Using GIS to Mitigate Deer-Vehicle Accidents in Winona County, MN

Michael T. Yarnes
Department of Resource Analysis, Saint Mary's University of Minnesota, Winona, MN 55987

Keywords: GIS, DVC, Deer, Vehicle, Collision, White-tailed, Winona, Minnesota, DNR, DOT, Spatial Analysis, Deer Seasons, Linear Referencing, DVC Mitigation

Abstract

The rise in white-tailed deer populations has created the potential for increased deer-vehicle collisions (DVCs) throughout the country. The goal of this study was to use Geographic Information Systems (GIS) to identify spatial relationships of DVC events in Winona County, MN. Two public DVC datasets were acquired from state and local law enforcement for use in this study. One was from the Minnesota Department of Natural Resources (MNDNR) and the other from the Minnesota Department of Transportation (MNDOT). Each dataset contained DVC events recorded from 1995-2006. Linear referencing techniques and kernel density patterns were utilized to determine which roadways had higher DVC events and which portions of roadways had the highest deer densities. Seasonal effects were examined to investigate potential correlations between the volume of reported DVCs and deer seasons. Spatial patterns specified high density DVC areas along the Highway 61/14 roadway. Seasonal analysis of the possession permit dataset revealed the highest DVC volume occurred during the breeding season, while the unclaimed/unsalvageable report (UUR) dataset recorded the highest DVC volume during the fawning season. The spatial structure of high deer densities and seasonal trends in DVCs can assist in the targeting of “hot spots” for future DVC mitigation efforts.

Introduction

U.S. motorists face an increasing risk of deer-vehicle collisions (DVCs) due to soaring deer populations. In a detailed study done by Conover et al. in 1995, results for U.S. deer populations, vehicle damage, and human and deer fatalities were estimated. These results concluded that deer numbers in the U.S. exceeded 30 million by the end of the 20th century. From the mid-1990s to 2000 alone, the population rose by an estimated 15 million. Consequently, the number of reported DVCs also multiplied. Over 1.5 million DVCs were reported in the U.S. in 2002, causing approximately $1.1 billion in vehicle damage. Roughly 150 human and 1.5 million deer fatalities resulted from these encounters. In Minnesota, recent estimates show DVCs account for over 90 percent of all reported animal-related deaths (USDOT, 1995). Even with such, less than 50 percent of all DVCs are actually reported to the proper authorities (Conover et al., 1995). Thus what is noted is a drastic underestimate of the severity of the

Yarnes, Michael. 2008. Using GIS to Mitigate Deer-Vehicle Accidents in Winona County, MN. Volume 11, Papers in Resource Analysis. 16 pp. Saint Mary’s University of Minnesota Central Services Press. Winona, MN. Retrieved (date) from http://www.gis.smumn.edu

problem.

In a DVC mitigation study by Curtis and Hedlund in 2005, one of the major recommendations for future DVC data collection and reporting was for state and local agencies to document DVC locations in order to find areas of high DVC frequency utilizing GIS. The Curtis and Hedlund study suggestion spoke directly to the primary goal of this project; to use GIS to decrease the number of DVCs that occur in the future by utilizing density patterns from existing DVC events collected from state and local agency datasets. A secondary focus of this study was to determine the correlation between DVC events and deer seasons over a twelve year period (1995-2006). This portion of the project followed the methodology described by Ramakrishnan et al. (2005). The results from these two areas of study can then be used in the development of management options for reducing the frequency of DVCs in the future.

Improved Mitigation

Positive steps have been implemented; however, more can be done by local and state departments to help aid in the DVC management process. Currently, insufficient information is being captured and documented to provide sufficient evidence for spatial and temporal patterns in relation to DVC events. More information gathered for DVC documentation would allow for a much more thorough investigation into DVC patterns. The most informative variables would include: land cover surrounding the DVC site, weather, location, road conditions, deer sex, deer age, road surface type, warning-device proximity, speed limit, vehicle speed, estimated time of collision, and approximate number of deer sighted. The main element impeding management options is monetary distributions (Sullivan et al., 2000). Most states simply do not place a high priority on reducing DVCs. In fact, many states do not document their DVCs at all. In a survey taken by Sullivan et al. in 2000, preliminary results from 35 state wildlife agencies indicated that only half maintained DVC records. Sullivan et al. also reported that 11 of the 35 reporting state agencies lacked the proper information to verify change in DVC frequencies.

Studying DVC frequencies more closely could magnify the DVC problem enough to activate state and local agencies to take on a more active role in DVC mitigation. Management options may include improved deer sign locations, over- or under-passes, reflectors, whistles, repellants, feeding stations, fences, and larger hunting harvests. The potential for this study to affect future DVC management is high due to a current lack of management strategy and pending revision of current mitigation efforts in Minnesota. If GIS were implemented into the DVC mitigation process, areas with high DVC frequency could be more easily identified and controlled.

The MNDOT was contacted to determine spatial locations of current deer warning signs within the study area. Presently, there is a statewide policy to phase out deer warning signs in Minnesota (Hanson, 2007). The MNDOT has conducted studies that show these signs do not aid in the prevention of DVCs. The MNDOT also reported that only 9 deer-warning signs still remain in Winona County. Three were located along State Highway 74 (Hwy 74) and two were along State Highway 43 (Hwy 43), Federal Highway 61 (Hwy 61) and Interstate 90 (I-90).

Comprehensive telemetry data would also assist current management efforts. However, telemetry data collected for this study area was temporally and spatially inadequate. Only one deer herd was being studied and their location was only being collected every two weeks. More frequent and extensive population movement data would be essential to documenting spatial and temporal habitat-use patterns.

Data

Data Sets

Data sets included DVC data for each county in the entire state of Minnesota, from 1995-2006. Statistically, this data was biased due to the underreporting of DVCs (Haroldson, 2007). Although underreporting of DVCs occurs, reports can still be produced to aid in the efforts to mitigate those that are reported to authorities. The first data set utilized information obtained from the MNDNR and law enforcement agencies through "possession permits". These permits are required if the driver, or other citizen, wants to retain possession of a deer carcass (Haroldson, 2007). Upon request, the responding officer then completes the form and documents characteristics of the DVC site, such as the age and sex of the deer involved, location, and time. These permits are then submitted to the MNDNR and filed into their database.

The second data set utilized documented a file known as an "unclaimed/unsalvageable report" (UUR). These reports are filed when a MNDOT officer responds to a crash site and the deer is either unclaimed or unsalvageable (Haroldson, 2007). The information recorded here includes kill location, deer sex, date, etc. Documentation is sent to the MNDNR on a monthly basis.

Roads Data

The road shapefiles were downloaded from the MNDNR Data Deli (http://deli.dnr.state.mn.us/). This free, public database contains a wide variety of political, environmental, and transportation GIS-based data. The road layers display all municipal roads within the prescribed area. For this study, a roads layer was downloaded for Winona County and the other 27 counties that compose southern Minnesota (Figure 1).

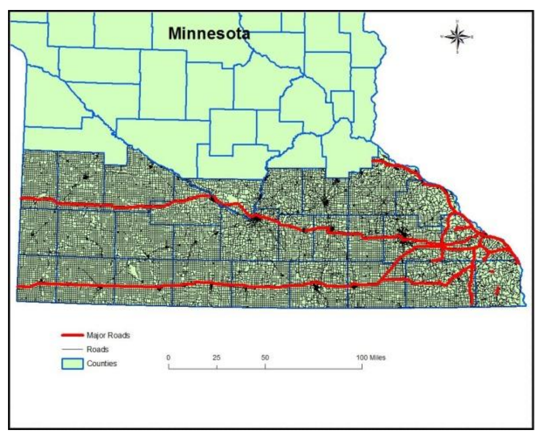

Figure 1. Twenty-eight county road layers.

Study Area

White-tailed deer (*Odocoileus virginianus)* can be found from southern Canada to Central America, along with some parts of South America and Europe. White-tailed deer are the species of deer located within the study area. The study area used for this project was Winona County, Minnesota. Winona County is located in the southeast portion of Minnesota, with the Mississippi River as its eastern border (Figure 2).

Figure 2. Overview, state scale map of the study area.

Winona County was chosen due to its close proximity to a major river, undulating topology, and forested land cover. All of these factors provide prime habitat for the white-tailed deer to thrive. Heavily traveled roads, such as I-90, traverse this county as well. These distinguishing features make Winona County a prime study area for DVC events.

Methods

Deer Seasons

Deer seasons were established using a project done by Ramakrishnan et al. (2005), titled "*Effects of Gender and Season on Spatial and Temporal Patterns of Deer-Vehicle Collisions*", as a template. This study used bar and box plot graphs to show how deer sex was a defining characteristic behind the frequency of reported DVC's during each deer season. The authors segmented deer seasons into three periods: herding/yarding season, fawning season, and breeding season. Each period was divided into four month segments. The herding season is the period between January and April, when deer begin to herd together and females (does) begin their gestation periods. The fawning season is the time when fawns (deer 0-1 years of age) learn from their protective mothers how to survive. This season spans May through August; additionally, the home-range of the fawns and does decreases substantially during this period. At the same time, bucks (male, adult deer) roam as individuals or in groups with other ranging males. Lastly, the breeding season stretches from September through December. During the breeding season, males significantly widen their home-ranges, in search for does in heat, as well as to defend established territories.

Database Design

A personal and file geodatabase were established in ArcGIS 9.2 to help facilitate data access and storage. The file geodatabase was used after earlier problems with a personal geodatabase caused a significant number of feature data sets to become corrupt and were permanently lost. The file geodatabase, labeled as "PP_LinerRef", was the file database used for this project. It contains all possession permit and linearly referenced data in this report. The personal geodatabase "Route_Event" was created for the UURs. The data tree in Figure 3 displays the databases, data sets and a feature class utilized in this study.

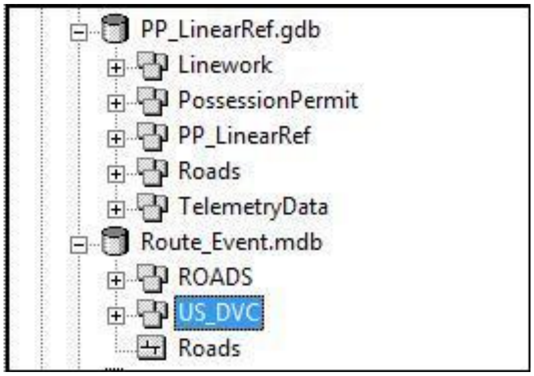

Figure 3. A hierarchical tree display of the databases.

The spatial reference used for these two databases was as follows:

Projection: Transverse_Mercator
False_Easting: 500000.000000
False_Northing: 0.000000
Central_Meridian: -93.000000
Scale_Factor: 0.999600
Latitude_Of_Origin: 0.000000
Linear Unit: Meter (1.000000)

Geographic Coordinate System: GCS_North_American_1983
Angular Unit: Degree (0.017453292519943295)
Prime Meridian: Greenwich (0.000000000000000000)
Datum: D_North_American_1983
Spheroid: GRS_1980
Semimajor Axis: 6378137.000000000000000000
Semiminor Axis: 6356752.314140356100000000
Inverse Flattening: 298.257222101000020000

The Universal Transverse Mercator (UTM) projection was used due to its consistency in shape, area, direction, and distance. This spatial reference was also chosen because it was the same reference used by data downloaded from the MNDNR Data Deli.

Linear Analysis

Linear Features

Roads represented the linear features used in the linear referencing and analysis processes. A roads shapefile for Winona County was downloaded from the MNDNR Data Deli. In ArcMap, major road segments were merged together to form a single road layer. Each road was then exported into the feature dataset as a feature class.

The major roads for this project included Interstate 90, State Highways' 248, 76, 74, 43, 16, and Federal Highways' 61 and 14. The main reason for only choosing to focus on the major roads was because of the complexity involved with each road during the linear referencing process. Furthermore, the majority of reported DVCs occurred on these major roads. Each road segment had two name fields, a primary and secondary road name. If a secondary road name matched the primary major road, it was included as part of the road. Overall, two road feature classes were created from the original road shapefile. One was created for the possession permit and another for the UUR.

Possession Permits

The possession permits did not contain mile marker data. Therefore, a simple linear analysis was done to find the major roads in the study area and attribute them accurately. First, the possession permit table was modified to show only the DVC's occurring on the major roads. These DVC's were summed for each road and the numbers were transferred into the attribute table for the roads feature class. The total possession permit DVCs from 1995-

2006 are shown in Figure 11.

Linear Referencing and Spatial Analysis

The UURs are unique when compared to the possession permits. UURs contain a specific locator for each DVC. This locator is the mile point at which the DVC took place along the roadway. To extrapolate where each DVC occurred, the linear referencing tool was utilized in ArcGIS 9.2. This tool allows the user to find specific point or line locations along linear features.

Establishing start points for major roads in the study area was the first step for pinpointing where each DVC occurred along these roadways. Mile markers in Minnesota begin at the origin of each road, located in the southern or western end of the road (Ross, 2008). This facilitated where the road origins were to be formed through the linear referencing tool. Mile markers are only found on state, federal and U.S highways (Ross, 2008). Therefore, these major roads became the primary focus for both the possession permits and UURs. This correlation between the two data sets was crucial for data referencing purposes.

Shapefiles covering the entire southern portion of Minnesota were downloaded from the MN Data Deli. This was done to find the entire linear length for each major road intersecting Winona County. The roads shapefile was then exported into a feature dataset in the file geodatabase to retain spatial reference.

Winona County cells were exported into a new table with corresponding tabs for each year. The mile point column was then reformatted, so the decimal was rounded to the nearest whole number. Since the length of linear features in the shapefile was in meters and the mile points were in miles in the UUR data set, a miles-to-meters conversion was performed on the data set. This rounding and conversion process had a minimal influence on the overall accuracy of the linear referencing process. ArcCatalog was then used to import yearly UURs into a separate folder as a database file format (.dbf). These .dbf files are supported for viewing and manipulation in ArcMap.

In order to relate information between two fields in ArcGIS, the character names of the relating features must match. Therefore, the roads layer was chosen to be the permanent layer and the DVC data set's road field names were changed to correspond with the roads feature class naming system. This allowed for a smooth transition in the linear referencing process.

Linear Referencing

Once the data was in order, linear referencing could begin. First, the "Create Routes" tool in the Linear Referencing Toolbox was used to create DVC events for each year (Figure 4). This method was executed on the merged roads data. However, the Hwy 61 results did not fall within the study area. Therefore, each road was exported as a separate feature class and analysis was done on each road to find the correct road origin (coordinate priority).

All road origins were found to have "lower_left" coordinate priority (south/west origin), except Hwy 61. Hwy 61 data points only fell inside the study area when given a "lower_right" coordinate priority (south/east origin).

All roads, excluding Hwy 61, were then selected and merged together into a feature class. A different feature class was created which included only Hwy 61. Separate analyses were then conducted for these two road feature classes. This technique created routes for each road, giving priority to the origin of the road. A route identifier field (road name) and measure source field (length in meters) were also needed to create the route feature class. In this case, the route identifier field was the road name and the measure source field was the length that had been calculated from miles to meters.

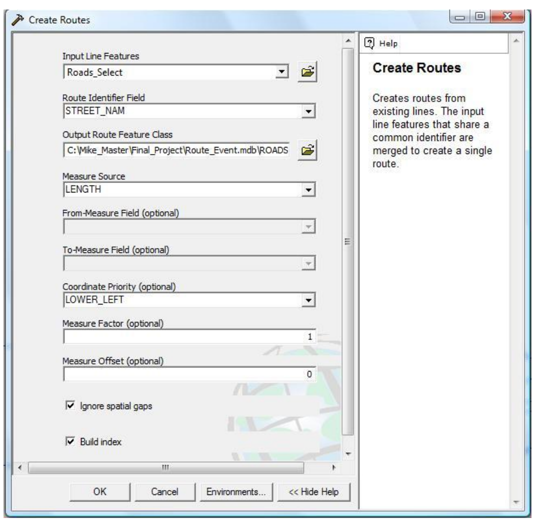

Figure 4. “Create Routes” tool.

The final part of the linear referencing process utilized in this study used the “Make Route Event Layer” tool, located under the linear referencing toolbox (Figure 5). This tool takes point information (UURs) and places them along a linear feature (roads) at designated locations. These assigned locations are calculated through the measure fields from both the route feature class (roads) and input layer (UUR database file). Events were computed for each year on both road feature classes. Every event layer for each year was then clipped and saved as a feature class into a feature data set, for spatial reference retention. The clip tool preserved only the UUR’s contained within Winona County. Both feature classes for each year were merged together, forming a singular UUR event feature class for each year.

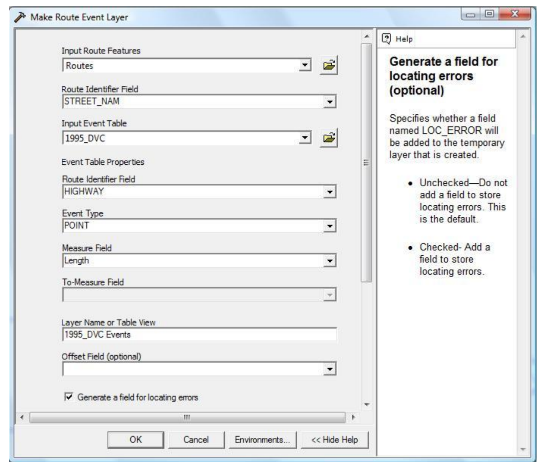

Figure 5. “Make Route Event Layer” tool.

Spatial Analysis

The Spatial Analyst extension was used to calculate density patterns for the linear referenced UURs. These density patterns helped show “hot spots” of DVC activity. Kernel density was chosen for the point analysis because the user can determine the output raster cell size and the search radius for each point. The cell size chosen for this study was 120 meters. The search radius was left at the default of 1288.24535 meters, which is less than one mile. This specific search radius was used for analysis on all remaining yearly data. The area unit was changed to show output values of UUR density in square miles. The square miles unit was easier to work with and understand. The environment setting for the kernel density tool was changed to operate as a clipping tool within the kernel density analysis. This allowed the extent and mask to be set to the study area.

A new classification system for the final output kernel density raster was needed, in order to show the UUR "hot spots". No templates were found to exist that conveyed a true DVC density classification. Therefore, a new grouping method had to be formed for this project. A three-tiered classification style was chosen to represent these varying densities. These three classes are displayed in Figure 12. The lowest class was between 0-2 UUR/square mile/year, the middle class from 2-5 UUR/square mile/year, and the hot spots contained anywhere from 5-9.3 UUR/square mile/year. This method of classification was based on the results of the kernel density analysis. A manual classification method was selected, and break values were input individually. The default classification was chosen for the yearly UUR kernel density output rasters.

Results

During seasonal analysis of the two datasets, the breeding season was found to have the highest DVC frequency of the three seasons (Figure 8). However, the fawning season was found to have the highest amount of DVC recorded through UURs from 1995-2006 (Figure 7). For both the spatial and linear analysis, the Hwy 61/14 corridor that follows the bluff and riparian features along the eastern border of Winona County was found to contain the highest number of DVCs in both datasets (Figures 12 & 13).

Seasonal DVC

Approximately 70 percent of possession permits occurred during the breeding season (Figure 6). Furthermore, the three highest monthly totals occurred during this season (Figure 9). October, November, and December accounted for 65 percent of the total possession permits from 1995-2006 in Winona County.

The fawning season totaled 43 percent of the UURs during the twelve year span (Figure 7). The breeding season was a close second, representing 39 percent of the total UURs. Combined, the fawning and breeding seasons accounted for approximately 82 percent of the total UURs in Winona County from 1995-2006. Only 18 percent of the total UURs were recorded during the herding/yarding season. Monthly analysis indicated that over 60 percent of UURs occurred in May, June, October and November (Figure 10).

The total reported DVCs, summed between the two data sets, equaled 2,950. Approximately 82 percent of the total DVC's occurred during the breeding and fawning seasons. The highest monthly totals were recorded during the first 2 months of the fawning season and the middle two months of the breeding season (Figure 11). The herding season was the lowest, accounting for only 19 percent of the total DVC's reported from 1995-2006.

Linear and Spatial Analysis

Linear Analysis

Vector and raster layers were produced

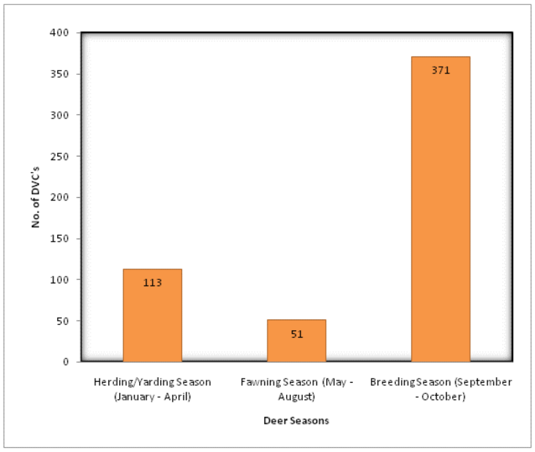

Figure 6. Total possession permits reported during each deer season from 1995-2006.

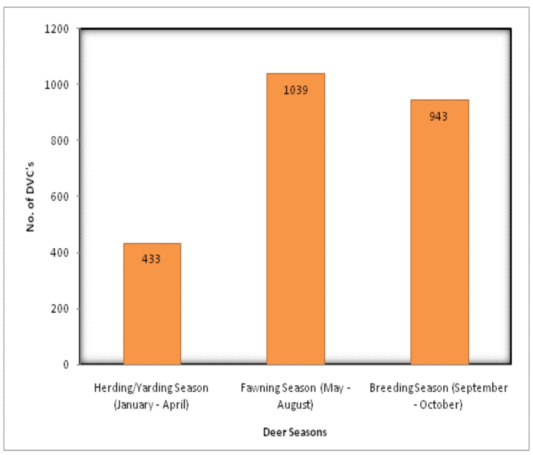

Figure 7. Total unclaimed/unsalvageable reports from 1995-2006.

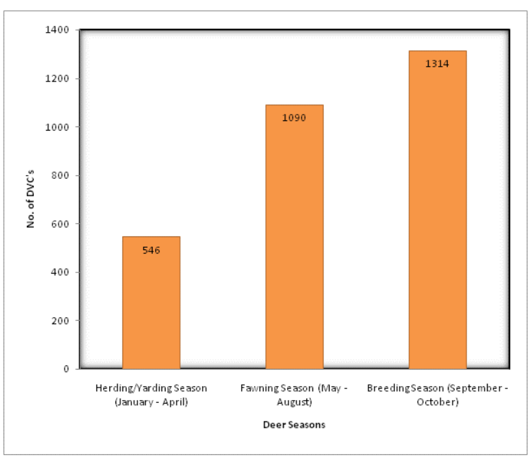

Figure 8. Total DVC count from 1995-2006.

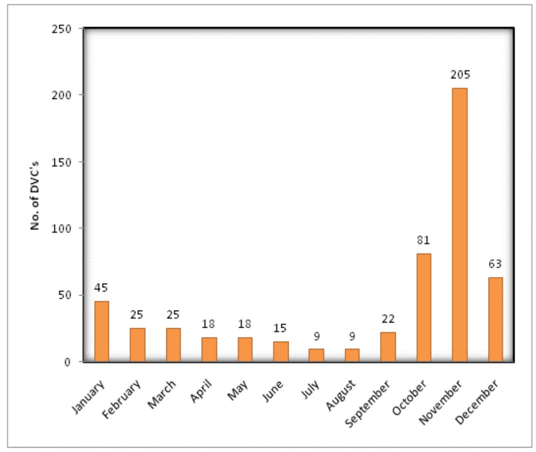

Figure 9. Total monthly possession permits reported from 1995-2006.

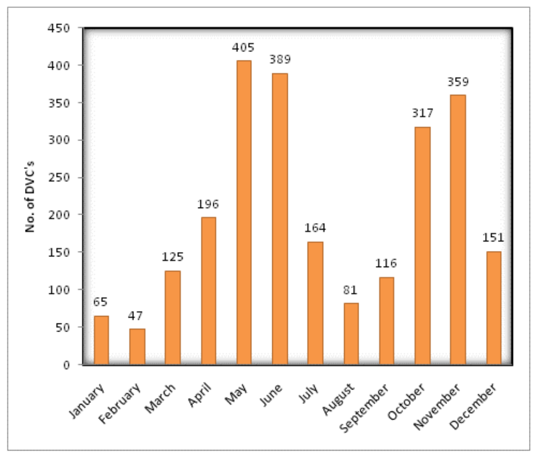

Figure 10. Total monthly unclaimed/unsalvageable reports from 1995-2006.

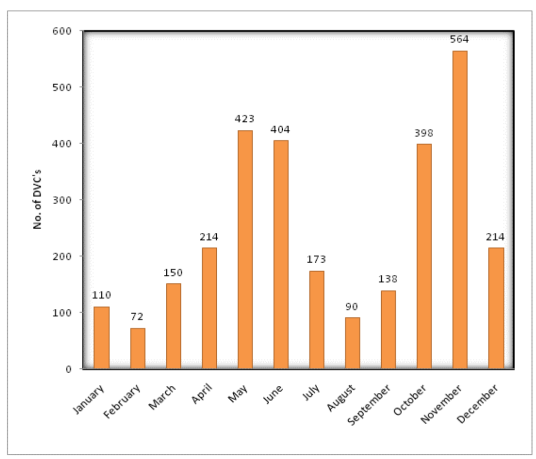

Figure 11. Total monthly DVC count from 1995-2006.

from the analysis methods. The vector layer was the product of the general, linear analysis. This layer found that Hwy 61 and Federal Highway 14 (Hwy 14) accounted for nearly 60% of the possession permits written for the major roads in Winona County from 1995 - 2006 (Figure 12).

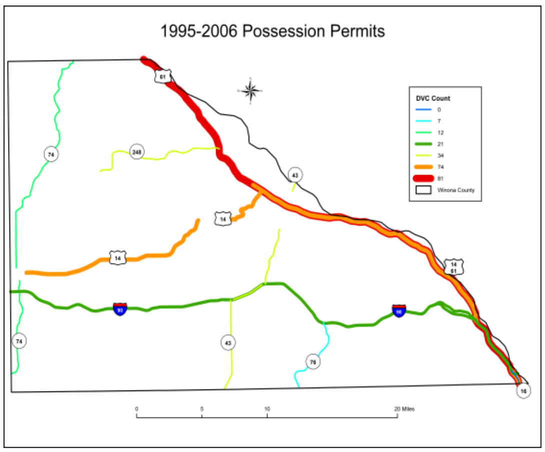

Figure 12. Linear Analysis of Possession Permits from 1995-2006 in Winona County.

UUR Count

From 1995 to 2006, 2,415 UUR's occurred in Winona County. Linear referencing located 2,030 of these. The clip tool reduced the number even further to 1,991, extracting only the UURs that occurred within Winona County.

Spatial Analysis

Yearly Analysis

Yearly analysis between 1995 and 2006 highlighted patterns in DVC activity across the study area (Figures 13-24). Comparatively, Hwy 61 and Hwy 61/14 had the most consistent patterns. For every year, besides 2002, DVCs occurred over this stretch at the highest rates in the county. Another area which continuously showed high density DVCs was around the interchange of State Highway 248 (Hwy 248) and State Highway 68 (Hwy 68). For every year, except 2002, the Hwy 248/68 interchange had an average number of DVCs above two/year.

Along I-90, between Hwy's 74 and 43, pockets of mid-level DVCs (> 2) were evident in 1995. Over the next couple of years, these pockets began to transform into high-level DVC areas (> 5). Then, from 1998-99, the pockets vanished, reforming again as mid-level pockets in 2000. The numbers again rose in this area during 2001, displaying many areas of high-level DVCs. However, the numbers again dropped in 2002 and were almost non-existent from 2003-06.

The interchange where Hwy 60/14 and I-90 meet is another area of great concern. DVC density patterns showed a high level of DVCs from 1995 to 1997. This 3-year trend picked back up in 2000 and continued through 2002. High levels were also found just south of the interchange during these two 3-year periods.

Only a few other areas displayed high levels of DVC activity. Hwy 248 showed an increasing level of activity from 1996-98. There was also sporadic mid- to high-level activity from 2001-02 and 2004-05. One area along Hwy 14 was of marginal concern, displayed in Figure 19 as a red oval with a green outline. This location displayed medium to high DVC activity, however was not as consistent as the other areas of concern. The final road section displaying high levels of DVC activity was along hwy 43 between I-90 and hwy 60/14. This stretch showed high levels of DVC activity from 1995-97 and again

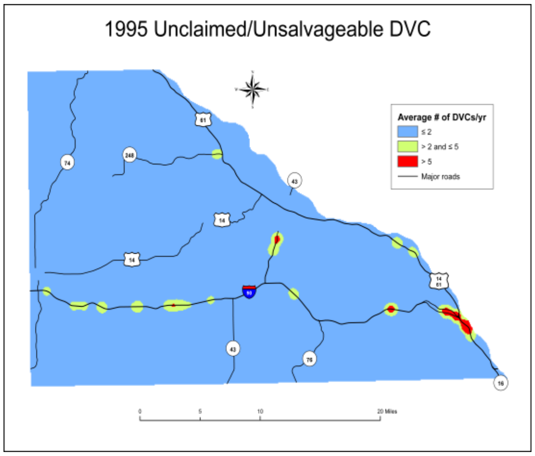

Figure 13. 1995 Kernel Density Analysis of UURs in Winona County.

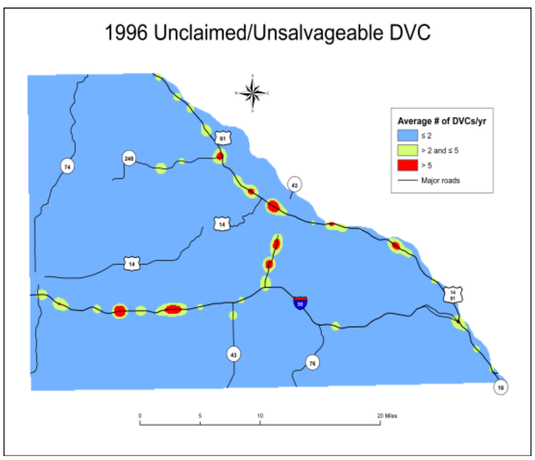

Figure 14. 1996 Kernel Density Analysis of UURs in Winona County.

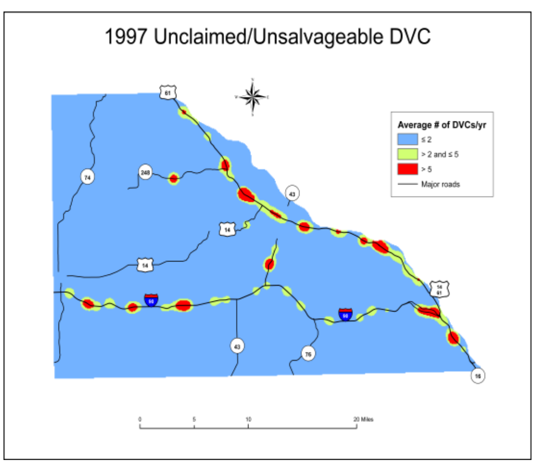

Figure 15. 1997 Kernel Density Analysis of UURs in Winona County.

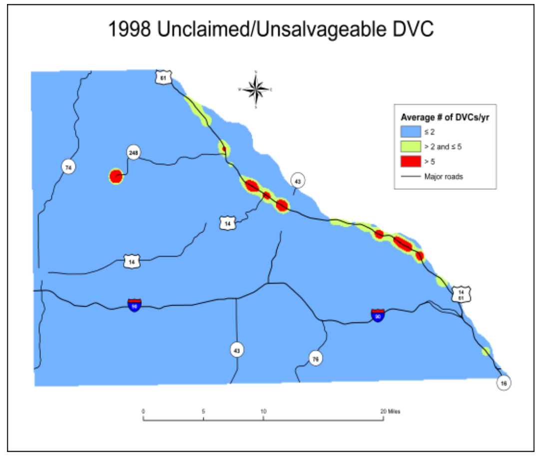

Figure 16. 1998 Kernel Density Analysis of UURs in Winona County.

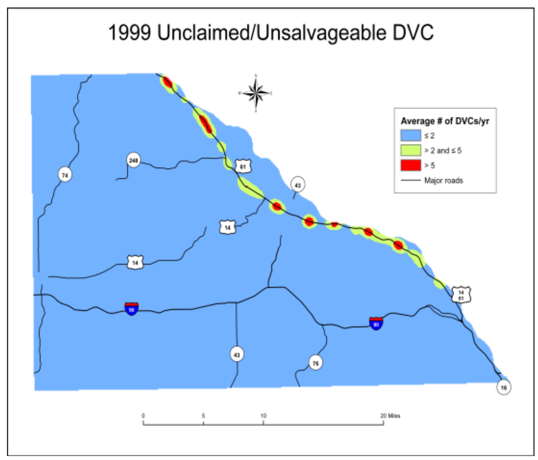

Figure 17. 1999 Kernel Density Analysis of UURs in Winona County.

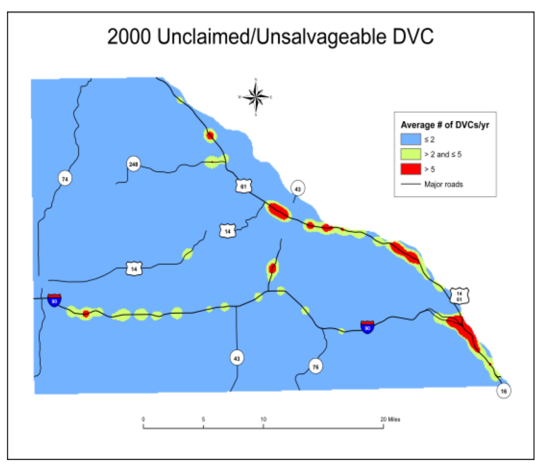

Figure 18. 2000 Kernel Density Analysis of UURs in Winona County.

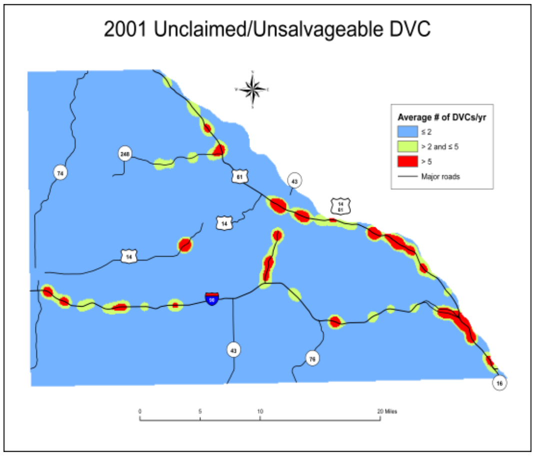

Figure 19. 2001 Kernel Density Analysis of UURs in Winona County.

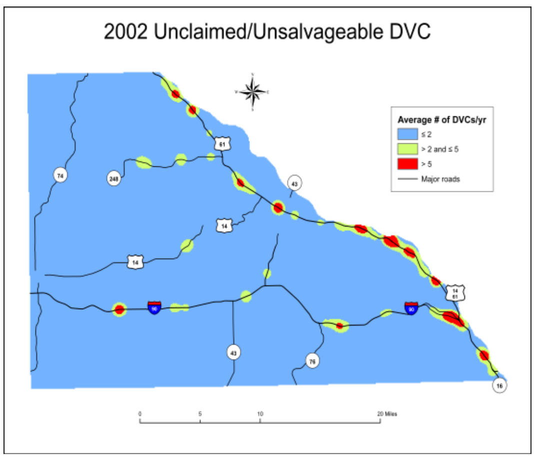

Figure 20. 2002 Kernel Density Analysis of UURs in Winona County.

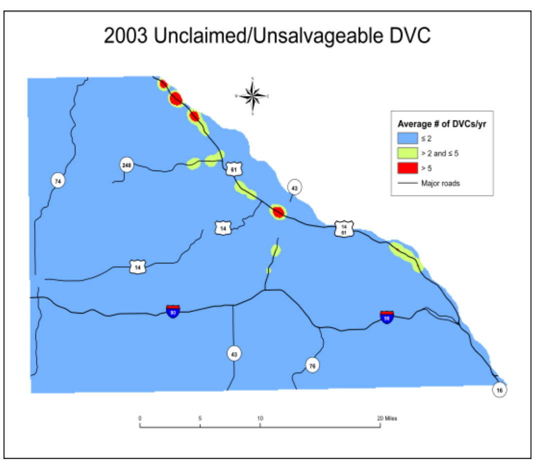

Figure 21. 2003 Kernel Density Analysis of UURs in Winona County.

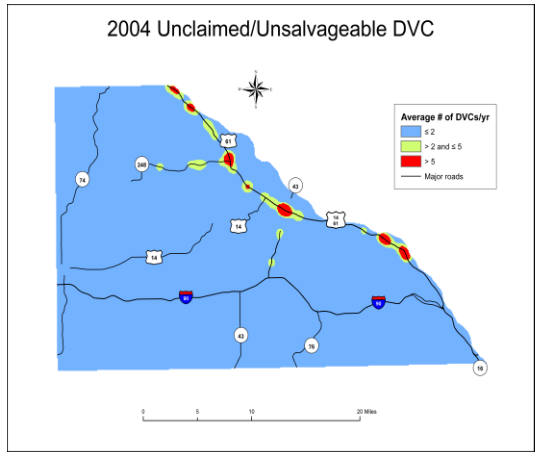

Figure 22. 2004 Kernel Density Analysis of UURs in Winona County.

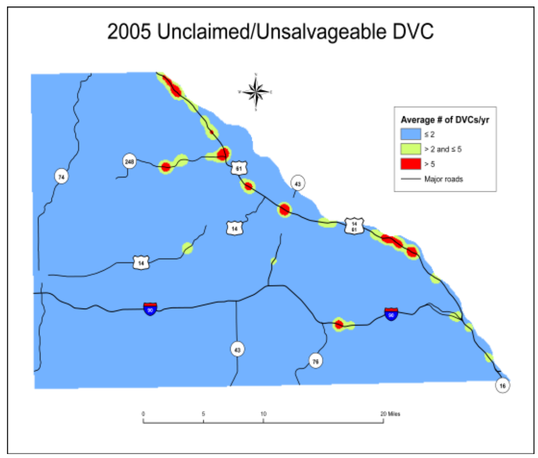

Figure 23. 2005 Kernel Density Analysis of UURs in Winona County.

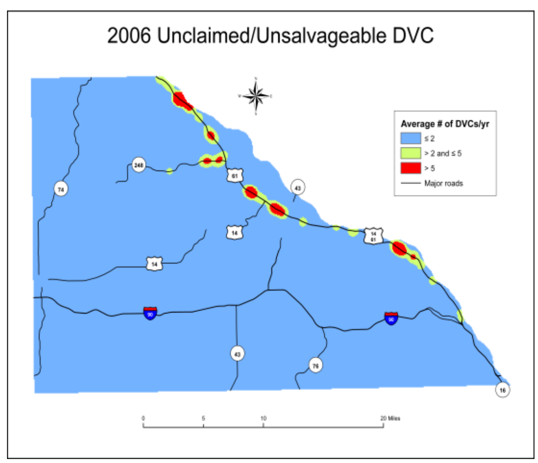

Figure 24. 2006 Kernel Density Analysis of UURs in Winona County.

in 2000-01.

Yearly Analysis Summation

The final raster layer is exhibited in Figure 13. The "hot spots" of UURs are highlighted in red (5-9.3 DVCs/square mile/year). The intermediate zones are featured in light green (2-5 DVCs/square mile/year), while the color blue indicates the areas of relatively insignificant amounts of UURs (0-2 DVCs/square mile/year). These UUR "hot spots" preserve the high density mean for the merged UUR data set.

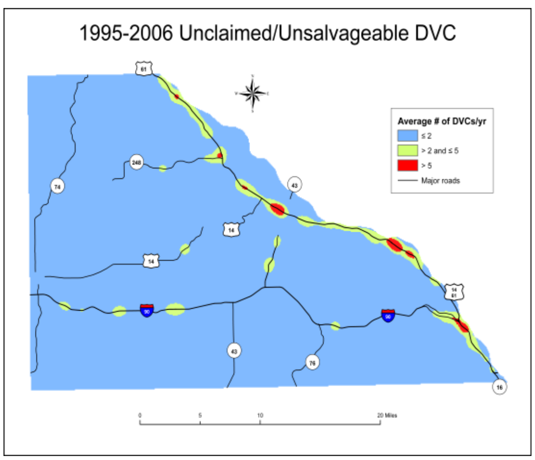

Figure 25. Kernel Density Analysis of UURs from 1995-2006 in Winona County.

Discussion and Conclusion

Seasonal patterns were noted during the analysis of this project. With such a low number of possession permits and high number of UURs, the pattern for the total number of DVCs followed the UUR's fluctuation trends very closely. The DVC seasonal trend study by Ramakrishnan et al. (2005) outlined some possible reasons for the results obtained for each season. The high number of DVCs during the breeding season could be a product of increased territory covered by males traveling to find breeding females. During this season, males expand their home ranges in order to mate and are driven by hormonal instincts.

Ramakrishnan et al. suggests that the large number of DVCs noted during the fawning season could be due to newborn fawns unfamiliarity with vehicles. Furthermore, yearling deer are forced from their home ranges by their expecting mothers during this time. This type of displacement puts a heavy amount of stress on the young deer, resulting in more DVC's. The herding season DVC totals were found to be much lower than the other seasons. This may be from the pregnancy of females and formation of segregated herds. The females are not traveling as much, anticipating the arrival of their newborns. The herding season is more of a feeding and protection period for the females, with less travel.

Summary

The base-level, spatial analysis model detailed in this study provided a foundation for future DVC density studies. This model was highly predictive and informative, retaining only the essential data necessary to find DVC density patterns. The study focused directly on the data set obtained from the MNDNR. The addition of other elements into the model, such as habitat or land cover, would have created error, therefore were not included in the study. However, this model could be further implemented into more dynamic, relational studies to provide public and private agencies with the adequate tools and methodologies to catalyze effective DVC mitigation efforts across the nation.

Deer habitat and land cover was not factored into this project, however it seemed to play a role in the locations of the high density DVC's. The Mississippi River forms the entire eastern border of Winona County and a bluff system runs along the western edge of the roadway (Hwy 61/14) that follows the river. The river and its riparian basin provide a key resource for deer to flourish. The bluffs are predominately uninhabited due to the steep terrain and local geology, providing critical habitat refuges for deer. The majority of high density UUR and possession permit DVCs occurred along portions of I-90 and Hwy's 61 and 14, which all cut between the bluffs and river in certain areas. Additionally, the MNDNR or MNDOT should investigate local deer movement patterns on a more regular basis. Increasing the amount of knowledge about how deer transect the landscape would provide advanced spatial and temporal attributes. These movements and attributes, grouped together with spatially analyzed DVC patterns, would allow authorities to find "hot spots" even more accurately.

Overlap of the road designator (name) occurred during linear analysis, where segments of road had multiple designators. Presenting this overlap without distorting the perception of DVC information was not possible for this method. However, the map still retained linear representation, while displaying DVC information.

The loss of data during linear referencing was due to the inaccuracy of mileage records. Human error during the handling of UURs seemed to be the most plausible reason for these mistakes. The flaws may have occurred in the field when the report was filled out, or when all the information was later transferred from paper to computer format. Furthermore, quality control practices, such as field testing with a GPS, would have significantly increased UUR location accuracy and could have been utilized to cross-reference the spatial location for each event. Resources for such data management practices were not available for this project.

Discrepancies in the results were evident because all reported possession permits and UURs were included in the seasonal analysis, while only those occurring on the major roads were evaluated for linear and spatial analysis. Additionally, the number of possession permits were fewer than the number of UURs, primarily because a deer must still be salvageable and sought by a citizen in order to file a possession permit. Many anthropogenic reasons could be responsible for lower possession permit numbers. Many people would not find it practical to dress and clean a deer if it was a fawn or smaller deer. Furthermore, if the deer was mostly destroyed in the accident, filing for a possession permit would not be an option either. However, if a driver was to accidentally collide with a large deer, in particular a buck, they may be more likely to retain possession of the deer due to its size and prized antlers. Therefore, it was not surprising to find that the most possession permits were obtained during the breeding season, when male deer have reached peak antler mass.

Linear analysis was not able to identify the specific locations of DVC "hot spots". The spatial analysis of this project was only projected on the sum of the merged data for the study area. Yearly densities could be further analyzed to provide an even more detailed analysis.

With both data sets analyzed, the importance of detailed information for DVC mitigation is clear. The mile marker attribute was crucial for spatial analysis of the UUR data. The kernel density patterns noted in this study could assist in developing deer mitigation practices for the future.

Acknowledgements

The staff of the Department of Resource Analysis at Saint Mary's University of Minnesota went to great lengths to nurture my educational drive. Dr. David McConville, John Ebert and Patrick Thorsell all deserve my deepest appreciation for their guidance and hard work. Brian Haroldson of the Minnesota Department of Natural Resources provided all necessary DVC information for this study. Without his correspondence over the last year, none of this would have been possible. Chad Hanson and Dan Ross of the Minnesota Department of Transportation also provided information vital to this study. Finally, I wanted to give a special thank you to my friends and family for accompanying me on this long, arduous journey. My love and gratitude goes out to you all.

References

Conover, M.R., Pitt, W.C., Kessler, K.K., DuBow, T.J., and Sanborn, W.A. 1995. Review of Human Injuries, Illnesses, and Economic Losses Caused by Wildlife in the United States. Wildlife Society Bulletin, vol. 23, pp. 407-414.

Curtis, P.D., Hedlund, J.H. 2005. Reducing Deer-Vehicle Crashes. Wildlife Damage Management Fact Sheet Series, Cornell Cooperative Extension. Ithaca, NY. Cornell University.

Hanson, Chad. 2007. Minnesota Department of Transportation District 6 Traffic Engineer. Telephone Interview. August 23, 2007.

Haroldson, Brian. 2007. "Re: Graduate Project Info – parts 1-4". E-mail to Michael T. Yarnes. August 06, 2007.

Minnesota Department of Natural Resources GIS Data Deli (MNDNR Data Deli). 2007. Road data and state and county political boundaries data. Retrieved: October 1, 2007 from http://deli.dnr.state.mn.us.

Ramakrishnan, U., Daugherty, L., Pelkey, N.W., and Williams, S.C. 2005. Effects of Gender and Season on Spatial and Temporal Patterns of Deer-Vehicle Collisions. Road Ecology Center eScholarship Repository - John Muir Institute of the Environment. Davis, CA. University of California, Davis.

Ross, Dan. 2008. Minnesota Department of Transportation GIS Project Manager. Telephone Interview. July 09, 2008.

Sullivan, T., Messmer, T.A., and Conover, M.R. 2000. State Wildlife Agency Responses in Wildlife-Highway Conflicts: Who is Doing What? Wildlife and Highways. T.A. Messmer and B. West (eds.). The Wildlife Society and Jack H. Berryman Institute. Logan, Utah. pp. 91-98.

U.S. Department of Transportation Federal Highway Administration (USDOT). 1995. Highway Safety Information System Summary Report. Investigation of Crashes with Animals. http://www.hsisinfo.org/pdf/94-156.htm.