Montana US Highway 93 South Wildlife Crossings Research
MDT # HWY – 308445-RP

2013 First Quarter Progress Report

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1. Study Area and Purpose

The Montana Department of Transportation (MDT) installed 19 large wildlife crossing structures along US Highway 93 South between Florence and Hamilton from 2004 to 2012. Wildlife exclusion fencing was installed during construction at 17 of these structures. This fencing is 8 feet high (2.3 meters) and extends various distances from the entrances of wildlife crossing structures. Fencing was not installed at Bass Creek North and Bass Creek South. Additional details of the 19 wildlife crossing structures are presented in Table 1. A map of the study area is presented in Figure 1.

The purpose of this research is to determine the effectiveness of wildlife crossing structures by investigating:

1. white-tailed deer (*Odocoileus virginianus*) use of wildlife crossing structures and wildlife crossing sites,
2. white-tailed deer usage rates of wildlife crossing structures by type and across types (including height, width, length, and material),
3. relationships between usage rates of wildlife crossing structures and landscape variables,
4. changes in animal-vehicle collisions between pre-construction and post-construction of wildlife crossing structures within a twenty-five mile stretch of US Highway 93 South, mile post (mp) 74 to mp 49, and,
5. relationships between animal-vehicle collisions and wildlife crossing structures over time and space.

This research began in 2008 and will be completed in 2015. This research is approximately 64% complete. This report presents preliminary results which preclude discussion and conclusion sections. The project is on time and on budget for all tasks.

Table 1. Wildlife Crossings Structures, US Highway 93 South, Montana.

Structures	Year Completed	Approximate Mile Post	Structure Type
Bass Creek North	2005	71	Bridge
Bass Creek South	2005	70	Bridge
Bass Creek Fishing Access	2005	70	Round Corrugated Steel Culvert
Dawn's Crossing	2005	70	Bridge
Kootenai Creek	2009	66	Bridge
McCalla Creek North	2009	66	Bridge
McCalla Creek South	2010	65	Bridge
Kootenai Springs Ranch	2010	65	Concrete Box Culvert
Indian Prairie Loop	2010	63	Concrete Box Culvert
Big Creek	2011	61	Bridge
Axmen Propane	2010	61	Round Corrugated Steel Culvert
Sweathouse Creek	2011	60	Bridge
Bear Creek North	2012	58	Bridge
Bear Creek South	2012	57	Bridge
Mountain Gallery	2011	56	Concrete Box Culvert
Lupine	2012	56	Concrete Box Culvert
Fun Park	2011	55	Concrete Box Culvert
Mill Creek	2011	55	Bridge
Blodgett Creek	2008	50	Bridge

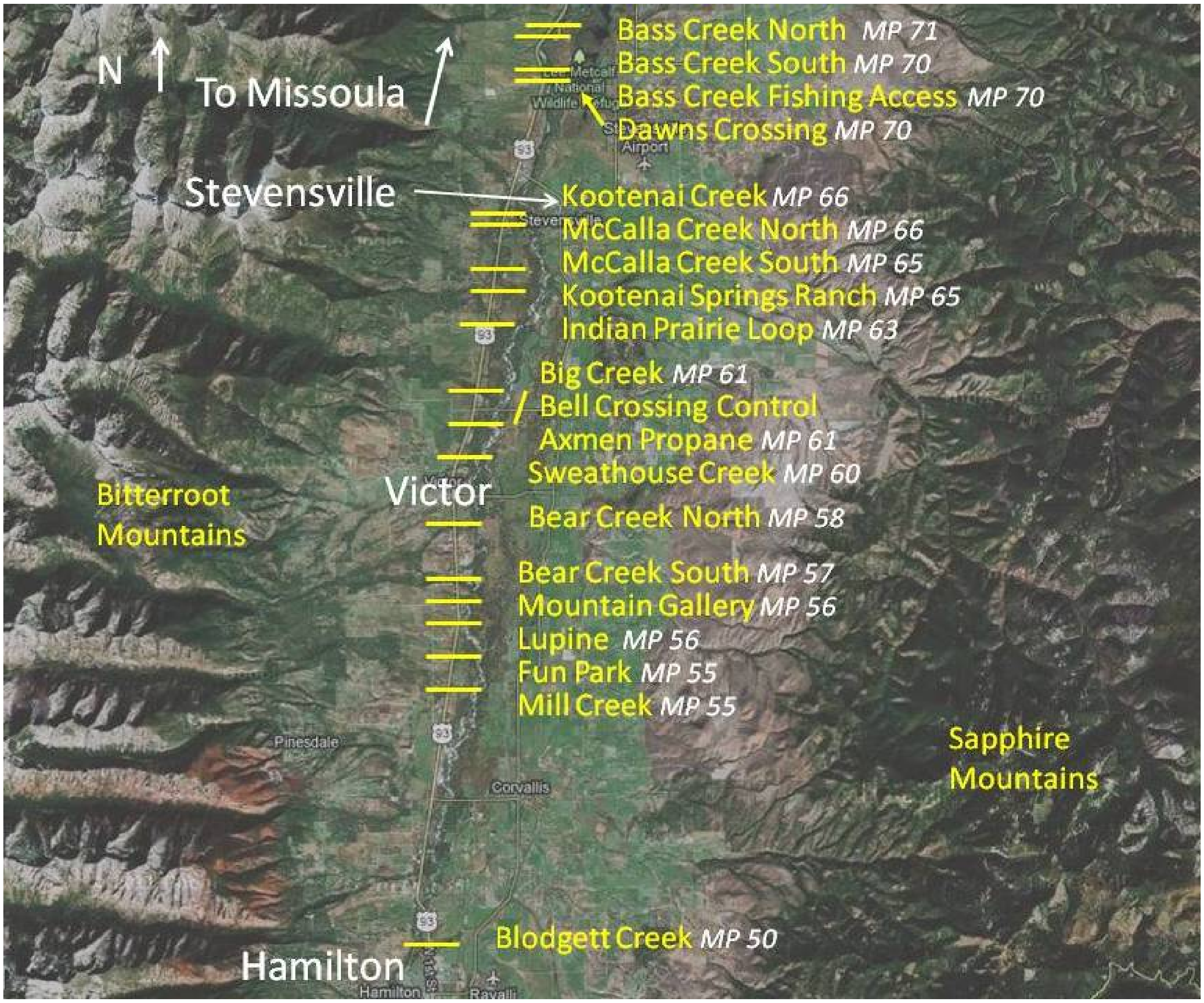

Figure 1. Map of US Highway 93 South Study Area, Montana.

2. White-tailed Deer Use of Wildlife Crossing Structure Sites and Wildlife Crossing Structures

2.1. Methods

White-tailed deer usage rates were determined by monitoring wildlife crossing structure sites and wildlife crossing structures with Reconyx Professional Cameras, Model PC85 and Model PC800. Cameras were triggered by motion and took pictures of large and small animals, day and night. Cameras were installed inside metal telephone-utility boxes or metal Reconyx Bear Boxes. Each telephone-utility box was secured by a cable locked to the camera on one end and buried in concrete at the other. Reconyx Bear Boxes were mounted on large fence posts or trees and secured with locked cables. All cameras were also secured by electronic code locks.

The following calculations were made for each camera location or wildlife crossing structure, where applicable:

- **deer per day** = the total number of deer observed divided by the number of days the camera was in operation
- **success per day** = the total number of deer observed successfully using a wildlife crossing structure divided by the number of days the camera was in operation
- **success rate** = the total number of deer moving through a wildlife crossing structure or onto the road right of way at a wildlife crossing structure site, divided by the total number of deer recorded at the structure or site
- **rate of repellency** = the total number of deer repelled at a wildlife crossing structure or the road right of way at a wildlife crossing structure site divided by the total number of deer recorded at the structure or site
- **parallel rate** = the total number of deer moving parallel to a structure or site right of way divided by the total number of deer recorded at the structure or site.

2.1.1. Pre-construction Monitoring

Two cameras were installed at each of the wildlife crossing structure sites. One camera was placed as near as possible to any original bridge, or the proposed location of the structure. These cameras were designated “structure cameras” if they recorded white-tailed deer use of the original bridges. A second camera was placed within 50 meters of the first camera at each site. These cameras were designated either “right of way cameras” or “habitat cameras.” Right of way cameras recorded animal movements as they approached or departed the road right of way. Habitat cameras recorded only parallel movements, calculated as deer per day. Pre-construction monitoring was completed in April, 2011.

2.1.2. Post-construction Monitoring

A single camera was installed near one entrance of the following wildlife crossing structures: Bass Creek North (mp 71), Bass Creek South (mp 70), Bass Creek Fishing Access (mp 70), Dawn’s Crossing (mp 70), Kootenai Creek (mp 66), and Blodgett Creek (mp 50). Two cameras were installed, one near each entrance, of the following wildlife crossing structures: McCalla Creek North (mp 66), McCalla Creek South (mp 65), Kootenai Springs Ranch (mp 65), Indian Prairie Loop (mp 63), Axmen Propane (mp 61), Sweathouse Creek (mp 60), Bear Creek North (mp 58), Mountain Gallery (mp 56), Lupine (mp 56), Fun Park (mp 55), and Mill Creek (mp 55). Lupine (mp 56) was monitored with only one camera after September 13, 2012. Three cameras were installed at Bear Creek South (mp 57) and at Big Creek (mp 61). Cameras were placed near the entrances of wildlife crossing structures in order to record the number of white-tailed deer successfully using, moving parallel to, and repelled from the crossing structures. Structures completed prior to this study were monitored with one camera (McCalla Creek North is an exception). Structures completed during this study were monitored with two or more cameras (Lupine (mp 56) is an exception). Pre-construction monitoring data will be compared with post-construction monitoring data, where applicable.

2.1.3. Control Cameras

Two cameras were installed at Bell Crossing (east and west cameras, control) near a bridge over an unnamed spring run on County Road 370, approximately one-quarter mile east of the Bitterroot River. The east camera is a “habitat camera” and the west camera is a road “right of way camera.” This location was selected as a long-term control site to monitor white-tailed deer population and activity in an area where road construction, wildlife crossing structure construction, and wildlife exclusion fencing were not scheduled to occur. One camera was installed at McCalla Creek South (ramp camera, mp 65) to monitor the jump off ramp and to serve as a long-term control site. Big Creek (south camera, control, mp 61) was also selected as a long-term control site.

2.1.4. Work this Quarter

During this quarter, approximately 42,000 images were collected and analyzed. Locations, approximate mile posts, and installation dates of cameras currently monitoring post-construction wildlife activity at wildlife crossing structures, and cameras at control sites are presented in Table 2.

Table 2. Cameras Currently Installed at Wildlife Crossing Structures on US Highway 93 South, Montana, and at Control Sites.

Camera Location	Approximate Mile Post	Date Installed
Bass Creek North	71	Oct. 10, 2008
Bass Creek South	70	Nov 22, 2008
Bass Creek Fishing Access	70	Nov 22, 2008
Dawn’s Crossing	70	Nov 23, 2008
Kootenai Creek	66	Apr 21, 2009
McCalla Creek North (east camera)	66	Apr 22, 2009
McCalla Creek North (west camera)	66	Apr 22, 2009
McCalla Creek South (east camera)	65	July 30, 2010
McCalla Creek South (west camera)	65	June 16, 2010
McCalla Creek South (ramp camera)	65	June 16, 2010
Kootenai Springs Ranch (east camera)	65	June 10, 2010
Kootenai Springs Ranch (west camera)	65	July 29, 2010
Indian Prairie Loop (east camera)	63	Oct 25, 2011
Indian Prairie Loop (west camera)	63	Sept 27, 2010

Camera Location	**Approximate Mile Post**	**Date Installed**
Big Creek (northeast camera)	61	July 28, 2011
Big Creek (southeast camera)	61	July 29, 2011
Big Creek (southwest camera)	61	Aug 12, 2011
Big Creek (south camera, control)	61	Apr 21, 2009
Axmen Propane (east camera)	61	Sept 28, 2010
Axmen Propane (west camera)	61	April 25, 2012
Sweathouse Creek (east camera)	60	Dec 10, 2011
Sweathouse Creek (west camera)	60	Dec 10, 2011
Bear Creek North (east camera)	58	June 25, 2012
Bear Creek North (west camera)	58	June 25, 2012
Bear Creek South (east camera)	57	June 26, 2012
Bear Creek South (west camera)	57	June 26, 2012
Bear Creek South (birch camera)	57	Sept 14, 2012
Mountain Gallery (east camera)	56	April 25, 2012
Mountain Gallery (west camera)	56	Mar 2, 2012
Lupine (west camera)	56	June 26, 2012
Fun Park (east camera)	55	Mar 2, 2012
Fun Park (west camera)	55	April 25, 2012
Mill Creek (east camera)	55	Dec 10, 2011
Mill Creek (west camera)	55	Mar 2, 2012
Blodgett Creek	50	Mar 15, 2010
Bell Crossing (east camera, control)	CR 370	May 29, 2009
Bell Crossing (west camera, control)	CR 370	May 29, 2009

2.2. Results

2.2.1. Pre-construction Monitoring

Pre-construction monitoring was completed in April, 2011. Twenty-six pre-construction data sets are summarized by camera designation in Table 3. The order of camera locations is based on the number of deer per day photographed at each camera site. The pre-construction Bear Creek South bridge was functioning as a successful wildlife crossing structure, even though it was not designed as one (success rate 98%). The success rate for the other five structure cameras monitoring original bridges averaged 11%. For road right of way cameras, the average success rate was 59% and the average rate of repellency was 8% (n=10, excluding Lupine north right of way). The road right of way cameras recorded deer successfully crossing US Highway 93 on 1,755 occasions during pre-construction.

Table 3. Summary of Complete Pre-construction Data Sets.

Structure Camera Location	Mile Post	Camera Days	Deer Per Day	Successful Crossings	Success Rate (%)	Rate of Repellency (%)	Parallel Rate (%)
Bear Creek South (structure)	57	629	2.6	1662	98	1	1
McCalla Creek South (structure)	65	109	2.3	21	9	7	84
Sweathouse Creek (structure)	60	452	1.1	65	13	1	86
Big Creek (structure)	61	277	0.8	33	14	14	72
Mill Creek (structure)	55	599	0.07	1	3	0	97
Bear Creek North (structure)	58	536	0.03	2	14	14	72
Right of Way Camera Location	**Mile Post**	**Camera Days**	**Deer Per Day**	**Successful Crossings**	**Success Rate (%)**	**Rate of Repellency (%)**	**Parallel Rate (%)**
Kootenai Springs Ranch (east right of way)	65	107	2.1	78	32	8	60
Fun Park (east right of way)	55	490	1.5	606	79	11	10
Mill Creek (right of way)	55	566	1.2	525	70	15	15
Kootenai Springs Ranch (west right of way)	65	55	0.9	26	54	10	36
Sweathouse Creek (right of way)	60	503	0.8	219	52	4	44
Bear Creek South (right of way)	57	509	0.4	140	68	7	25
Mountain Gallery (north right of way)	56	440	0.3	64	45	4	51
Fun Park (west right of way)	55	556	0.2	57	52	3	45

Right of Way Camera Location	**Mile Post**	**Camera Days**	**Deer Per Day**	**Successful Crossings**	**Success Rate (%)**	**Rate of Repellency (%)**	**Parallel Rate (%)**
Lupine (south right of way)	56	172	0.1	16	80	15	5
Mountain Gallery (south right of way)	56	587	0.06	24	61	3	36
Lupine (north right of way)	56	204	0.005	0	0	100	0
Habitat Camera Location	**Mile Post**	**Camera Days**	**Deer Per Day**				
McCalla Creek South (habitat)	65	93	5.0				
Indian Prairie Loop (north habitat)	63	78	4.7				
Indian Prairie Loop (south habitat)	63	150	4.5				
Big Creek (habitat)	61	260	2.2				
Axmen Propane (north habitat)	61	212	1.5				
Lupine (west habitat)	56	382	1.3				
Bear Creek North (habitat)	58	454	0.6				
Lupine (east habitat)	56	385	0.6				
Axmen Propane (south habitat)	61	176	0.4				

2.2.2. Post-construction Monitoring

Post-construction monitoring of the 19 wildlife crossing structures is ongoing. White-tailed deer use of wildlife crossing structures is presented in Table 4. The order of camera locations is based on success per day. Camera data reported were analyzed through March 13, 2013. During this study, cameras recorded individual white-tailed deer successfully moving through wildlife crossing structures on 15,455 occasions (this number includes pre-construction data reported in Table 3).

2.2.3. Control Monitoring

Control camera data were analyzed through November 24, 2012. At Bell Crossing (west camera, control) 3.2 deer per day were recorded. Deer successfully crossed County Road 370 on 2,833 occasions. The success rate was 65%, the rate of repellency was 6%, and the parallel rate was 29%. At Bell Crossing (east camera, control) 2.6 deer per day were recorded. At Big Creek (south camera, control), there were 2.2 deer per day during pre-construction monitoring, 1.3 deer per day during construction, and 1.2 deer per day post-construction. At McCalla Creek South (ramp camera) 5 deer per day were recorded during pre-construction, 0.5 deer per day during construction, and 1.1 deer per day post-construction.

Table 4. White-tailed Deer Use of Wildlife Crossing Structures.

Camera Location	Mile Post	Success Per Day	Successful Crossings	Success Rate (%)	Rate of Repellency (%)	Parallel Rate (%)
Bear Creek South	57	4.4	1097	96	1	3
Big Creek	61	2.2	1035	84	8	8
Dawn's Crossing	70	1.9	3047	96	2	2
Sweathouse Creek	60	1.9	869	92	3	5
Bass Creek Fishing Access	70	1.5	2247	96	3	1
Kootenai Creek	66	1.5	2050	91	4	5
McCalla Creek North	66	1.2	1508	83	6	11
Blodgett Creek	50	0.7	695	95	2	3
Indian Prairie Loop	63	0.6	367	24	8	68
Lupine	56	0.5	70	37	13	50
Mill Creek	55	0.3	116	44	12	44
McCalla Creek South	65	0.2	214	40	17	43
Bass Creek North	71	0.15	229	52	7	41
Kootenai Springs Ranch	65	0.07	64	4	12	84
Axmen Propane	61	0.05	27	4	11	85
Mountain Gallery	56	0.03	18	22	17	61
Bear Creek North	58	0.02	5	15	24	62
Bass Creek South	71	0.01	13	50	15	35
Fun Park	55	0	0	0	9	91

3. White-Tailed Deer Usage Rates of Wildlife Crossing Structures by Type and Across Types

A detailed statistical analysis of white-tailed deer usage rates of wildlife crossing structures by type and across types will be reported when data are compiled. Multivariate statistics will be used to analyze how variables such as height, width, length, shape, construction material, presence or absence of wildlife exclusion fencing, length of fencing and guardrails, and human presence or other disturbances may affect usage rates.

4. Relationships among Wildlife Crossing Structures with Landscape Variables and Crossing Rates

A methodology was developed to quantify landscape variables such as road, traffic, vegetation, topography, and deer fecal pellets at wildlife crossing structures and sites. Data were collected in 2010 at wildlife crossing structures, wildlife crossing structure sites, and control sites, except for the following: Indian Prairie Loop, Big Creek, and Axmen Propane. Construction activities were occurring at these three locations; and landscape variables there were drastically changed by the construction activities. Landscape variables data were collected again in 2012 at all structures and control sites, with the exception of the east side of Lupine, where landowner permission could not be obtained.

In 2010 vegetation data were collected in 25 plots in a 25 meter grid, on each side of the structure or site (50 total plots, each 25 meters apart). Each plot was a circle with a 2 meter radius. Vegetation was categorized as trees, shrubs, or grasses/non-woody and the percentage cover (density) of each category was visually estimated. In 2012, five additional plots on each side of the structures were sampled (60 total plots).

Fecal pellets were counted in each plot at each structure or site as described above, and tabulated as number of piles (a pile was more than 10 pellets but less than 50 pellets) and number of scatters (a scatter was less than 10 pellets). Pellet counts will be analyzed to determine if they can be used as an index or estimate of deer abundance. Statistical analyses will also explore if pellet data correlate with vegetation and number of deer photographed at the structure or site.

Vegetation characteristics and deer abundance at each structure and control site may be analyzed in an Akaike Information Criterion (AIC). AIC-based statistics allow multiple statistical models to be built. The AIC software selects the most appropriate model that explains deer presence as related to the different landscape variables. The researchers will conduct a literature search to determine how other studies have used this analysis to predict animal presence. This is but one of several statistical analyses to be used.

5. Changes in Animal-Vehicle Collisions between Pre-construction and Post-construction of Wildlife Crossing Structures

Generalized Additive Models (GAM) will be used to analyze changes in animal-vehicle collisions (AVC) between pre-construction and post-construction of wildlife crossing structures. Models developed for this study will determine how deer abundance and traffic volume influence AVC and may predict future AVC if there were no wildlife crossing structures, based on pre-construction data. A direct comparison of pre-construction and post-construction AVC would be incomplete because deer abundance and traffic volume change over time. The predicted AVC can be compared to actual AVC once wildlife crossing structures and fencing are completed.

This quarter, Dr. Greenwood continued to develop pre-construction (2000 to 2010) GAM with monthly AVC data at the nearest milepost (mp 48 to mp 85) as the response variable and monthly traffic volume from traffic counters A-47 and A-56 as the predictor variable. Dr. Greenwood's detailed report on GAM with spatial and temporal effects of pre-construction traffic volume and AVC is provided in Appendix A. One model was used to demonstrate the pre-construction relationship between traffic volumes (x-axis) and AVC counts (y-axis) in Figure 2. The model predicted that AVC increased as traffic volume increased, and peaked around 10,500 vehicles per day. AVC then decreased as traffic volume increased, up to approximately 12,200 vehicles per day. AVC then increased slightly again as traffic volume approached 13,000 vehicles per day. Dr. Greenwood used another Generalized Additive Model to control for the spatial and temporal effects of AVC and traffic volume data, and the estimated effect of traffic volumes on AVC counts is demonstrated in Figure 3. In this model, AVC increased only slightly with traffic volume, peaked between 9000 and 10,200 vehicles per day, and continued to decrease as traffic volume increased beyond 10,200 vehicles per day. This model shows less effect on AVC at lower traffic volumes between 8000 and 9000 vehicles per day than the model presented in Figure 2. The GAM demonstrate that plotting traffic volume and AVC may be too simplistic. Statistical models that take into account the spatial and temporal aspects of the study site help to decompose different aspects of the variability in AVC patterns. These GAM and future statistical models will be adapted to include both traffic volume and deer abundance as predictor variables. When the best fitting GAM are complete they will predict what AVC would be under specific traffic volumes and deer abundances without wildlife mitigation.

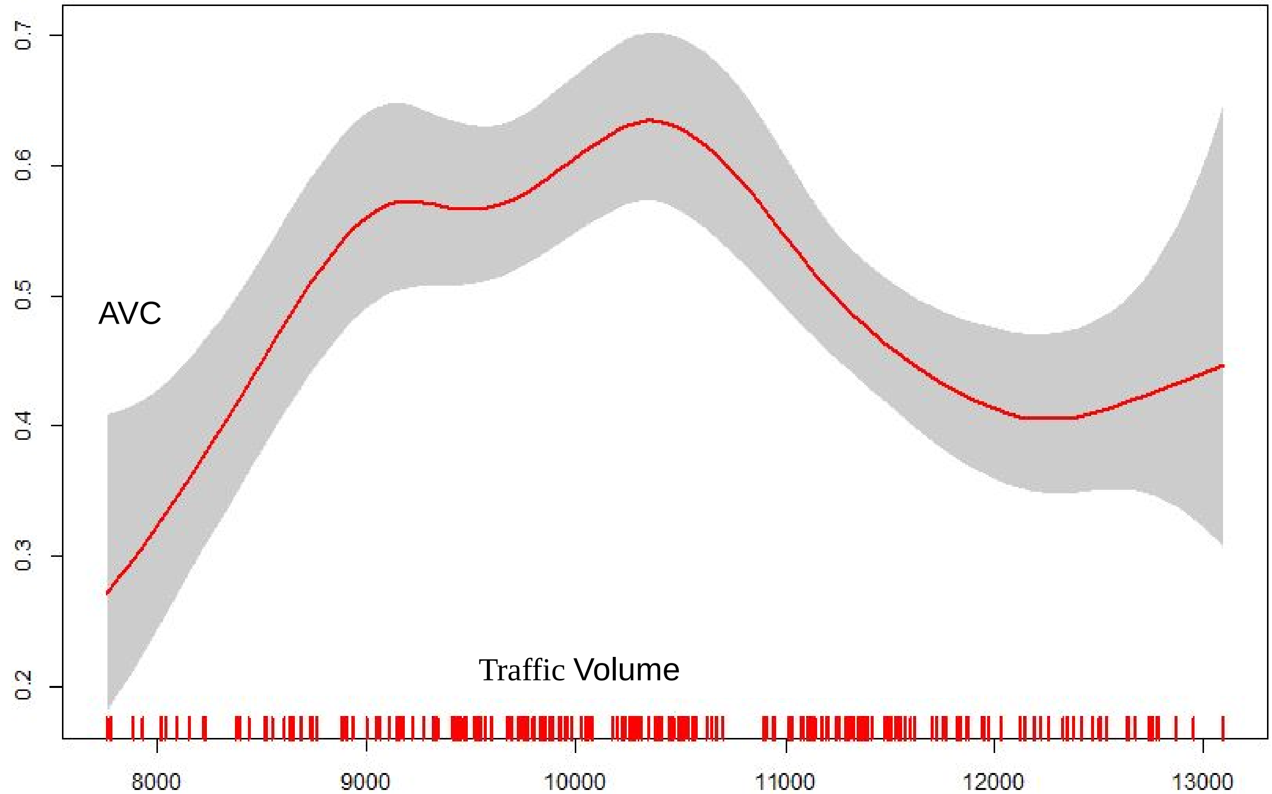

Figure 2. Effect of Traffic Volume on AVC, Pre-Construction.

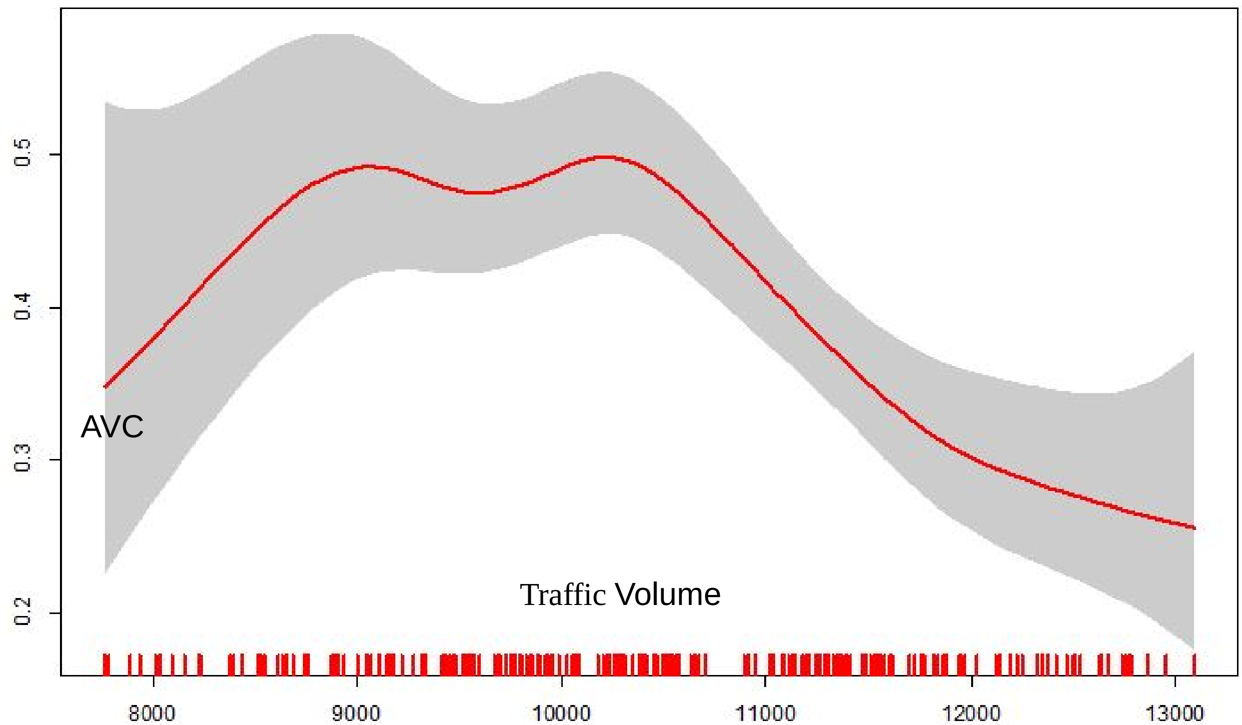

Figure 3. Effect of Traffic Volume on AVC Pre-Construction with Control of Spatial and Temporal Variations.

6. Relationships between AVC Numbers and Wildlife Crossing Structures over Time and Space, Kernel Density Analysis

Ms. Gunson conducted an updated Kernel Density Analysis that indicates AVC numbers over time and space (Figure 4). This updated KDA includes AVC data from 2012. Wildlife crossing structure type, location, date installed, wildlife fencing, and the names of key areas with high AVC concentrations are indicated. AVC decreased in 2012 from mp 60 to mp 67 compared to 2011. AVC increased in 2012 near mile posts 58 and 82. This analysis will continue.

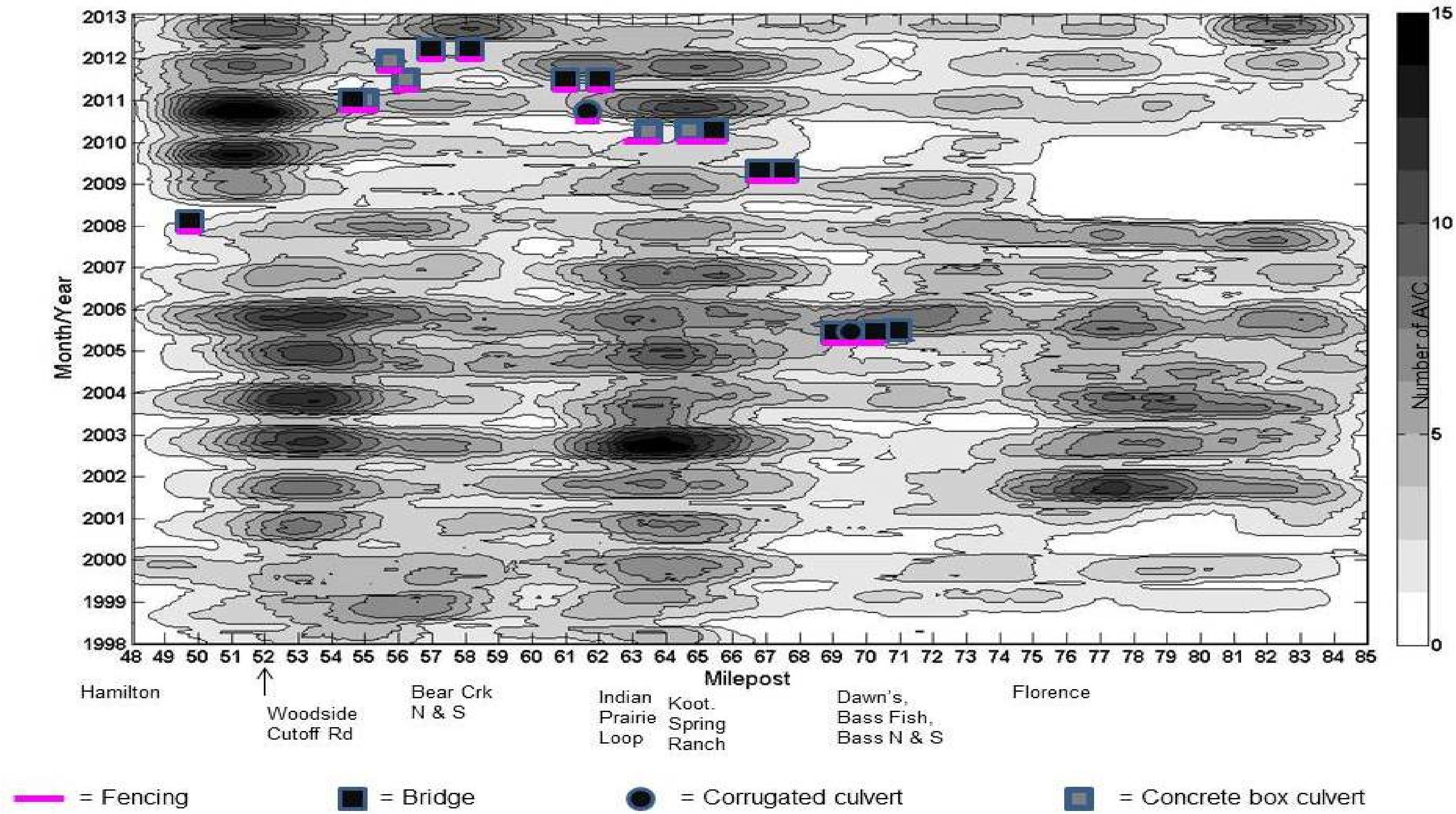

Figure 4. Kernel Density Analysis of AVC carcass data, US 93 South, mp 48 through 85, 1998 to 2013. Darker spots reflect higher carcass counts at specific mile posts. Wildlife crossing structure type,

location, date installed, and wildlife fencing are indicated. Wildlife crossing structure icons are not to scale of graph.

Major Task Progress

Task	Description	Estimated Span of calendar years Estimated after kickoff	Cost	Total billed to date	Percentage complete: based on percentage complete & billed this report as a % of original budget
1	Task 1 Purchase equipment	Oct 1, 08 - Aug 31, 09	$49,650	48,706	98%
2	Task 2 Install equipment…	Oct 9, 08 – Aug 31, 09	6,300	6,300	100%
3	Task 3 Monitor wildlife movement	Nov 1 08 – May 1, 09, 6 months	18,105	18,105	100%
4	Task 4 Obtain & analyze current a-v-c	Fall, 08 - Aug 31, 09	8,520	8,520	100 %
5	Task 5 Hold public meeting	Summer 09	Not applicable	Not applicable	Not applicable
6	Task 6 Create a-v-c prediction models	Spring/ Summer/ Fall 09	9,880	3,341	34%
7	Task 7 Monitor wildlife movement	May 1, 09- April 30 ‘10 = 12 months	41,810	41,810	100%
8	Task 8 Create Interim Report	Aug 09	3,720	3,720	100%
9	Task 9 Hold public meeting	Summer ‘10	2,760	2,760	100%
10	Task 10 Monitor wildlife movement	May 1 10 – April 30 ’11 = 12 months	40,560	40,560	100%
11	Task 11 Create Interim Report	Jan 1 ’10- Dec 31 ‘10	3,720	3,720	100%

Task	Description	Estimated Span of calendar years Estimated after kickoff	Cost	Total billed to date	Percentage complete: based on percentage complete & billed this report as a % of original budget
12	Task 12 Analyze pre-construction data	July '09 – June '10	13,360	6,496	49%
13	Task 13 Reinstall Equipment	June '10 – July '11	2,760	2,760	100%
14	Task 14 Monitor Wildlife Movement	May '11 – April '30 12	40,560	40,560	100%
15	Task 15 Create Interim Report	Jan 1 '11 – Dec 31 '11	3,720	3,720	100%
16	Task 16 Analyze pre-construction data & compare to predicted	June 1 '12 – Dec 31 '13	14,800	0	0
17	Task 17 Hold public meeting- Changed to re-install cameras	2012	3,690	3,690	100%
18	Task 18 Monitor wildlife movement	May 1, 2012- April 30, 2013	40,560	37,184	92%
19	Task 19 Create Interim Report	Jan 1 2012 – Dec 31 2012	3,720	3,720	100%
20	Task 20 Hold public meeting	2013	2,760	2,760	100%
21	Task 21 Monitor wildlife movement	May 1, 2013- April 30, 2014	40,560	0	0
22	Task 22 Create Interim Report	Jan 1 2013 – Dec 31	2,080	0	0

Task	Description	Estimated Span of calendar years Estimated after kickoff	Cost	Total billed to date	Percentage complete: based on percentage complete & billed this report as a % of original budget
		2013			
23	Task 23 Hold public meeting	2014	2,760	na	na
24	Task 24 Monitor wildlife movement	May 1, 2014- April 30, 2015	40,560	0	0
25	Task 25 Create Interim Report	Jan 1 2014 – Dec 31 2014	2,080	0	0
26	Task 26 Analyze avc data and compare results with expected	2014 - June 30, 2015	18,800	0	0
27	Task 27 Hold public meeting	2015	2,760	na	na
28	Task 28 Submit draft final report	June 30 2015	16,520	0	0
29	Task 29 Meet with MDT officials	Summer 2015	3,680	0	0
30	Task 30 Submit final report	Sept 30 2015	27,040	0	0
	Total		467,795	278,428	59%

* na = not applicable

Appendix A.

Spatial-Temporal Modeling of Animal-Vehicle Collisions on HWY 93 South:

Preliminary Pre-Construction Generalized Additive Model Results

Prepared by Dr. Mark Greenwood
Department of Mathematical Sciences
Montana State University

Data:

This analysis combines monthly animal vehicle collision (avc) carcass data, which only included white-tailed deer, along US HWY 93 South from mile post 48 to 85 from 2000 to 2010 during periods of pre-construction. This includes 4,547 month-mile post combinations in the pre-construction portion of the data set with 1,381 that were not and so were not considered in these analyses. Information on monthly highway traffic volumes from A-47 at reference post 72.5 and A-56 at reference post 50.8 are used to explain variability in the monthly counts at each milepost due to variability in traffic volume. Missing traffic observations were imputed using seasonal autoregressive models discussed in a separate report. The monthly AVC carcass counts at each mile post ranged from zero to seven with a mean of 0.474. The monthly mean per mile being so close to zero suggests the need for modeling the responses using a Poisson distribution as opposed to some sort of normal approximation. There are some indications of seasonality in AVCs and traffic across each year.

Methods:

Animal vehicle collisions (AVCs) generally follow a count process and are often usefully and most appropriately modeled by Poisson distribution models, typically in a generalized linear model (GLM) framework. GLMs allow the responses (Counts) to be modeled using a Poisson distribution whose mean (μ) is modeled via the log-link function, log(μ), as a linear function of predictor variables. For example, a Poisson model for AVCs can be defined as AVC_i is modeled as following a Poisson distribution with mean μ_I, where $\log(\mu_i)=\beta_0 + x_{1i}\beta_1$. This provides a parametric, linear function of x_i to explain variation in the log-mean counts. When considering counts referenced both in space (mile-marker) and time (year and month of observation), those same variables become useful predictors of the responses. In future models, the time-space prediction of the responses can be corrected by accounting for the Pre/Post status of each observation. In this report, only the pre-construction observations are considered. In GLMs, it is possible to adjust the space-time surface for traffic volumes and the number of deer in the vicinity. Traffic volumes are available on a monthly basis but are not at the milepost resolution of the AVCs. Similarly, when deer density is incorporated into the models, it will be available at the yearly scale, which will be considered in future work. It is important to consider the scale of variation of predictor variables, because they can only explain variation at the level that they vary – yearly data can explain year to year variation in responses while spatially-varying predictors can explain differences between the locations. By using the traffic counter closest to the each milepost, some differences between the upper and lower stretches of the study area can be explained by differences in traffic volume. Generally, the traffic volume will explain month to month variation in the AVCs and the deer density information will explain year to year variation. Based on the estimated models, a predicted mean spatial-temporal trend surface can be created where the deer population and traffic are held constant over time.

Generalized additive models (GAMs, Wood, 2006) extend GLMs to allow smooth, nonparametric functions as well as regular, parametric model components to explain the count responses within a Poisson framework. The notation $s(x_i)$ is used to represent a nonparametric smooth function of an explanatory variable, in contrast to $x_{1i}\beta_1$, which represents a linear function of the explanatory variable x_i. Functions of two variables can also be defined as $s(x_{1i}, x_{2i})$ with the GAM model of $\log(\mu_i)=\beta_0 + s(x_{1i}, x_{2i})$. Different models for these types of model components are possible, but a good option is to use tensor products of thin-plate B-splines, which are recommended when variables with different scales are combined in this fashion. This is implemented using the `gam` function from the statistical software R (R Project Core Team, 2013) package mgcv and discussed in detail in Wood (2006). This provides an efficient and flexible surface to fit a spatial-temporal trend surface that explains both spatial and temporal variation in the log-scale mean counts. The estimated mean log-counts can be exponentiated to provide estimates on the original count scale. The real strength of GAMs is that it is then possible to incorporate other variables, either parametrically or nonparametrically, into the model which is how pre/post construction will be treated as well as deer population and traffic counts. The nonparametric effects can be tested for inclusion in the model and are partially described by the effective degrees of freedom (*edf*) and mostly by plotting the fitted functions. The *edf* quantify the amount of information used up by the model component from the total information available in the data set. The estimation process in fitting the GAMs starts with an initial assumption of the maximal degrees of freedom for each model component and then a smoothing/estimation process to obtain the final estimated model component and *edf*. Higher *edf* correspond to more complex model components with 1 *edf* corresponding to linear component.

The standard Poisson GLMs and GAMs assume that the observations (avc) are independent. When observations are dependent, the estimates of model and component precision, such as standard errors, can be underestimated. A simple method to allow standard errors to be inflated possibly due to correlation of observations is based on “Quasi-Poisson” methods. This estimates an additional correction factor to potentially correct for un-modeled correlation between observations. It provides more conservative inferences for effects to include this correction. An overdispersion estimate quantifies the amount of increase required. This approach is used for modeling the spatial-temporal counts since there are likely correlations between neighboring avcs in time and/or space.

There are two main benefits to using GAMs for modeling avc carcasses in contrast to kernel density estimation. First, it is possible to incorporate a variety of effects in the model, allowing for the variability in AVCs due to traffic volume and eventually deer density to be explored while continuing to model the spatial-temporal trend in the counts. It is then possible to explore the model-based predicted mean trend surface as a function of space and time while holding the traffic volume constant. Note that the traffic volume is held constant at its mean after the model is estimated in order to understand the visualize the other effect if the traffic volume had not varied over time. The nonlinearity in the log-link in the model means that changing the overall mean will impact the form of the predicted mean on the count scale, enhancing variation in effects as the overall mean is increased. Second, by modeling the mean of the Poisson process, model results match the count properties of AVCs and automatically account for changing variation in the responses as a function of the mean. All models employ the quasi-poisson method to potentially account for correlation between observations not directly accounted for in the model.

Results:

As a simpler introduction to GAMs and the different variables available here to explain AVCs, the relationship between AVCs and the time, space, and traffic volume are considered individually. These effects will be combined with the interaction between space and time in the more complicated models below. Each effect was statistically significant in four quasi-Poisson GAMs with the traffic volume effect being the closest to linear with 5.3 *edf* and the year being most nonlinear with 39 *edf*. The individual variables used in each of the four models seem to explain some variation in the AVCs although the variability of the Poisson count process around the mean is also quite noticeable in the plots. Figure 1 contains "jittered" counts, which is a graphical devise to add a small amount of random variation to the discrete counts to allow visualization of all the counts at a particular value. Panel (i) in Figure 1 shows the seasonal variation in the AVCs that could be attributed to the seasonal variation in traffic flows, the seasonal variation in animal movements, seasonal variation in driving conditions or to some combination of those factors. The higher AVC rates seem to be associated with fall-winter months when the traffic volumes tend to be lowest (see Figure 1 in report concerning imputation of missing traffic volumes). The seasonal pattern emerges in panel (ii) which considered the time trend of the counts but also may show some variation over time in the seasonal trend in the counts. There also appears to be a slight increasing trend that ends in 2006, then decreases slightly toward the end of the study. Considering the variation as a function of mile post, there are a few locations that seemed to have higher average AVCs than others. Finally, the traffic volume seems to show a slight increase in AVCs as the traffic volumes increase and then a decrease as the traffic volumes attain their highest levels. Figure 2 displays this effect in more detail.

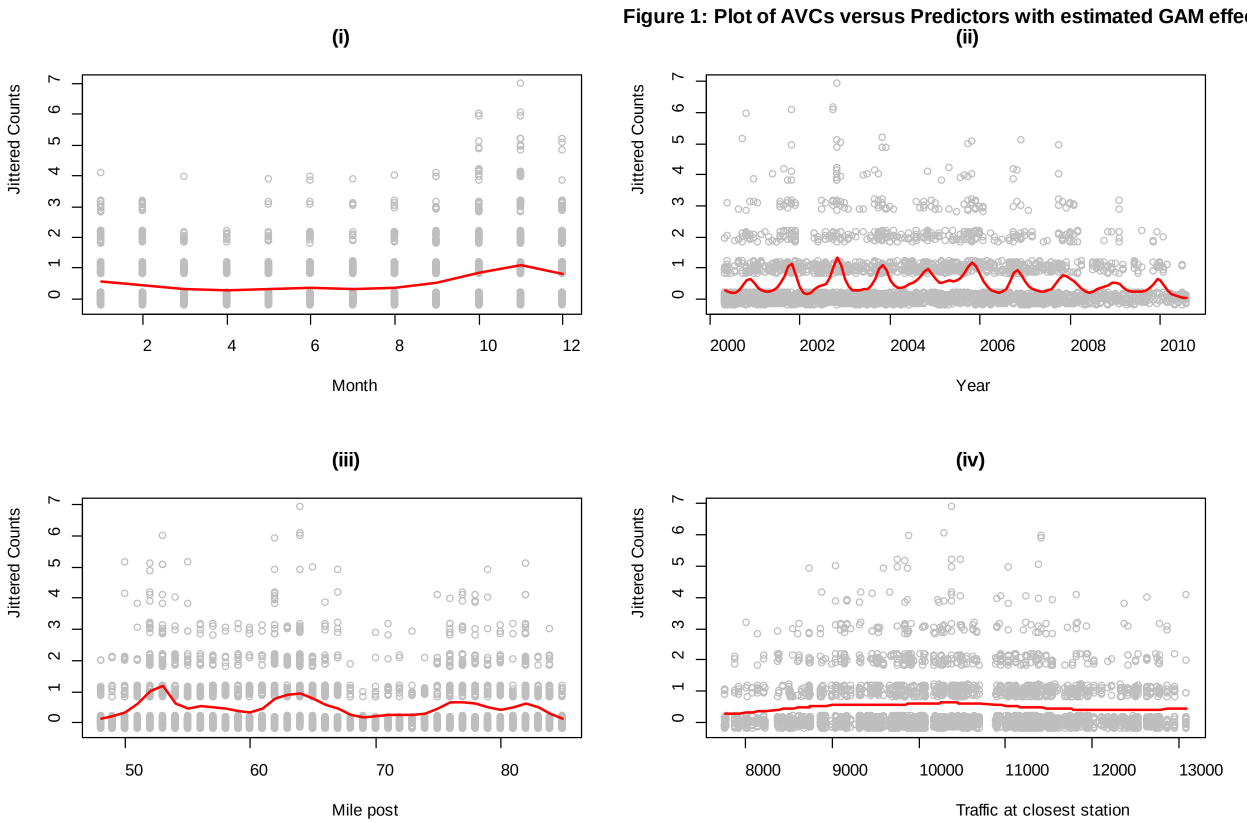

Figure 1. Plots of AVCs versus month (i), year (ii), mile post (iii), and traffic volume at closest station (iv). Red lines provide estimated GAM smooth effects based on models fit with each variable displayed.

The effect of traffic volume takes on a slightly unexpected pattern as displayed in Figure 2. It may be suggesting a barrier effect at higher volumes, but this could also be explained because of the strong seasonal fluctuation in traffic being related to animal movements at various times of year.

Figure 2. Plot of estimate traffic volume effect

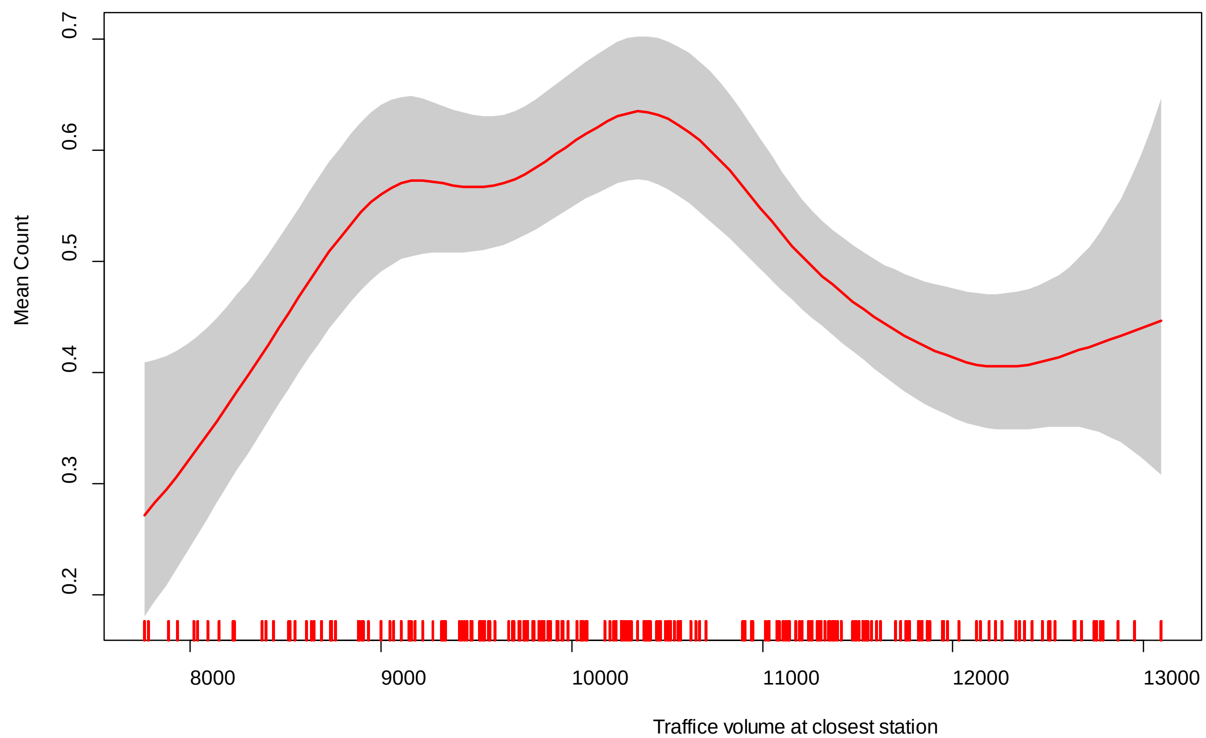

Figure 2. Plot of the estimated mean count per mile per month based on a model that includes only a traffic volume effect.

Next, a model is considered that contains the spatial and temporal effects and an interaction between them using the tensor product method. Initially, a quasi-Poisson GAM was fit. The estimated spatial-temporal model on the count is displayed in Figure 3. The tensor-product bivariate model component was initialized with 648 degrees of freedom (36 for the monthly time by 18 for the mileposts). The model component uses 304 *edf* and has a p-value<0.0001. The model generates an overdispersion estimate of 0.902 which actually suggests slightly less variability in the responses than expected based on the Poisson, called “underdispersion”. This could be due to negative correlation in responses (less likely) or just a very good fit to the observed counts based on the nonparametric model component (more likely). A more conservative option in this situation is then to use a regular Poisson model and these results are displayed in Figure 3. There appears to be certain areas in some years where there are increases in the average AVC rate. In some areas there is more limited variation in the results. There continues to be some evidence of seasonality in the results with the winter parts of many years in many locations involving increased AVC rates.

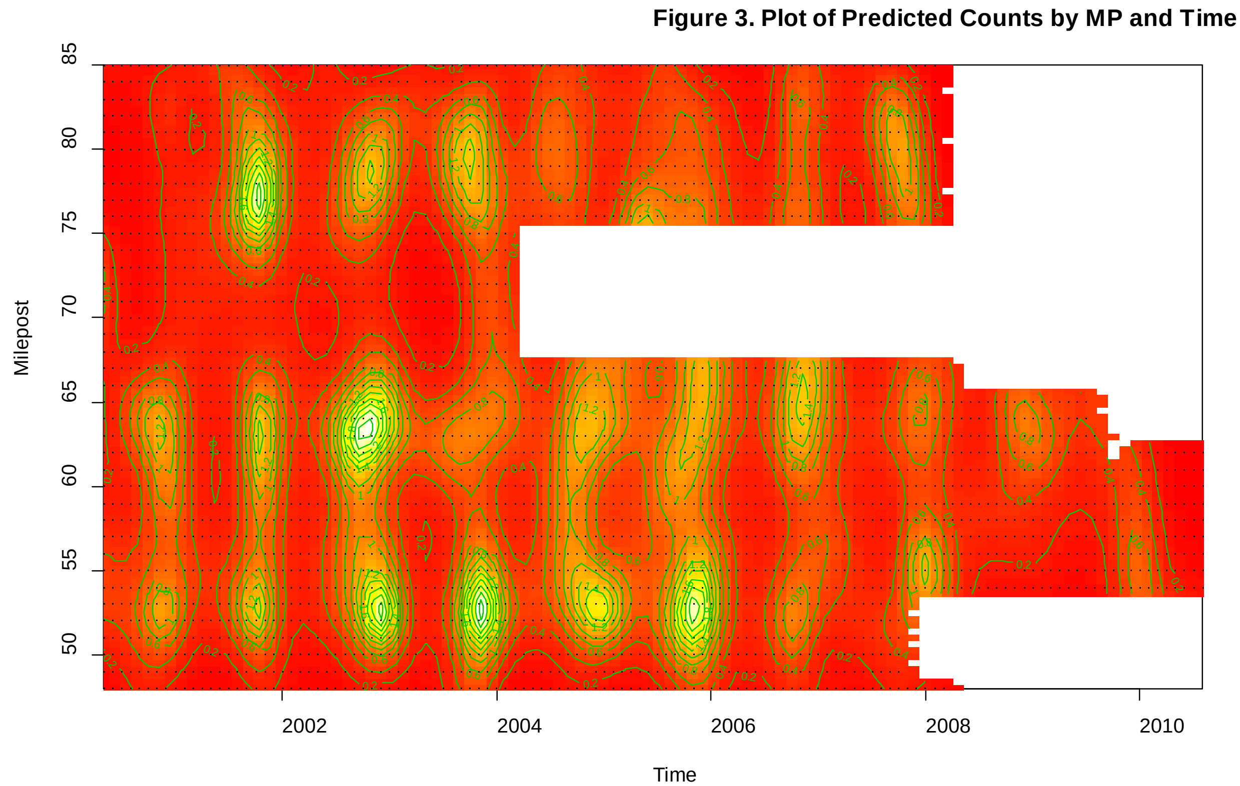

Figure 3. Plot of the estimated counts based on the spatial-temporal GAM model. White areas were not modeled because construction began in those locations, red is close to 0, with lighter yellow into white peaks suggesting higher count areas with a peak predicted mean of 2 AVCs per mile per month.

Since each mile post is observed through time, it is possible to slice through this estimated count surface at each milepost to provide estimated count time-courses based on the spatial-temporal model. Figure 4 shows the different time trajectories. The seasonal pattern in the counts becomes more prominent in this display. This also allows more detailed exploration of some mileposts of interest.

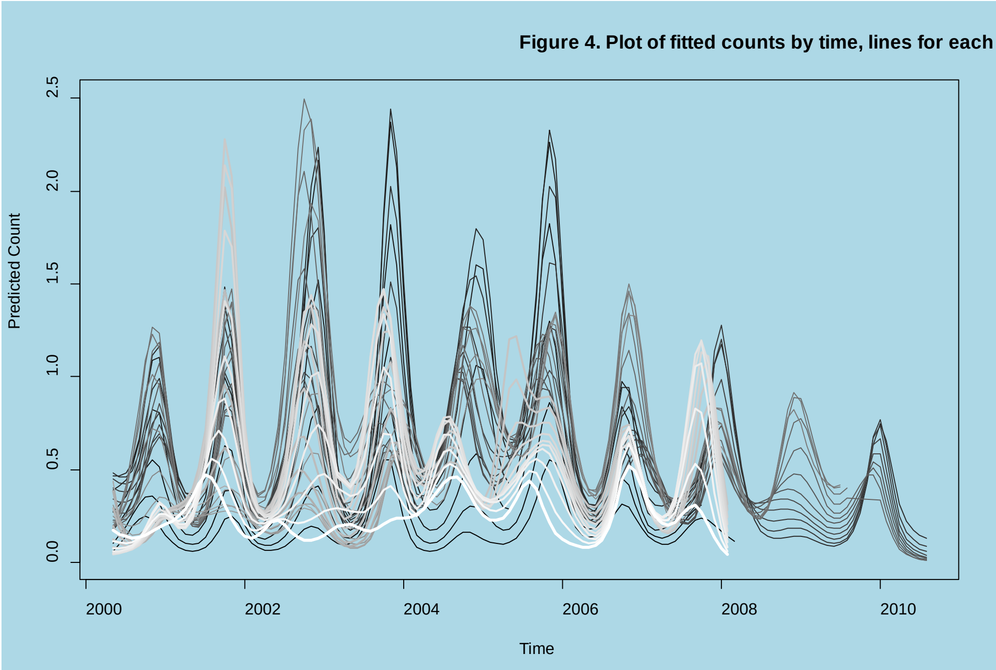

Figure 4. Plot of the estimated mean counts based on the GAM model. Each line corresponds to a different milepost with lighter shades and wider lines corresponding to the larger mileposts in the study area.

The time by location effect in this model ignores the variation in traffic volume which may help to explain the variation in AVCs. The same spatial-temporal effect is included in a GAM with the addition of a traffic volume effect, te(space,time)+s(traffic volume). Both effects a significant in the models with the spatial temporal effect using 190 *edf* (p-value<0.0001) and the traffic volume effect using 4.7 *edf* (p-value=0.0017). Figure 5 displays the predicted mean counts for the spatial-temporal effect, which is a little less variable over time and space when traffic volume is accounted for. The predictions also tend to have a higher magnitude because Figure 5 displays the estimated spatial-temporal results holding the traffic volume at the average for the data set. In Figure 3, the traffic volume was not included in the model so the estimated spatial-temporal effect was not controlled for traffic volume variation. These models include traffic volume, with the comparison of Figures 4 and 7 useful for assessing the impacts of correcting for traffic volume on the predicted mean counts over time at each milepost. The peaks are more pronounced in Figure 7 because they are estimates at the average for the data set with a traffic volume of 10,500 cars per month. This happens to be a traffic volume with one of the highest avc rates, as seen in Figure 6. The individual time courses for each mile post are slightly less variable with the inclusion of the traffic volume effect in the model.

Figure 6 shows the estimated effect of the traffic volume on the counts, controlling for the average spatial-temporal effect. The effect has a more pronounced decrease for the higher traffic volumes and even suggest little effect of changing the traffic volume between 9,000 and 10,000 cars per month. Similar effects were found using only one of the two traffic measurements as representative of traffic volume for the entire study area for each month although A-56 provided a more enhanced increase around a traffic volume of 10,000 cars/month and A-47 was a more smoothed curve using fewer *edf*. Both effects were significant in their models and the spatial-temporal effect was similar to the results presented here.

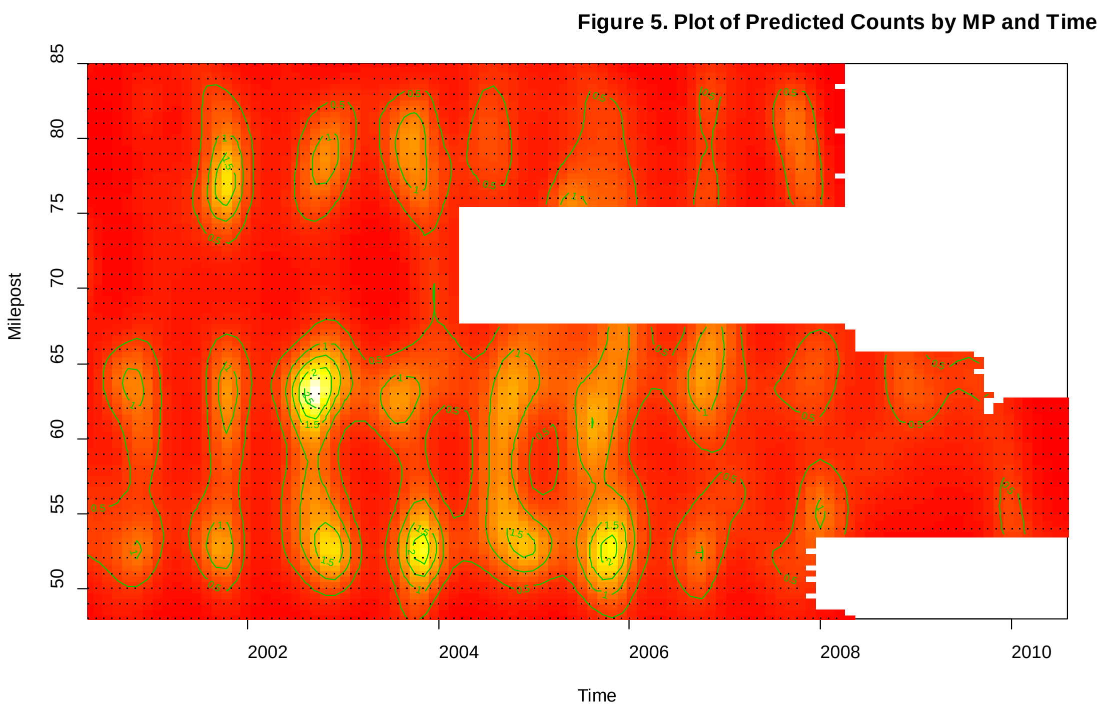

Figure 5. Plot of the estimated mean counts based on the spatial-temporal GAM that includes traffic volume held constant at its average for the data set. Peak predicted values were close to 3.5 AVCs per mile per month.

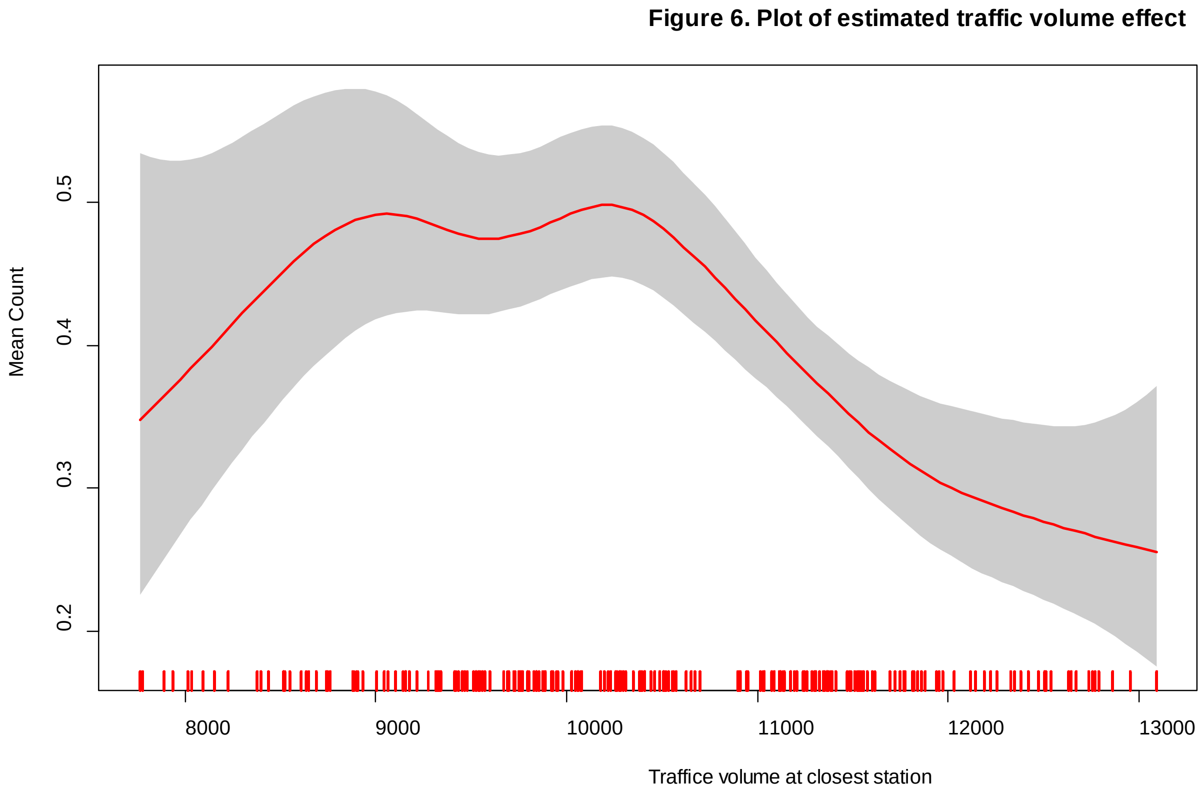

Figure 6. Estimate mean counts based on the traffic volume effect in model that incorporates a spatial-temporal effect.

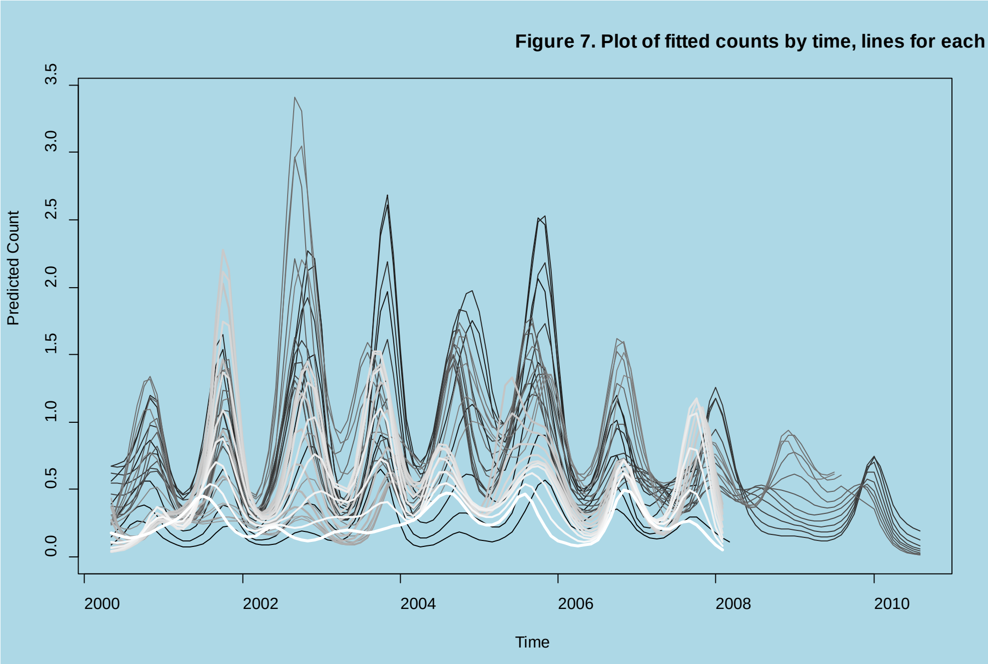

Figure 7. Plot of the estimated counts based on the GAM model that includes a spatial-temporal and traffic volume effect. Each line corresponds to a different milepost with lighter shades and wider lines corresponding to the larger mileposts in the study area, based on holding the traffic volume at its average for the data set.

Conclusions:

The avcs can be successfully modeled using the location and time of the occurrence using GAM models. The spatial-temporal effect on AVC occurrence can be corrected for traffic volume and provides slightly different results in terms of variability of the estimated mean counts than if the traffic effect is not included in the model. The ability to estimate the effect of traffic volume is also interesting. Often effects like the traffic volume are incorporated into GAMs using an “offset” (see Agresti, 2007, for example). The typical assumption would be that the count response variable has a one-to-one relationship with the rate variable. In the models, it is usually included using the log of the offset is included in the model and its coefficient is fixed at 1. In this situation, the natural log of the monthly volume of vehicle traffic and eventually deer density can be used in this fashion. This would scale the log-mean of the counts linearly with the log-traffic volume or models the log-rate responses (here AVC per car) with the other predictors in the model. This corrects the responses for the variable used in the offset. Initial exploratory modeling suggested that the relationship between traffic volume was not positive or even monotonic, so this offset style of adjustment for this effect was not considered in the model. The traffic volume could be log-transformed to use in the model and it would impact the form the estimated effect, but it would still be non-linear. Deer density will be explored in a similar fashion in future models.

Next steps:

The integration of deer population estimates will provide the ability to adjust the estimated spatial-temporal trend for changes in the estimated number of deer in the area from year to year along with explaining variability due to changes in traffic volume. When Pre/Post construction changes are of interest in the future, both traffic volume and deer population effects can be incorporated in a more comprehensive spatial-temporal analysis of the AVC data set.

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