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FINAL REPORT

ASSESSING THE EFFECTIVENESS OF DEER WARNING SIGNS

Eric Meyer

The University of Kansas
Lawrence, Kansas

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In Kansas, the most common countermeasure is the deer warning sign, even though its effectiveness is suspect, and accident records have traditionally been used to identify locations for installation. This study examined the effectiveness of deer warning signs by a comparison of crash rates before and after sign installation. Deer-vehicle crashes were then studied with respect to an array of potential predictor variables with the intent of developing a predictive model for deer-vehicle crash rate that could be used to prioritize segments for mitigative action. Two separate analysis techniques were employed: Principal Component Analysis (PCA) followed by Multiple Linear Regression, and Logistic Regression. Principal Component Analysis (PCA) was used to reduce colinearities prior to applying linear regression. A total of 45 predictor variable were considered, 20 of which required field data collection. Data was collected for 123 segments spanning 15 counties in Kansas. One hundred one data points were used for model calibration and 22 data points were used for model validation.

Neither analysis approach was able to generate a model with sufficient predictive capability to justify its use in prioritizing segments, but the analysis results provided some helpful insight into the nature of deer-vehicle crashes. The insufficiency of the database to yield a predictive model is in itself a valuable realization. Models developed with lesser data collection efforts must be held suspect unless they are supported by a strong validation effort.

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Final Report

Prepared by

Eric Meyer*
University of Kansas

A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

and

UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
LAWRENCE, KANSAS

April 2006

*Currently affiliated with Meyer Intelligent Transportation Services

PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

The construction of roads and highways across the country to support the increasing transportation demand invariably invades the habitats of many species of wildlife. Animal-vehicle collisions are a concern across the country, especially in states like Kansas, where most of the highway mileage is rural. The public concern about deer-vehicle crashes in Kansas resulted in the passage of Kansas Statute 32-966, which in turn resulted in the initiation of this study by the Department of Transportation.

A Federal Highway Administration (FHWA) study indicates that animal-vehicle crashes increased 69 percent between 1985 and 1991 (Hughes et al., 1996). There were 500,000 animal-vehicle crashes reported nationwide in 1996 including 110 human fatalities. In the year 2000, there were 750,000 animal-vehicle crashes, including 120 fatalities (McGowen, 2001).
Deer are by far the big-game animal most frequently involved in crashes, with an estimated $8 million being spent across the country each year just to collect deer carcasses (Ulberg and Albert, 1997). It is estimated that the annual cost to society for these fatalities and injuries is $200 million. Typical property damage from a crash with a deer is over $2,000, and there is an additional societal cost of between $700 and $1,000 resulting from the loss of the deer. (TransSafety, Inc., 1997).

In 1999, Michigan recorded 67,640 deer-vehicle crashes, a 44.6% increase since 1989. Wisconsin recorded 47,555 deer-vehicle accidents in 1999—a 63.4% increase from the number in 1989 (QDMA, 2001). Twenty-one percent of the crashes on two-lane rural roads in the states of Illinois, Maine, Michigan, Minnesota and Utah are animal related (HSIS Summary Report, 2001).

Kansas Accident Records System (KARS, 2002) data show that among all types of accidents in Kansas, *Collision with Animal* is noted as the third most frequent category. In 2002 animal-vehicle crashes accounted for 13% (10,041 out of 77,419) of all accidents, as shown in Figure 1.

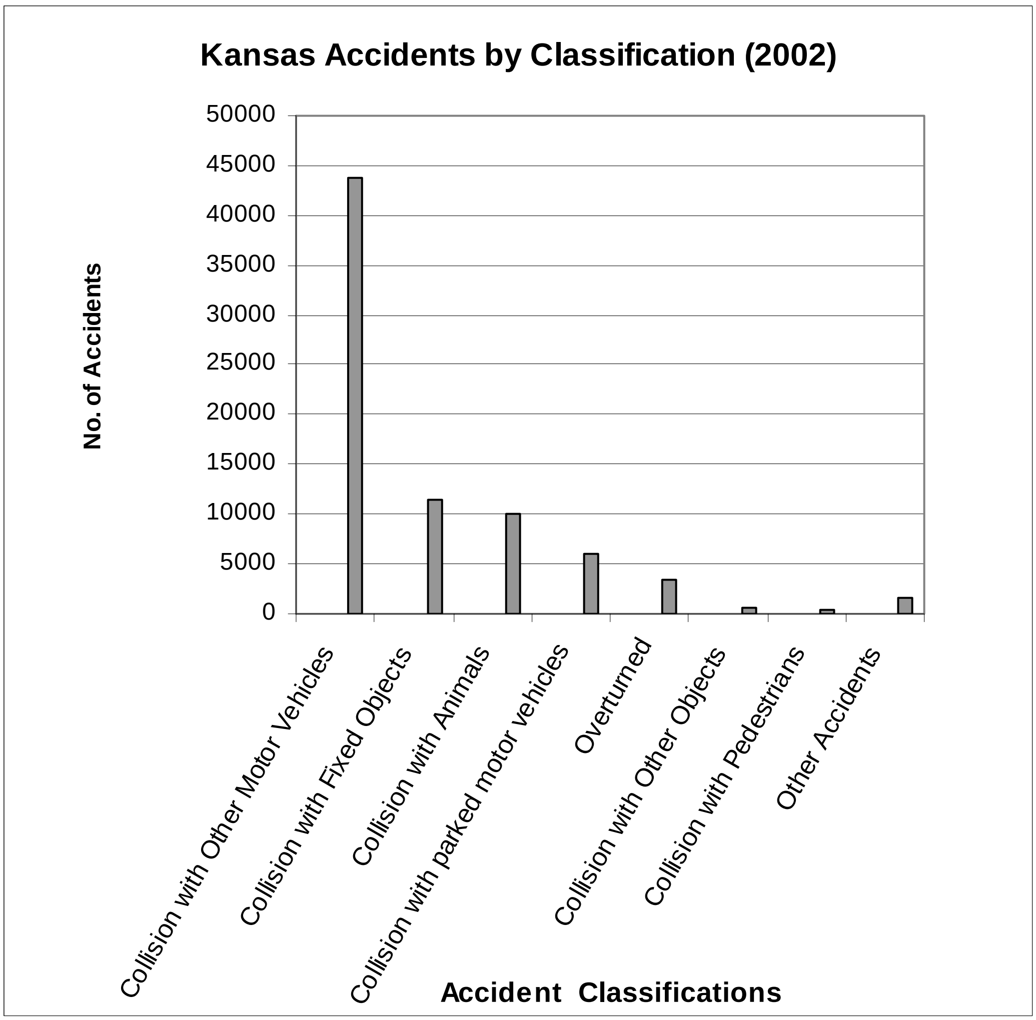

Figure 1: 2002 Traffic accidents by classification (KDOT, 2003)

Deer-vehicle crashes caused one death and 287 injuries to people in Kansas in the year 2002, whereas only 66 people were injured in deer-vehicle crashes in 1980. KARS shows a consistent increase in deer-vehicle collisions between the years 1980 and 1999, as shown in Figure 2. Of all the animal-vehicle collisions occurring in Kansas, those involving deer pose the greatest concern because of the combination of severity and frequency of crashes.

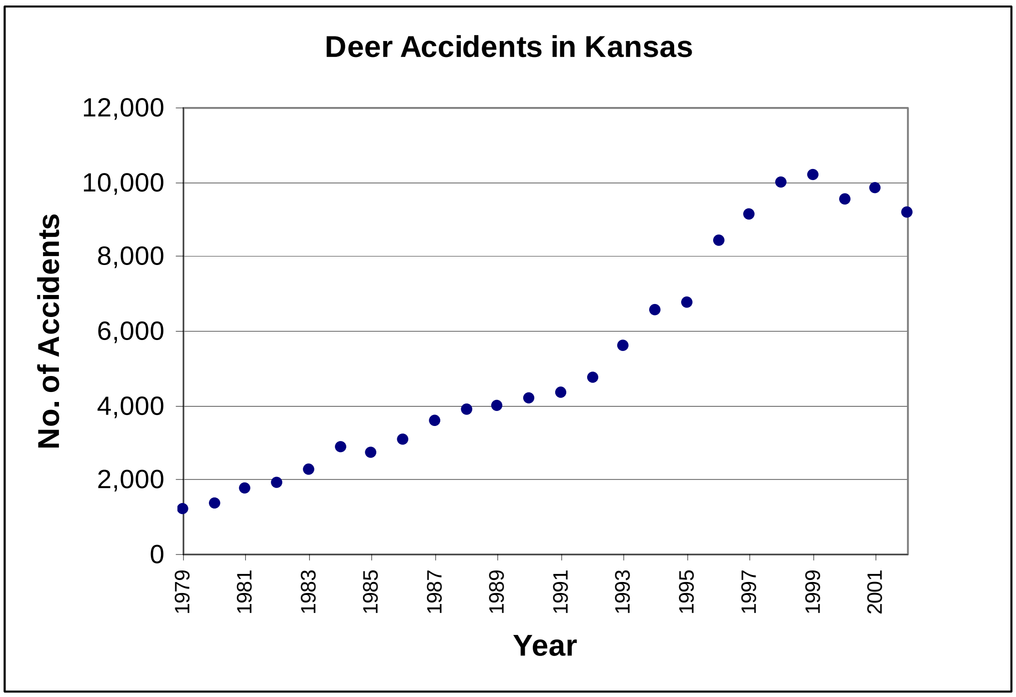

Figure 2: Kansas deer accident trends (KDOT, 2003)

1.1 Problem Statement

The need for countermeasures for deer-vehicle collisions implies the need for a comprehensive approach to identify and prioritize roadway segments. A systematic approach is needed to identify high-risk segments of the highway system so that the expense associate with implementing countermeasures can be justified prior to installation. Since the countermeasures can be expensive, the need for prior identification of high-risk locations is critical. Prior identification of high-risk segments may be useful at a preliminary highway planning level, including the process of route selection. It may also be beneficial in planning the distribution of emergency medical response resources, allowing the response time to high-risk segments to be considered along with other factors.

Countermeasures can be expensive to design, construct, install and maintain, therefore, it is not cost-effective to implement countermeasures on all highway segments. Moreover, frequent installation of driver-oriented countermeasures, such as deer-warning signs, can decrease a measure's credibility.

In Kansas, accident records have traditionally been used to identify locations where deer collisions occur most frequently, and warning signs or other mitigating measures have been installed as appropriate. However, the sites are not generally reassessed at a later date to determine if the signs are still needed or if the countermeasures were effective. Figure 3 shows a deer warning sign in Kansas that warns drivers to be cautious for the next ten miles of driving.

Figure 3: A deer warning sign in Kansas

The accident records can only be used to identify a high-risk location after many accidents have already occurred, and, unfortunately, there is currently not a way to identify high-risk segments proactively, before they become high-accident segments. Each year, additional segments are newly identified as high-accident segments. This emphasizes the importance of identifying high-risk segments before they become high-accident segments. A better understanding of the parameters most closely associated with deer-vehicle accident probability could allow agencies to reduce the number of accidents by implementing countermeasures proactively. Additionally, a methodology is needed to compare the relative risk of segments so that they can be prioritized and countermeasures can be applied as cost-effectively as possible.

The literature shows that only a limited number of studies have been performed by wildlife biologists and geography experts to identify high-risk locations. Those studies are mostly GIS-based and consider mainly land use, animal habitat use and migration patterns. Limited consideration has been given to engineering parameters. Moreover, each of these studies has been performed based on a case-by-case basis. Therefore, the applicability of the methodology to other regions has not been verified.

In January 2000, several agencies including the Federal Highway Administration (FHWA), the Western Transportation Institute in Montana, the National Forest Service, state departments of transportation and environmental groups formed a new sub-committee of the Transportation Research Board (TRB) to promote the study of transportation features, designs, and maintenance practices with respect to their impact on traffic safety and ecology (Subcommittee on Mitigating Animal Vehicle Crashes: A3B05-2). An early concern of the sub-committee was that although other conferences provide a forum for the discussion of animal-vehicle crashes (e.g., the International Conference on Wildlife Ecology and Transportation, or

ICOWET), not a single paper on this subject was presented at the 2000 annual TRB meeting. According to McGowen, "This suggested a lack of interest or awareness of the topic on the part of the U.S. transportation profession despite the raking of animal-vehicle crashes as a major concern by the public." (McGowen, 2001).

1.2 Purpose and Approach

This study examines the effectiveness of deer warning signs and makes recommendations regarding their use, and broadly examines the potential contributing factors to deer-vehicle crashes. The general approach comprised two separate studies. First, crash rates before and after the installation of a deer sign were compared. Second, a substantial data collection effort was undertaken to build a database of segment characteristics that was as comprehensive as possible (with respect to the characteristics included). The database contained information on 128 highway segments. Once compiled, two statistical approaches were employed to analyze the data. Principal components analysis (PCA) was applied to the data to provide information about the relationships between parameters and the relative influence of parameters on crash rates. Logistic regression was also performed on the data to attempt to develop a usable model for assigning crash risk indices to segments to help prioritize them for the application of deer-vehicle crash countermeasures.

1.3 Scope and Limitations of the Study

The study was performed in rural and suburban areas of the selected 15 counties in the state of Kansas. A majority of the segments were chosen from the rural areas. These counties were located in the region, where high deer population was present and high deer-vehicle accident rates have been observed.

1.4 Deer Biology

Two species of deer are native to Kansas. White-tailed deer (*Odocoileus virginianus*) live all over the state but are most common in the eastern two-thirds. Mule deer (*Odocoileus hemionus*) live mostly in the western part of the state. Both types of deer are shown in Figure 4. The mule deer is slightly larger than the white-tailed deer. Its tail is tipped with black and is white or brown elsewhere. The antlers of the male branch dichotomously. The white-tailed deer has smaller shank glands, while the mule deer has long shank glands. The white-tailed deer's tail is longer than that of the mule deer, brown above, white below, and fringed with white around the edges. The ears of the white-tailed deer are relatively small compared to those of the mule deer, which gets its name from its mule-like ears. The antlers of the white-tailed deer have vertical undivided prongs arising from a main beam, whereas mule deer antlers fork or branch from a prong. (Donald, 1964) In Kansas, mule deer exist primarily in the western third of the state, while white-tailed deer occur most commonly in the eastern half of the state. Western Kansas terrain is flatter than that of the eastern Kansas, and there is less wooded area. Roads are straight with long sight distances, and the deer population is lower than in the eastern areas, where the white-tailed deer reside. As a result, the vast majority of deer-vehicle crashes in Kansas pertain to white-tailed deer. Because this report is concerned with mitigative measures, the remainder of this report will focus on the white-tailed deer which represent the vast majority of deer-vehicle crashes in Kansas and are the primary concern with respect to most of the segments likely to be considered for preventive measures.

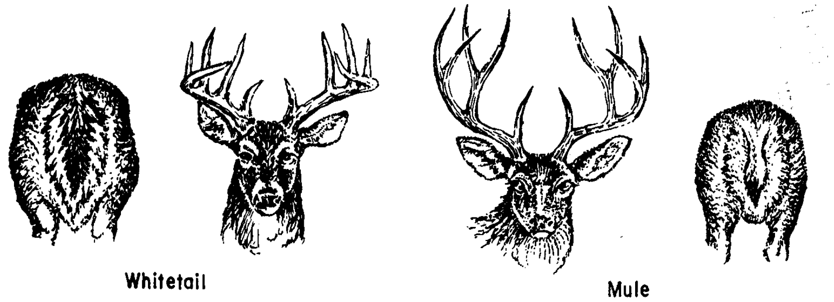

Figure 4: Two types of deer in Kansas (USDA, 1979)

1.4.1 White-Tailed Deer

The white-tailed deer have the following characteristics:

- medium size (average buck, 150 pounds; average doe,100 pounds)
- antlers present only in males, large and forked
- face is long and narrow
- long tail with a stark white underside, which is generally upraised when the deer moves away.

A white-tailed deer is shown in Figure 5.

Figure 5: White-tailed deer

1.4.2 Size and Weight

The size and weight of deer depends on the quality and quantity of the available habitat. The adult weight of bucks typically ranges from 90 to 300 pounds, averaging about 150 pounds; does weigh 70 to 175 pounds, averaging about 100 pounds (USDA, 1979). Bucks reach maximum weight in about five or six years. Does reach maximum weight in about four years (Scientific Hunters Division, 1995).

1.4.3 Diet

Deer are browsers, meaning that they forage on a variety of plants, including parts of shrubs and trees. Their specific diet depends on the season and the area. Figure 6 shows the seasonal diet variation.

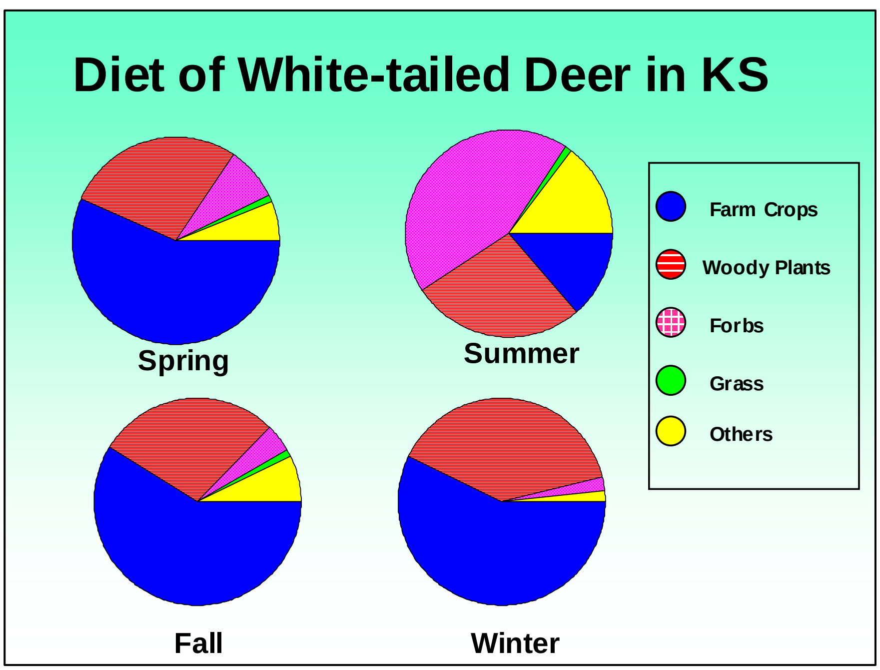

Figure 6: Seasonal diet variation of white-tailed deer (KDWP, 2002)

The movement patterns of deer are typically governed by the availability of the food in the area. This can depend on the local land use. A deer may eat one hundred different species of plants in Kansas but show particular choice for the most nutritious and palatable foods. Usually fifteen to twenty species make up the bulk of the annual diet (USDA, 1979).

In Kansas, farm crops (particularly corn, sorghum, winter wheat, alfalfa, and soybeans) comprise the bulk of the diet, except in summer, when green forbs become predominant. Woody plants such as coralberry, green brier, apples and oaks are also important. Deer commonly browse or graze grasses in the absence of preferred or more nutritious sources. In an emergency, deer may depend on survival food sources such as buds and twigs and fruits of woody vegetation.

1.4.4 Hearing and Vision

Deer have a keen, well developed hearing system. Deer also have good eyesight, but are best adapted to detect movement, often overlooking stationary objects. This may be a significant factor in deer collisions in that when deer are on the pavement, the headlights of an approaching vehicle may obscure the deer's perception of depth while otherwise moving very little relative to the deer. As a result, the deer may not be frightened and may not move at all.

1.4.5 Habitat

Deer are often classified as forest dwelling animals, but the primary requirement for deer habitat in Kansas is suitable permanent cover. Deer thrive in ecotones on forest edges. White-tailed deer survive best in habitats with diverse food and cover types. In Kansas, deer are often found along stream courses with associated woody cover. Bushy undergrowth and ungrazed under-story are also preferred (USDA, 1979). Woody cover provides the best whitetail habitat, though it is not essential for their survival. Grasslands are suitable where the topography provides concealment, especially when associated with marsh vegetation and wetlands. Croplands provide cover from July through October or November. Deer sometimes use croplands for extended periods, but they must return to permanent cover for protection from weather and predators after crops are harvested (NGPC, 2003). Figure 7, Figure 8, and Figure 9 show density distributions from three different sources.

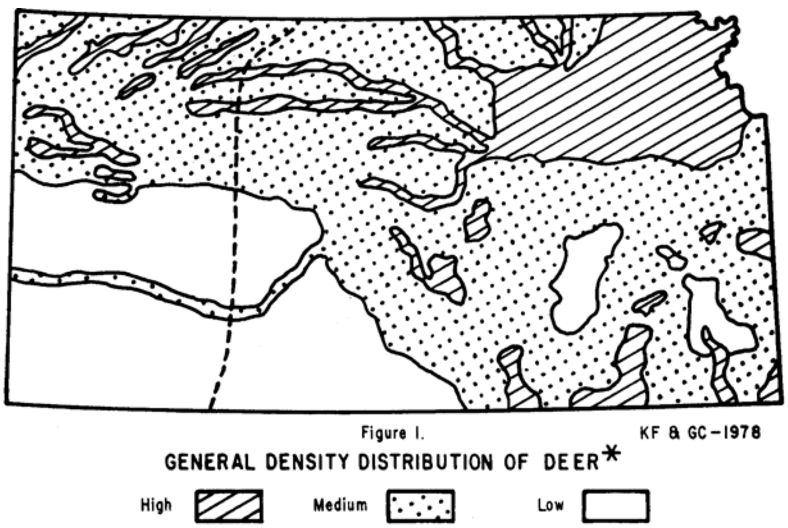

Figure 7: White-tailed deer density in Kansas (USDA, 1979)

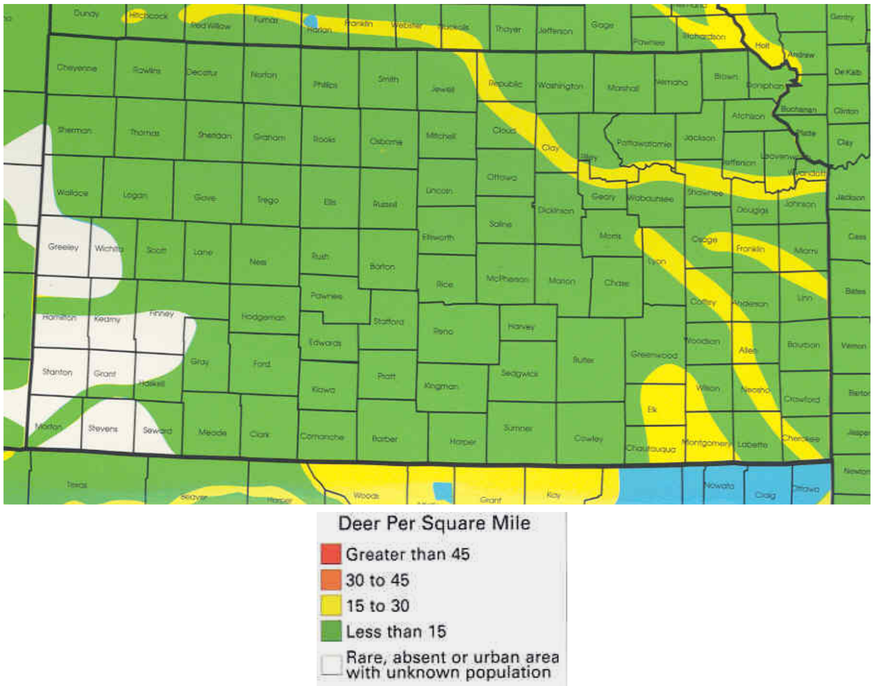

Figure 8: White-tailed deer density in Kansas (Scientific Hunters Division, 1995)

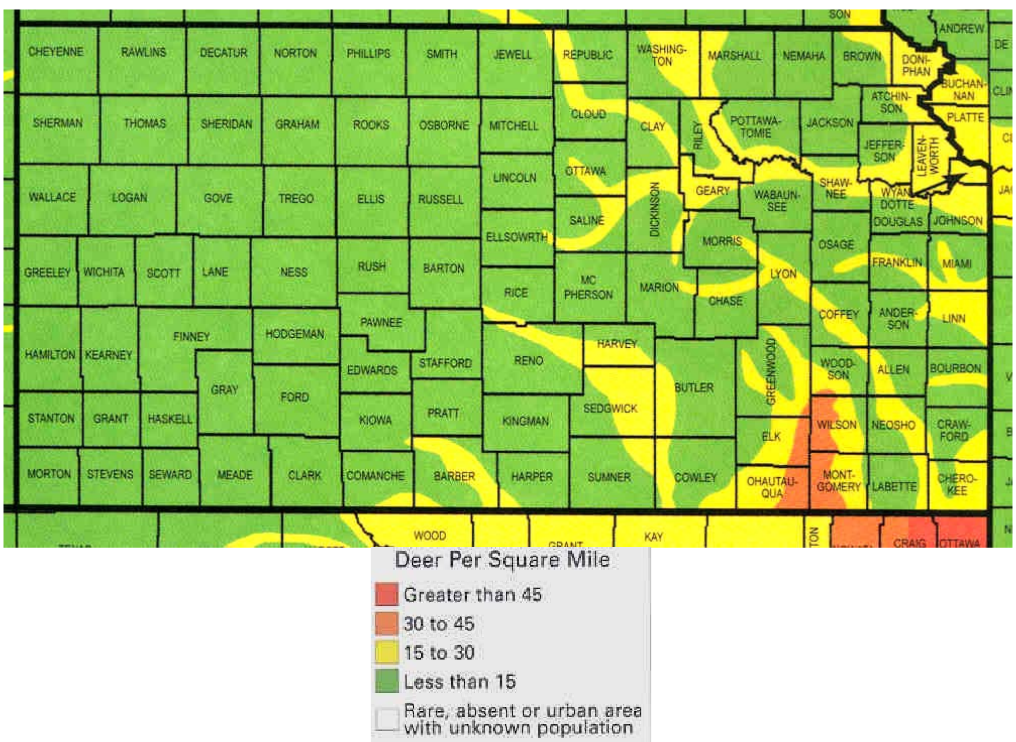

Figure 9: White-tailed deer density in Kansas
(Quality Deer Management Association, 2001)

Deer populations have changed dramatically since the first explorers entered the area, known as Kansas. Deer management has also changed. The first explorers to the region considered the large population of deer and other species, such as pronghorn, bison, elk and turkey, a gift of nature to the people as a food source. These resources were vast, but quickly over-exploited. Two important points were learned from those experiences. First, the habitats of Kansas are capable of supporting a large deer population, far larger than the level of current deer herds. The second lesson of the settlement era was that man, with modern hunting weapons and sufficient motivation, could over-exploit the deer resource. The result of that over-exploitation proved to be the loss of that resource for people to enjoy and use for many years (KDWP, 2002). In the early 1800's there were numerous deer in Kansas. Over-exploitation caused deer to be almost extirpated in the 1930s. After the 1960s there was an accelerated growth in deer population.

1.4.6 Deer Population Trends

Deer population in Kansas increased over the past few decades. The following reasons for this increase have been identified by the Kansas Department of Wildlife and Parks (KDWP, 2002):

1. Habitat Changes: The Conservation Reserve Program (CRP) made excellent fawning and escape cover, thus increased the survival rate of deer. The CRP program was designed to remove highly erodible lands from crop production and to plant them with cover that would reduce erosion. Most of that land in Kansas was planted with native tallgrass species like big bluestem, indiangrass and switchgrass. One of the requirements of the program was that the land could not be grazed or the grass could not be cut for hay. These species of grass when left ungrazed and unmowed tend to grow tall enough to allow deer to bed in them and be unseen by hunters and predators. The security that deer had in those areas resulted in higher survival rates, especially for fawns.

2. Years with high rainfall, and low disease: periodically a disease called EHD affects deer, which leads to a high mortality rate. The last severe outbreak was in the 1980s.

3. Change in types of permits issued: A reduced number of antlerless permits caused fewer deer to be killed by hunters.

While the deer population has been increasing overall, the last few years have brought a reversal of that trend. The reason for the decline in deer related accidents in Kansas in recent years is the aggressive program that KDWP instituted to lower the deer population (KDWP, 2002). That program included the following:

1. Authorizing and increasing the number of hunting permits,
2. Increasing the number of days that hunters could pursue deer,
3. Adding an antlerless-only season, and
4. Allowing landowners to kill deer outside the normal season dates. That change in and of itself had little effect on the deer population, but it may have encouraged landowners to allow more hunters to use their property for deer hunting.

1.4.7 Seasonal Movements of Deer

Deer have regular seasonal movements or seasonal migration. Deer move most frequently and for the longest distances during the months of May and June and especially in November and December. In late spring does may travel in search of fawning sites. Greater distances are traveled by yearlings on their own for the first time. Travel increases after the fall harvest, as deer leave croplands and begin their mating activities. Figure 10 and Figure 11 depict typical seasonal movements of deer. The dotted area indicates summer habitation of deer.

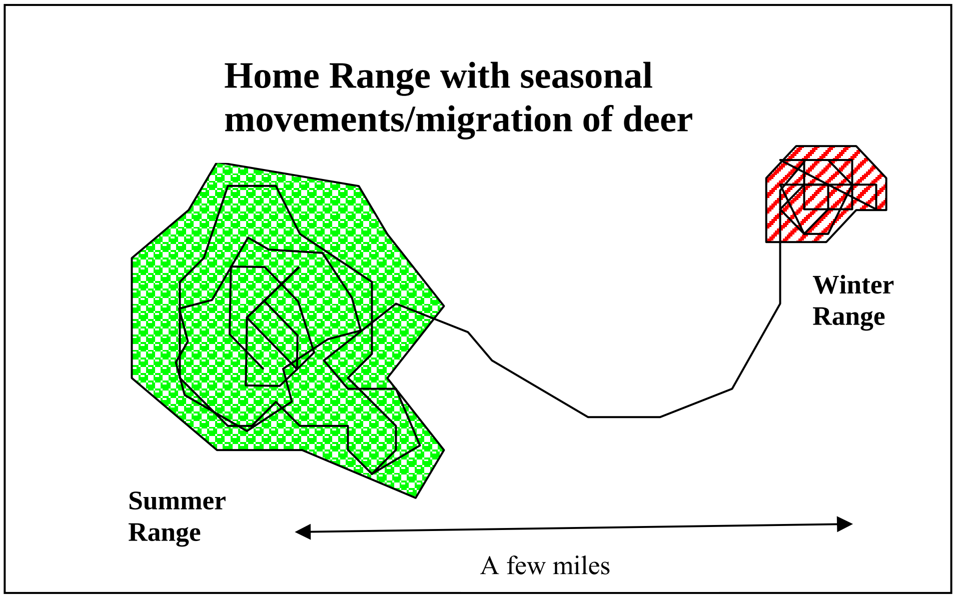

Figure 10: Seasonal deer movement

Deer move primarily within their home range during the summer. This home range is determined by a number of factors, including the availability of food and suitable cover. The hatched area indicates the winter yarding area.

In some areas where cover is extensive and other requirements are met, a deer may live its entire life within a few square miles. Sometimes, however, deer travel very long distances. Recoveries of 23 white-tailed deer tagged in the sand hills of Nebraska showed an average movement of 38 miles from the point of tagging, with two extremes of 125 and 137 miles (NGPC 2003).

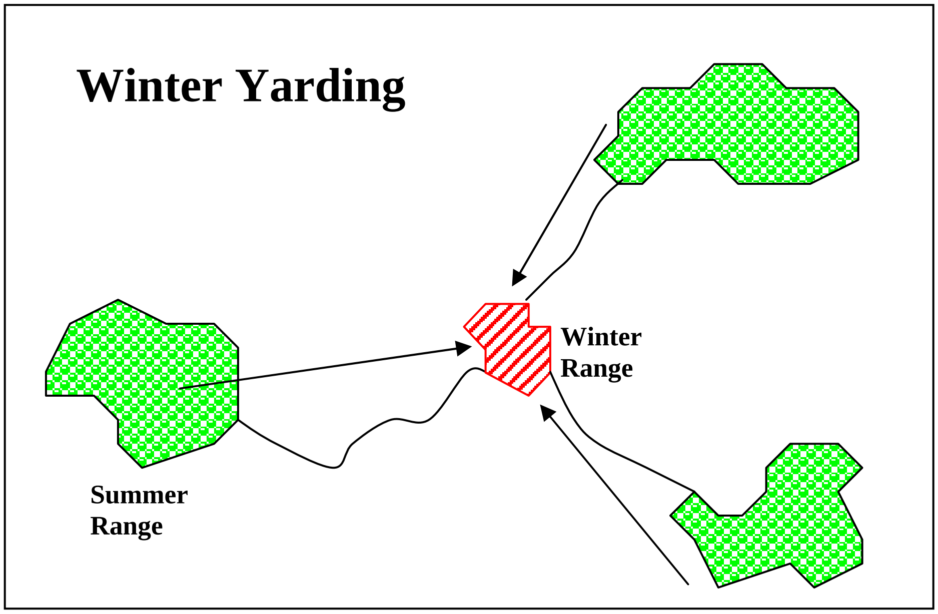

Figure 11: Winter Yarding

The seasonal movements sometimes cause deer to encroach on highways and occasionally to cross the roadway, oblivious to the associated risks.

1.4.8 Natural Deer Behavior and Deer-Vehicle Accidents

Patterns in deer-vehicle accident frequencies indicate a close relationship between the accident frequencies and the behavior patterns of deer in Kansas. Figure 12 shows a high deer-vehicle accident frequency during the month of November. November is the rutting season for deer, and the most frequent movement takes place during this period of the year. Figure 13 shows a sharp rise in breeding activity during the period of November 1-15. Males are also much more careless during rut, exhibiting more risky behavior than during other times of the year. Smaller males also flee from larger more dominant males.

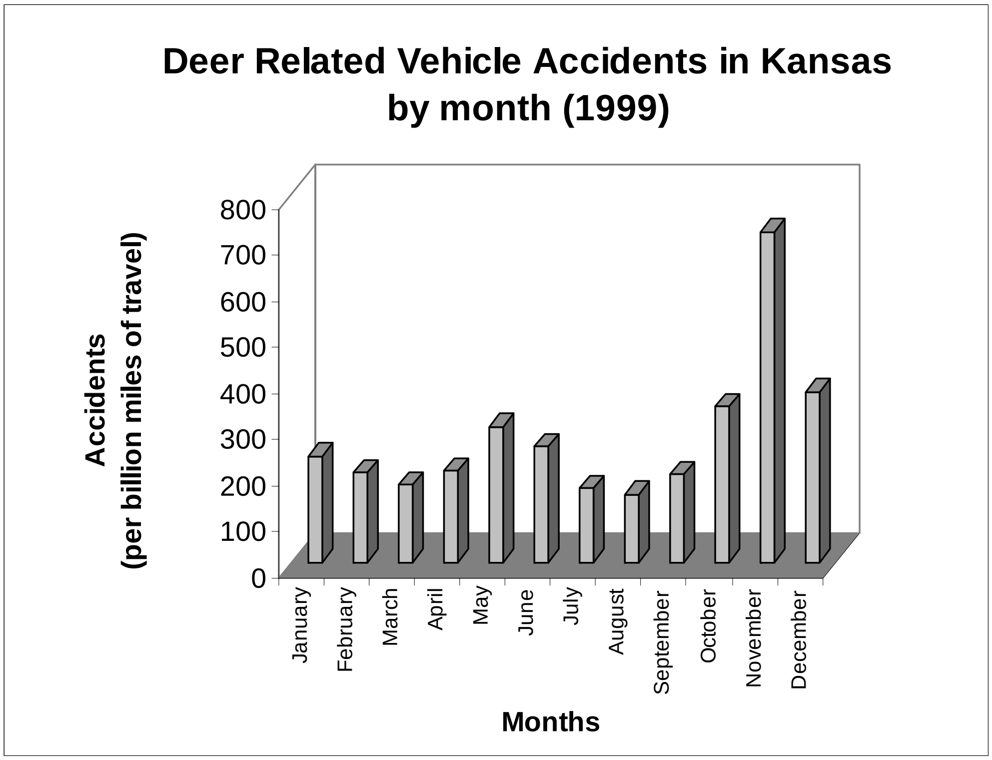

Figure 12: Deer-vehicle accident frequency in Kansas (KARS, 2002)

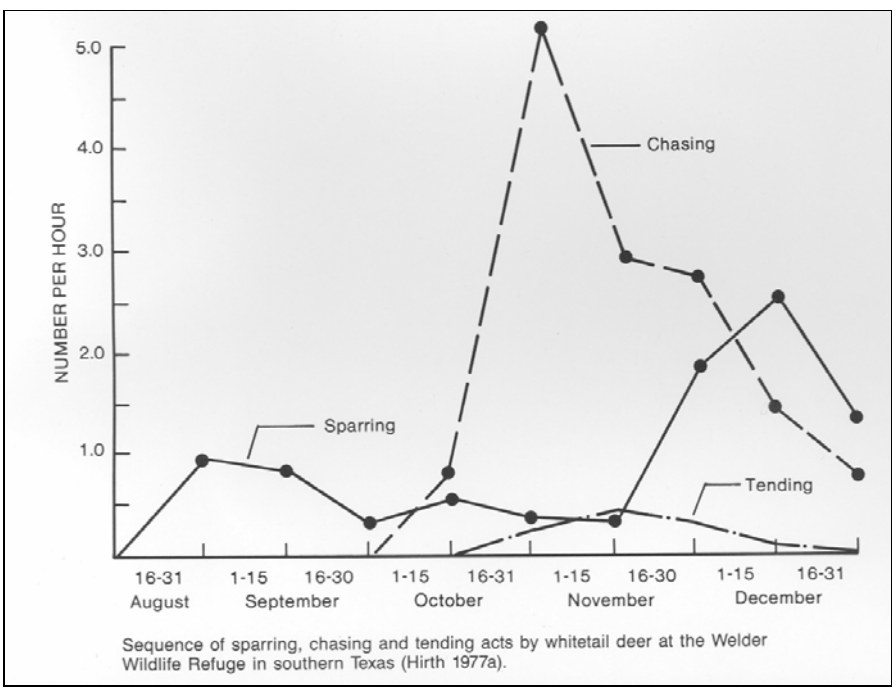

Figure 13: Fall breeding activity (Scientific Hunters Division, 1995)

Figure 14 shows that the accident rates are highest between dawn and dusk. These are adjusted values with respect to the vehicle-miles of travel in Kansas. The actual accident frequencies during dawn and dusk are even greater, as shown in Figure 15. The early morning peak occurs just before sunrise (approximately 25 min. before) and the evening peak occurs just after the sunset (approximately 30 min. after). The reason behind this increased frequency can be attributed to the increased movement of deer near dawn and dusk.

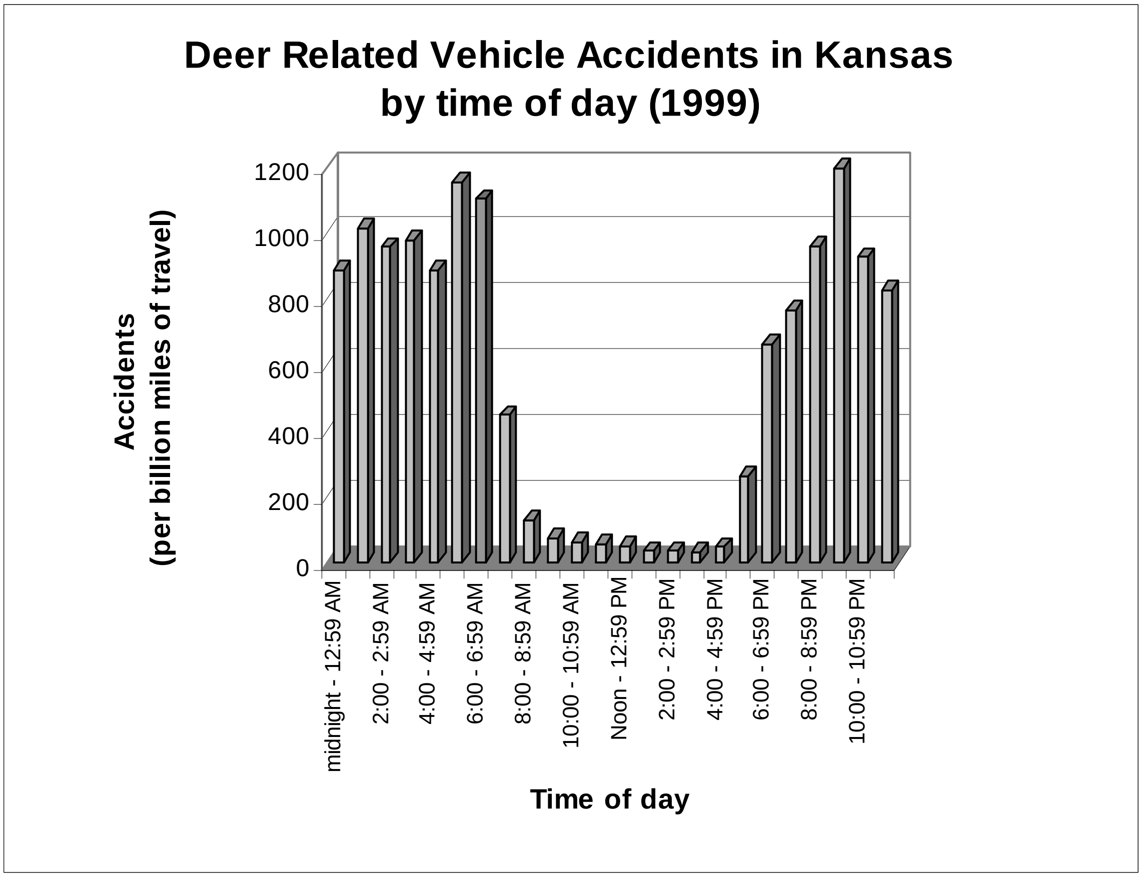

Figure 14: Deer-vehicle accidents by time of day (KARS, 2002)

It is important to note from Figure 16 that the dawn and dusk activities of white-tailed deer are much greater during the fall than that during the summer. Another notable aspect is that the peak activities are much greater near dawn during the fall season than at the same times during summer.

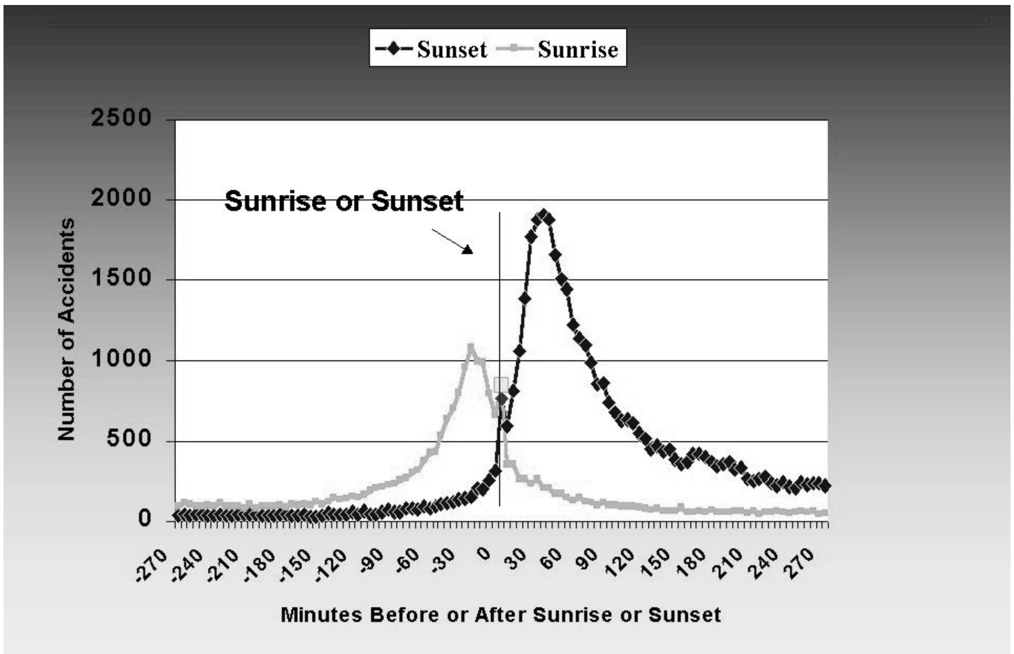

Figure 15: Deer-vehicle accidents near sunrise or sunset (1990-99) (Courtesy: KDWP)

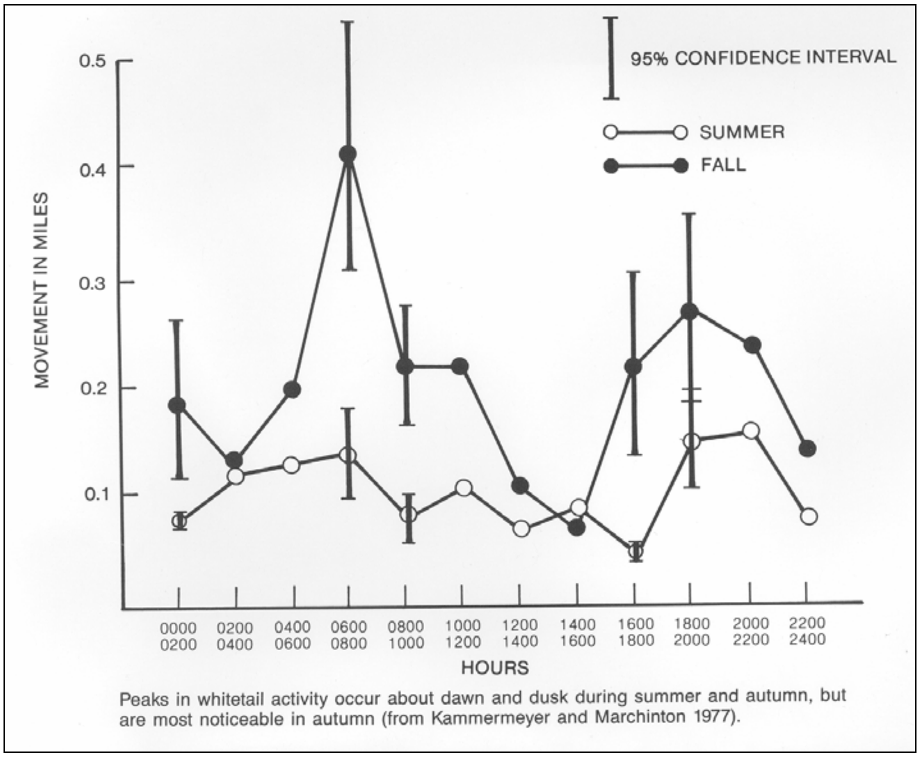

Figure 16: Daily activity of white-tailed deer (Scientific Hunters Division, 1995)

1.4.9 Deer Population Cycle

The number of deer killed in Kansas by hunters represents the majority of deer mortality. More deer are killed by hunters and more deer-vehicle accidents occur in November and December than during other months because these months coincide with rutting. Figure 17 shows deer mortality by cause and month, and Figure 18 shows a typical population cycle for Kansas.

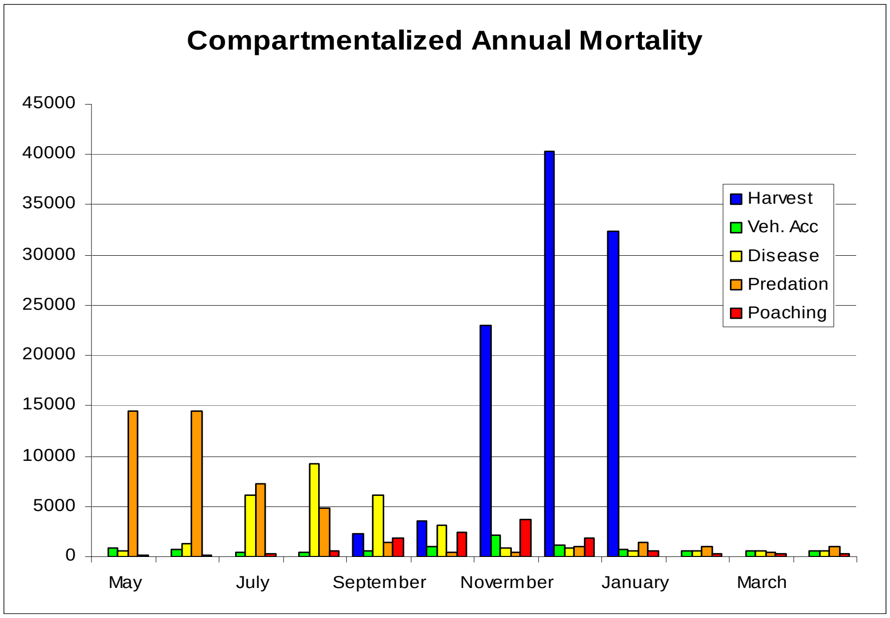

Figure 17: Deer mortality causes in Kansas (KDWP, 2002)

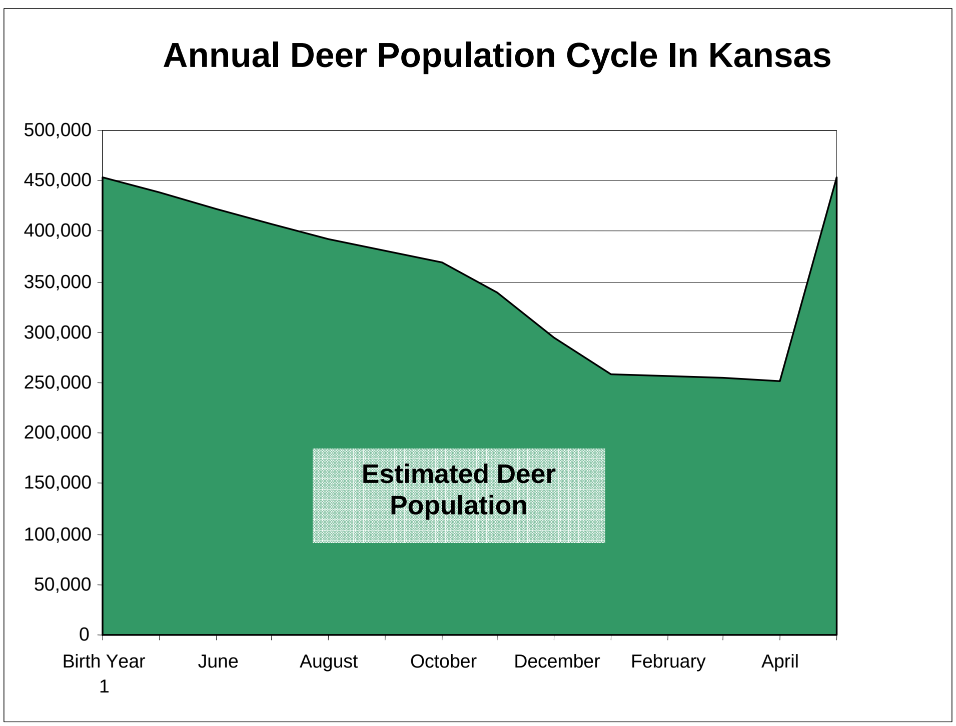

Figure 18: Annual deer population cycle in Kansas (KDWP, 2002)

1.4.10 Geographic Distribution of Deer-Vehicle Accidents in Kansas

Figure 19 and Figure 20 show that the majority of the counties with the highest frequency of deer-vehicle accidents are located in the north-eastern corner of the state. In 2002, the largest number of deer-vehicle accidents occurred in Johnson County (385), followed by Leavenworth County (303). The third county, Butler, is located in the south-central part of the state.

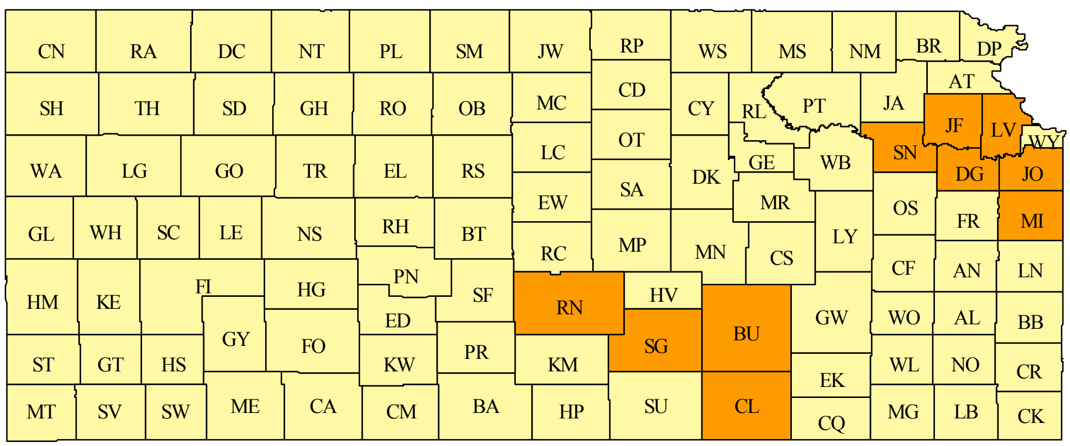

Figure 19: Ten counties with the most deer-vehicle accidents (1980-2000)

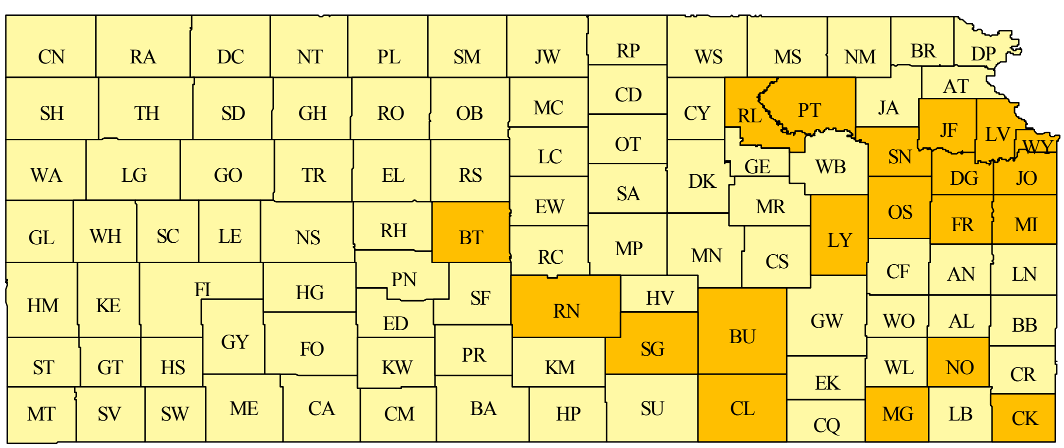

Figure 20: Twenty counties with the most deer-vehicle accidents (1980-2000)

Table 1, Figure 21 and Figure 22 indicate that all twenty of the counties with the lowest accident frequency are located in the western part of the state, and the ten lowest are all within the western quarter of the state. The lowest number of accidents in 2002 occurred in Haskell County (3) and Morton County (3). The low frequency of accidents in the western part of the state can be attributed to the fact that both deer population density and typical traffic volumes are much lower than in eastern Kansas.

Table 1. Counties with the most and least deer-vehicle accidents (1980 to 2000)

Rank	County	Accidents
1	Johnson	4145
2	Shawnee	3985
3	Butler	3466
4	Sedgwick	3311
5	Leavenworth	2954
6	Reno	2875
7	Douglas	2857
8	Cowley	2602
9	Miami	2274
10	Jefferson	2241
11	Riley	2193
12	Lyon	2112
13	Wyandotte	2045
14	Pottawatomie	2040
15	Osage	1755
16	Montgomery	1718
17	Neosho	1699
18	Franklin	1674
19	Cherokee	1632
20	Barton	1584

Rank	County	Accidents
105	Wallace	7
104	Stanton	34
103	Greeley	55
102	Morton	74
101	Haskell	77
100	Cheyenne	89
99	Stevens	91
98	Wichita	107
97	Grant	142
96	Logan	142
95	Comanche	173
94	Scott	200
93	Lane	202
92	Osborne	209
91	Clark	214
90	Seward	221
89	Hamilton	239
88	Edwards	264
87	Decatur	273
86	Sherman	277

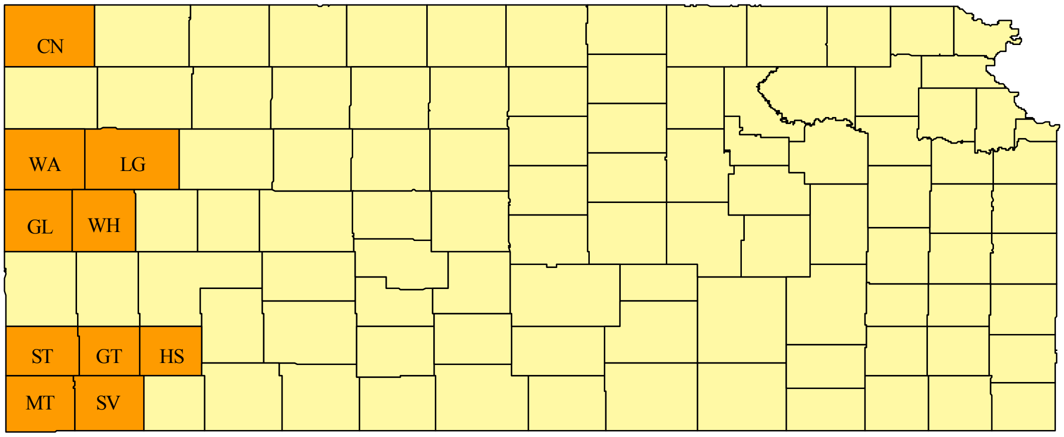

Figure 21: Ten counties with the fewest deer-vehicle accidents (1980-2000)

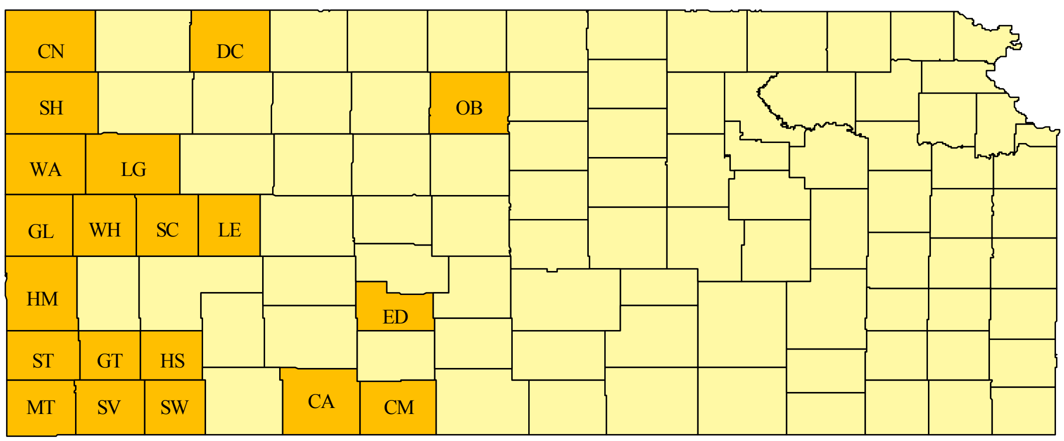

Figure 22: Twenty counties with the fewest deer-vehicle accidents (1980-2000)

Chapter 2

Previous Research

In 1999, the Florida Department of Transportation (FDOT) started a program to integrate road projects with statewide conservation objectives (Smith, 1999). As part of the program, FDOT installed underpasses and culverts at various locations around the state to restore landscape connectivity and processes. Smith advised, "The economics of an effort of such large scope of activities dictates the need for a method to identify and prioritize such projects." An ArcView GIS model was used to perform the analysis. The considered parameters were:

- chronic accident sites
- focal species hotspots
- riparian corridors
- greenway linkages
- strategic habitat conservation areas, existing and proposed conservation lands
- known or predicted movement/migration routes

The algorithm evaluated wildlife movement potential between core habitat areas through animal movement corridors. The priorities determined by the use of GIS indicated significant focus on conservation areas and riparian corridors. A total of 15,644 road segments were assigned a priority index between one and five.

In an Eastern European study, a methodology was developed for locating intersections of roads and ecological networks in order to help prioritize locations for implementing animal-vehicle crash countermeasures in Estonia. A special study was needed for locating cross points of roads and ecological networks for proper set up of counter measures (Klein, 1999). A case study for passage planning was carried out on a 74 km long and 500 m wide corridor of a planned new section of a highway. The study was divided into three stages: GIS analysis, gathering relevant information about car accidents, and gathering information from hunters about their selected locations. In the GIS analysis, the CORINE Land Cover database was used as the base layer. This database is maintained by the European Environment Agency. On top of land cover, working layers were created, representing the road network, river network, nature conservation areas, and protected parks. A GIS analysis was performed to identify conflict points, and these points were compared with the accident data. One limitation of the study was that it just pointed out only areas where wildlife trails were most concentrated. Additionally, the precision of one kilometer was too coarse to locate a very limited number of underpasses. Kobler and Miha (1999) developed a system to identify locations for the construction of wildlife bridges across highways in Slovenia. The system was based on GIS and artificial intelligence based modeling. An expert system for classifying the habitat suitability of the concerned animal (Brown Bear) was developed. The recorded bear sightings were linked to GIS layers. The main factors considered by the system were land use, human settlements, other human impacts (such as density of human population), and the topography. Geocoded data on bear population distribution, as well as GIS data layers covering several other ecological parameters, were also used. The assumption was that the recorded brown bear observations approximate the actual distribution of the bear population. The expert system was used to generate a mapping of suitable brown bear habitats. Thus, the most probable locations were identified.

A study performed by the University of Maryland, Baltimore County (UMBC), Department of Geography and Environmental Systems included an analysis of accident distribution patterns and studied the environmental and structural conditions that strongly influence deer-vehicle collisions in Howard County, Maryland (Armstrong, 1997). The study showed that traffic volume on I-70 displayed an inverse relationship to accident frequency. This trend did not follow the conventional wisdom that more cars result in more accidents. The author pointed out that the relationship between traffic volume and deer strikes obviously can be complicated and warned that traffic volume should be used as an indicator in developing predictive models, if at all, cautiously. Other studies support Armstrong's findings. A study by Carbaugh et al. (1975) found no relationship between traffic volume and accident frequency.

Another study by Allen and McCullough (1976) speculated that increased traffic volume might have caused higher accident frequencies. One of the important findings of the UMBC study was that 32 out of 55 accidents were the result of deer entering the roadway from the median. Such a finding indicates the importance of considering the roadway geometry in developing a frequency model. No model is currently available that considers this type of engineering factor. The paper also showed the importance of the amount of lighting present at the time of each accident. Fifty-one of 97 accidents took place at night on sections of I-70 with no streetlights.

A study conducted in Pennsylvania (Carbaugh et al., 1975) examined the behavior of deer near sections of highway. Two different sections of the highway were observed, and one section from each was selected based on distinct terrain characteristics, with one being forested and the other agricultural. The study results showed that more deer were observed on the segments through the forested areas, presumably because the deer are attracted to the shrubs and bushes that line the right of way. The highway through the forest dissects the area, creating a narrow, heavily planted "pasture." Eighty percent of the deer sighted at the forest location during the study were on the right-of-way. The agricultural area's study found only about 3% of the total deer sighted were grazing on the right-of-way. The feeding locations for the deer were thought to be spread out all along the agricultural area and farther away from the right-of-way of the road than the forested area. Another noticeable result of the study was that the deer populations were considerably higher at inclines and declines along the road, as opposed to level areas. It was speculated that this finding was due to deer being able to spot vegetation on the other side when opposite sides had positive gradients.

Another study found (Ulberg and Albert, 1997) that more large animal accidents happen on local roads than on state highways and interstates, since the local roads have more coverage area and less visibility (to the drivers) than the higher-class roads. Also, the closer the pavement is to the wood line, the greater the hazard animals become to drivers. This is an important parameter to be considered while developing a model.

A study performed at the Iowa State University Department of Animal Ecology (Hubbard et al., 2000) examined the influence of land use patterns and highway characteristics on Iowa deer-vehicle accidents. The study considered several landscape metrics, vehicle traffic levels, proximity to towns and cities, and local deer-harvest data. Six of the variables were found to be significant. Out of those six variables, four variables represented landscape features in the area surrounding the sample sites, and two variables represented highway characteristics. Those two highway-related variables were bridge frequency and the number of lanes. Number of bridges (defined by IDOT as a section of elevated roadway ≥ 6.1 m (20 ft) was found as the best predictor of accident frequency. Hubbard suggested that bridges were associated with animal travel corridors or features that can act as “drift fences” (e.g., streams, rivers), which funnel animals toward a single path. This study found that higher accident frequencies were associated positively with the number of lanes, contradicting the findings of previous studies by Ulberg and

Albert (1997) and Bashore et al. (1985). The estimated traffic volume in the Iowa study was not significantly related to the accident frequency. A limitation of the study was the lack of consideration of engineering parameters. In particular, roadway geometry was not considered. Puglisi et al. (1974) performed a study to identify the factors that are significant to deer-vehicle collisions in Pennsylvania. The analysis showed that higher deer-mortality occurred where 7.5-foot fencing existed. Puglisi attributed the high mortality to the fact that the 7.5-foot fencing was installed in areas where a deer-highway mortality problem had been anticipated. The study found that the distance of the fence to the nearest wooded area, regardless of vegetation type, had significant influence. High deer accidents also occurred where one side of the highway was wooded and the other side a field, and the fence was located within the woods. The study also found that the effect of vegetation was significant only where fencing was absent.

Finder et al. (1999) used remotely sensed data to determine characteristics associated with high accident frequency segments of roads in Illinois. The study emphasized that knowledge of factors influencing deer movements onto or across roads and highways may reduce deer-vehicle collision on existing roads, and improve planning for future roads. Finder suggested that transportation agencies should, "rather than waiting until several accidents occur over several years establish a site as a dangerous deer-vehicle accident road segment, utilizing models to determine if an area with high traffic volume has a high probability of being a deer-vehicle accident 'hotspot.'" Any segment of roadway that had more than 15 accidents between 1989 and 1993 was considered to be a high-risk segment. The use of this measure was a notable flaw in the study methodology, because the segments were not of uniform length, and the measure does not incorporate segment length. The study considered fifteen different variables, but only one of those was roadway geometry related–the curvature-meander of the road segment (actual length/straight length). Aerial photos and topographical maps were used to determine parameter values within a 0.8-km (0.5 mile) bandwidth about the road segment. The study revealed that the presence of adjacent gullies, riparian travel corridors crossing the roads and public recreational land increased the probability of an animal-vehicle accident, whereas greater distance of forest cover decreased the probability. The study concluded that fencing might not be an effective solution to the problem.

Feldhamer et al. (1986) evaluated the effectiveness of interstate highway fencing on white-tailed deer activity in Pike County, Pennsylvania. Although in a previous study Carbaugh et al. (1975) found no relationship between the number of deer observed and the number killed along a section of highway, this study found direct correlation between these factors. Similar to other studies performed by Bellis and Graves in 1971 (discussed later) and Puglisi et al. in 1974 (discussed previously), more deer were seen and killed on highways in fall and spring. In this study, no relationship could be established between road-kills and highway direction, habitat, topography or fence placement. This study concluded that despite the costs involved, fencing might be the most effective method of reducing deer-vehicle collisions in many eastern states of the country. It was found that 2.7 m (8.9 feet) fence was more effective than 2.2 m (7.2 feet) fence at reducing the number of deer groups in the right-of-way. It was recommended that the fencing should be well designed and maintained.

Reilly et al. (1974) studied a wintering area through which an interstate highway had been constructed to see if the underlying causes of an increase in highway-deer mortality could be identified. Interstate 75 intersects the eastern corner of the St. Martin Bay deer wintering area in Upper Michigan's Mackinac county. This expressway was constructed in 1963 about 0.25 mile east of the former US 2, now called Mackinac Trail. A great increase in highway deer killed was presumed to be due to construction of the new interstate. Before the construction of the I-75, six road kills was the maximum recorded for any year on US 2. After construction of the interstate in 1963, car-deer kills in the area increased to 41 per year by 1964. This increase in road accidents did not relate to an increased deer population since the deer population appeared to decline sharply during those years. The increase in deer-accidents could not be attributed to increased traffic volume either. Before construction of the interstate, the average daily traffic volume (ADT) was 2,300 vehicles per day (vpd), while after the construction of I-75 the ADT was 2,100 vpd. The study area did not fit the characteristics of the seasonal deer accident pattern for the rest of the state. This study area showed a peak in the month of February, whereas the general trend of the state was with a peak in November. The study assumed that this happened because this area had a high density of deer wintering areas and that deer-kills would be higher in the first part of the year. The study suggested that "newly opened sections of the highway often showed high car-deer mortality for 2 or 3 years, then decreased to a normal annual number". Reilly speculated that those deer killed represented family groups that might have been wiped out before the highway mortality ceased. The study concluded that "proposals for construction of highways which would intersect deer yards should be evaluated in greater detail for the potentially serious detrimental effect of construction on deer movements and populations within wintering area."

Iverson et al. (1999) discussed the dramatic increases of deer populations in the eastern United States between the 1940s and the 1990s and the resulting increase of deer browsing and deer-vehicle collisions. In Ohio, estimated deer population increased from near zero in 1940 to 450,000 in 1995. Estimates of deer harvest and deer-vehicle collisions in 1995 were analyzed and related to the length of major highways, urban land, rural land, crop land, forest land, all land, and human population. A positive relationship existed between the amount of urban land in the county, the human population, and the length of the major highways versus the number of deer-vehicle collisions. There was also a positive relationship between the amount of forest and number of deer harvested. The amount of cropland in a county was negatively related to both the number of deer-vehicle collisions and the number of deer harvested in that county. No apparent relationship was found between deer harvest and deer-vehicle accidents.

A previous study performed by Tonkovich (1995) had found a significant correlation between deer-vehicle accidents and deer harvest per square mile. The dramatic increase of deer population was attributed to increased forested land, more shrubby land, few predators, mild winters and the deer's ability to adapt to human-inhabited environments. One of the developed equations was

$$\text{Accidents} = 53.02 + 0.383\ (\text{Road length}) + 0.0015\ (\text{County Land}) + 0.0028\ (\text{Urban Land}) - 0.0003\ (\text{Crop Land})$$

One of the notable findings of the study was that the extension of the regression line showed the possibility of continued increases in deer-vehicle collisions, especially in those areas with high human population and forest covers.

Madsen et al. (2002) studied the factors causing traffic killings of roe deer in Denmark. One finding of this study was that collisions most often occur at sites with poor sight distance, poor lighting, dry pavement, and high speeds. The study observed that collisions between deer and cars were distributed in a clump-like pattern. The hotspots of the road sections had vegetation along the roadside with dense vegetation (e.g., hedgerows, bushes, and covers) on one or both sides of the road. The study found that there was no correlation between the number of deer accidents and the annual average daily traffic (AADT). The study speculated that roads with a high traffic volume might constitute home-range boundaries for roe deer. It may be that such boundaries prevent a few deer from being killed in traffic. In the long run, the deer group could have genetic influence on the population because the roadway with high volume of traffic prevents intermixing between members of different deer herds. The study also found that the portion of the study area where road geometry was slightly curved and hedgerows followed the road on both sides, resulting in very poor sight distance for both deer and drivers, exhibited high accident frequencies. This study suggested that dense vegetation (e.g., hedgerows) are used by deer as moving corridors, and, as a result, the road segment becomes a hotspot. Three recommendations were made for future consideration: increasing the areas with winter cereal or wintergreen on both sides of the roads, clearing the vegetation adjacent to the roads (hedgerows, forests and plantations) to allow the driver to see the animal before it enters the roadway (increasing clear zone), and reducing the vehicle speed in high-risk segments to allow the driver more time to react (install speed limit signs).

Bellis et al. (1971) emphasized that "knowledge of variables influencing deer movements across highways is needed to prevent deer-automobile accidents and to provide the highway user with a greater degree of protection." A long-term study was conducted to observe the activity and behavior of the white-tailed deer along interstate highways in Pennsylvania. No relation was found between the longitudinal slope of the roadway and the number of deer killed. The planted right-of-way adjacent to highways in forested regions provided an abundance of food for deer. Bellis explained that these "pastures" are limited in forested areas, and the probability of deer making frequent use of the highway pastures and crossing the roads is very high. Bellis added that while feeding on the narrow highway pastures, deer wander in search of food, following the natural contours of the land as well as those created by the construction of the highways. In this study, attempts were made to relate vegetative and topographic characteristics to number of deer-vehicle accidents. No correlation between the percent of cover (grass, vetch, clover) within the right of way and the frequency of deer-accidents was observed. The study also suggested that deer fences along highways should be continuous well beyond the hot spot. If short fences are constructed at hotspots, deer will probably cross the road at the end of fences, thereby shifting the hotspots along the segment but not eliminating them. The study also recommended that fences be erected close to the roadways so that deer are allowed to graze on the planted right-of-way, rather than placing fences where the right-of-way merges with the forest. Deer having access to food with the proposed placing of fencing would be less prone to jump the fence and enter the traveled lanes. With less impetus to jump the fencing, lower fence heights could be used.

Romin and Bissonette (1996) sent a survey to all state natural resource agencies in October 1992. The survey asked for an estimate of deer killed annually on highways, the source of the information, and information about methods used to reduce vehicle collisions with deer. Of 50 state departments, 43 agencies responded. Of the 29 states that reported deer-accident data by year, 90% showed an increasing trend from 1982 to 1991. Deer crossing signs were the most commonly implemented countermeasure. 93% of the respondents used “Warning Sign” as a countermeasure. Seventy percent of the respondents reported that they were not sure whether this technique was useful. Only 7% of the respondents who used this method indicated it was a successful countermeasure. Twenty-two responding agencies used “Swarflex Reflectors” and “Public Awareness Program” methods. Fifty-nine percent of those respondents who used “Swarflex Reflectors” and 62% of those who used “Public Awareness Program” could not draw any conclusion about the effectiveness. Twenty-four percent of those agencies who used "Public Awareness Program," and 5% of those who used "Swarflex Reflectors" believed that those were useful. The two most effective techniques were "Deer Proof Fencing" and "Underpasses or Overpasses." Of the respondents who used fencing, 91% found it effective. Of those who used grade-separated structures, 63% found them effective. Other implemented countermeasures were lower speed limits, mirrors, highway lighting, ultrasonic warning whistles, habitat alteration and hazing. Countermeasures that were regarded as ineffective include "Ultrasonic Warning Whistles" and "Highway Lighting."

Sullivan and Messmer (2002) sent a survey to two different types of agencies in 2000. State wildlife agency (SWA) administrators returned 49 questionnaires and state department of transportation (DOT) administrators returned 39 questionnaires. Less than 30% of all agencies reported maintaining long-term deer-vehicle collision databases. Both groups of administrators identified a number of factors as contributing to increasing deer-vehicle accidents. Increased traffic volumes (76% of respondents), higher deer populations (66% of respondents), increased vehicle speeds (51% of respondents), and habitat fragmentation (47% of the respondents) were the most commonly cited factors. Seventy three percent of all SWAs and DOTs reported that they did not conduct any research to evaluate the countermeasures they had implemented to reduce the deer-vehicle collisions. Permanent deer crossing signs were used by most agencies (89%). Other most commonly implemented countermeasures were "Highway Fencing" (42%), "Public Awareness via Newspapers" (39%), and "Reducing Deer Herds" (37%). The study also revealed that although deer crossing signs were the most commonly implemented countermeasure in many of the states, responding administrators indicated that deer signs were not effective. The frequent use of the deer-signs generated disrespect among motorists. The continued use is largely viewed as a token effort by DOTs to reduce liability (Hughes et al., 1996). In this study, recommendations were made for increased communications between SWAs and DOTs towards working together for a common goal. The study concluded that "increased development, marketing, and use of net-based news and information networks on deer-vehicle collisions may provide a critical link to increased SWA and DOT cooperation in deer-vehicle collision abatement programs."

Smathers (2001) expressed concern about animal-vehicle collisions, stating that "highways are … a new source of wildlife mortality." The damage caused by deer-vehicle accidents in an economic sense was described as "impact of one person or thing on other externalities." In this case, a negative external effect of deer upon humans or humans upon deer was identified. In South Carolina, deer habitat, number of vehicles, speed limits, natural or human induced funnels, roadside vegetation and roadside visibility were studied. Initially, type of roadside vegetative cover crops, funneling and time of year were identified as important factors along with the number and speed of vehicles. Driver education and awareness were emphasized as effective tools for reducing deer vehicle accidents.

West et al. (2000) initiated a statewide survey in Virginia in 1996 to study the occurrence and severity of deer-vehicle collisions and to evaluate the impacts they have on the attitudes of Virginia motorists. About 1500 landowners in the state were surveyed and asked about their experience with and fear of deer-vehicle collisions. Overall, 9.2 % of all respondents reported hitting a deer with a vehicle during 1995. Although, most individuals (79% of respondents) experienced only 1 collision during the year, 15.9% of respondents reported having 2 collisions. It is notable that 29 individuals (4.4% of respondents) had an accident while trying to avoid a deer, but did not actually hit the animal. In 83.1% of the deer-vehicle accidents, only property damage was sustained. For these individuals, the average reported cost to repair the damage was $1,868, with a range of $100 to $4,700. Only 3.1% of those who collided with a deer reported either themselves or their passengers being injured. Most individuals (68.8%) did not report the accident to any law enforcement agency. An individual's perception about the danger of having a deer-vehicle accident in their county was strongly influenced by their prior experience of accidents. The study concluded that deer-vehicle collisions could have a significant influence on the attitudes of motorists. It was proposed that state agencies proactively seek partnerships with other organizations interested in mitigating deer-vehicle accidents, particularly at the community level.

Gunther et al. (2000) analyzed the frequency of road accident wildlife mortality (including mule deer and white-tailed deer) with respect to adjacent roadside vegetation, posted speed limits, and wildlife population numbers in Yellowstone National Park (YNP). The study found that mule deer were killed by vehicles significantly more than expected in areas with forested cover. A significant influence of posted speed on animal-vehicle accidents was observed. Large mammals were killed significantly more than expected on roads with posted speeds of 90 kph (55 mph) and significantly less than expected on roads with posted speeds of 70 kph (45 mph), but it was also pointed out that road design might have had more influence on average vehicle speeds than the posted speed. The study also recommended that design specifications be such that vehicle speeds would tend to average 70 kph (45 mph) or less. Road segments that have more curves and smaller clear zones adjacent to the road had kept average vehicle speeds at or lower 70 kph (45 mph) in Yellowstone National Park for many years. Another recommendation was that other countermeasures be implemented to reduce the frequency of animal-vehicle collisions in areas where social and economic factors dictate higher speed limits.

Messmer et al. (2000) performed an evaluation of temporary warning signs to reduce deer-vehicle accidents. The pilot study was conducted on two sections of US Highway 89 between Kanab, Utah, and Page, Arizona. In November 1997 Utah Department of Transportation (UDOT) erected large black and yellow warning signs equipped with battery-powered flashing amber lights and reflective flags at the ends of each migration corridor. The size of the sign was 1.83 m (6 ft) by 0.91 m (3 ft). These signs were used to inform motorists that they were about to enter a deer migration area. Smaller warning signs of 0.9 m (36 in) diameter equipped with flashing amber lights were erected facing both directions at every mile point within the study areas. Both types of signs were designed so that they could be set up during the deer migration period or seasonal movement period and folded down with the lights turned off during other times. Lower vehicular speeds were recorded during the spring and fall migration periods. The study concluded that signs were able to alert motorists to the risk of a deer-vehicle accident. Drivers may have initially reduced their speed in response to the signs, then accelerated if they did not encounter any deer. The signs appeared to have a residual effect on motorist behavior, and the accident frequency in the study area was lower in 1999 than in 1995-1997. Messmer recommended that temporary signs may be an effective alternative for reducing deer-vehicle accidents, but, prior to wide scale implementation of this technique, agencies should conduct adaptive resource management experiments to justify their use over other alternatives.

McMurtray (2000) described the proactive project undertaken by the Florida Department of Transportation (FDOT) to improve wildlife protection and to identify hotspots for wildlife-vehicle collisions on the existing road system that require improvement. Initially, the "Regional

Bio-diversity Hotspots" were identified. Knowing the hotspots in the area where continued threat and endangered wildlife existed, it was possible to "avoid, minimize, and mitigate" these threats. Secondly, FDOT used wildlife mapping data while planning highways in order to identify projects with serious environmental problems. Thirdly, FDOT funded a computer modeling effort to identify and prioritize habitat corridors where wildlife-vehicle collisions are likely to occur. This model considered eleven elements, such as previous accident records, known movement routes, and strategic habitat conservation areas. This model helps to locate areas on existing roads that need underpasses or other structural solutions and also helps to identify potential wildlife-vehicle conflicts on planned roads.

The NCHRP Synthesis Report No. 305 (FHWA NCHRP, 2002) on *Interaction Between Roadways and Wildlife Ecology* was published in 2002. The study reviewed the interactions that occur during planning, design, construction, operation, and maintenance of roadways that can affect ecological systems and wildlife. A questionnaire was sent to determine how the state departments of transportation (DOTs) are addressing ecological and wildlife related matters.

Jeffrey (1995) studied the impacts of urbanization of white-tailed deer habitat in Johnson County, Kansas. A model was developed to predict potential white-tailed deer habitat. The impact of urbanization on white-tailed deer habitat was also evaluated. The pattern of future urban growth was also directed to reduce detrimental impacts on white-tailed deer habitat.

The review of the literature was followed by the selection of a number of variables and study of segments of highways in terms of deer-vehicle accident rate. The methodology is described in Chapter 3.

Chapter 3

Crash Rate Analysis

The simplest and most straightforward approach to studying the effectiveness of deer warning signs is to examine the crash rates on segments where a warning sign has been installed. If, following the sign installation, crash rates decrease, it may be an indication that the warning sign is an effective countermeasure.

Surveys have confirmed that warning signs are widely used and that most agencies are at best unsure of their effectiveness, while most believe them to be ineffective and very few feel they are effective. No definitive field studies have been performed. Some studies have been conducted, but generally with very limited geographic and temporal scope. Often, conclusions have been drawn from a single year of crash data.

The objective of this portion of this study was to evaluate deer warning signs (type W11-3 in USDOT MUTCD, 2000) in terms of effectiveness to reduce deer-vehicle collisions on selected Kansas highway segments. A direct approach was used, comparing the crash histories of segments before and after a sign was installed.

3.1 Data Collection

Data were collected from two different sources.

1. Road Safety Audit Reports were collected from Kansas Department of Transportation (KDOT), Topeka office, and
2. Sedgwick County Public Works Department.

Sign-installations were assumed to take place with in 06 (six) months of the publishing of each Road Safety Report. Most of the reports were published during 1999. The data were extracted from the reports of Commanche County (2 segments), Montgomery County (5 segments), Scott County (1 segment), Stafford County (4 segments.), Republic County (1 segment), and Trego County (1 segment). Information about fourteen segments was collected from the Road Safety Reports. Eight additional segments were identified from data obtained from Sedgwick County Public Works Department. A total of 22 (twenty two) segments were considered in the study. These segments are listed in Appendix A.

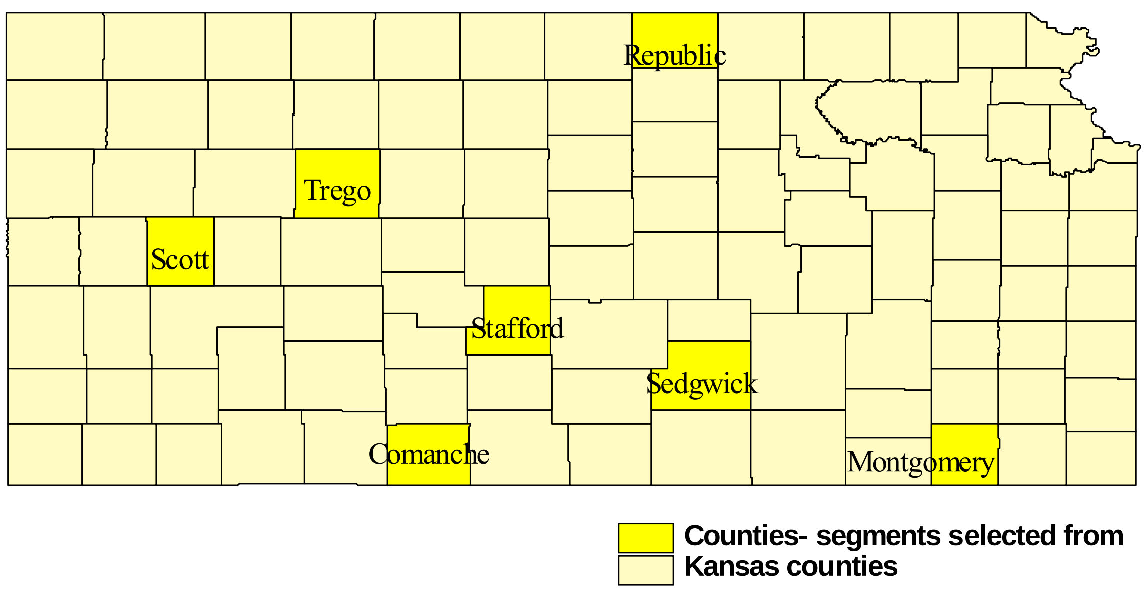

Figure 23: Counties from which data was available

Deer accident histories were collected from the Kansas Accident Records System (KARS) database, maintained by the Kansas Department of Transportation (KDOT).

All segments for which the requisite data were available were included in this analysis. The requirements imposed were the installation of a deer warning sign and a record of deer-vehicle crash history that includes at least 2 years prior to the installation of the sign and 2 years following the installation of the sign. Most segments had 2 years of crash data after the installation of the warning sign and 10 years of data prior to sign installation.

Because the sign installations occurred in different years and the segments were at diverse locations, no control group was included in the analysis. Inclusion of a control group is generally desirable, but with such temporal and geographic diversity in such a small data set, it was deemed infeasible to develop a set of control groups within the scope of this study.

3.2 Statistical Analyses

Before and after installation accident records were compared using a paired-t test (95 percent confidence level). Initially, a t-test was performed using only the three years immediately prior to sign installation. The results are shown in Table 2. The mean crash rate decreased by almost a factor of two between the before and after time periods, and the t-test showed the difference to be statistically significant, even at a 99% confidence level.

Table 2. Results of t-Test using 3 years of before data.

t-Test: Paired Two Sample for Means		
	Before	*After*
Mean	1.159	0.705
Variance	0.800	0.804
Observations	22	22
Pearson Correlation	0.724	
Hypothesized Mean Difference	0	
df	21	
t Stat	3.206	
P(T<=t) one-tail	0.002	
t Critical one-tail	1.721	
P(T<=t) two-tail	0.004	
t Critical two-tail	2.080	

The data was then analyzed a second time, using all the available data. Crash rates before sign installation were averaged over a period of between 2 and 10 years, and crash rates after installation were averaged over a period of between 2 and 5 years. The results are shown in Table 3. In contrast to the results from the previous test, Table 3 shows the mean crash rate decreased by only about 7%, and the difference was not statistically significant.

Table 3. Results of t-Test using all available data.

t-Test: Paired Two Sample for Means		
	Before	*After*
Mean	0.834	0.779
Variance	0.447	0.879
Observations	22	22
Pearson Correlation	0.587	
Hypothesized Mean Difference	0	
df	21	
t Stat	0.338	
P(T<=t) one-tail	0.369	
t Critical one-tail	1.721	
P(T<=t) two-tail	0.739	
t Critical two-tail	2.080	

3.3 Results

The contrast between these two analyses emphasizes the great caution that should be used when conducting analyses with deer-vehicle crashes. A cursory analysis of the data for the three years surrounding the sign installation (see Table 2) would conclude that the sign was effective, perhaps even very effective. However, when the broader context of data was examined, serious doubt was cast on the potential effectiveness of the signs (see Table 3).

Figure 2 on page 3 shows that deer crashes statewide peaked in 1999. The trends in deer crashes follow closely the trends in deer population, which increased over several decades, peaked around 1999, and then began decreasing. There are several potential causes for the change in trends (see Section 1.4.6 Deer Population Trends), but none of them support the installation of deer warning signs as the cause.

In summary, the results of this analysis are not sufficient to conclusively prove that deer warning signs are not effective, but the fact that no statistically significant relationship was found between sign installation and crash rates is important to note. These results do not prove that no such relationship exists, but they are evidence in that direction.

Chapter 4

Principal Components Analysis

The analysis of crash histories before and after the installation of warning signs was very limited with respect to the number of segments included and the time periods for which data was available, particularly after sign installation. To further explore the nature of deer-vehicle crashes, a second approach was taken. This approach was intended to look at deer-vehicle crashes in a broader context to see what relationships could be identified between crash rates and potentially causal factors. It was hoped that this information would not only address the potential effectiveness of warning signs, but also provide guidance as to what other countermeasures might be most likely to prove effective.

4.1 Factors Being Considered

The literature shows that a number of factors have been considered in prior research to identify high-risk locations; however, the factors associated with the deer-vehicle accidents are not well understood. Researchers have given emphasis to a few of the selected parameters in each study. No study has given sufficient consideration to engineering parameters such as roadway geometry (e.g., clear width and median type), roadside adjacent slope, and certain traffic characteristics while developing a model. Study results show that the significance of various parameters that have been included also varies widely from location to location. Some of these factors may be interrelated. Some of the factors may have significant influence, whereas others may not.

The following factors that were considered in this study:

1. Prior accident rate on the segment as the predicted variable
2. Roadside land use type—a total of 18 variables were considered from this group
3. Deer harvest density

4. Curvature ratio (ratio between the straight length and the actual length of the highway segment)
5. Number of rivers and creeks intersecting the highway segment
6. Number of bridges or visible culverts—2 variables were considered from this group
7. Clear width available on the highway segment—4 variables were considered from this group
8. Roadside adjacent side slope—5 (five) variables were considered from this group
9. Roadside topography in the transverse direction—5 variables were considered from this group
10. Traffic volume on the segment—2 variables were considered from this group
11. Posted speed
12. Number of lanes
13. Presence of deer warning sign
14. Presence of right of way fencing
15. Median type

The definition of variables used in the statistical analysis are listed in Appendix B.

4.1.1 Prior Accident Rate

Prior accident rate was defined as "accidents per year per mile of roadway." The actual length of the segment was used. The average accident frequency between 1997 and 2001 was calculated. The accidents per mile of roadway were calculated. Figure 24 shows a segment in Riley (RL) County with multiple accidents, and Figure 25 shows a segment in Wabaunsee (WB) County with no accidents recorded during 1997-2001.

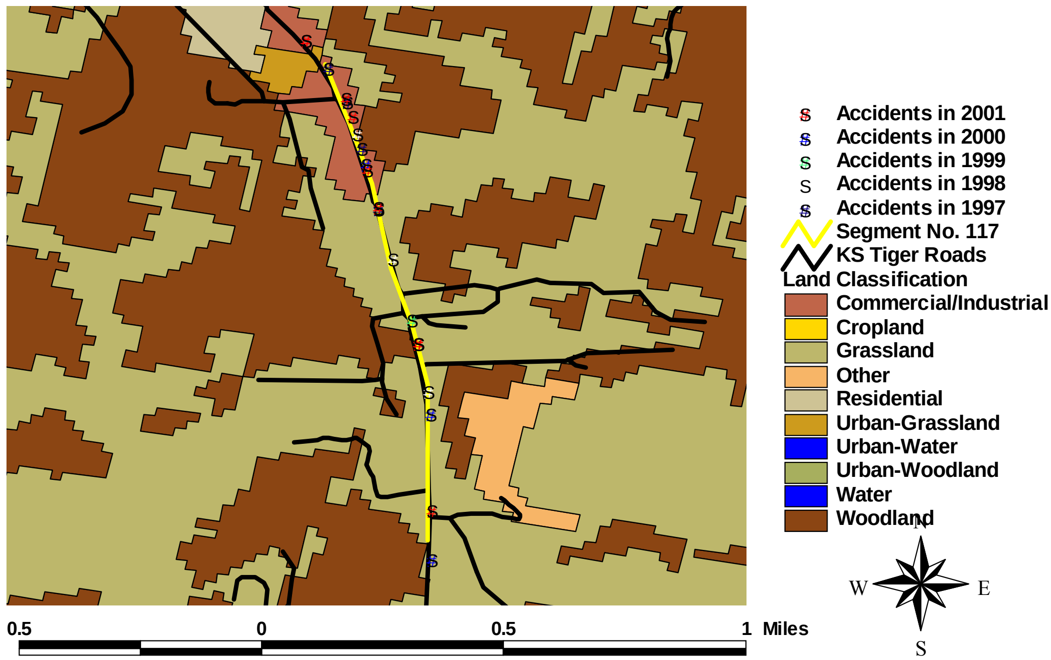

Figure 24: Accident map for segment in RL County

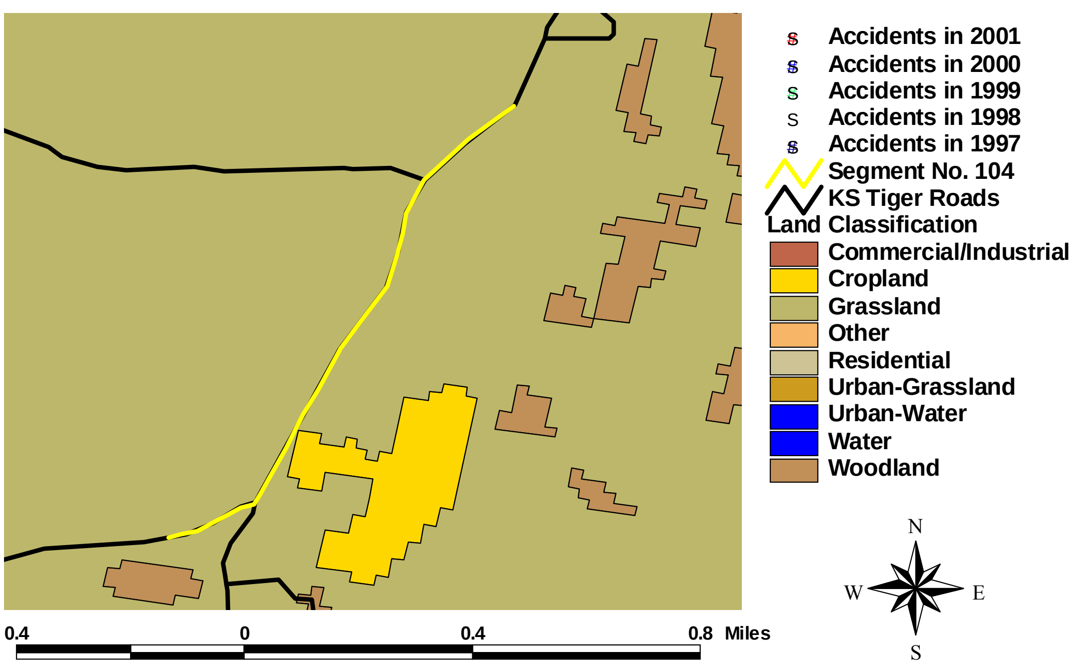

Figure 25: Accident map for segment in WB County

4.1.2 Roadside Land Use

Land use on each side of the roadway segment was considered. Two major types of land use were considered. The first and the main land use type was *wooded land*. Deer often use wooded land as their permanent shelter. The second land use considered was *crop land*. During the fall, winter and beginning of the spring season, seasonal crops comprise more than 50% of the diet of white-tailed deer (KDWP, 2002).

The study by Hubbard et al. (2000) identified six variables as significant to deer accident frequency, and, out of those six predictor variables, four represented land use types in the area surrounding the sample sites. The study results by Carbaugh et. al. (1975) showed that wooded areas attracted the most deer to the highway since the right-of-ways provided a lot of the shrubs and bushes that deer like to feed upon. It was also found that 80% of the deer sighted at the wooded area during the study were on the right-of-way. The agricultural area's study found only about 3% of the total deer sighted grazing on the right-of-way. Iverson et al. (1999) found a positive relationship between the amount of wooded land and deer-related crashes. The amount of cropland in a county was found to be negatively related to the number of deer-vehicle collisions.

The considered parameter group was subdivided into eighteen individual parameters, including all combinations of the following:

1. Three different distances off the roadway in the transverse direction were considered (1000 feet, 3000 feet, and 5000 feet).
2. A separate value was calculated for each side of the roadway, and a value assigned to the segment in two ways:
    a. By taking the greater value of the two sides, and
    b. By taking the average value of the two sides.
3. Three different land use combinations were considered.

a. Percentage of wooded land in the area

b. Percentage of crop land in the area

c. Percentage of sum of wooded land and crop land in the area.

Figure 26 shows an example of the land use being studied.

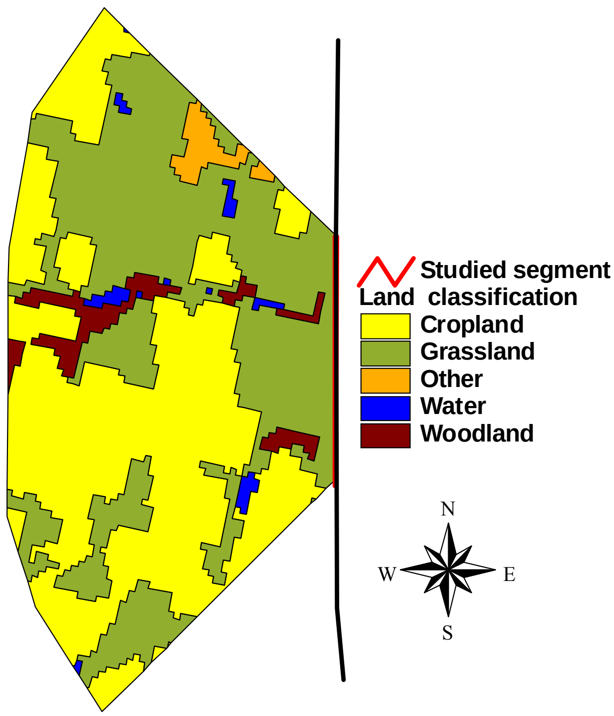

Figure 26: Land use for 5000 ft (1524 m) to the west of a segment

4.1.3 Deer-Harvest Density

Deer-harvest density in the Deer Management Unit (DMU), in which each segment is located, was defined as the number of deer harvested each year per 100 mi^2. Deer Management Unit (DMU) 10 (Figure 27), located in northeastern Kansas, is bounded by the KS–MO state line, US 75, and I-35. Harvest density data from the 2001-02 season were used in the study.

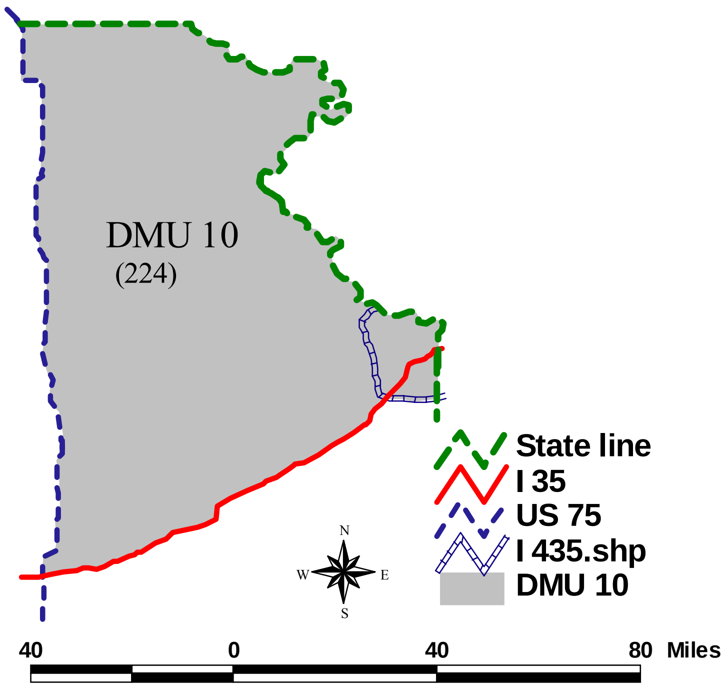

Figure 27: Deer Management Unit 10

Iverson et al. (1999) found that a positive relationship existed between the amount of forest and number of deer harvested, but no apparent relationship was found between deer harvest and deer-vehicle accidents. A previous study performed by Tonkovich (1995) found a significant correlation between deer-vehicle accidents and deer harvest per square mile. Hubbard et al. (2000) examined the local deer harvest data but found no correlation with the accident frequency.

4.1.4 Curvature Ratio

Curvature Ratio of a segment is a useful indicator for measuring the horizontal curvature present in the road segment. Indirectly, it may be related to the horizontal sight distance available on the segment. The more curvature present in the segment, the greater the actual length in comparison to the straight length. More curvature indicates less overall sight distance. The numerator is the straight length of the segment. The denominator is the actual length of the segment. The denominator is always greater or equal to the numerator. So the maximum value of the ratio is equal to 1 (one). Figure 28 shows the actual length and straight length of a segment.

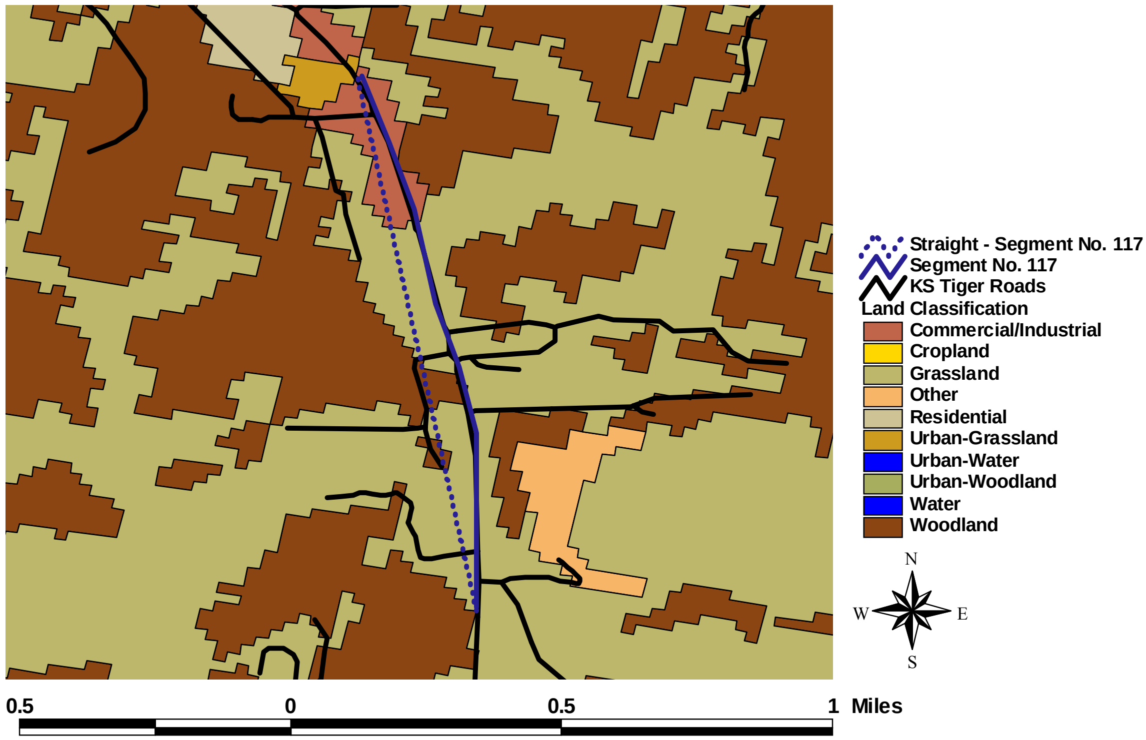

Figure 28: Straight length and actual length for a segment

The values of the ratios for the study segments were between 0.765 and 1.00. About 55% of the segments (66) had a curvature ratio value of 1.00, implying a straight segment.

4.1.5 Number of Rivers and Creeks Intersecting the Highway Segment

The data were collected in the form of GIS shape files. The analysis was performed using ArcView GIS (ESRI, 2003) software as described in the following section on data analysis. The number of rivers and creeks was expressed as *the number of river or creek per mile of the roadway*.

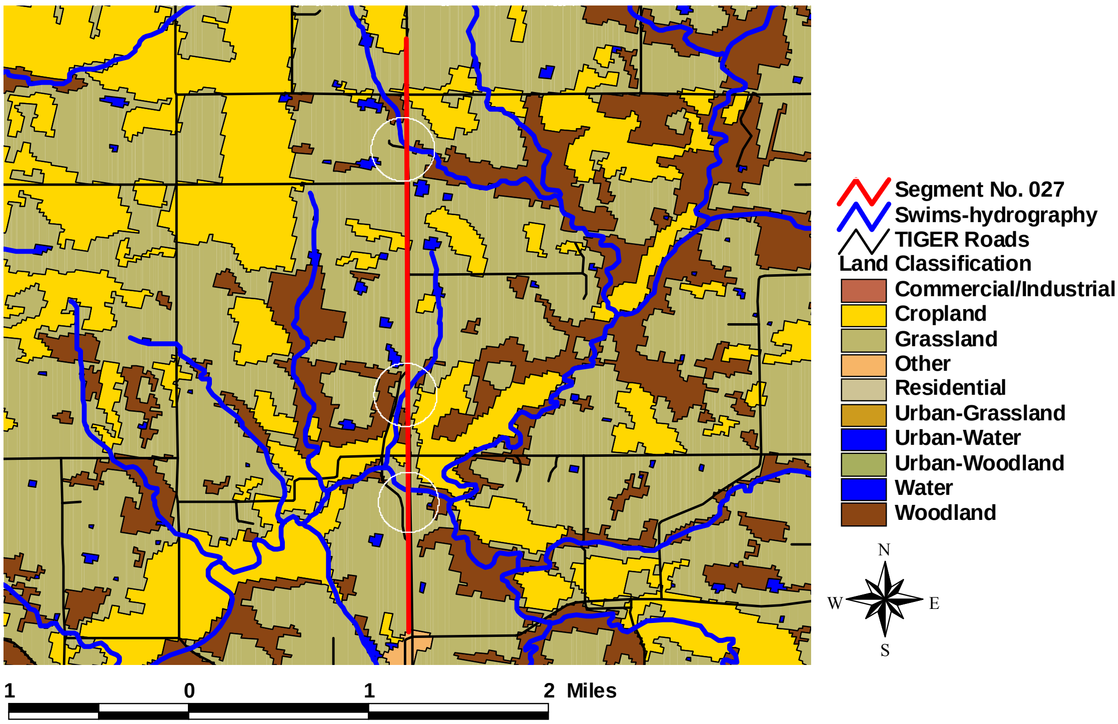

Figure 29: A segment with 3 intersecting creeks

4.1.6 Number of Bridges and Visible Culverts

The number of bridges (defined by Iowa DOT or Kansas DOT as a section of elevated roadway ≥6.1 m or 20 ft) was found as the best predictor of accident frequency in a study performed at the Iowa State University (Hubbard et al., 2000). It was believed that bridges were associated with travel corridors, acting as *drift fences* (e.g., streams, rivers) that gather deer from moving through the landscape and funnel them along a particular path (See Figure 30). In this study, *the number of bridges and visible culverts per mile of roadway* was considered as a variable.

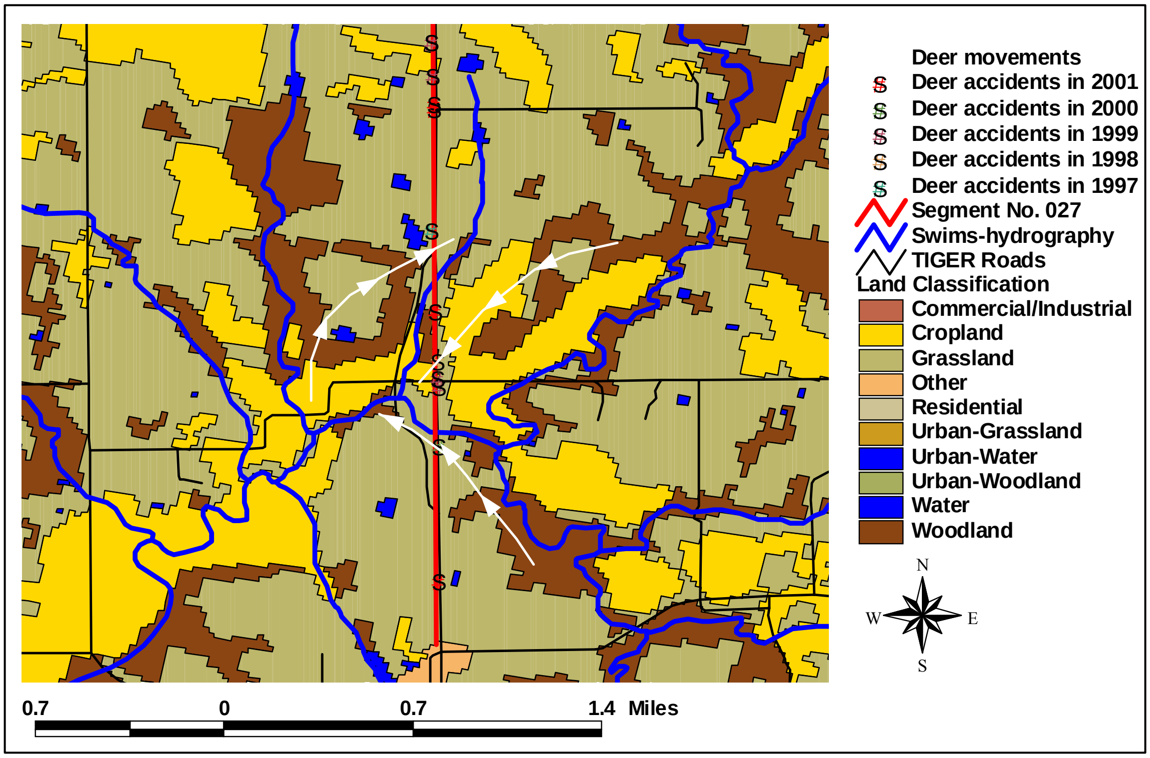

Figure 30: Wooded corridors that can act as "drift fences" for deer movement

4.1.7 Clear Width

A study by Finder et al. (1999) revealed that as the distance of forest cover from the roadway increased, the probability of a deer-vehicle accident decreased. Madsen et al. (2002) found that for portions of the study area where road geometry was slightly curved and hedgerows followed the road on both sides, resulting in poor sight distance for both deer and drivers, accident frequencies tended to be high. The premise that greater clear width reduces accident frequency was not examined statistically.

The AASHTO Green Book (AASHTO, 2001) defines the term *clear zone* as "the unobstructed, relatively flat area provided beyond the edge of the traveled way for the recovery of the errant vehicles." The Roadside Design Guide (AASHTO, 1996) recommends clear zone distance values according to roadside slope, design speed, Annual Average Daily Traffic

(AADT) and whether a location is a cut or a fill section. The Guide is used as a reference for determination of clear-zone widths for freeways, rural arterials, and high-speed rural collectors. For low-speed rural collectors and rural local roads, a minimum clear zone width of 10 feet should be provided.

4.1.8 The Redefinition of Clear Width

The clear width concept used in this study differs from that discussed in the Roadside Design Guide (AASHTO, 1996), in that the concern is not an obstacle for errant vehicles, but the obstructions behind which deer could hide. To be considered as an obstruction, the width must be at least 3 feet and the height must be at least 2.5 feet. For example, a single telephone post could obstruct the recovery of an errant vehicle, but could not hide a deer.

Four different ranges of clear widths were considered as four different variables. The following four variables were considered:

1. Percentage of highway segment that has clear width less than 30 feet
2. Percentage of highway segment that has clear width less than 60 feet
3. Percentage of highway segment that has clear width less than 90 feet
4. Percentage of highway segment that has clear width less than 120 feet

For each segment, a percentage was recorded for each clear width category, indicating how much of the segment has a clear width of the associated range. The clear width for a sample segment is illustrated in Figure 31. The clear widths required to avoid collision for different vehicular speeds were calculated and presented in Table 4. The calculation assumes a brake reaction time of 1.5 seconds. The deceleration rate of the vehicle is assumed to be15 feet per sec^2 (4.6 m per sec.^{2}). The average running speed of the deer was taken to be 15 fps (4.6 mps). The calculation for maximum vehicular speed of 70 mph (110 kph) and deer speed of 50 fps (15.24 mps) is shown in Table 4.

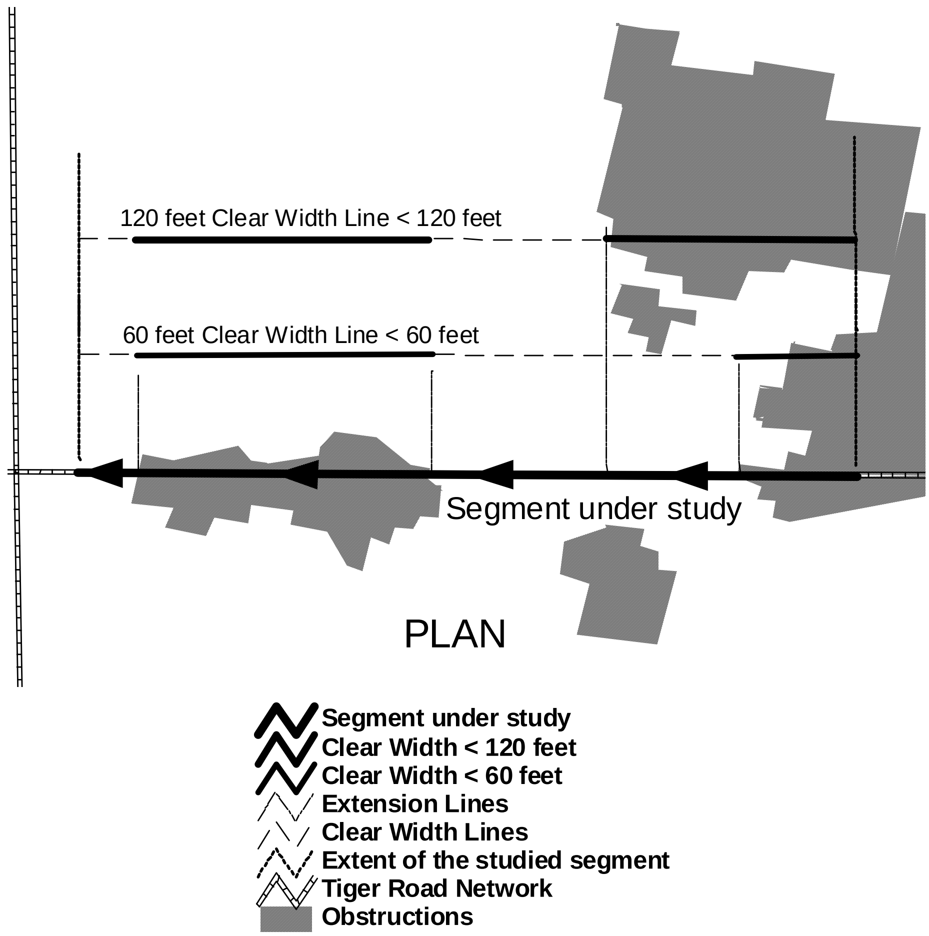

Figure 31: Clear Width for a Sample Segment

Table 4. Clear width requirements for avoiding deer-vehicle collision

VEHICULAR SPEED LIMIT (MPH)	BRAKING TIME (SECONDS)	TOTAL TIME ELAPSED (SEC.)	CLEAR WIDTH REQUIREMENT (FEET) FOR VARIOUS DEER SPEEDS, (FPS)					
			5	10	**15**	25	35	50
30	2.94	4.5	23	45	**68**	113	158	203
35	3.43	5	25	50	**75**	125	175	225
40	3.92	5.5	28	55	**83**	138	193	248
45	4.41	6	30	60	**90**	150	210	270
50	4.9	6.5	33	65	**98**	163	228	293
55	5.4	7	35	70	**105**	175	245	315
60	5.9	7.5	38	75	**113**	188	263	338
65	6.4	8	40	80	**120**	200	280	360
70	6.84	8.5	43	85	**128**	213	298	383

Note: The 15 fps (10 mph) deer speed is considered as the average deer approaching speed

4.1.9 Roadside Adjacent Side Slope

The side slope is an element of the cross section design of the highway. Side slopes are designed to ensure roadway stability and to provide a reasonable opportunity for recovery for an out-of-control vehicle. Recommended values of fore-slopes are generally 1V:4H and 1V:3H with barriers (AASHTO, 2001). The slope adjacent to the shoulder is generally within the control of the geometric designer and the variation of these slopes from place to place is also very small.

The transverse slope beyond the designed forward slope is the slope under consideration in this study. This slope is the natural slope or sometimes the designed back slope immediately beyond the designed foreslope. In Figure 32, the transverse slopes of the pavement and the shoulder (shown by the dotted line) are designed and pre-set. The gradients (shown with solid lines in the figure), which vary considerably along segments and from place to place (both sides have positive slopes here), were considered. The side slopes to the right hand side of the travel direction were considered separately for each direction and both values were combined at the end. The side slope on the right hand side in the picture is less than 45 degrees, and the slope on the left in the picture is greater than 75 degrees.

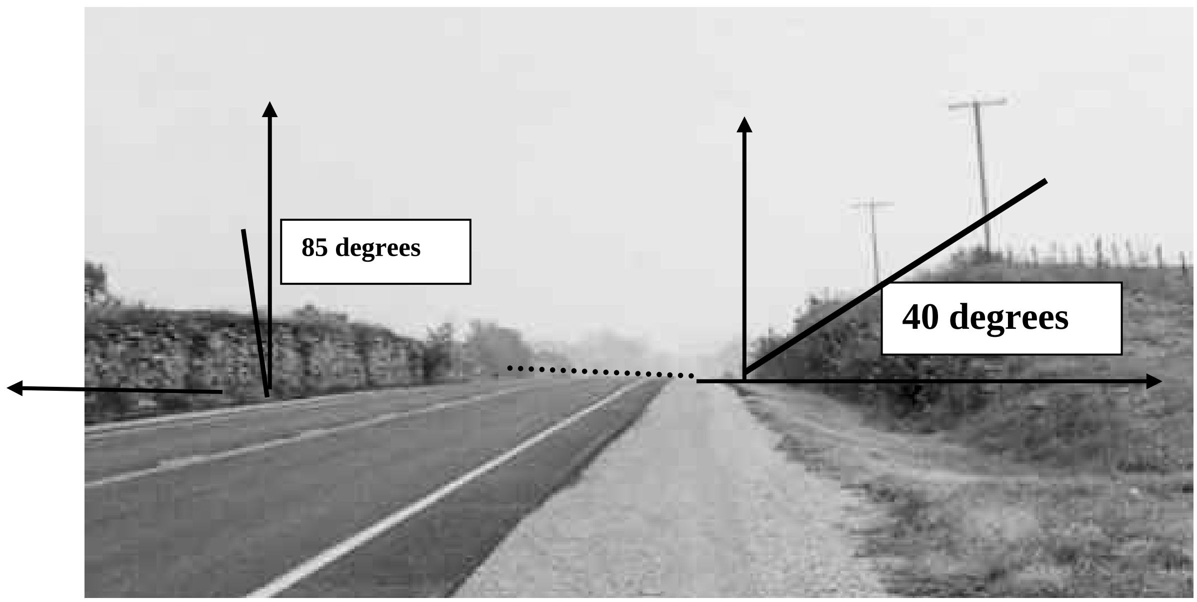

Figure 32: Transverse side slope

The consideration of this parameter arises from the idea that steeper roadside transverse gradients may discourage deer from entering the right of way. Many wildlife animals have a natural tendency of to move along flatter slopes to conserve energy. This parameter was included in the study to evaluate the possibility that a very high gradient adjacent to the roadside will reduce the probability of deer entering the roadway. Apart from this, very high gradient might be difficult for a deer to climb up or down, though information from wildlife biologists (KDWP, 2002) showed that deer are capable of climbing very steep slopes, if needed. A few research projects have been previously performed to study whether roadside overall topography has any relationship with deer-vehicle accident frequency, but no research has been performed that studied what slope angle is crucial in this aspect. A study by Bellis et al. (1971) found no relationship between the slope of the right-of-way and the number of deer-accidents.

The following five variables were considered in the study:

1. Percentage of the segment that has side slope greater than 15 degrees
2. Percentage of the segment that has side slope greater than 30 degrees
3. Percentage of the segment that has side slope greater than 45 degrees
4. Percentage of the segment that has side slope greater than 60 degrees
5. Percentage of the segment that has side slope greater than 75 degrees

The lengths of the portions of each segment that have side slopes between 0 degree and 15 degrees, between 16 degrees and 30 degrees, between 31 degrees and 45 degrees, between 46 degrees and 60 degrees, between 61 degrees and 75 degrees and between 76 degrees and 90 degrees were calculated. These individual lengths were converted to cumulative lengths for 15, 30, 45, 60 and 75 degree slopes. Thus, the total percentages of each segment that have side slopes greater than 15, 30, 45, 60, 75 degrees were calculated.

4.1.10 Roadside Topography in the Transverse Direction

A study conducted in Pennsylvania (Carbaugh et. al, 1975) looked at the behavior of deer near sections of highway and found that deer populations were considerably higher at inclines and declines, as opposed to level areas. In contrast, a study by Feldhamer et al. (1985) in the same state could establish no relationship between deer-vehicle accidents and topography.

Values for both sides of each segment were averaged to obtain the value used for analysis. The following five variables were considered in the study:

1. Percentage of the segment that has topography (overall transverse slope) greater than 15 degrees

2. Percentage of the segment that has topography (overall transverse slope) greater than 30 degrees
3. Percentage of the segment that has topography (overall transverse slope) greater than 45 degrees
4. Percentage of the segment that has topography (overall transverse slope) greater than 60 degrees
5. Percentage of the segment that has topography (overall transverse slope) greater than 75 degrees

Figure 33: Topography (slope) in the transverse direction.

The lengths of the portions of each segment that have overall slopes in the transverse direction between 0 degree and 15 degree, between 16 degree and 30 degree, between 31 degree and 45 degree, between 46 degree and 60 degree, between 61 degree and 75 degree and between 76 degree and 90 degree were calculated. These individual lengths were converted to cumulative lengths for 15, 30, 45, 60 and 75 degree slopes. Thus, the total percentages of each segment that have overall slopes in the transverse direction greater than 15, 30, 45, 60, 75 degree were calculated.

4.1.11 Traffic Volume on the Segment

A number of researchers have considered traffic volume and have found varied results. A study in Howard County, Maryland showed that traffic volume on I–70 displayed an inverse relationship to accident frequency (Armstrong, 1997). The author warned to use traffic volume cautiously. A study in Iowa by Hubbard et al. (2000) could not find any relationship between ADT and deer-accidents. An earlier study by Carbaugh et al. (1975) also found no relationship between traffic volume and accident frequency. Another study by Allen and McCullough (1976) speculated that increased traffic volume might have caused higher accident frequencies. As a whole, the literature shows that the relationship between traffic volume and deer-vehicle accident frequency is ambiguous and needs to be studied. Traffic volume was considered in this study as two parameters, Annual Average Daily Traffic (AADT), and AADT per lane.

4.1.12 Traffic Speed

In this study, it has been assumed that the *Posted Speed Limit* is related to the eighty-fifth percentile speed. Madsen (2002) found some relationship between deer-vehicle accident frequency and traffic speeds. Gunther et al. (2000) observed that there was a significant influence of posted speed on the animal-vehicle accidents, and large mammals were killed significantly more than expected on roads with posted speeds of 55 mph (88 kph) and significantly less than expected on roads with posted speeds of 45 mph (72 kph) in Yellowstone National Park.

4.1.13 Number of Lanes

Two-lane, four-lane and six-lane road segments were considered in this study. Ulberg (1997) found that more large animal accidents happened on local roads with two lanes. The study by Hubbard et al. (2000) revealed that higher accident frequencies were positively correlated with the number of lanes, contradicting the findings of two previous studies by Ulberg (1997) and Bashore et al. (1985).

4.1.14 Presence of Deer Warning Signs

No studies have considered the presence of *deer warning signs (type W11-3 in USDOT MUTCD, 2000)* as a predictor variable while developing a model. In this study, the presence of deer warning signs was recorded during the primary data collection. The variable only considered whether a deer warning sign was present or not. The specific location of the sign relative to the beginning of the segment was not considered

4.1.15 Presence of Traditional Fencing

A study by Puglisi et al. (1974) showed that higher deer-mortality occurred where the 7.5-ft (2.29 m) fence existed. The reason was explained by saying that the 7.5-ft (2.29 m) fencing was installed in areas where a deer-highway mortality problem had been anticipated. The study by Finder et al. (1999) concluded that fencing might not be an effective solution to this problem. Most of the studies have evaluated high-fencing as a counter-measure to this problem. This study considers the traditional right-of-way fencing as a predictor variable. Right-of-way fencing or any other fencing with a height less than 5 ft (1.5 m) was considered in this study.

4.1.16 Median Type

The segments used in this study included segments with three types of medians. All of the two-lane highways were undivided, and two-directional traffic was separated by pavement markings only. One type of median was a grassy median separating two-directional traffic and approximately 15-40 ft (4.6 to 12.2 m) wide. This type of median provides deer plenty of refuge area in between two-directional traffic movements but increases the right-of-way width. The other of median was the concrete safety shape barrier (New Jersey Shape–AASHTO SGM11a in the *Roadside Design Guide,* 1996), found mostly on Interstate segments. This type of median creates some sort of obstruction to deer crossing the roadway. One of the important findings of the UMBC study (Armstrong, 2000) was that 32 out of 55 accidents were the result of deer entering the roadway from the median side. No study was found that considered median type.

4.2 Selection of Segments

Based on a detailed literature review, the availability of data, the relative costs and time involvement in data collection and the specific characteristics of the candidate segments, 123 segments were selected for this study. Descriptions of the selected segments are listed in Appendix C. The segments were selected from fifteen counties. Most of the counties are from the northeastern part of the state, with the exception of Elk County. Collectively, these counties represented a variety of roadway characteristics and contexts in areas where deer-vehicle crashes are of particular concern.

The selected counties are shown in Figure 34.

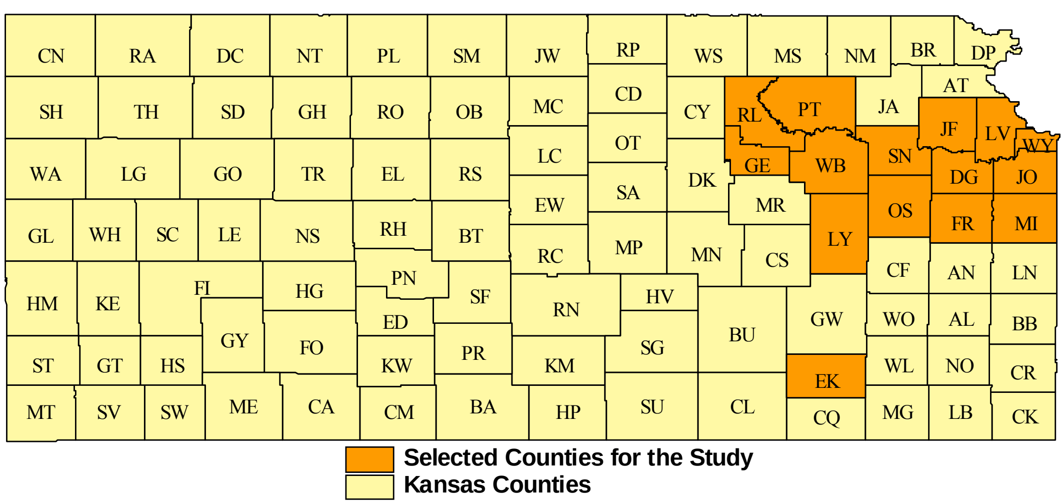

Figure 34: Counties from which field data was collected

The literature review suggested that more deer-vehicle accidents took place on two-lane highways and local roads due to greater coverage and typically narrower clear zones (Ulberg, 1997). Sixty-seven percent of the selected segments were two-lane roads. Thirty-two percent of the segments were four-lane segments. The distribution of segments used in the study is shown in Table 5.

Table 5. Distribution of selected segments by lane

Lanes	Number of segments selected
2	82
4	40
6	1
Total	123

The distribution of selected segments by deer-vehicle accident rate is shown in Table 6. The accident rate varied from 0.0 to 3.6 accidents per mile per year between 1997 and 2001.

Table 6. Distribution of selected segments by accident rate

Accident Rate, a (accidents/mile/year)	Number of segments selected
0	30
$0 < a \leq 1$	30
$1 < a \leq 2$	34
$2 < a \leq 3$	24
$3 < a$	5
Total	123

Segments were selected from various road classifications and traffic volume levels. Traffic volume levels of segments are listed in Table 7. The lowest volume segment was 225 vpd, and the highest volume was 67,900 vpd.

Table 7. Distribution of selected segments by AADT

Annual Average Daily Traffic (vpd)	Number of segments selected
AADT ≤ 1,000	26
1,000 < AADT ≤ 5,000	40
5,000 < AADT ≤ 10,000	28
10,000 < AADT ≤ 20,000	12
20,000 < AADT ≤ 30,000	13
AADT > 30,000	4
Total	123

Segments represented areas with different hydrological characteristics (areas with many rivers and creeks and no rivers or creeks). At least one river or creek intersected with 88 segments, about two-thirds of the segments. The distribution is shown in Table 8.

Table 8. Distribution of selected segments by number of intersecting waterways

Waterways	Number of segments selected
0	39
1	61
2	15
3	7
4	0
5	1
Total	123

The distribution of selected segments by posted speed is shown in Table 9.

Table 9. Distribution of selected segments by posted speed

Speed Limit	Number of segments selected
35	5
40	1
45	9
50	1
55	40
60	5
65	32
70	30
Total	123

Segments were selected from areas with diverse densities of deer population and Deer Management Units (DMUs) with various deer harvesting success rates. Segments were selected from different types of land use (woodland, cropland, grassland etc.). It is notable that while selecting the segments, a rural highway segment was given priority over an urban segment. Segments were selected from different types of terrain classifications.

Three different median types were considered. Table 10 shows the distribution of selected segments with respect to median type.

Table 10. Distribution of selected segments by median type

Median Type	Number of segments selected
Undivided	85
Jersey Barrier	13
Divided Highway with Grass Median	25
Total	123

Selected segments were with diverse clear zones and sight distances (wider right-of-ways and narrow, vision obstructed local roads).

4.3 Data Collection

Primary data were collected by visiting all of the one hundred twenty three segments located in 15 counties of the state of Kansas. Secondary data were collected from various agencies after consultation with responsible agency personnel. Values for 21 of the variables considered in the study were collected during site visits. Values for the remaining 25 variables considered in the study were obtained from secondary sources or generated using secondary data and a GIS.

4.3.1 Primary Data Collection

The primary data were collected by visiting segments in the Fall of 2002 during the months of October and November. The first week was spent collecting test data, adjusting the software, and refining the data collection process. The actual data collection began the second week of October and continued for six weeks. The data were collected during the daytime. It was possible to collect data for approximately six segments each day.

The data was collected by a two-person crew comprising, the author and an assistant. One of the persons (the author) drove the car, while the second person operated the computer. Prior permissions were obtained from the relevant agencies (The Kansas Department of Transportation and The Kansas Turnpike Authority) for these activities. A GPS (Global Positioning System) Receiver was magnetically mounted to the roof of the vehicle and connected to a laptop computer. The computer operator sat in the front passenger seat and held the laptop computer. A lap desk was used to support the computer comfortably for the operation. A laser range finder was used for measuring clear widths from the vehicle.

4.3.2 Daily Segment Groups

The selected segments were identified on paper maps so that the site visits could be planned so as to minimize the required travel. Generally, six site visits were planned for each day. The number varied slightly according to the distances of the segments from the starting point (Lawrence, Kansas, in Douglas County). For example, in a single day, it was possible to collect data for eight segments located in Douglas County, but it was difficult to collect data for more than four segments per day when traveling to Elk County, about three hours from Lawrence. The planned segments for each day were selected to minimize the overall travel time, including travel to and from Lawrence as well as travel between study segments.

4.3.3. Data Collection Process

One crew member served as the driver, while the second served as navigator. After reaching at the segment area, the beginning of the segment was identified, and the vehicle amber warning light was turned on. During the data collection, the computer was being operated by the second person. The range finder was either operated by the driver (when stopped on the shoulder) or by the computer operator. The driver of the car, after measuring the distance, repeated out loud the *clear width measurement* and the computer operator recorded the reading. The actual data collection operation for any segment took between ten and fifteen minutes. The average overall time for any segment took between thirty minutes to one and a half hours depending on the location of the segment, complexity involved in locating it and the volume of traffic on the segment.

A Microsoft Excel workbook was created and macros were developed to help log the data, reading the latitude and longitude from the GPS receiver and entering them into the spreadsheet. A description of the data collection spread sheet is shown in Appendix D. The Excel workbook initially contained three different worksheets. The first sheet was used to record a general description of the segment, including the following items.

1. Segment identification number
2. Date of the survey
3. Location by County
4. *On road* names
5. *At road* names
6. Posted speed
7. Number of lanes
8. Median type

The second and third sheets were used for recording information about each direction of travel. The data logged in these sheets included the following items.

1. Landmarks (beginning of the segment, end of the segment, bridge structure)
2. Clear width

3. Adjacent side slope
4. Topography
5. Presence of Deer crossing sign
6. Fencing details (beginning or end of fencing within the segment)
7. Longitude and Latitude (of the point where any information is entered).

The car was driven from one end of the segment to the other end of the segment and then back. At the outset, the values for applicable variables were filled in. Whenever there was any change observed in any variable (e.g. clear width changed from 45 feet to 28 feet) the car was stopped, and the change was recorded. The corresponding latitude and longitude values were recorded automatically by the computer each time data was entered.

4.3.4 Data Items

Whenever any information was entered in a designated cell of the Microsoft Excel spreadsheet, the corresponding latitude and longitude data were recorded automatically in the same row in the appropriate cells. As a result, segment characteristics could later be used in calculating lengths for each parameter value.

4.3.5 Posted Speed Limit

The posted speed limit (if any) was recorded. If more than one posted speed limit existed, all of them were recorded. If no speed limit was posted, the standard speed limit for the functional type of the highway was recorded. For example, on Interstate 70 or Kansas 10 (both 4-lane divided highways), if no speed limit was posted on the study segment, a speed limit of 70 mph was assumed based on the typical practice in Kansas for highways of similar functional classification and design.

4.3.6 Number of Lanes

The basic number of lanes was recorded. Any additional lanes (e.g. acceleration or deceleration lane) were ignored.

4.3.7 Median Type

Three basic median types were considered in the study as listed in Table 11.

Table 11. Description of median types

Code	Median type
1	Undivided 2-lane highways
2	Divided highway with grassy median
3	Divided highway with concrete safety shape barrier (New Jersey (NJ) Shape – AASHTO SGM11a in the Roadside Design Guide, 1996)

4.3.8 Landmarks

The locations of the beginning and end of the segment and any bridges or culverts were identified and their locations were logged as geodetic coordinates.

4.3.9 Deer Warning Sign

The location of deer warning signs (type-W11-3 in *USDOT MUTCD*, 2000), if any, was noted. A length of approximately 5 miles (8 km) beyond the beginning and end of the each segment was also examined to identify any deer signs that apply to the segment. The information for each side of the segment was noted separately. The description of the warning sign (i.e., any distance mentioned on it) was also noted.

4.3.10 Fencing Details

The fencing end points that occurred within the segment were noted. The information for each side of the segment was noted separately on a separate work sheet.

4.3.11 Clear Width

Clear width values were aggregated into five groups, each representing a 30 ft (about 9 m) range. The size of the ranges was based on the trial data collection. A smaller value would increase the precision but would require more frequent stopping of the data collection vehicle. The range size was chosen as a balance of these considerations. The distance groups are listed in Table 12.

Table 12. Description of clear width groups

Groups	Description
1	The nearest obstruction to vision is 0 to 30 ft from the edge of the traveled way in the transverse direction.
2	The nearest obstruction to vision is 31 to 60 ft from the edge of the traveled way in the transverse direction
3	The nearest obstruction to vision is 61 to 90 ft from the edge of the traveled way in the transverse direction
4	The nearest obstruction to vision is 91 to 120 ft from the edge of the traveled way in the transverse direction.
5	The nearest obstruction to the vision is greater than 120 ft from the edge of the traveled way in the transverse direction.

4.3.12 Adjacent Side Slope

The adjacent side slope values were aggregated into six ranges, each range had a span of 15 degrees. The range size was decided based on the trial data, striking a balance between the level of detail and the effort required to collect the data. The description of adjacent side slope groups is shown in Table 13.

Table 13. Description of adjacent side slope groups

Groups	Description
1	The adjacent side slope was between 0 degree and 15 degree angle (either positive or negative) measured from the horizontal line of sight.
2	The adjacent side slope was between 16 degree and 30 degree angle (either positive or negative) measured from the horizontal line of sight.
3	The adjacent side slope was between 31 degree and 45 degree angle (either positive or negative) measured from the horizontal line of sight.
4	The adjacent side slope was between 46 degree and 60 degree angle (either positive or negative) measured from the horizontal line of sight.
5	The adjacent side slope was between 61 degree and 75 degree angle (either positive or negative) measured from the horizontal line of sight.

4.3.13 Roadside Topography

Roadside topography is the general slope of the area just beyond the adjacent side slope. The procedures involved in data collection and data recording for both parameters adjacent side slope and roadside topography were the same. Roadside topography is a generalization of the terrain beyond the immediate roadside, whereas transverse slope is an estimation of the slope immediately adjacent to the roadway (beyond the foreslope).

4.4 Secondary Data

4.4.1 Accident Information

The accident data were collected from KDOT in two different ways:

a) The Kansas Accidents Record System (KARS) database records were provided by the Kansas Department of Transportation (KDOT). The data contained accident records from 1990 to 2001. The data were filtered to extract deer-vehicle accident related records only.

b) The plotted deer-accidents from (1990-2001) on KDOT highway network in the form of GIS shape files were also provided by Kansas Department of

Transportation (KDOT). The deer-accidents between 1999 and 2001 are shown in Figure 35. An enlarged view of this figure is provide in Appendix E.

Deer-vehicle accident records were also collected from the following agencies:

1. Douglas County Public Works Department
2. Johnson County Public Works Department
3. Jefferson County Road Administration Office
4. Elk County Sheriff's Department

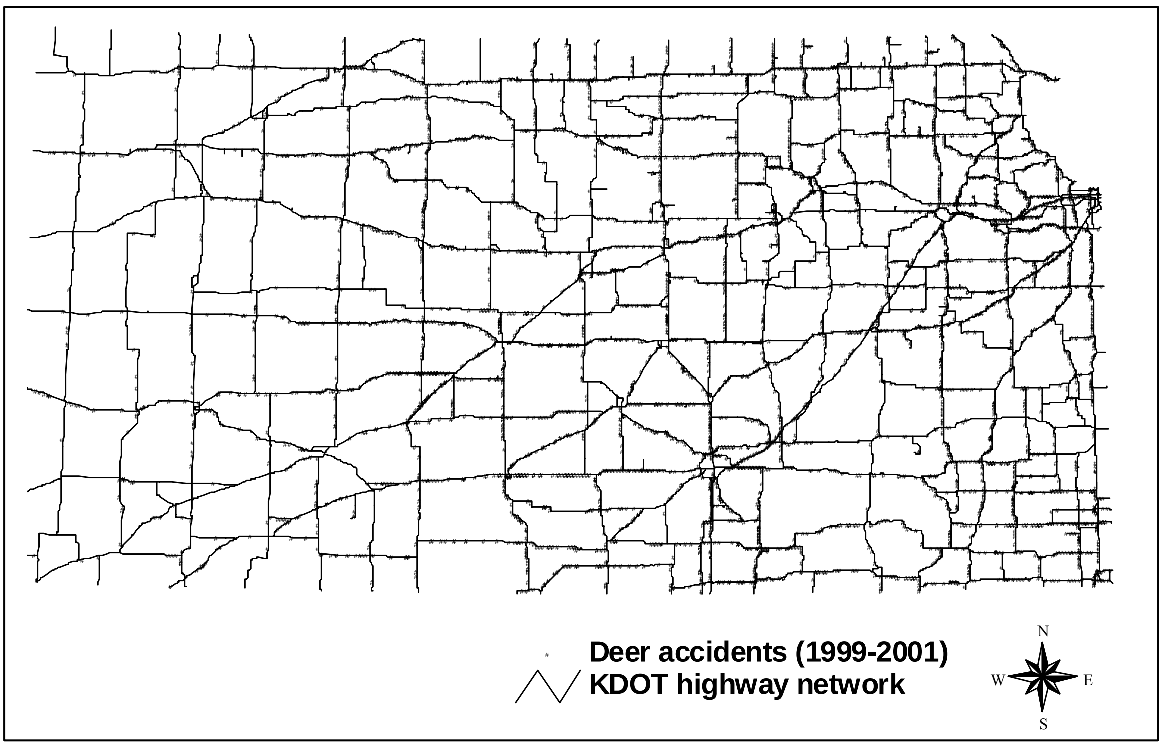

Figure 35: KDOT highway network and deer-vehicle accidents (1999-01)

4.4.2 Land Use

The Land use data were obtained from the website of the Kansas Geological Survey, the Data Access and Support Center (DASC, 2001). Figure 36 shows a portion of a Land Cover file. The DASC website (DASC, 2001) provides the *Land Cover* data for the state of Kansas. The originator of the Land Cover files is the Kansas Applied Remote Sensing Program (KARS) and was first published in 1993. The Land Cover database contains 10 general land cover classes for the state of Kansas. It is suited for county-level and watershed-level analyses that involve land use and land cover. The interpretations derived from its use are intended for planning purposes. Land use files are available for each county. The map projection was “Geographic.” The data for relevant counties were downloaded from the website. The files were extracted, and GIS shape files were created.

4.4.3 Hydrograph

The Surface Water Information Management System (SWIMS) hydrograph files were used in this study (Kansas GIS Policy Board, 2001). The relevant files were downloaded from the DASC (2001) web site. SWIMS was designed and published in 1996 to meet multi-agency hydrologic database needs for Kansas. The purposes of the design of SWIMS were to provide agency related hydrographic data and to provide support for all GIS analyses. The SWIMS was developed by the Kansas Department of Health and Environment (KDHE) and the Geographic Research, Analysis and Information Laboratory (GRAIL). A total of 23 hydrographic files were needed to cover the entire study area. Each file contained information on one hydrological basin such as that shown on Figure 37.

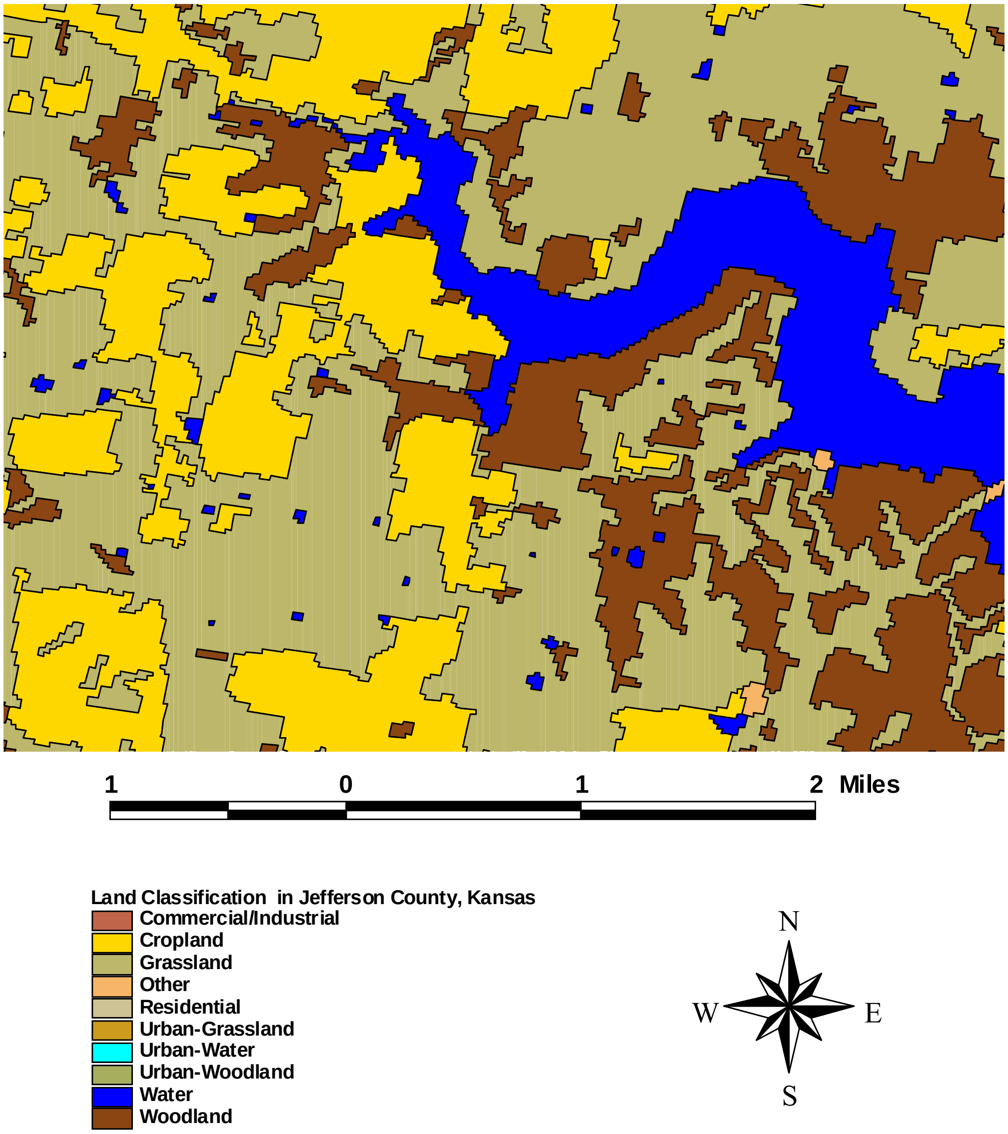

Figure 36: Map Showing Land Cover in a portion of Jefferson County, KS

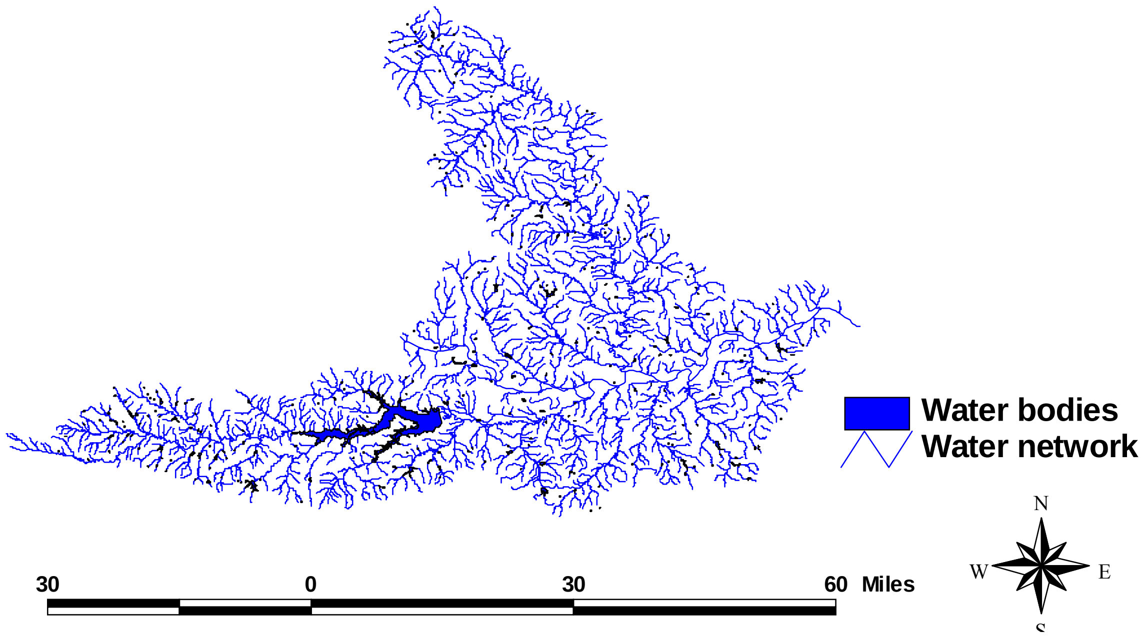

Figure 37: SWIMS hydrographs showing Lower Kansas River Basin

4.4.4 KDOT Highway Network

A KDOT Highway network GIS file was received with the accident locations plotted on it. The KDOT highway network contains highways classified as Interstate, US Highways, and State Highways. The size of the shape file or GIS layer is also much smaller, making it much easier to handle with any GIS software. This file was published in 2002 by the KDOT Bureau of Transportation Planning. This file was projected along with the accident files to check that the highway network of KDOT overlaps with the TIGER 2000 network.

4.4.5 TIGER Road Network

The U.S. Bureau of Census 2000 TIGER (Topologically Integrated Geographic Encoding and Referencing) System Line files were imported by the Kansas DASC staff and converted to derive a subset of shape files for the state of Kansas. It was published in 2002. Figure 38 shows the TIGER road network for Topeka and vicinity.. The advantage of the TIGER 2000 road network over the KDOT road network is that TIGER 2000 contains county and local roads as well as state and federal highways.

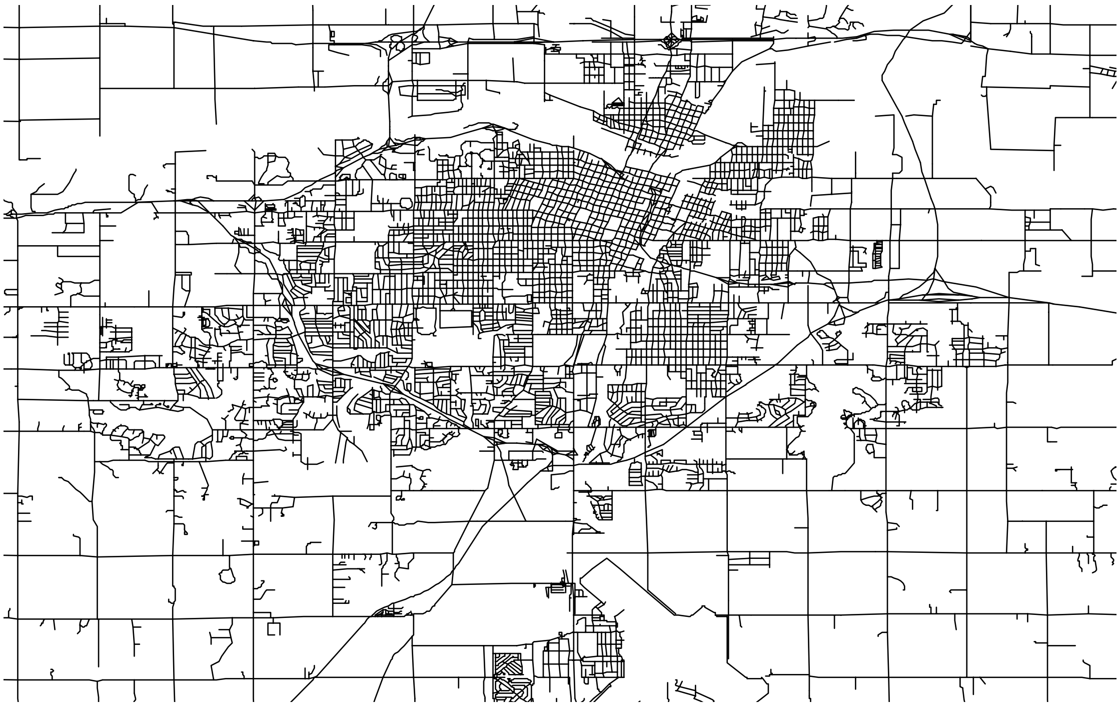

Figure 38: TIGER 2000 road network for Topeka and vicinity

4.4.6 Traffic Volumes

The traffic data were collected from the KDOT Bureau of Transportation Planning. The Kansas State Highway System Traffic Flow Map used in this study was published in 2002. The traffic counts were recorded in FY 2001 (July 2000-June 2001).

The Annual Average Daily Traffic (AADT) volumes on County Major Collector Rural Roads for various KDOT districts were also collected from the same agency. The District 1 traffic volume data map was published in January 2002. The traffic volume data were collected for all of the six districts between July 1998 and June 2001.

4.4.7 Harvest Density

Deer-harvest density information was collected from the Kansas Department of Wildlife and Parks (KDWP), Emporia Research Office. The data were available by Deer Management Unit (DMU) as deer harvested per 100 square miles. The information was only available for the 2001-02 season. The 18 DMUs in Kansas and associated densities are shown in Figure 39.

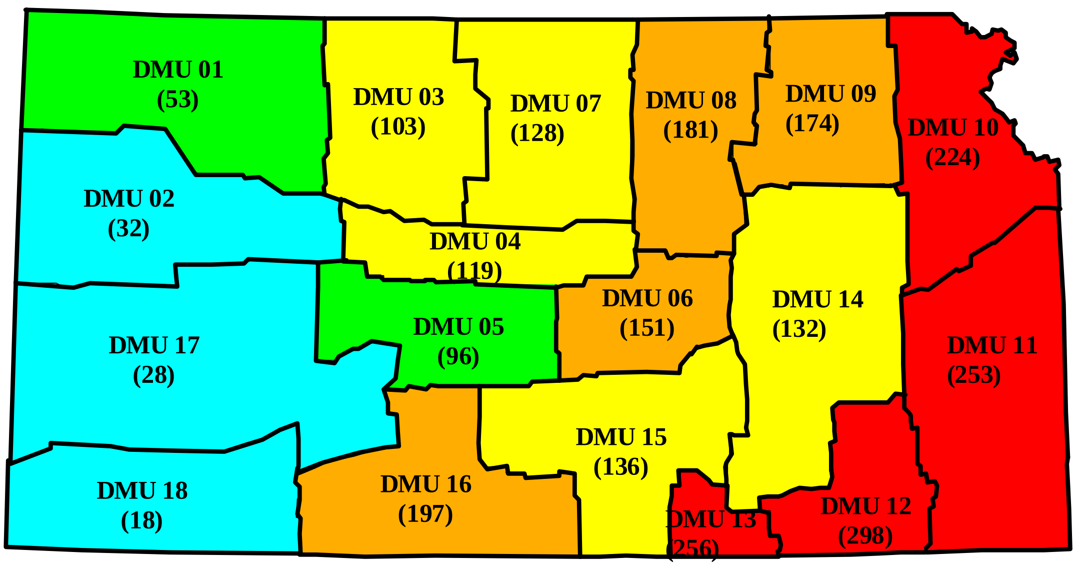

Figure 39: Deer Harvest density (deer/100 square-miles) in 2001-02 (KDWP, 2002)

4.5 Data Analysis

After the primary and secondary data were collected, the collected raw data were analyzed. Different data were analyzed in different ways according to the form in which the raw data existed and the requirement of the input for further analysis.

4.5.1 Preparation of the Field Data

The primary data collected during site visits to each segment were saved in Microsoft Excel files. The distances between data points were calculated from the geodetic coordinates. Using these distances, the percentage of the length of the segment for which each parameter had a given value was determined. For example, summation of the portions of the segment with a clear width of 31 ft (9.45 m) to 60 ft (18.28 m) was divided by the length of the segment to obtain the parameter value.

All information about the presence of deer signs, bridges or visible culverts, number of lanes, posted speed limit, and median type were gathered from the respective segment files and transferred to a separate database.

A database was created to include all data pertaining to the study. All of the above mentioned data computed and extracted from the Excel spreadsheets were stored in the database.

4.5.2 Establishing a Common Spatial Reference

The GIS data obtained used a variety of spatial reference systems and could not be overlapped without projecting the data to a common spatial reference system. ArcView GIS version 3.2 (ESRI, 2003) was used to perform the necessary reference system conversions. For example, the SWIMS data files, containing hydrographic information, had been projected using a Lambert Conformal Conic projection. The TIGER 2000 data, which contains detailed road network information, are in geodetic coordinates. All of the data were converted to geodetic coordinates so that all of the data could be superimposed accurately and analyzed collectively within the GIS.

4.5.3 Determining Accident Rates

Accident locations were added to the GIS project. Accident locations for a five-year period (1997-2001) were studied. For each study segment, the number of accidents for each year was counted and the yearly counts averaged to determine the average accident frequency. The frequency was divided by the segment length to obtain the accident rate in accidents per year per mile.

4.5.4 Determining Roadside Land Use Values

ARCView GIS was used for computation of various areas with land uses of

1. Wooded Land
2. Crop Land
3. Wooded and Crop Land

The procedure comprised the following four steps.

1. The land use data and selected segments were projected on a Universal Transverse Mercator so that the measurement of lengths and areas could be easily performed.
2. Buffers were created about the segment at 1,000 ft. increments up to 5,000 feet, as shown in Figure 40.

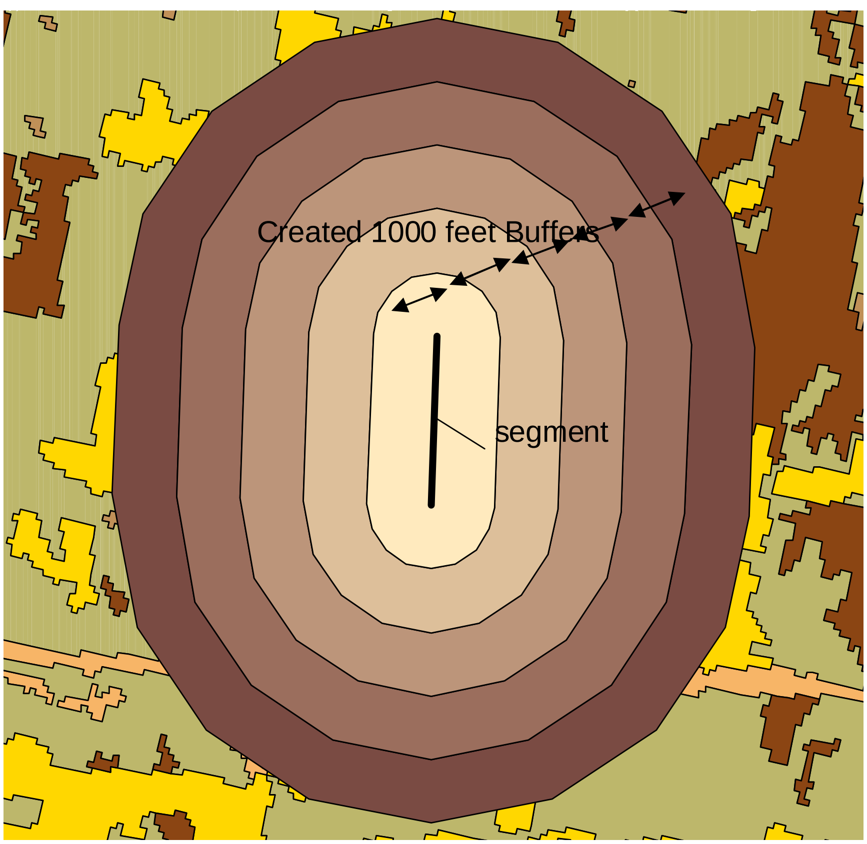

Figure 40: Buffers overlaid on land use

3. Buffers were considered for 1,000–ft (about 305 m), 3,000-ft (914 m) and 5,000-ft (1,524 m) distances surrounding the segment. The portions of each buffer used in the processing comprises the area whose border is parallel to the segment and the area beyond the endpoint that lies within a 45° arc, as shown in Figure 41. The resulting data used in the calculation of the parameter values are shown in Figure 42. The 1,000-ft (about 305 m), 3,000-ft (914 m) and 5,000-ft (1,524 m) buffers were used.

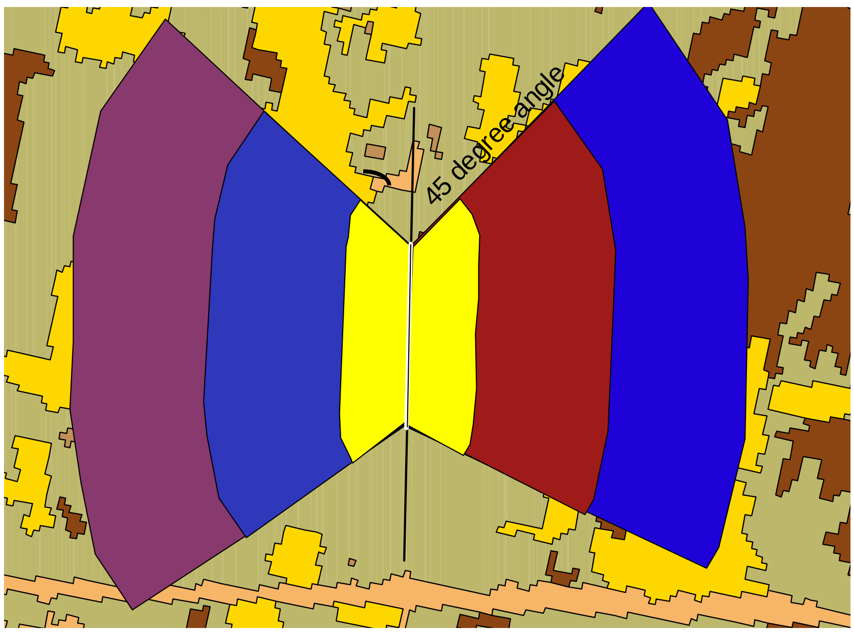

Figure 41: Buffers for intersection with the land use data

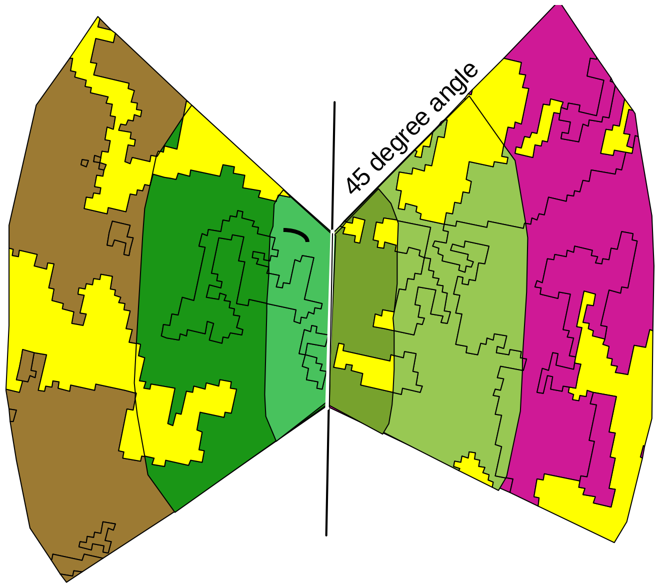

Figure 42: Land use data extracted from analysis

4. The area of wooded land and crop land within each buffer was determined and divided by the total buffer area to yield the percentage of the area that has wooded land, crop land and summation of wooded and crop land.

The calculated parameters for a 1,000-ft buffer are listed in Table 14. Similarly, six parameters were calculated for the 3,000 and 5,000-ft buffers.

Table 14. Calculated land use parameters for 1,000 ft buffer

Parameter	Description
1	MAXW1: maximum value of two sides: percentage of wooded land within the buffer, 1000 ft (305 m) from the roadway, each side separately
2	MAXC1: maximum value of two sides: percentage of crop land with in the buffer, 1000 ft (305 m) from the roadway, each side separately.
3	AVGW1: average value of two sides: percentage of wooded land with in the buffer, 1000 ft (305 m) from the roadway, each side separately.
4	AVGC1: average value of two sides: percentage of crop land with in the buffer, 1000 ft (305 m) from the roadway, each side separately.
5	MAXWC1: maximum value of two sides: percentage of wooded and crop land with in the buffer, 1000 ft (305 m) from the roadway, each side separately.
6	AVGWC1: average value of two sides: percentage of wooded and crop land with in the buffer, 1000 ft (305 m) from the roadway, each side separately.

4.5.5 Calculation of Straight Length and Actual Length

The straight length of the segment was measured by connecting the two ends of the segment, as shown in Figure 28. The straight length was divided by the actual length to calculate the curvature ratio.

4.5.6 Number of Rivers and Creeks

The SWIMS shape files were used to read this information for each segment of roadway. The numbers of rivers or creeks intersecting the segment were counted from the shape file. The number was adjusted for the length of the segment to find out the value of rivers or creeks intersecting per mile of roadway.

4.6 Principal Component Analysis (PCA)

The preliminary analysis of the data indicated that multiple-collinearity existed among predictor variables, making the application of linear regression analysis infeasible. To help identify the variables into groups, Principal Component Analysis (PCA) was applied with the intent of eliminating the collinearities so that regression analysis might be applied.

PCA is a mathematical procedure that linearly transforms a set of correlated response variables into a substantially smaller set of uncorrelated variables that still represents most of the information of the original set of variables. The uncorrelated variables are called *principal components* (Johnson, 1998).

4.6.1 Uses of PCA

By a careful look at the Principal Components, a number of important questions can be answered. Answers to these questions are important to proceed to the next steps of data analysis. One of the questions is whether there is multi-colinearity among the predictor variables? This is important to know because the existence of multi-co linearity greatly affects the interpretation of any fitted regression model. Multiple regression analysis yields invalid results when predictor variables are highly correlated.

4.6.2 Objectives of PCA

PCA was applied to find out the true dimensionality of the data. The intention was not necessarily to reduce the dimensionality of the data. It was expected that the PCA would answer the following question: "If the data are plotted in a *p*-dimensional space (here 45 dimensional spaces), will the data take up all *p* (here 45) dimensions?" If not, then even though *p* (45) variables are measured, the actual dimensionality of the variable is less than *p*. PCA can be used to assess the actual dimensionality of the data. "When the actual dimensionality of the data is less than *p*, the original variables can be replaced by a smaller number of underlying variables without losing any major information" (Johnson, 1998).

It is believed that though PCA will always identify new variables, it is not always true that these new variables will have some practical meaning or can be interpreted directly. However, the principal component variables will be still useful. One researcher stated:

> It is unreasonable to try to give some meaning to the principal components or exceptional cases to be able to interpret the principal component variables. If the principal components can be interpreted, it is a bonus to the researcher. But we should remember that a PCA is always useful whether the principal components can be explained or not (Johnson, 1998).

The principal component resulting from an analysis may relate several variables whose relationships are non-intuitive and which collectively have no direct connection to any particular characteristic of the overall data set.

4.6.3 Application of PCA

In this study SPSS was used to apply PCA to the database. SPSS is one of the statistical programs that can perform PCA on standardized data. The SPSS package version-11 does not have any separate routine to perform PCA. One must to perform PCA with the Factor Analysis program. SPSS standardizes the data, and then performs on it.

There are two ways to perform PCA:

a) PCA on the Variance-Covariance Matrix (Σ)

b) PCA on Correlation Matrix (P)

The first method uses the variance-covariance matrix of the data set, whereas the second method uses the correlation matrix of the data set to apply the PCA. The second method has the advantage over the first method that when variables do not occur on equal footings, the second method can be used but not the first one. It is necessary to apply PCA methods to standardized data (Z scores). The Z scores are obtained by subtracting the mean of the variable scores from each value of the variable and dividing them by the standard deviation of the variable.

The second method was selected for analysis in this study. The PCA with the second method is done by computing the eigenvalues and eigenvectors of the correlation matrix. When the correlation matrix is analyzed, the SPSS program produces estimates of C_j^*. The C_j^* are known as the component correlation vectors. These vectors have lengths equal to the square roots of their corresponding eigenvalues. Generally, PCA computer programs produce estimates of a_j^*. (these values always have lengths equal to 1). a_j^* are the eigenvectors of correlation matrix P. (These "*" indicate that the value comes from standardized data or Z scores). C_j^{*}'s directly give the correlation between the original variables and the newly derived principal component variables. This is helpful because the interpretation is easy and straightforward.

It is notable here that the determinant of the sample correlation matrix (*denoted by R*) should be close to zero because it is an essential condition for applying a PCA. The value of R is calculated by the program and available as an output. If it is believed that the data come from a multivariate normal distribution, the response variables should be checked to see if they are independent (i.e. correlated) before performing a PCA.

A likelihood ratio test statistic for testing H_0 : $\mathbf{P} = \mathbf{I}$ (here I is an identity matrix) is given by V = | R | (P is the correlation matrix). For large values of number of samples N, we reject H_0 if

$$-a \log V > \chi^2_{\alpha,\, p(p-1)/2}$$

where a = N -1 – (2 p + 5) / 6. and p = number of parameters. If H_0 can not be rejected, a PCA should not be performed.

4.6.4 Determining the Number of Principal Components

It was essential for the multivariate data analysis to find out the actual dimensionality of the space in which the data fall, or in other words, the number of principal components that have variances larger than zero. All of the methods generally used by researchers were considered in this study. Johnson (1998) explained three methods for determining the number of principal components.

Method 1

The first method is based on how much variability the researcher wants to account for. This decision should be based on the type of population being sampled. For laboratory data, it may be easy to account for more than 95% of the total variability with only a couple of principal components. But for field data, especially data related to animal behavior, five to seven principal components may be required to account for the greater variation within the sample population or about 75% of the total variation. The SPSS program allows the researcher to select the number of principal components to be used. It is noteworthy here that greater the number of principal components, the less useful each principal component will be, because the greater the number of principal components the smaller the percentage of variance explained by each principal component.

Method 2

The second method utilizes a Scree Plot of the eigenvalues. A Scree Plot is constructed by plotting the value of each eigenvalue against its ordinal number. A sample Scree Plot is shown in Figure 43. As the ordinal number increases, the eigenvalues tend toward zero until they are small enough that they most likely represent only random noise in the data and can be ignored.

Method 3

If PCA is applied by analyzing the correlation matrix, a third method can be used. This method looks for eigenvalues that are greater than 1. This method estimates the dimensionality of the sample space to be that of the number of eigenvalues that are greater than 1. When the analysis is done on standardized data (for example, the correlation matrix), the variance of each variable is equal to 1. Method 3 is not applicable when analyzing raw data or when using the second PCA technique, which uses the sample variance-covariance matrix.

Figure 43: A sample Scree Plot

Method 3 was used first to determine the number of principal components. At a later stage, the first two techniques were used to decide about the number of principal components.

Two separate PCAs were performed in this study. The first PCA used all components with eigenvalues greater than one, and the second PCA used seven principal components. The decision of considering seven principal components was based on the total variance explained by the principal components and the curve of the Scree Plot as discussed before.

4.6.5 Calculation of the Principal Component Scores

To use principal components in further statistical analysis, it is necessary to compute principal component scores for each experimental data point. When PCA is performed on a correlation matrix, principal component scores must be computed from the Z scores. The principal component scores are the values of the principal component variables. These scores provide location of the observations in the data set with respect to its principal component axis. The product is generally a set of standardized principal component scores. In this study, the standardized scores were used.

The principal component scores provide the locations of the observations in a data set with respect to its principal component axis. To use the principal component variables in ensuing statistical analyses, these principal component scores are necessary.

4.7 Data Analysis

PCA requires that all variables be continuous. Parameters that are discreet or categorical can be introduced as dummy variables in the regression analysis following the PCA. Three parameters were treated as categorical variables. They include the following:

- presence of deer warning sign
- median type
- number of lanes (one record had a value of 6, all others had values of either 2 or 4)

Three other parameters were neither clearly continuous nor clearly categorical. The following were treated as continuous variables, although it could be argued either way.

- number of intersecting rivers and creeks
- bridges and culverts
- posted speed limit

All continuous parameters were standardized. PCA resulted in 10 principal components (PCs) with eigenvalues greater than 1.0. The component matrix was rotated to minimize colinearity. For each PC, variables were included if their component score was 0.6 or greater.

Other variables were considered to have a negligible influence on the PC scores. Table 15 shows the component scores with the scores of the parameters included in each PC shaded. More output from the PCA is given in Appendix F.

Table 15. Rotated Component Matrix

0.6	1	2	3	4	5	6	7	8	9	10
BridCulv		0.165		0.142		0.214	0.443	0.722		
Fencing	-0.101	-0.15	0.103	-0.141		0.351	0.139	-0.286	-0.658	
PSLimit	0.231		0.204	-0.205		0.629	0.277		-0.119	0.129
CW30	-0.124	0.344		0.564		-0.477				
CW60		0.204		0.884		-0.203				
CW90		0.159		0.926						
CW120		0.134	0.106	0.889					0.116	
SSlpgt15	-0.173	0.13	0.816	0.18		0.175		-0.168		
SSlpgt30	-0.149		0.91			0.13				
SSlpgt45	-0.116		0.864			0.118		0.294	-0.131	
SSlpgt60	-0.173		0.805			0.121		0.35	-0.148	
SSlpgt75						-0.194				0.789
Topogt15		0.168	0.705		0.369			-0.251		0.147
Topogt30		0.126	0.56		0.596		0.177	-0.224		0.124
Topogt45			0.23		0.876			-0.109	0.111	
Topogt60		-0.104			0.929					
Topogt75	-0.102		-0.113		0.904					
RivCrk				0.101			0.9	0.206		
RivCrkpM			0.127				0.896	0.102		
BriCulpM		0.254		0.102		0.315	0.377	0.687	0.114	
StbyALen		-0.132				0.297			-0.214	0.69
AADT	0.133		0.177			0.896		0.122		
LaneAADT	0.129		0.183			0.885		0.178		
HarvDens		0.287	-0.105	0.189		0.206			0.611	-0.137
MaxW1		0.883		0.11				0.124	-0.174	
MaxC1	0.914	-0.171						0.105		
MaxWC1	0.902	0.215						0.154		
AvgW1		0.899		0.108				0.128	-0.169	
AvgC1	0.926	-0.193								
AvgWC1	0.924	0.202						0.148		
MaxW3		0.931		0.159					0.174	
MaxC3	0.912	-0.222	-0.113							
MaxWC3	0.915	0.267								
AvgW3		0.967		0.126					0.103	
AvgC3	0.924	-0.236	-0.124							
AvgWC3	0.915	0.274								
MaxW5		0.891		0.126					0.277	
MaxC5	0.87	-0.282				0.126		-0.119		
MaxWC5	0.862	0.223				0.153			0.162	
AvgW5		0.912							0.225	
AvgC5	0.879	-0.281				0.177		-0.106		
AvgWC5	0.873	0.272				0.173			0.156	

Based on the parameters included in each PC, the 10 components could be characterized as shown in Table 16.

Table 16. Principal Component Characterizations

PC	Included Parameters	Possible Characterization
1	All cropland and wooded land plus cropland variables	Cropland
2	All wooded land variables	Wooded Land
3	Sideslope variables (except 75 deg), Topo 15 deg	
4	Clear width variables (except 30 ft)	Clear Width
5	Topo 45, 60, and 75 deg	Topography
6	Posted speed, AADT, AADT per lane	Traffic density
7	Rivers/Creeks, Rivers/Creeks per mile	Riparian corridors
8	Bridges and Culverts, Bridges and Culverts per mile	Collectors
9	Fencing, harvest density	
10	Sideslope 75 deg, Straight length/actual length	Sight distance (indirectly)

PC3 and PC9 do not have an obvious commonality among the included parameters, so no possible characterization is suggested. The components generated by PCA do not always have an interpretable meaning, or characterization. It can be helpful when they do, but it is not strictly necessary.

4.7.1 Regression Analysis

PCA does not produce a predictive model, but simply helps arrange the data so as to minimize colinearity among the independent variables, and to sift out variables which have little or no effect on the independent variable. Each PC represents a new variable (comprised of one or more of the original variables, each weighted appropriately). Linear regression can be applied to the PCs to yield a predictive model.

For each record, the appropriate component score coefficients were used to calculate the record's *z*-values for each PC. The categorical parameters were coded as index parameters, and 80% of the 128 records were selected (randomly) for inclusion in the linear regression analysis.

The remaining 20% of the records were used for validation. Portions of the output from the regression analysis are given in Appendix G.

4.7.2 Results

Stepwise linear regression was employed, resulting in 5 variables: PC 2, PC 6, PC 10, Number of Lanes, and Median type. PC 2 comprises the parameters related to wooded area. PC 6 pertains to traffic volume and posted speed. PC 10 included a measure of the overall curvature of the segment and the percent of the segment with a sideslope greater than 75 degrees. The combination of these two variables could be interpreted as an indirect indicator of sight distance. The resulting model had an overall $R^2 = 0.357$, suggesting that the model's predictive value is minimal.

Most influential variables were those pertaining to wooded area, then traffic volume and speed, then sight distance. Variables not represented in the final regression equation include

- cropland
- harvest density (very coarse geographically)
- fencing (5 ft high or less)
- clear width
- rivers, creeks and culverts
- topography

The most surprising of the omitted variables was clear width. When a logarithmic transformation was applied to the dependant variable, clear width was the next PC included in the regression equation (PC 4).

Although the model's predictive capability is poor, the analysis is useful for identifying the relative importance of parameters with respect to crash modeling. It also suggests that the most important factors are either not included in the parameters under study, or they are not represented in adequate detail.

Chapter 5

Logistic Regression

Given that PCA did not provide satisfying results with respect to a usable model, logistic regression was applied to the data. Two separate sets of input parameters were used: the first being all available parameter types, and the second, only the parameters that were identified by PCA as having the strongest influence on crash rates. In both cases, the dependant variable was a discretized form of *deer-related accident rate.*

5.1 Dependant Variable

The intuitive choice for the dependant variable, *deer-related accident rate*, is a continuous variable (units are deer-related accidents per mile per year). KDOT's current methodology for identifying deer crash hot spots essentially applies a threshold to the historical rate, and segments whose rate is above the threshold are deemed to merit attention. To emulate this methodology, a threshold of 2 crashes per mile per year was established, and a binary variable was created whose value is 1 if the segment's rate is >=2.0 and 0 if the rate is less than 2. The threshold value of 2 was chosen based on the data. For practical purposes, this may be rather low, but for this data, any higher value would result in so few segments with a crash rate above the threshold that validation would be meaningless.

5.2 Covariates

Two separate approaches were used to establish a pool of candidate covariates. First, variables were chosen to represent all the types of variables represented in the collected data. For example, one measure of wooded land (max percent area wooded within 3000 ft of the roadway) was included, and all other similar measures (e.g., average percent area and other buffer distances) were excluded.

In the second approach, the results of the PCA were examined. For each of the component variables included in the final model (i.e., 2, 6, and 10), one measure of each parameter type was included. When several similar measures were present, the one with the highest component score was used. For example, PC2 contains the maximum and average percent wooded land for each of the three buffer distances, 1000 ft, 3000 ft, and 5000 ft. The average percent wooded land within 3000 ft has the highest component score, 0.967, as shown in Appendix F, and was consequently the parameter from PC2 that was selected for inclusion in the logistic regression analysis.

5.3 Approach 1: Results

5.3.1 Model 1

Forward stepwise regression resulted in the inclusion of 3 covariates. As shown in Table 15, for the cases used to generate the model, the accuracy of the model in correctly identifying high risk segments (i.e., accident rate >= 2.0) was less than 50% correct. Performance on the validation data was exactly 50%.

The variables added in each of the three steps were *max pct wooded within 3000 ft*, *median type*, and *presence of a deer warning sign*, respectively. It's interesting to note that while deer signs are installed on segments with a history of deer crashes, its addition to the equation had little practical effect.

Table 17. Performance of Model 1

Classification Table[c]

Observed			Selected Cases[a] V3 0	Selected Cases[a] V3 1	Selected Cases[a] Percentage Correct	Unselected Cases[b] V3 0	Unselected Cases[b] V3 1	Unselected Cases[b] Percentage Correct
Step 1	V3	0	78	4	95.1	13	2	86.7
		1	22	4	15.4	4	0	.0
	Overall Percentage				75.9			68.4
Step 2	V3	0	77	5	93.9	13	2	86.7
		1	16	10	38.5	2	2	50.0
	Overall Percentage				80.6			78.9
Step 3	V3	0	78	4	95.1	14	1	93.3
		1	16	10	38.5	2	2	50.0
	Overall Percentage				81.5			84.2

a. Selected cases Filter EQ 1

b. Unselected cases Filter NE 1

c. The cut value is .500

Table 18. Variables in Model 1

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	MaxW3	6.399	1.908	11.240	1	.001	600.997
	Constant	-2.264	.433	27.313	1	.000	.104
Step 2[b]	DUMMed3(1)	-1.922	.582	10.888	1	.001	.146
	MaxW3	6.902	2.105	10.754	1	.001	993.809
	Constant	-.908	.572	2.519	1	.112	.404
Step 3[c]	DeeSign(1)	-1.470	.621	5.608	1	.018	.230
	DUMMed3(1)	-2.236	.631	12.572	1	.000	.107
	MaxW3	6.688	2.213	9.134	1	.003	802.748
	Constant	.464	.820	.320	1	.572	1.590

a. Variable(s) entered on step 1: MaxW3.

b. Variable(s) entered on step 2: DUMMed3.

c. Variable(s) entered on step 3: DeeSign.

The analysis was repeated using a larger portion of the samples for validation. The results of that analysis were similar, and are given in Appendix H.

5.4 Approach 2: Results

5.4.1 Model 2

In the second approach, covariates were selected based on the results of the PCA and their respective component scores. Of the three components identified in the PCA, one of each type of parameter was used as input for the regression analysis. For example, of the wooded land variables included in PC2, only the one with the highest component score was used. Table 19 shows the variables considered. When variables were determined via a backward conditional method, one variable was eliminated. Of the 4 covariates remaining in step 2, only *average percent wooded land within a 3000 ft buffer (AvgW3)* was statistically significant (95% conf level).

Table 19. Variables in Model 2

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	AvgW3	11.967	3.162	14.320	1	.000	157436.9
	PSLimit	.041	.038	1.173	1	.279	1.042
	AADT	.000	.000	.439	1	.508	1.000
	StbyALen	33.042	18.222	3.288	1	.070	2.2E+14
	SSlpgt75	-22832.2	13805.462	2.735	1	.098	.000
	Constant	-37.805	18.546	4.155	1	.042	.000
Step 2[a]	AvgW3	12.092	3.128	14.948	1	.000	178468.9
	PSLimit	.056	.032	3.080	1	.079	1.058
	StbyALen	34.050	18.172	3.511	1	.061	6.1E+14
	SSlpgt75	-20987.2	12974.767	2.616	1	.106	.000
	Constant	-39.530	18.398	4.616	1	.032	.000

a. Variable(s) entered on step 1: AvgW3, PSLimit, AADT, StbyALen, SSlpgt75.

Table 20. Performance of Model 2

Classification Table[c]

Observed			Predicted: Selected Cases[a] V3 0	Selected Cases[a] V3 1	Selected Cases[a] Percentage Correct	Unselected Cases[b] V3 0	Unselected Cases[b] V3 1	Unselected Cases[b] Percentage Correct
Step 1	V3	0	77	5	93.9	14	1	93.3
		1	18	8	30.8	2	2	50.0
	Overall Percentage				78.7			84.2
Step 2	V3	0	76	6	92.7	14	1	93.3
		1	18	8	30.8	2	2	50.0
	Overall Percentage				77.8			84.2

a. Selected cases Filter EQ 1

b. Unselected cases Filter NE 1

c. The cut value is .500

5.4.2 Model 3

The same data was analyzed again, this time using a forward conditional method for including variables. The covariates added were the wooded land parameter and the speed limit parameter, both significant in the final model. Table 21 shows a summary of the model. Table 22 shows that the performance of the model is very poor.

Table 21. Variables in Model 3

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	AvgW3	8.273	2.459	11.320	1	.001	3915.827
	Constant	-2.205	.415	28.163	1	.000	.110
Step 2[b]	AvgW3	9.389	2.668	12.385	1	.000	11955.022
	PSLimit	.065	.031	4.414	1	.036	1.068
	Constant	-6.300	2.053	9.413	1	.002	.002

a. Variable(s) entered on step 1: AvgW3.

b. Variable(s) entered on step 2: PSLimit.

Table 22. Performance of Model 3

Classification Table[c]

Observed			Predicted: Selected Cases[a] V3 0	Selected Cases[a] V3 1	Selected Cases[a] Percentage Correct	Unselected Cases[b] V3 0	Unselected Cases[b] V3 1	Unselected Cases[b] Percentage Correct
Step 1	V3	0	78	4	95.1	13	2	86.7
		1	22	4	15.4	4	0	.0
	Overall Percentage				75.9			68.4
Step 2	V3	0	78	4	95.1	12	3	80.0
		1	20	6	23.1	3	1	25.0
	Overall Percentage				77.8			68.4

a. Selected cases Filter EQ 1

b. Unselected cases Filter NE 1

c. The cut value is .500

5.4.3 Model 4 and Model 5

Conceivably, the apparent poor performance of Models 1-3 was not really representative of the models' true predictive capabilities because the validating data set contained so few (only 4) high risk segments. The data set was split again, randomly selecting 25% of the cases to serve as a validation data set. Logistic regression was then applied using a backward conditional method of variable selection (Model 4) and then a forward conditional method of variable selection (Model 5). The resulting variables are shown in Table 23 and Table 25, respectively. Neither model performed any better than its predecessors. Table 24 and Table show the models' performance results.

Table 23. Variables in Model 4

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	AvgW3	14.950	3.968	14.192	1	.000	3109182
	PSLimit	.096	.051	3.492	1	.062	1.101
	AADT	.000	.000	.112	1	.738	1.000
	SSlpgt75	-34127.5	20214.639	2.850	1	.091	.000
	StbyALen	48.499	26.141	3.442	1	.064	1.2E+21
	Constant	-56.853	26.548	4.586	1	.032	.000
Step 2[a]	AvgW3	14.980	3.945	14.417	1	.000	3204984
	PSLimit	.105	.045	5.461	1	.019	1.110
	SSlpgt75	-32024.6	18732.235	2.923	1	.087	.000
	StbyALen	49.079	26.067	3.545	1	.060	2.1E+21
	Constant	-57.867	26.374	4.814	1	.028	.000

a. Variable(s) entered on step 1: AvgW3, PSLimit, AADT, SSlpgt75, StbyALen.

Table 24. Performance of Model 4

Classification Table[c]

			Predicted					
			Selected Cases[a]			Unselected Cases[b]		
			V3		Percentage Correct	V3		Percentage Correct
	Observed		0	1		0	1	
Step 1	V3	0	71	4	94.7	19	2	90.5
		1	13	8	38.1	7	2	22.2
	Overall Percentage				82.3			70.0
Step 2	V3	0	71	4	94.7	19	2	90.5
		1	13	8	38.1	7	2	22.2
	Overall Percentage				82.3			70.0

a. Selected cases Approximately 20 % of cases (SAMPLE) EQ 0

b. Unselected cases Approximately 20 % of cases (SAMPLE) NE 0

c. The cut value is .500

Table 25. Variables in Model 5

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	AvgW3	7.260	2.517	8.322	1	.004	1422.137
	Constant	-2.157	.427	25.534	1	.000	.116
Step 2[b]	AvgW3	9.081	2.832	10.280	1	.001	8785.496
	PSLimit	.097	.040	5.979	1	.014	1.102
	Constant	-8.380	2.685	9.738	1	.002	.000
Step 3[c]	AvgW3	12.702	3.393	14.019	1	.000	328442.9
	PSLimit	.093	.042	4.922	1	.027	1.098
	StbyALen	49.436	27.354	3.266	1	.071	2.9E+21
	Constant	-57.550	27.550	4.364	1	.037	.000

a. Variable(s) entered on step 1: AvgW3.

b. Variable(s) entered on step 2: PSLimit.

c. Variable(s) entered on step 3: StbyALen.

Table 26. Performance of Model 5

Classification Table[c]

			Predicted					
			Selected Cases[a]			Unselected Cases[b]		
			V3		Percentage	V3		Percentage
	Observed		0	1	Correct	0	1	Correct
Step 1	V3	0	72	3	96.0	19	2	90.5
		1	19	2	9.5	8	1	11.1
	Overall Percentage				77.1			66.7
Step 2	V3	0	70	5	93.3	20	1	95.2
		1	17	4	19.0	7	2	22.2
	Overall Percentage				77.1			73.3
Step 3	V3	0	70	5	93.3	18	3	85.7
		1	14	7	33.3	8	1	11.1
	Overall Percentage				80.2			63.3

a. Selected cases Approximately 20 % of cases (SAMPLE) EQ 0

b. Unselected cases Approximately 20 % of cases (SAMPLE) NE 0

c. The cut value is .500

Chapter 6

Conclusions and Recommendations

Three types of analyses were performed to study the relationship between deer-vehicle crash rates and various parameters, including the presence of a deer warning sign. First, a crash rate analysis was performed, comparing the rates on 22 segments before and after a deer warning sign was installed. Then data including more than 40 parameters for 128 highway segments was analyzed using Principal Components Analysis followed by linear regression. Finally, the same data were analyzed using logistic regression. Collectively, these analyses suggest that static deer warning signs are not an effective tool for mitigating deer-vehicle crashes. They also suggest that, among the parameters included in the study, wooded area near a roadway is the most closely related to deer-vehicle crash rates. While the analyses did not yield a usable predictive model, they did provide much useful information about the nature of these crashes and the potential for modeling crash rates.

6.1 Crash Rate Analysis

For most of the 22 segments used in this analysis, crash data was available for at least 3 years before and after the installation of a deer warning sign. Comparing the mean crash rates before and after sign installation showed a statistically significant decrease in crashes. However, when the full range of available data was used (up to 10 years of before data and up to 5 years of after data), the difference in mean crash rates before and after sign installation was not statistically significant. The small size of the data set, the absence of any control segments, and the conflicting results of the first analysis make it difficult to draw any hard conclusions about the effectiveness of the warning signs. The analysis does highlight the importance of developing larger, more comprehensive data sets so that more conclusive results can be obtained. It also emphasizes that short term studies of crash rates may provide misleading results.

6.2 Principal Components Analysis

The application of PCA to the data and the subsequent regression analysis revealed several important aspects to the problem of deer crashes.

1. The absence of the variable "presence of deer warning sign" suggests that there is little or no relationship between deer warning signs and crash rates. This supports the findings of the crash rates before and after analysis. Based on this data, static deer warning signs as they have been used in Kansas are not an effective measure for mitigating deer-vehicle crashes.
2. The most significant parameter was the amount of surrounding area that is wooded. Most likely, the amount of wooded area is acting in this data as a surrogate for deer population. The only direct measure of deer population in the data (harvest density) was only available at an extremely coarse geographical resolution for this application. The lack of detail likely rendered the data meaningless when considering specific highway segments. Wooded area, however, was available at a more appropriate level of detail, and appears to be related to deer population.
3. Other than *percent wooded area*, the other parameters identified as having a significant influence on crash rate were traffic volume and speed, sight distance (indirectly implied by the curvature ratio and side slope), and clear width. These parameters are all related to the driver (in contrast to land use or fencing, which pertain to the number of deer entering the roadway). These are parameters which have seldom been used in previous studies, but have now been shown by this study to be important factors to consider. These results suggest that significantly better modeling can be obtained by devoting more resources to collecting data pertaining to the driver.
4. The overall R^2 of 0.357 indicates that the predictive value of the developed model is minimal. However, with such a comprehensive array of input parameters, the

poor predictive quality of the resulting model is a very useful result. It indicates that much of the variability in crash rates is due to factors that are either not considered at all in this study or were of poor quality or resolution.

a) For example, deer population is intuitively an important consideration in modeling deer-vehicle crashes. The only direct measure of population—harvest density—was of too coarse a geographic resolution to be useful. Wooded area appears to be a viable surrogate.
b) The available data pertaining to rivers, creeks, and culverts were of good quality and so can be taken to be insignificant in modeling crashes in the contexts represented in the data set (i.e., this statement may not be applicable to other contexts such as very mountainous terrain or areas where the water availability is very different than in Kansas). Similarly, standard right of way fencing and the amount of nearby cropland appear to have little or no influence on deer-vehicle crash rates.
c) Several parameters considered were related to the driver's ability to detect deer and respond in a timely fashion (e.g., traffic speed, clear width, and sight distance—indirectly implied by the curvature ratio and side slope). These were shown by the analysis to play a significant role. Improving the accuracy and resolution of these data fields would presumably improve the predictive capability of the resulting model. Incorporating accurate elevation data in the highway network data may provide improvements in the ability to model sight distance. GPS mapping is capable of producing such data, although no such data is currently available for Kansas highways.

6.3 Logistic Regression Analysis

Logistic regression proved to be no more successful than PCA at producing a model that could reliably identify high risk segments; however, several important points can be derived from the logistic regression analysis results.

1. The percent of the area surrounding a segment that is wooded appears to be the most significant parameter of all those considered in this study, given the units and measurement methodology.
2. Logistic regression results suggested that the posted speed limit may also be a significant parameter, presumably as a surrogate for vehicle speeds.
3. The poor performance of both the PCA and the logistic regression analysis suggests that either important variables were missing from the data, the resolution or the measurement techniques were insufficient to capture the effects of some parameters, or both.
4. The presence of a deer sign was a poor predictor of crash history even though they are placed based on crash history. This suggests that crash history and the likelihood of future crashes are weakly related at best, and crash history in and of itself is not an effective means of identifying high risk segments.

6.4 Deficiencies

There were several potential deficiencies in the data that were understood prior to the study and which persisted because the data was not available and could not be obtained with reasonable effort. Possible deficiencies in the data included the following:

1. Attentional characteristics of the driver were not considered.
2. Actual speeds were approximated by using a surrogate, posted speeds.
3. Sight distance was considered indirectly in the side slope parameters, clear width parameters, and the ratio of straight line distance to actual segment length. Obstacles and specific vertical and horizontal curvature were not considered.
4. The geographic resolution of the measure of deer population (i.e., harvest density) was extremely coarse. It is possible that the percent wooded land served as a surrogate measure for deer population, explaining why it was so significant in all of the models.
5. More segments would have been helpful, although impractical within the scope of this study due to budget and time constraints.

6. Crash rates are based on reported accidents. Reliable data from other states suggest that up to 50% of crashes go unreported, presumably to avoid the associated insurance-related consequences of being involved in a crash. Such substantial omission is a significant hindrance to studies utilizing reported crash data.

6.5 Recommendations

The following recommendations are made based on the conclusions discussed in the previous sections.

6.5.1 Model Implications

Substantial validation should be required before other models are used in practice. This study incorporated an extensive data collection effort and considered a wider array of parameters than nearly all prior studies on this topic. In spite of the relatively rich pool of data, the predictive capability of the resulting models was too poor for them to be recommended for direct use. This suggests that other models developed with lesser data pools should be used with great caution.

6.5.2 Track Deer Carcass Collection

A statewide system should be developed and implemented for tracking the removal of deer carcasses from the right of way. Their locations should be considered in future studies of deer-vehicle crashes. More complete records could substantially improve the predictive capabilities of models such as those developed in this study. Such a system should identify the location of the carcass, the time it was first reported, and whether or not the implied crash was reported (to help minimize double counting).

6.5.3 Revise Deer Warning Sign Policies

This study found no support for the supposition that deer warning signs as they are currently used in Kansas are effective at reducing deer-vehicle crashes. Current policies should be revised appropriately. Given the seasonal and hourly distribution of crashes (sharply peaked during mid-October to mid-December and 2 hours after sunset and 2 hours before sunrise), a temporal component needs to be integrated with the deployment of deer warning signs. Some possible measures include the following.

1. Add placard added identifying key seasons and times when extra caution is needed
2. Use flashers that operated only during the key season and times of day
3. Cover or remove signs during Jan-Sept, and use placard to indicate time of day when extra caution is most needed
4. Use public awareness techniques to educate the public regarding the seasonal and time of day characteristics of deer crashes

6.5.4 Investigate Deer Fencing

Deer-vehicle crashes can be addressed from two different angles: reducing the frequency of deer presence on the traveled way and improving the driver's ability to see deer and respond in a timely fashion. Deer fencing is a countermeasure addressing the former that is widely thought to have significant promise. Further investigation is needed to confirm its crash reducing potential, determine the fencing characteristics that will maximize its effectiveness, and identify the segment characteristics with which fencing will work most effectively. One idea suggested in the literature that should be considered is to provide some grazing area outside the fencing so that deer might be less motivated to jump the fence. Several ongoing studies will hopefully provide more light on the effective use of deer fencing.

6.5.5 Consider Crashes in Developing Wildlife Policies

Wildlife population control policy is a complex subject, and, as a whole, is beyond the scope of this study. It should be noted, however, that the most influential parameter on deer-vehicle crash rates among those considered in this study was the amount of wooded area, which apparently served as a surrogate for deer population density. Thus, changes to the deer population density affect deer-vehicle crash rates. While this is insufficient to suggest a specific policy, it is certainly sufficient to recommend that the effect of deer population on crash rates be carefully considered in the wildlife policy development process.

6.5.6 Improve Sight Distance

In this study, indirect measures of sight distance were the most influential parameters on crash rates among those related to the driver. Any measures that can improve sight distance will improve the driver's ability to avert a crash. Changing the geometry of a section is often infeasible given the costs involved, but sight distance for deer-crash avoidance should be considered whenever a segment is being constructed or reconstructed, especially in a wooded area. Clearing brush or tall grass further from the traveled way may sometimes be a less costly means of improving sight distance and should also be considered, especially in areas where wooded land is prevalent.

6.5.7 Reduce Driver Speed

Any measure that reduces driver speed will provide the driver more time to respond in the event of a deer in the traveled way and will reduce the severity of a crash, should one occur. One technique that deserves investigation is the use of warning speed placards, such as those commonly used on tight curves. A temporal component is necessary, as discussed above with respect to deer warning signs, and the speed should be identified somehow as being associated with deer-crash avoidance.

6.5.8 Examine Driver Attentional Response

Driver attention is an important component of deer-vehicle crashes that was not feasible to have represented in this study. A study should be conducted to examine driver attentional changes when presented with various warnings related to deer. Eye tracking technology can track subject eye movement to see if there is a significant change after passing a static deer warning sign. The same technique could be used to examine the relative effectiveness of various modifications, such as flashing lights.

6.5.9 Repeat This Study

There is still a need for a more reliable means of prioritizing segments for countermeasure deployment. This study provided a promising technique for performing such prioritization, but the available data could not adequately support the statistical analysis. A similar study should be conducted under the following conditions:

1. Deer carcass collection tracking is implemented and operational for at least 4 years prior beginning the study.
2. A larger sampling of segments should be used. As many segments should be included as is feasible with the available budget and manpower for data collection.
3. If deer warning signs are to be examined again, a longer time frame would be needed, and control segments should be included (i.e., segments with similar characteristics and available data for the study time frame, but for which no warning sign was erected.)

6.5.10 Summary

This study applied several statistical techniques to data collected for 128 highway segments with the goal of developing a model of deer-vehicle crash likelihood that could be used to prioritize segments for mitigative treatment. The predictive capability of the models developed was not sufficient for them to be recommended for segment prioritization, but the analyses provided some helpful insight into the data and the relative influence of various parameters on crash rates.

None of the analyses found support for the effectiveness of deer warning signs as they are currently used in Kansas. The highly peaked nature of crash distributions and deer movement characteristics suggests that any device employed to warn drivers of the potential for deer on the roadway should include a temporal component, emphasizing to drivers the heightened need for caution during the late fall and near dawn or dusk.

Percent wooded area was the most influential parameter with respect to crash rates. Parameters related to sight distance, traffic speed, and traffic volume also showed some influence on crash rates, but to a much lesser degree than those related to wooded area. Percent wooded area presumably acted as a surrogate for deer population. Harvest density, the only direct measure of deer population included in this study, was evidently of too coarse a geographic resolution to be useful in modeling crash rates on individual segments.

A system should be developed and implemented to track the collection of deer carcasses, recognizing that the carcasses are the result of crashes, even if no associated crash was formally reported. These crashes are very important to improving the ability to model crash likelihood.

Once some history of carcass collection is available in addition to the accident records, another study should be conducted. A larger pool of segments should be included in the study, including control segments, if possible.

The literature review suggested that fencing techniques should be investigated for reducing the occurrence of deer encroaching on the traveled way. The evaluation of deer fencing will be much more effective once a system is in place for collecting a richer pool of data.

With appropriate planning to improve the data available on deer-vehicle crashes, the techniques employed and lessons learned during this study can lead toward a more effective methodology for identifying high-risk segments. Better data and sound modeling techniques can provide an effective tool for prioritizing segments so that resources can be most effectively applied, and mitigating actions can have the greatest possible impact on deer-vehicle crashes, improving the overall safety of Kansas highways.

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APPENDIX A

Segments Included in Crash Rate Analysis

Seg No.	Description	From	To	County
1	US-160/183	0.3 mi N of Jct K-1	0.55 mi N of Jct K-1	Commanche County
2	US-160/184	0.5 mi S of south city limit Cold Water	south city limit Cold Water	Commanche County
3	US 75	0.14 mi N of the Oklahoma Line	0.56 mi N of the Oklahoma Line	Montgomery County
4	US 75	4.95 mi N of the US75/US166 Interchange	5.45 mi N of the US75/US166 Interchange	Montgomery County
5	US 160	5.25 mi W of WJCT US 75	5.75 mi W of WJCT US 75	Montgomery County
6	US 161	3.32 mi W of WJct US 75	3.82 mi W of WJct US 75	Montgomery County
7	US 169	1.05 mi N of Ejct US 166	1.55 mi N of Ejct US 166	Montgomery County
8	US 83	0.75 mi S of south junction K 95	0.25 mi S of south junction K 95	Scott County
9	US 50	1.25 mi E of US 281	1.75 mi E of US 281	Stafford County
10	US 50	1.9 mi E of US 281	2.4 mi E of US 281	Stafford County
11	US 281	2.7 mi S of K 19	2.2 mi S of K 19	Stafford County
12	US 281	1.3 mi S of K 19	0.3 mi S of K 19	Stafford County
13	US 36	0.4 mi W of K 139	0.1 mi E of K 139	Republic County
14	US 283	RP 6.150	RP 6.640	Trego County
15	79th Street S	143rd E A	159th E	Sedgwick County
16	47th Street S	Webb Road B	Greenwich Road	Sedgwick County
17	Ridge Road	K 96 C	45th N	Sedgwick County
18	71st S	295th W F	3111th W	Sedgwick County
19	85th N	West Street G	Hoover Road	Sedgwick County
20	263rd W	71st Street S H	87th S	Sedgwick County
21	39th S	263rd W I	279th W	Sedgwick County
22	151st W	85th N J	93rd N	Sedgwick County

APPENDIX B

Variable Definitions

ACCIDENT– accident rate

DEERSIGN– presence of deer sign

BRIDCULV– number of bridges or visible culverts within the segment
BRIDCULVPM– number of bridges or visible culverts per mile within the segment

FENCING– percentage of the segment that has traditional fencing

NOLANES– number of lanes

PSLIMIT– posted speed in mph

MEDIAN– median type

CW30– percentage of the segment that has clear width less than 30 feet
CW60– percentage of the segment that has clear width less than 60 feet
CW90– percentage of the segment that has clear width less than 90 feet
CW120– percentage of the segment that has clear width less than 120 feet

SSLPGT15– percentage of the segment that has side slopes greater than 15 degrees
SSLPGT30– percentage of the segment that has side slopes greater than 30 degrees
SSLPGT45– percentage of the segment that has side slopes greater than 45 degrees
SSLPGT60– percentage of the segment that has side slopes greater than 60 degrees
SSLPGT75– percentage of the segment that has side slopes greater than 75 degrees

TOPO15– percentage of the segment that has topography in the transverse direction greater than 15 degrees
TOPO30– percentage of the segment that has topography in the transverse direction greater than 30 degrees
TOPO45– percentage of the segment that has topography in the transverse direction greater than 45 degrees
TOPO60– percentage of the segment that has topography in the transverse direction greater than 60 degrees
TOPO75– percentage of the segment that has topography in the transverse direction greater than 75 degrees

RIVCRK– number of rivers or creeks intersecting the segment
RIVCRKPM– number of rivers or creeks intersecting per mile of the segment

STBYALEN– straight length by actual length of the segment (curvature ratio)

AADT– annual average daily traffic
LANEAADT– annual average daily traffic per lane

HARVDENS– density of deer harvest per 100 square miles of area
MAXW1– Maximum value of two sides: percentage of wooded land with in the buffer, 1000 feet off the roadway, each side separately

MAXC1– Maximum value of two sides: percentage of crop land with in the buffer, 1000 feet off the roadway, each side separately

MAXWC1– Maximum value of two sides: percentage of (wooded + crop) land with in the buffer, 1000 feet off the roadway, each side separately

AVGW1– Average value of two sides: percentage of wooded land with in the buffer, 1000 feet off the roadway, each side separately

AVGC1– Average value of two sides: percentage of crop land with in the buffer, 1000 feet off the roadway, each side separately

AVGWC1– Average value of two sides: percentage of (wooded + crop) land with in the buffer, 1000 feet off the roadway, each side separately

MAXW3– Maximum value of two sides: percentage of wooded land with in the buffer, 3000 feet off the roadway, each side separately

MAXC3– Maximum value of two sides: percentage of crop land with in the buffer, 3000 feet off the roadway, each side separately

MAXWC3– Maximum value of two sides: percentage of (wooded + crop) land with in the buffer, 3000 feet off the roadway, each side separately

AVGW3– Average value of two sides: percentage of wooded land with in the buffer, 3000 feet off the roadway, each side separately

AVGC3– Average value of two sides: percentage of crop land with in the buffer, 3000 feet off the roadway, each side separately

AVGWC3– Average value of two sides: percentage of (wooded + crop) land with in the buffer, 3000 feet off the roadway, each side separately

MAXW5– Maximum value of two sides: percentage of wooded land with in the buffer, 5000 feet off the roadway, each side separately

MAXC5– Maximum value of two sides: percentage of crop land with in the buffer, 5000 feet off the roadway, each side separately

MAXWC5– Maximum value of two sides: percentage of (wooded + crop) land with in the buffer, 5000 feet off the roadway, each side separately

AVGW5– Average value of two sides: percentage of wooded land with in the buffer, 5000 feet off the roadway, each side separately

AVGC5– Average value of two sides: percentage of crop land with in the buffer, 5000 feet off the roadway, each side separately

AVGWC5– Average value of two sides: percentage of (wooded + crop) land with in the buffer, 5000 feet off the roadway, each side separately

APPENDIX C

One hundred twenty three segments were selected from 15 counties of the state of Kansas. One hundred one segments were used for model calibration and 22 segments were used for validation of the calibrated models. The selected segments are listed in the following table. The shaded segments were used for model validation.

Description of the Segments

Sr No.	County	On Road	Beginning of the segment description			End of the segment description		
			At road No.	Dist from At Road	Dir. from the At Road	At road No.	Dist. from At Road	Direc from the At Road
1	DG	DG 1023	E 350	0.25 mile	East	E 500	0.25 mile	West
2	DG	DG 1023	N 2000	0	X	I - 70	0	X
3	DG	DG 1029	N 1850	0	X	N 1850	0.5	North
4	DG	DG 438	K 10	0	X	E 700	0.5 mile	East
5	DG	DG 438	E 1000	0	X	E 1100	0	X
6	DG	K 10	HWY 40	0	X	I - 70	0	X
7	DG	HWY 40	K 10	0.5 mile	West	K 10	1.5 mile	West
8	DG	DG 442	DG 1029	0	X	E 650	0	X
9	DG	K 10	HWY 59	1 mile	West	HWY 59	2 mile	West
10	DG	DG 458	E 1100	0	X	E 1100	1 mile	West
11	DG	DG 1055	DG 458	0	X	N 1100	0	X
12	DG	N 1000	E1400	0	X	E 1500	0	X
13	DG	N 1000	E 1800	0	X	E 1900	0	X
14	DG	DG 1055	DG 12	0.5 mile	North	DG 12	1.5 mile	North
15	DG	HWY 59	K 10	2.5	South	K 10	3.5	South
16	DG	HWY 56	HWY 59	9.5 miles	West	HWY 59	11 miles	West
17	DG	K 10	DG 442	1 mile	East	DG 442	2 miles	East
18	DG	I 70	K 10	3 miles	East	K 10	4 miles	East
19	DG	HWY 59/HWY 24	HWY 24	0	X	HWY 24	1 mile	North
20	DG+JO	K 10	E 2300	0	X	E 2400	0	X
21	JF	HWY 59/Williamstown	HWY 24	0.5 mile	North	HWY 24	1.5 miles	North
22	JF	Wellman	13th	0	X	21st	1	N
23	JF	Union	21st	0	X	35th	0	X
24	JF	Wellman	13th	0	X	3rd	0	X
25	JF	Ferguson	31st	0	X	46th	0	X

26	JF	Ferguson	74th	0	X	94th	0	x
27	JF	HWY 59	HWY 92	1	North	HWY 92	3.5 miles	North
28	JF	HWY 92	HWY 4	2 miles	East	HWY 4	4 miles	East
29	JF	HWY 4	HWY 92	0	X	HWY 92	2.5 miles	North
30	JF	HWY 24	Thomsonville	0	X	Newman	0	X
31	JF	HWY 16	Wellman	0	X	Washington	0	X
32	JO	Gardner Road	151st Street	0	X	151st Street	0.5 mile	North
33	JO	143rd Street	Gardner Road	0	X	Gardner Road	1 mile	West
34	JO	135th	Kimberly	0	X	Kimberly	1mile	East
35	JO	199th	Hedge LN	0	X	Lone ELM Road	0	X
36	JO	Metcalf Avenue	179th	0	X	191st	0	X
37	JO	Mission	175th	0	X	183rd	0	x
38	JO	191st	Nall Avenue	0	X	Mission Road	0	X
39	JO	Mission Road	199th	0	X	207th	0	x
40	JO	K 10	Edgerton Road	0	X	Edgerton Road	1 mile	West
41	JO	K 10	Kill Creek Road	0	X	Kill Creek Road	1 mile	East
42	JO	K 7	K 10	0.7 mile	South	K 7	1.7 mile	South
43	JO	I 35	151 st	0.5 mile	North East	151st Street	1.5 miles	North East
44	JO	I 35	151st Street	0.5 mile	South West	151st Street	1.5 miles	South West
45	JO	HWY 69	179th	0	X	179th	1 mile	North
46	JO	HWY 169	167th	0	X	159th	0	X
47	SN	US 75	NW 54th	0	X	NW 62nd	0	X
48	SN	US 24	NW Hodges Road	0	X	NW Humphrey Road	0	X
49	SN	US 40	SE Shawnee heights RD	0	X	SE Stanley RD	0	X
50	SN	US 40	SE Stanley RD	0	X	SE Stanley RD	1 mile	East
51	SN	I 70	Milepost 175	0	X	MilePost176	0	X
52	SN	I335	MilePost167	0	X	MilePost168	0	X
53	SN	I335	MilePost 172	0	X	MilePost173	0	X

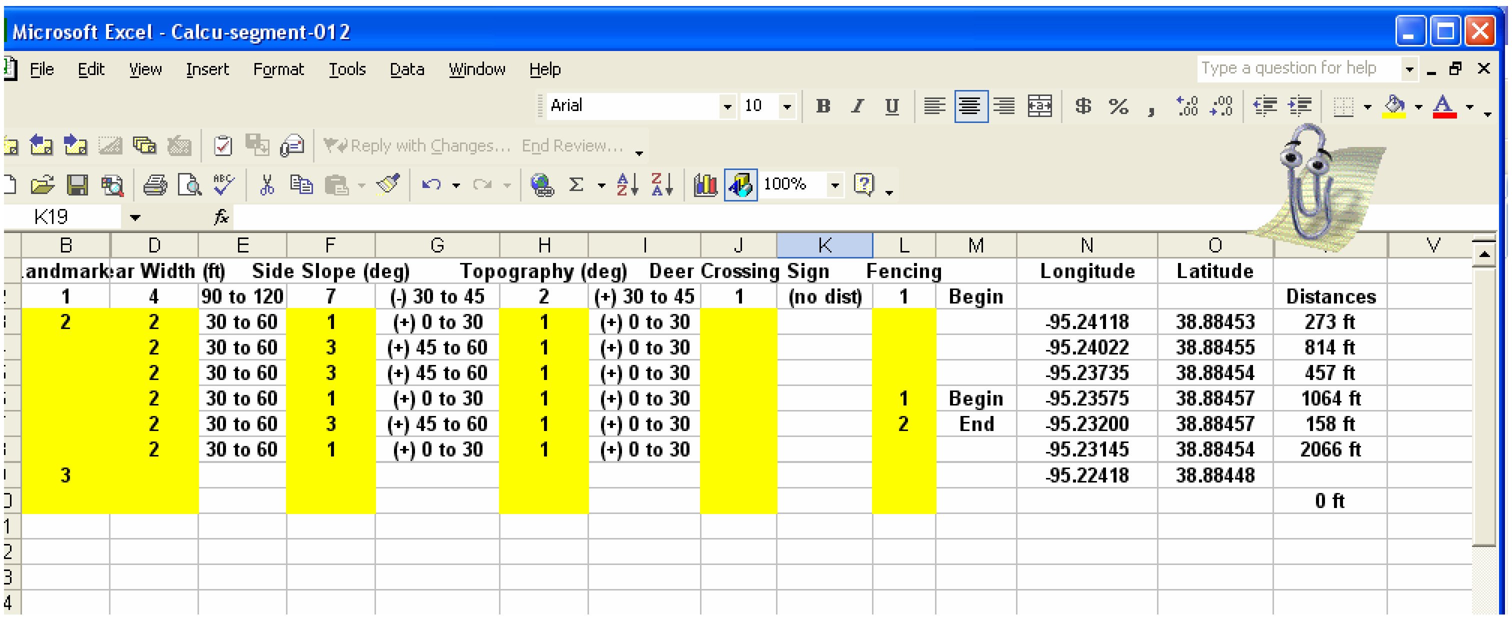
54	SN	US 75	SW 77th Street	0	X	SW 77th Street	1 mile	SouthEast
55	SN	US 75	SW 93rd Street	0	X	SE 101st Street	0	X
56	SN	SW Auburn Road	SW 29th Street	0.7 mile	North	SW 29th Streer	1.5 miles	North
57	SN	SW K4 HWY	SW Hoch Road	0	X	SW Hodges Road	0	X
58	SN	SW US 40	SW Valencia Road	0	X	SW Hoch Road	0	X
59	SN	NW US 24 HWY	NW Docking Road	0	X	Humphrey Road / NW Valencia Road	0	X
60	OS	HWY 75	HWY 56	2	North	HWY 56	3	North
61	OS	HWY 75	HWY 56	1	North	HWY 56	2	North
62	OS	HWY 56	HWY 75	6	East	HWY 75	7	East
63	OS	HWY 56	I 335	8.5	East	I 335	9.5	East
64	OS	HWY 56	I 335	3	East	I 335	4	East
65	OS	I 335	HWY 56	1	North	HWY 56	2	North
66	OS	I 335	HWY 56	5	North	HWY 56	6	North
67	OS	HWY 75	K 31	0	X	K 31	2	North
68	OS	HWY 75	K 31	1	South	K 31	2	South
69	OS	I 335	HWY 56	2	South	HWY 56	4	South
70	FR	US 59	I 35	1	South	I 35	2	South
71	DG	US 59	US 56	2	S	US 56	3	S
72	FR	HWY 59	I 35	6.5	South	I 35	7.2	South
73	FR	K 68	HWY 59	5	West	HWY 59	7	West
74	FR	K 68	HWY 59	10	West	HWY 59	11	West
75	FR	K 68	I 35	3	East	I 35	4	East
76	FR	K 68	I 35	5	East	I 35	6	East
77	FR	HWY 59	I 35	9	South	I 35	10	South
78	FR	I 35	HWY 59	6	South-West	I 35	7	South-West
79	LV	HWY 24	HWY 16	3	East	HWY 16	4	East
80	LV	HWY 24	HWY 16	4	East	HWY 16	5	East
81	LV	HWY 24	HWY 16	8	East	HWY 18	9	East

82	LV	K 16	HWY 24	1.5	West	HWY 24	2.5	West
83	LV	K 16	HWY 24	3	West	HWY 24	4	West
84	LV	K 92	HWY 16	9.5	North-East	HWY 16	10.5	North-East
85	LV	K 92	HWY 16	11	East	HWY 16	12	East
86	LV	K 192	HWY 73	1	West	HWY 73	2	West
87	LV	K 7	HWY 24	3	North	HWY 24	4	North
88	LV	K 7	HWY 24	6	North	HWY 24	7	North
89	MI	HWY 69	K 68	3	South	K 68	4	South
90	MI	HWY 169	K 68	3.2	South	K 68	4	South
91	MI	K 68	HWY 169	1	East	HWY 169	2	East
92	MI	HWY 169	K 68	2.5	North	K 68	4	North
93	MI	HWY 169	K 68	2	South	K 68	3	South
94	JO	US 169	I 35	3	South	US 169	4	South
95	JO	I 35	US 56	3.5	South	US 56	4.5	South
96	MI	K 68	HWY 169	3	West	HWY 169	4	West
97	WB	I 70	K 99	3	East	K 99	4	East
98	WB	K 99	I 70	2	North	I 70	3	North
99	RL	I 70	K 99	5.5	West	K 99	6.5	West
100	WB	K 4	K 99	1	West	K 99	2	West
101	WB	K 99	I 70	1.5	South	I 70	3	South
102	WB	K 99	K 4	3	South	K 4	4	South
103	WB	K 31	K 99	2	East	K 99	3	East
104	WB	K 31	K 99	5	East	K 99	6	East
105	WB	K 4	K 177	3	East	K 177	4	East
106	PT	K 63	K 16	3	South	K 16	4	South
107	PT	K 16	K 63	6	West	K 63	7	West
108	PT	K 63	K 16	6	South	K 16	7	South
109	GE	HWY 77	K 244	0	X	K 244	2	South
110	GE	I 70	K 114	0	X	K 114	1	East
111	GE	K 57	I 70	3	South	I 70	4	South
112	RL	K 177	K 18	0.5	South	K 18	1.5	South
113	RL	K 113	HWY 24	2	South	HWY 24	2.5	South

114	RL	K 13	HWY 24	3	North	HWY 24	4	North
115	LV	I 70	K 32	0	X	K 32	1	East
116	LV	I 70	K 32	1	East	K 32	2	East
117	LV+WY	I 70	K 7	1	West	K 7	2	West
118	LV	I 70	K 7	4	West	K 7	5	West
119	EK	HWY 160	Montgomery County Line	4	West	Montgomery County Line	5	West
120	EK	HWY 160	Moline	5	East	Moline	6	East
121	EK	HWY 160	Montgomery County Line	3	West	Montgomery County Line	4	West
122	EK	HWY 160	Moline city limit	1	West	Moline city limit	2	West
123	PT	K 16	K 63	1.5	West	K 63	2	West

APPENDIX D

An Microsoft Excel spreadsheet was used to collect primary data. Whenever any reading was entered, the corresponding Latitude and Longitude values got recorded automatically. A screen shot of the spreadsheet is shown below. The content of the spreadsheet used to record the description of the segments is shown on the next page.

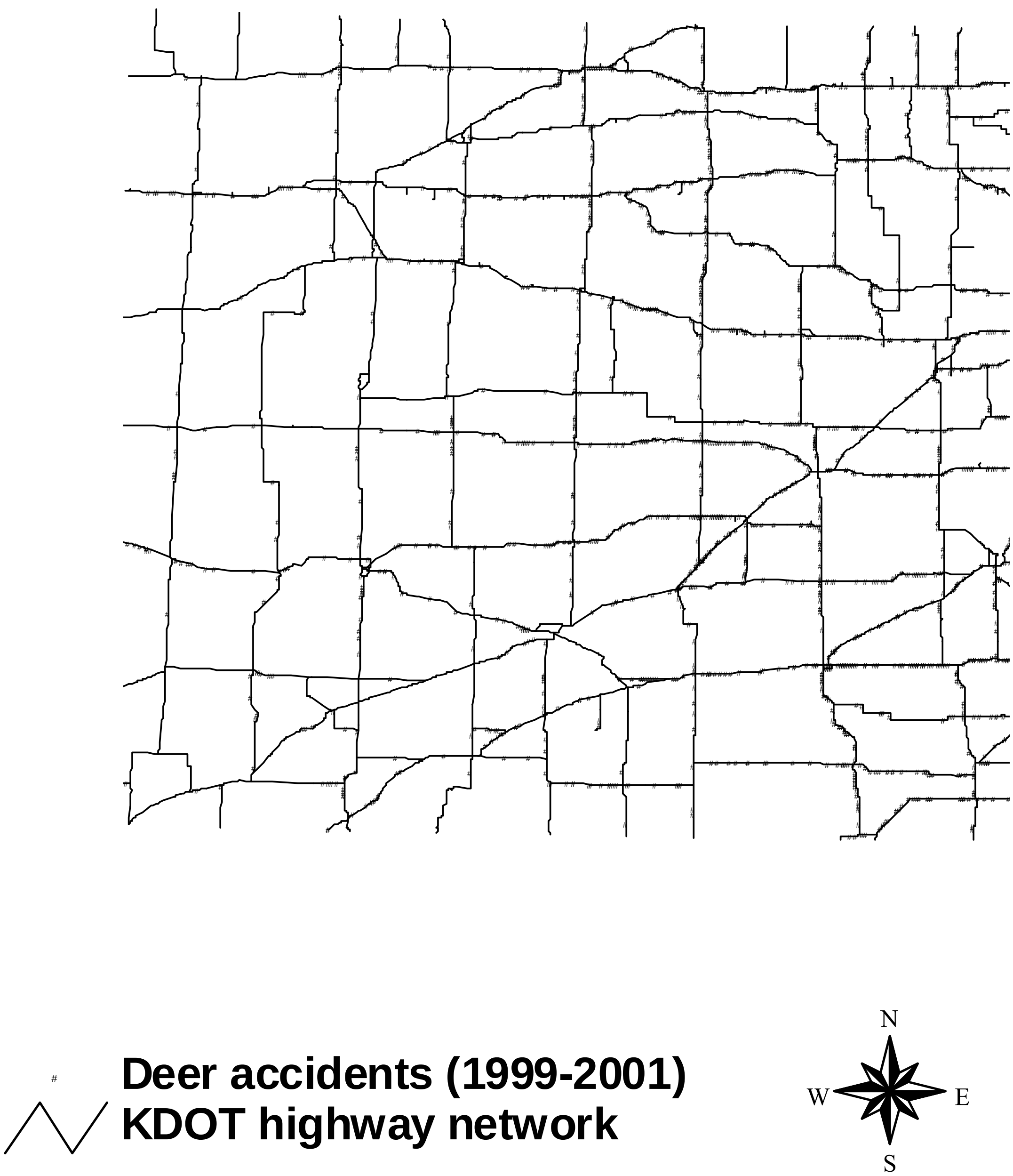


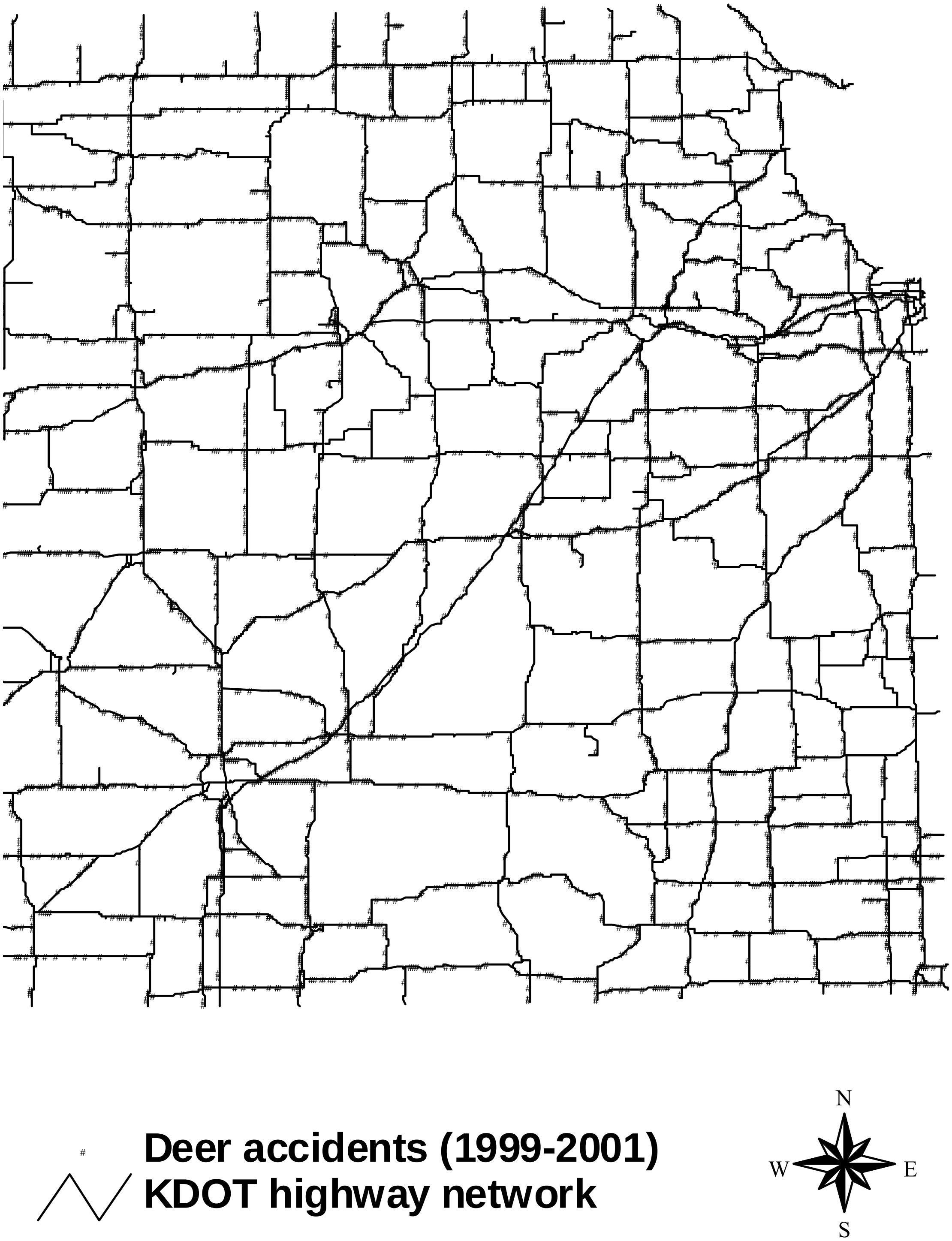
B	D	E	F	G	H	I	J	K	L	M	N	O		V
andmark	ear Width (ft)	Side Slope (deg)		Topography (deg)		Deer Crossing Sign			Fencing		Longitude	Latitude		
1	4	90 to 120	7	(-) 30 to 45	2	(+) 30 to 45	1	(no dist)	1	Begin			Distances	
2	2	30 to 60	1	(+) 0 to 30	1	(+) 0 to 30					-95.24118	38.88453	273 ft	
	2	30 to 60	3	(+) 45 to 60	1	(+) 0 to 30					-95.24022	38.88455	814 ft	
	2	30 to 60	3	(+) 45 to 60	1	(+) 0 to 30					-95.23735	38.88454	457 ft	
	2	30 to 60	1	(+) 0 to 30	1	(+) 0 to 30			1	Begin	-95.23575	38.88457	1064 ft	
	2	30 to 60	3	(+) 45 to 60	1	(+) 0 to 30			2	End	-95.23200	38.88457	158 ft	
	2	30 to 60	1	(+) 0 to 30	1	(+) 0 to 30					-95.23145	38.88454	2066 ft	
3											-95.22418	38.88448		
													0 ft	

The description of the spreadsheet used in data collection

Travel Details				
Departure Time	8:00 AM		☐ Auto-Save	
Odometer	65032			
Return Time	7:00 PM		FALSE	
Odometer	65233			
Miles Driven	201			
Segment Description				
Segment ID	2			
Date Surveyed	7-Oct			
County	DG			
On Road	DG1023			
At Road	N2000			
Posted Speed (mph)	40			
Lanes	2			
Median Type	1	undivided		
(specify if other)				
Fencing Height (ft)	4 feet	Fencing Ht		
Lane Width (ft)	12			

APPENDIX E
Enlarged version of Figure 35




Deer accidents (1999-2001)
KDOT highway network
N
W
E
S

APPENDIX F

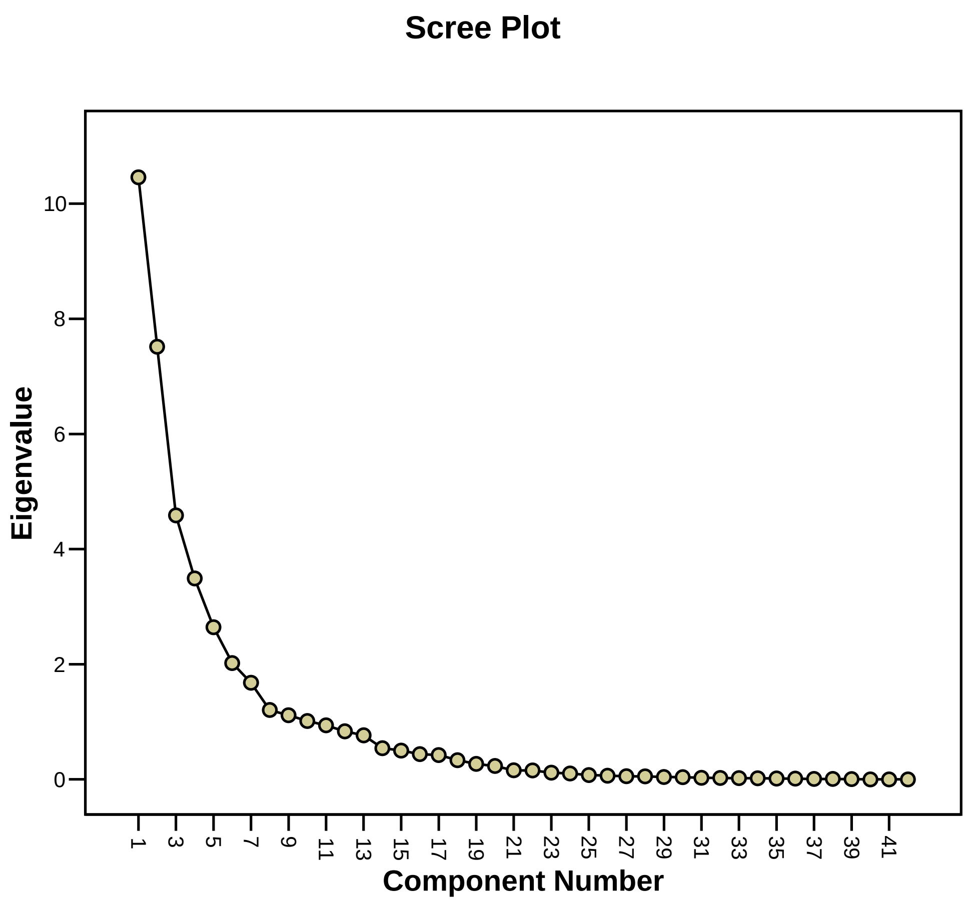
Output from one of the Principal Component Analyses is shown below. Components with eigenvalues >= 1.0 were extracted.

Total Variance Explained[a]

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	10.459	24.903	24.903	10.459	24.903	24.903	10.018	23.852	23.852
2	7.516	17.895	42.798	7.516	17.895	42.798	6.233	14.841	38.693
3	4.587	10.921	53.720	4.587	10.921	53.720	4.053	9.649	48.342
4	3.491	8.311	62.031	3.491	8.311	62.031	3.071	7.312	55.654
5	2.644	6.294	68.325	2.644	6.294	68.325	3.016	7.182	62.836
6	2.020	4.810	73.135	2.020	4.810	73.135	2.925	6.965	69.800
7	1.678	3.996	77.131	1.678	3.996	77.131	2.177	5.184	74.984
8	1.204	2.867	79.998	1.204	2.867	79.998	1.727	4.111	79.095
9	1.114	2.651	82.650	1.114	2.651	82.650	1.291	3.074	82.169
10	1.014	2.415	85.065	1.014	2.415	85.065	1.216	2.896	85.065
11	.938	2.234	87.299						
12	.835	1.988	89.287						
13	.764	1.820	91.107						
14	.542	1.290	92.397						
15	.500	1.190	93.587						
16	.438	1.044	94.631						
17	.423	1.008	95.639						
18	.334	.794	96.433						
19	.268	.639	97.073						
20	.231	.551	97.623						
21	.157	.374	97.998						
22	.155	.369	98.367						
23	.117	.279	98.646						
24	.102	.242	98.888						
25	.076	.181	99.069						
26	.064	.153	99.221						
27	.055	.130	99.352						
28	.052	.125	99.477						
29	.041	.098	99.575						
30	.037	.088	99.663						
31	.027	.065	99.728						
32	.025	.060	99.789						
33	.022	.052	99.841						
34	.020	.047	99.888						
35	.015	.035	99.924						
36	.013	.030	99.954						
37	.008	.018	99.972						
38	.007	.017	99.990						
39	.004	.010	100.000						
40	.000	.000	100.000						
41	.000	.000	100.000						
42	.000	.000	100.000						

Extraction Method: Principal Component Analysis.

a. Only cases for which filter_$ = 1 are used in the analysis phase.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Component Number

Rotated Component Matrix[a,b]

	Component									
	1	2	3	4	5	6	7	8	9	10
BridCulv		.165		.142		.214	.443	.722		
Fencing	-.101	-.150	.103	-.141		.351	.139	-.286	-.658	
PSLimit	.231		.204	-.205		.629	.277		-.119	.129
CW30	-.124	.344		.564		-.477				
CW60		.204		.884		-.203				
CW90		.159		.926						
CW120		.134	.106	.889					.116	
SSlpgt15	-.173	.130	.816	.180		.175		-.168		
SSlpgt30	-.149		.910			.130				
SSlpgt45	-.116		.864			.118		.294	-.131	
SSlpgt60	-.173		.805			.121		.350	-.148	
SSlpgt75						-.194				.789
Topogt15		.168	.705		.369			-.251		.147
Topogt30		.126	.560		.596		.177	-.224		.124
Topogt45			.230		.876			-.109	.111	
Topogt60		-.104			.929					
Topogt75	-.102		-.113		.904					
RivCrk				.101			.900	.206		
RivCrkpM			.127				.896	.102		
BriCulpM		.254		.102		.315	.377	.687	.114	
StbyALen		-.132				.297			-.214	.690
AADT	.133		.177			.896		.122		
LaneAADT	.129		.183			.885		.178		
HarvDens		.287	-.105	.189		.206			.611	-.137
MaxW1		.883		.110				.124	-.174	
MaxC1	.914	-.171						.105		
MaxWC1	.902	.215						.154		
AvgW1		.899		.108				.128	-.169	
AvgC1	.926	-.193								
AvgWC1	.924	.202						.148		
MaxW3		.931		.159					.174	
MaxC3	.912	-.222	-.113							
MaxWC3	.915	.267								
AvgW3		.967		.126					.103	
AvgC3	.924	-.236	-.124							
AvgWC3	.915	.274								
MaxW5		.891		.126					.277	
MaxC5	.870	-.282				.126		-.119		
MaxWC5	.862	.223				.153			.162	
AvgW5		.912							.225	
AvgC5	.879	-.281				.177		-.106		
AvgWC5	.873	.272				.173			.156	

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 10 iterations.

b. Only cases for which filter_$ = 1 are used in the analysis phase.

Component Score Coefficient Matrix[a]

	Component									
	1	2	3	4	5	6	7	8	9	10
BridCulv	-.006	-.021	-.026	-.020	.029	.009	.085	.402	.066	.043
Fencing	-.007	.057	-.046	.061	.023	.144	.093	-.265	-.557	-.092
PSLimit	.003	.003	-.006	-.032	.017	.201	.108	-.065	-.052	.092
CW30	.012	.038	.027	.163	-.018	-.161	-.011	.012	-.155	.012
CW60	.003	-.030	-.013	.318	-.018	-.014	-.031	-.006	-.068	-.010
CW90	-.001	-.051	-.011	.345	-.006	.058	-.016	-.025	-.005	.050
CW120	-.010	-.055	-.010	.346	-.007	.104	.014	-.116	.019	.004
SSlpgt15	-.002	-.020	.220	.064	-.066	.031	.007	-.166	.074	-.034
SSlpgt30	.014	-.034	.260	.006	-.064	-.029	-.018	-.030	.034	.008
SSlpgt45	.029	-.028	.248	-.015	-.044	-.062	-.088	.191	-.067	-.082
SSlpgt60	.022	-.028	.232	-.013	-.051	-.058	-.117	.236	-.080	-.068
SSlpgt75	.001	.011	.035	-.044	-.010	-.091	-.047	.082	.119	.660
Topogt15	.017	.027	.183	-.065	.062	-.045	.046	-.165	.075	.105
Topogt30	.024	.021	.117	-.054	.158	-.026	.115	-.162	.072	.084
Topogt45	.005	.012	-.004	-.032	.291	.014	.046	-.046	.058	.031
Topogt60	.012	-.008	-.046	.006	.335	.004	-.072	.132	-.055	-.039
Topogt75	.000	.006	-.118	.027	.350	.063	-.049	.090	-.120	-.077
RivCrk	.000	-.019	-.036	-.014	.016	-.071	.458	-.038	-.023	-.031
RivCrkpM	-.004	-.010	-.010	-.026	-.028	-.047	.474	-.121	.027	-.027
BriCulpM	-.009	-.006	-.022	-.033	.017	.050	.051	.379	.105	.051
StbyALen	-.024	.006	-.078	.099	-.011	.137	.008	-.041	-.154	.569
AADT	-.021	.007	-.028	.042	.021	.346	-.103	.013	.002	-.028
LaneAADT	-.022	-.006	-.020	.042	.012	.338	-.114	.054	.058	-.030
HarvDens	-.029	-.023	-.037	.027	.009	.131	.041	-.099	.495	-.082
MaxW1	.002	.187	-.046	-.010	.047	.026	-.029	.028	-.267	.009
MaxC1	.109	-.035	.046	-.021	.014	-.086	-.044	.121	-.010	.003
MaxWC1	.107	.044	.025	-.025	.028	-.057	-.056	.125	-.109	-.008
AvgW1	.006	.189	-.041	-.018	.037	-.003	-.018	.033	-.264	.006
AvgC1	.109	-.038	.039	-.005	.006	-.078	-.057	.113	-.025	-.031
AvgWC1	.112	.045	.021	-.013	.022	-.080	-.065	.128	-.142	-.029
MaxW3	-.002	.155	-.004	-.023	-.007	-.008	.006	-.053	.042	.010
MaxC3	.094	-.036	.011	-.002	.008	-.012	.000	-.023	.008	-.006
MaxWC3	.093	.050	.000	-.006	.008	-.005	-.009	-.024	-.026	-.002
AvgW3	.000	.172	-.016	-.035	.004	-.012	-.008	-.018	-.026	.007
AvgC3	.095	-.034	.002	.008	.012	.003	-.005	-.019	-.038	-.007
AvgWC3	.093	.057	-.007	-.011	.014	-.004	-.009	-.028	-.051	-.003
MaxW5	-.007	.137	.012	-.037	-.029	-.001	.006	-.072	.147	.005
MaxC5	.083	-.058	.016	.025	-.019	.021	.065	-.088	.040	.000
MaxWC5	.077	.022	.014	.005	-.027	.030	.047	-.088	.095	.009
AvgW5	-.002	.149	-.003	-.054	-.014	-.006	-.018	-.012	.095	-.005
AvgC5	.081	-.055	-.003	.034	-.003	.047	.053	-.080	.023	-.002
AvgWC5	.077	.036	-.004	.001	-.011	.042	.041	-.085	.079	-.005

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Only cases for which filter_$ = 1 are used in the analysis phase.

APPENDIX G

The results of a multiple linear regression analysis using the principal component for predictor variables are shown below.

Model Summary[f,g]

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
	Filter = 1 (Selected)	Filter ~= 1 (Unselected)				R Square Change	F Change	df1	df2	Sig. F Change
1	.491[a]		.241	.234	.9029	.241	33.717	1	106	.000
2	.549[b]		.302	.288	.8703	.060	9.072	1	105	.003
3	.578[c]		.334	.315	.8540	.032	5.071	1	104	.026
4	.587[d]		.344	.319	.8517	.010	1.559	1	103	.215
5	.598[e]	.485	.357	.319	.8514	.013	1.034	2	101	.359

a. Predictors: (Constant), PC2

b. Predictors: (Constant), PC2, PC6

c. Predictors: (Constant), PC2, PC6, PC10

d. Predictors: (Constant), PC2, PC6, PC10, NoLanes_4

e. Predictors: (Constant), PC2, PC6, PC10, NoLanes_4, Median_2, Median_1

f. Unless noted otherwise, statistics are based only on cases for which Filter = 1.

g. Dependent Variable: Accident Rate

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients			Correlations			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	1.252	.087		14.415	.000					
	PC2	.563	.097	.491	5.807	.000	.491	.491	.491	1.000	1.000
2	(Constant)	1.257	.084		15.005	.000					
	PC2	.537	.094	.469	5.726	.000	.491	.488	.467	.992	1.008
	PC6	.333	.111	.247	3.012	.003	.289	.282	.246	.992	1.008
3	(Constant)	1.275	.083		15.441	.000					
	PC2	.572	.093	.499	6.127	.000	.491	.515	.490	.965	1.036
	PC6	.275	.112	.204	2.464	.015	.289	.235	.197	.938	1.066
	PC10	.370	.164	.187	2.252	.026	.161	.216	.180	.927	1.078
4	(Constant)	1.168	.119		9.815	.000					
	PC2	.586	.094	.512	6.251	.000	.491	.524	.499	.950	1.053
	PC6	.118	.168	.087	.702	.484	.289	.069	.056	.412	2.428
	PC10	.361	.164	.183	2.203	.030	.161	.212	.176	.926	1.080
	NoLanes_4	.342	.274	.154	1.249	.215	.248	.122	.100	.421	2.377
5	(Constant)	1.778	.646		2.752	.007					
	PC2	.554	.098	.483	5.640	.000	.491	.489	.450	.866	1.154
	PC6	.138	.169	.102	.818	.415	.289	.081	.065	.409	2.445
	PC10	.341	.165	.173	2.071	.041	.161	.202	.165	.917	1.091
	NoLanes_4	-.122	.677	-.055	-.180	.858	.248	-.018	-.014	.069	14.481
	Median_1	-.612	.641	-.275	-.955	.342	-.298	-.095	-.076	.077	12.970
	Median_2	-.362	.306	-.115	-1.182	.240	.051	-.117	-.094	.676	1.480

a. Dependent Variable: Accident Rate

b. Selecting only cases for which Filter = 1

APPENDIX H

The results of one of the logistic regression analyses are shown here.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	AvgW3	7.260	2.517	8.322	1	.004	1422.137
	Constant	-2.157	.427	25.534	1	.000	.116
Step 2[b]	AvgW3	9.081	2.832	10.280	1	.001	8785.496
	PSLimit	.097	.040	5.979	1	.014	1.102
	Constant	-8.380	2.685	9.738	1	.002	.000
Step 3[c]	AvgW3	12.702	3.393	14.019	1	.000	328442.9
	PSLimit	.093	.042	4.922	1	.027	1.098
	StbyALen	49.436	27.354	3.266	1	.071	2.9E+21
	Constant	-57.550	27.550	4.364	1	.037	.000

a. Variable(s) entered on step 1: AvgW3.

b. Variable(s) entered on step 2: PSLimit.

c. Variable(s) entered on step 3: StbyALen.

Variables not in the Equation[a]

			Score	df	Sig.
Step 0	Variables	AvgW3	9.714	1	.002
		PSLimit	4.514	1	.034
		AADT	2.672	1	.102
		SSlpgt75	.286	1	.593
		StbyALen	1.795	1	.180

a. Residual Chi-Squares are not computed because of redundancies.

Classification Table[c]

			Predicted					
			Selected Cases[a]			Unselected Cases[b]		
			V3		Percentage Correct	V3		Percentage Correct
	Observed		0	1		0	1	
Step 1	V3	0	72	3	96.0	19	2	90.5
		1	19	2	9.5	8	1	11.1
	Overall Percentage				77.1			66.7
Step 2	V3	0	70	5	93.3	20	1	95.2
		1	17	4	19.0	7	2	22.2
	Overall Percentage				77.1			73.3
Step 3	V3	0	70	5	93.3	18	3	85.7
		1	14	7	33.3	8	1	11.1
	Overall Percentage				80.2			63.3

a. Selected cases Approximately 20 % of cases (SAMPLE) EQ 0

b. Unselected cases Approximately 20 % of cases (SAMPLE) NE 0

c. The cut value is .500

K - TRAN

KANSAS TRANSPORTATION RESEARCH
AND
NEW - DEVELOPMENTS PROGRAM

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:

KANSAS DEPARTMENT OF TRANSPORTATION

THE UNIVERSITY OF KANSAS

KANSAS STATE UNIVERSITY