High and Low Deer-Vehicle Collision Roadway Sections - What Makes Them Different?

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Abstract: This paper studies deer-vehicle collisions (DVCs) by examining roadway geometric and roadside characteristics in northeast Ohio. A total of 1,208 non-intersection crashes in rural highways have been investigated for three years (2001-2003), covering 173.5 miles of two-lane highways on which 46% of the crashes are DVCs. In order to find the main differences between the sections that showed high DVC rate and those with low or no crashes in the same highway, field surveys have been performed to collect necessary geometric and roadside information in support of the study. Data analysis has been performed to identify feature variables that are statistically significant in the high DVC sections.

The results of the analysis suggest that the distance between the wooded areas to the roadway, the percentage of the ditches, and the number of vertical curves are the most important factors that distinguish the high and low DVC sections. The probability of hitting a deer is three times as large if a farm is nearby. The result also shows that there is no association between high DVC and high run-off-road (ROR) crashes in the study area.

Keywords: Deer-vehicle collision (DVC), traffic safety, wooded area, roadway ditches, vertical curves, run-off-road (ROR).

INTRODUCTION

Deer-Vehicle Collisions (DVCs) are a common problem in North America causing injury or even death to travelers each year. According to the General Estimate System of National Highway Traffic Safety Administration (NHTSA), there were approximately 305,000 (5.13% of total) reported crashes that involved a motor vehicle hitting an animal on the roadway in the year of 2006 leading to $1.6 billion lost in economy [1]. NHTSA also indicates that approximately 200 human deaths result from crashes involving animals annually. Since many DVCs are not reported, Conover *et al.* [2] estimated that 1.5 million deer are killed each year in motor vehicle crashes in United States. In Ohio, there were on the average 26,000 DVCs reported annually from 2006 to 2008 [3]. Schwabe *et al.* estimated the average cost of each DVC is about $2,372 [4]. According to Tonkovich [5], traffic volume on Ohio's highways rose at an average annual rate of 3.2% between 1977 and 1994 while DVCs increased 7% each year in rural and urban areas. Although many studies have been undertaken on DVCs as a safety hazard to travelers, effective and economical methods to reduce this type of accidents are still lacking. This is partly due to the nature of complexity of DVCs that involve human, deer, and the environment; and it is also due to our inexperience in collecting and studying the corresponding data and conducting preventive experiments in the field. The objectives of this paper include finding the temporal and spatial characteristics associated with DVC in northeast Ohio, and studying the factors that increase the probability of DVCs.

LITERATURE REVIEW

Many studies have investigated the DVC problem to identify the characteristics of DVCs. Elzohairy *et al.* [6] studied motor vehicle-wild animal collision in Ontario and found that 88.7% of these collisions occurred along undivided two-way roads. Khattak [7] showed that unrestrained persons in the vehicle are more likely to be killed than the restrained persons when there is a DVC.

In the efforts of identifying characters of high DVC sites, Malo *et al.* [8] founded that road sections with high DVC rates were associated with areas having high forest cover, low crop cover, low numbers of buildings, and high habitat diversity. Bashore *et al.* [9] used nineteen habitat and highway characteristics along Pennsylvania two-lane highways to predict the probability of DVCs for each section of highways. Contrary to [8], they found that in-line visibility and non-wooded areas increased the probability of collision, and five other variables (residence, commercial buildings, shortest visibility, distance to wood land, and fencing) decreased this probability. Webb *et al.* [10] studied the deer accidents in South Carolina and concluded that time of year, time of day, and proximity to rivers are the most important factors whereas road condition and proximity to towns are not important.

Many models are also developed during the study of DVCs. Finder *et al.* [11] analyzed the data of 86 high DVC locations in Illinois. Variables were measured on aerial photographs and topographic maps within a 0.8 km (0.5 mi) radius of the road segments. A logistic regression model composed of site variables predicted that the presence of adjacent gullies, riparian travel corridors crossing the road, and public recreational land within the 0.8 km radius increased DVC probability. A countywide DVC model is developed by Knapp *et al.* [12] using a negative binomial

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regression approach. The DVC frequency model developed shows an increase in DVCs with deer population and vehicle travel; and a decrease with increased estimates of wolf population and woodland acreage. The authors suggested that multiple linear regressions cannot recognize the typical characteristics of crash data when estimating DVCs.

Other researchers not only analyzed the key factors of DVC but also presented countermeasures to reduce the number of collisions. Haikonen and Summala [13] concluded from a study of 8191 recorded DVCs in Finland that a large proportion of DVCs occurred just after sunset in some "black spots"; and suggested that drivers can reduce crash risk by lowering their speed and keeping alert for deer during the short period of the peak. They also recommend the use of variable speed limits and informing drivers of the high-risk period. Schwabe *et al.* (2002) hypothesize that DVCs are influenced by deer population, traffic density, mitigation strategies, proximity to urban area, habitat, time of year, time of day, day of week, road conditions, and weather conditions, and suggested using mitigation method and hunting regulations to reduce the deer population.

In summary, although a number of studies have been conducted to investigate the DVC problem, only limited findings are reported over factors that contribute to high DVC sections *vs* low ones on the same highway. In order to develop further understanding of the DVC problem, we conducted this study using the crash data from northeast Ohio.

METHODOLOGY

Finding the high DVC sections is essential to the study of DVC problem and ultimately the countermeasures strategies. If the number of the crashes in a section exceeds a pre-established threshold from local data, this section can be considered as a high DVC section. To identify causal factors to DVCs, we used "control sections" to compare the difference between the high and low DVC sections. The control sections are those sections with low or no DVC, and they were chosen to be located as close as possible to the high DVC sections in the same highway in order to reduce possible data biases between the two types of sections in terms of traffic, general geometric characteristics, and deer population. The data we used for the study consist of these three subsets:

- Highway geometric and traffic data
- Crashes data
- Field survey

Highway Data

The study area includes 173.5 miles of two-lane rural highways in Ashtabula County of Ohio; all of the roadways have a posted speed of 55 miles per hour. We try to choose these highways to be far away from township centers and spread them around the county. To find the high DVC sites, the highways are divided into short sections and the number of DVCs is summarized for each section. In dividing the highways, we have kept the geometric condition and traffic volume fairly uniform within the section. Experiments shown that as the section length gets shorter, the number of DVCs tends towards zero or unity; on the other hand, when the section length gets too long, the contributions of certain individual variables to the crashes will be hard to identify as they are all mixed together. Shankar *et al.* [14] used fixed length sections instead of homogeneous sections. Resend and Benekohal [15] suggested that shorter segments had an undesirable impact on the estimation model; they recommended using 0.5 miles length for two lane rural highways. Accordingly, we divided the highway into half-mile sections resulting in 347 sections. We obtained AADT and the horizontal roadway alignment data from the information service system provided by the Ohio Department of Transportation (ODOT).

Traffic Crashes Data

The crashes data were obtained from ODOT for the years 2001-2003; all the crashes were assigned to log points (miles numbers along the highway) in the OH-1 data sheets. A total of 1208 non-intersection crashes during the three-year period were used for the study. The OH-1 form contains information about many variables associated with the crashes such as:

- Type of crashes
- Where the crashes occurred: road name and start and end log points.
- When the crashes occurred: year, month, day, time.
- What was involved: drivers, vehicles, animals, roadside objects.
- Environmental conditions: weather and pavement condition.
- Crashes outcome: fatal, injury, or property damage only.

Among the 1,208 crashes about 556 crashes are DVCs (about 46.0%), which represents the largest type of crashes among all and our research is conducted based on these 556 DVCs.

Field Survey

The highway data obtained from ODOT doesn't include some important information for DVC study such as lateral clearance, roadway alignment and ditches. In order to supplement geometric and roadside information, we performed a field survey and collected the following data:

Lateral Clearance

In each section we measured the distance between the wooded area and the highway edge line for every 100 feet along both sides of the roadway using a laser range measurement tool. If the distance between the trees/shrubs and the edge of the highway is 30 feet or less, we consider this part to be a wooded subsection. The 30-foot distance is chosen based on the result of field experiments that drivers can only identify deer when it is less than 30 feet away from the roadside under the vehicle headlights. At the end of the collection process, we combined all the subsections together to get the total percentage of the wooded area for each section.

Roadway Alignment

As supplement to horizontal alignment, vertical alignment information is collected in the field. At mean time, horizontal alignment is also verified. Only those that impact effective sight distance are considered in the data analysis.

Ditches

We identified the ditches on either side of the highway by measuring their depths. If the depth of a ditch is large enough to hide a deer (e.g. five feet in most instances), we consider this ditch a possible contributing factor in the data. The ditches were measured every 100 feet and the total length is calculated to generate the percentage of ditches for each section.

GENERAL ANALYSIS ON DVC DATA

We first obtained the number of the DVC at each 0.5-mile section for the 347 sections. The results showed that DVC tend to be aggregated at certain sites. Specifically, 130 crashes or about 23.4% occurred in only 20 roadway sections which represent only 5.7% of the total roadway segments. About 80.7% of the total number of segments included only zero, one, or at most two crashes in the three-year period.

Table **1** shows the frequency of DVC distribution with respect to the light conditions. Most of the DVCs occurred in dark condition. When we also included the dawn and the dusk time (low visibility), the total DVCs are about 82% of all the 556 DVCs occurred.

Table 1. Frequency of DVC with Respect to the Light Condition

Light Condition	Number of Accidents	Percentage
Dark-No-Lights	406	73.0%
Daylight	87	15.6%
Dusk	21	3.77%
Dawn	31	5.57%
Darklighted	8	1.43%
Not Stated	3	0.53%
Total	**556**	**100%**

The data distribution in Table **2** suggests that there is a strong relationship between DVC and the light condition. Deer are more mobile at night and around sunset and sunrise leading to an increase in DVC. At the same time, it is more difficult for the drivers to see the deer crossing due to low visibility.

The above finding is also supported by Fig. (**1**). In this figure, it shows the DVC frequency with respect to the hour of the day. It is clear that most of the crashes occurred from 5 pm to 7 am. The maximum peak is around the dusk and dawn times because of the increase of deer activity and the low visibility discussed above.

Fig. (**2**) shows the deer vehicle crash frequency by month. The month of November has the highest crash frequency, which accounts for about 23% total crashes and indicates seasonality of DVCs. About 50% of the crashes occurred in three months (October, November, and December). These three months constitute the mating and hunting season for deer, which resulted in increase in deer activity and movement.

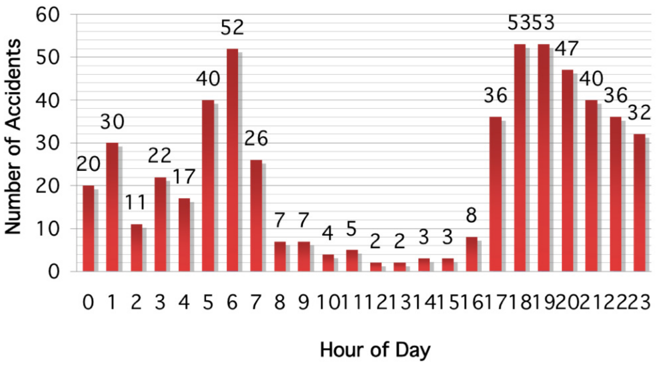

Fig. (1). DVC frequency by hour of day.

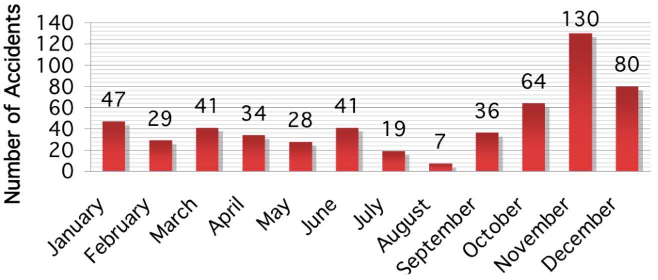

Fig. (2). DVC frequency by month.

Fig. (**3**) shows the DVC frequency distribution for each day of the week. There is little difference among them.

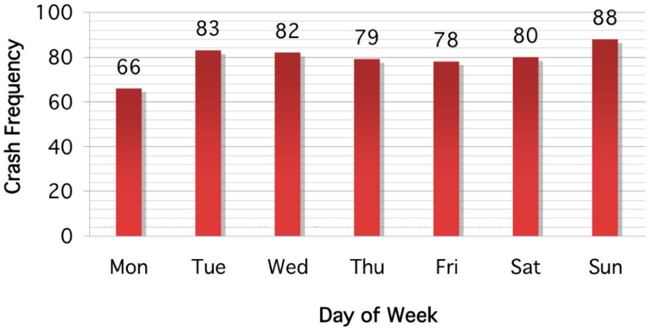

Fig. (3). DVC frequency by day of week.

Table **2** shows the DVC frequency with respect to the weather conditions. Most of the crashes (86%) are occurred under normal weather conditions, which indicate that the weather is not a major influencing factor according to our data.

Table 2. DVC Frequency by Weather Condition

Weather	Number of Accidents	Percentage
Normal	477	86%
Rain	40	7.2%
Snow	17	3.0%
Fog	16	2.8%
Not Stated	6	1.1%
Total	556	100%

Table **3** shows the DVC frequency with respect to the speed distribution of the striking vehicles. About 62% of all vehicles struck the deer with speed between 46-55 MPH, and 26.6% with speed between 36 and 45 MPH. From these data we can see that about 97% of the drivers were driving under or at the posted speed limit, thus speeding is not a major contributing factor to DVC in two lane highways.

Table 3. DVC Frequency by Reported Speed

Speed Estimated	Number of Crashes	Percentage
Not Stated	5	0.90%
26-35 MPH	42	7.54%
36-45 MPH	148	26.60%
46-55 MPH	343	61.70%
56-65 MPH	16	2.90%
66-75 MPH	2	0.36%
Total	556	100%

The above discussion shows that DVCs are more likely to occur under low visibility during certain months of the year. Our purpose is to find the most likely factors associated with high DVC sections. Therefore, we need to conduct more detailed analysis of the crash data.

FURTHER ANALYSIS ON DVC DATA

Identification of High DVC Sections

To distinguish the road sections with high DVC rate from other sections, we used the Poisson distribution, a statistical method used to find the probability of an occurrence of discrete events (Devor2006). The probability of crashes has been identified by comparing the actual number of crashes with the expected number of crashes. The likelihood of crashes for each road segment can be found by using the following formula:

$$P(x) = \frac{e^{-\lambda}\lambda^{x}}{x!}$$

where

$P(x)$: the probability of a 0.5 mile road section to have x number of crashes.

λ: the expected number of crashes per 0.5 mile (the average number of crashes per section)

Table 4. DVC Probability Distributions

Number of Crashes	Probability
0-1	0.522
2-4	0.451
5 or more crashes	0.027

It can be seen from Table **4** that the probability of having four or fewer crashes in three years period is 97%, and the probability for a section to have five or more crashes is only 2.7%. Using the 95% significant level, we defined a section with five or more crashes as a high crash section and found 22 such sections in the study area. Although other sections with lower DVC rates may contain useful information, we focused on those 22 “exceptional” cases and hope to better identify the causes of DVC crashes. To assist in the analysis, we have selected 22 control sections (low DVCs) from the adjacent sections to the crash sites.

Evaluation of Factors with T-Test

The Two-Sample T-Test was used to perform a hypothesis test and compute a confidence interval of the difference between two population means:

$$t = \frac{\mu_1 - \mu_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where

μ_1, μ_2: the mean values of the two samples

n_1, n_2: the samples sizes

s_1, s_2: the sample standard deviations

H_0 (null hypothesis): $\mu_1 = \mu_2$ *vs* H_1 (alternative): $\mu_1 \neq \mu_2$

The purpose of the test is to check if there is any significant difference in the mean values between the high and low DVC sections with respect to the contributing (independent) variables. If the difference in the means is statistically significant (at 0.05 level) then we can consider the difference to be significant between the two groups. The results are shown in Table **5**.

Table **5** shows that the difference in AADT between two groups is not significant. The percentage of the wooded area close to the highway edge is the strongest variable separating high verses low DVC sections. The percentage of the ditches in the section is the second most important variable in identifying high DVC sites. The high DVC sections have more ditches than the low sections. This could be explained by the potential hidden places provided by ditches will prevent the deer observed by the drivers. The third significant variable is the number of vertical curves that impact sight distance in the sections. The number of horizontal curves and number of houses in the section are not significant factors.

Relationship with Run-Off-Road

Some references stated that sometimes drivers try to avoid the deer and end up with Run-Off-Road (ROR) crashes [16]. Accordingly, we investigated whether this assertion is supported by our data. We identified the ROR crashes from the data and used the correlation coefficient (Pearson-r) to draw inferences about the strength of the relationship between the two categories. For the two variables x and y, the correlation factor is:

$$r = \frac{\sum (x-\bar{x})(y-\bar{y})}{(n-1)S_x S_y}$$

where

r: the Pearson’s sample correlation

$\bar{x}$, S_x: the sample mean and standard deviation for the first sample (DVC sections).

Table 5. Results of Group Mean Comparison

Variable	High DVC Sites Mean±SD	Control Sites Mean±SD	P-Value	T-Value
AADT	4123±1138	3533 ± 1069	0.0900	1.69
Percentage of Wooded Area	39.2 ± 27.6	12.7 ± 15.8	0.0008	3.74
Number of Ditches	1.45 ± 1.32	0.650±0.933	0.0330	2.22
Number of Vertical Curves	0.450 ±0.686	0.100 ±0.308	0.0470	2.08
Number of Houses	11.95±8.55	15.71±9.41	0.1100	-1.65
Number of Horizontal Curves	0.200±0.410	0.250±0.444	0.6400	-0.47

$\bar{y}$, S_y: the sample mean and standard deviation for the second sample (ROR sections).

Based on the analysis of 347 sections, the correlation coefficient r is 0.368 with P-value of 0.11, which indicates there is no significant correlation between the DVC sections and ROR sections in our study.

Farm Locations

Since farms along the highway grow crops and there may be a need to feed other animals on the farms, they could become a food source for deer and attract them. In order to find if there is any relationship between the farms locations and the high DVC sections, we conducted field trips to count the number of the farms in the DVC sections. Since the data contains either yes or no information, we used the logistic regression to find the probability of having DVC in the section if there is a farm.

The detailed mathematical model and application is not described here. The result of the logistic regression analysis showed that in high DVC sections the probability of a DVC is 77% if there is a farm in the section, compared with the probability of 27% if there is no farm in the section. It shows that the risk factor of hitting a deer is nearly three times as large if there is a farm in the section compare to the sections without any farms. Realizing that such finding could be generally true, we also want to mention that it may be not supported in other studies as it depends on how available deer can get food without coming to the farms.

Drivers Area Familiarity

We investigated the familiarity of the drivers with the area where the DVC occurred by locating how far away the drivers who involved in DVC live from the DVC locations. The results showed that about 85% of the drivers live within 10 miles from where they hit a deer and about 10% live within 30 miles from the location where they hit a deer. Whether this finding indicates local residents tend to hit deer more often (perhaps due to inattention?) or this simply reflects most people have a trip length of less than 10 miles, a further investigation is needed.

CONCLUSION

DVCs are a common problem and they cause safety concerns for drivers on rural roads. This paper intends to contribute to the limited number of studies existing today on DVCs, especially in an effort to identify causal factors and help develop countermeasures to the crashes. This study found that most of the DVCs occur in the months of October, November, December, and a majority of them are under normal weather and dry roadway conditions. Since deer activities seem to concentrate at nighttime, the low visibility increases the probability of the crashes. Analysis showed that AADT difference between the low and the high sections is not a significant contributing factor, whereas the percentage of the wooded area close to the roadway is the most important factor in separating the high and low DVC sections. There is no correlation between the high DVC locations and high ROR locations in our study, and a logistic regression study shows that in high DVC sections, the probability of hitting a deer is about three times as high if there is a farm in the section, compared to a section without a farm. About 85% of the drivers live with 10 miles where they hit a deer, but we do not know if it is result of a coincidence and further work is needed to develop better understanding.

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