffic sign data collection process. More than 97,000 traffic signs

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