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RELATIONSHIPS BETWEEN LIGHTING AND ANIMAL-VEHICLE COLLISIONS

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Relationships between Lighting and Animal-Vehicle Collisions

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16. Abstract

In 1990, there were 106 traffic fatalities in the United States in crashes for which a collision with an animal was the first harmful event; by 2007 this level had risen to 223—a 110% increase. Analyses of annual trends suggest that this increase cannot be fully explained by increases in vehicle miles travelled, nor by changes in the general fatal and nonfatal crash rates. Animal-vehicle collisions (AVCs) represent a small but increasing share of the overall crash picture.

Daily and seasonal AVC crash trends were examined and appear to follow the activity patterns of the U.S. deer population. This involves peaks in the hourly crash levels around dawn and dusk, and a seasonal peak during October and November. AVC crash distributions are presented by state.

The odds of an AVC in darkness were modeled as a function of posted speed limit in a series of logistic regressions. Higher posted speeds were associated with proportionally greater crash risk in darkness. The effect is observed for fatal collisions compiled from the Fatality Analysis Reporting System (FARS), and for injury and property-damage-only (PDO) crashes compiled from Michigan crash datasets. One implication of the effect is that countermeasures designed to extend a driver's preview time for animals, such as headlighting and night-vision systems may help reduce the risk of AVCs.

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Introduction

Recent fatal crash statistics indicate that approximately 200 persons are killed annually on roadways as a consequence of animal-vehicle collisions (AVCs) (averaged from FARS 2002-2007). The Centers for Disease Control and Prevention estimated that 26,647 motor vehicle occupants were involved in crashes with animals in 2001-2002 that required treatment for nonfatal injuries (Centers for Disease Control, 2004). The Insurance Institute for Highway Safety estimates that there are 1.5 million deer-vehicle crashes in the United States each year, with a cost of $1.1 billion in vehicle damages alone (Insurance Institute for Highway Safety, 2004). AVCs are clearly a significant roadway hazard, and great effort has been expended investigating measures to mitigate the extensive damage.

Two broad classes of mitigation approaches have been taken. One attempts to reduce the exposure of animals (primarily deer) to roadway traffic either by constructing physical barriers or by using animal behavioral inducements. Physical barriers include use of fencing along strategic sections of roadway to restrict roadway access, construction of underpasses or overpasses to provide protected road-crossing paths, and reduction in the size of the herd in the roadway environs. Animal behavioral measures include use of roadside reflectors, deer whistles, and the scent of predators around roadways to induce animals to stay away. Although less expensive, these latter methods appear to be of limited effectiveness (Hedlund, Curtis, Curtis, & Williams, 2004).

The other approach is intended to influence driver behavior by providing some form of warning or advisory information to better prepare drivers to avoid a collision with an animal in the road. Methods include placement of static road signs at locations where animals frequently cross, use of active signs that detect and signal the presence of animals, seasonal educational campaigns to advise drivers about periods of elevated risk, clearing densely wooded areas along roadsides to provide greater preview area to detect animals, use of restricted speed limits in problem areas, installation of roadway lighting, and use of in-vehicle night vision systems to assist detection at night (see Hedlund et al., 2004 for a thorough discussion of the effectiveness of these countermeasures). Most of these countermeasures depend on the assumption that driver behavior can directly influence crash risk. That is, an AVC may be avoided with adequate prior warning. Indeed, it is probable that reduced speed could mitigate the severity of damage resulting from an AVC. Thus, *fatal* AVCs may be avoided by the simple reduction of impact forces. However, it is also clear that many measures seek to identify the animal's location for the driver so that a collision might be avoided entirely. If AVCs result from situations in which the animal darts into the roadway, it may well be the case that such collisions *cannot* be avoided because drivers do not have sufficient time to detect the animal and make an effective avoidance maneuver. Indeed, the evidence about the usefulness of a preview is either scant or indicates no effect. For example, in one of the few studies of the use of roadway lighting to mitigate deer-vehicle collisions, there was no observed reduction in deer-vehicle accidents when lighting was present (Reed & Woodard, 1981). Few other studies have attempted to address this question directly.

This report examines some of the characteristics of AVCs. First, crash trends in the United States from 1990 to 2007 are examined to determine how the animal collision picture is developing. Next, diurnal and seasonal trends are examined to obtain a general view of how AVC risk varies over time. This is followed by a geographic breakdown of AVCs by state to describe how risk varies within the United States. Finally, the interaction of vehicle speed and ambient light is examined to determine whether they interact in a way that suggests vehicle lighting and driver vision can influence crash avoidance.

Crash Analyses

Overview

The following analyses examine characteristics of fatal AVCs in the United States between 1990 and 2007. Nonfatal AVCs were also examined using crash data from Michigan 2004-2009 and estimates provided by the General Estimate System (GES) 1991-2007 datasets.

Annual Trends 1990-2007

There are increasing trends in both fatal AVCs and in the number of fatalities involved over the 18-year period examined (shown in Figure 1). A regression analysis suggests that the increase is nearly 7 additional fatalities per year (t = 10.95, $p < .001$). The number of fatalities closely tracks the number of fatal crashes and is about 6% greater, reflecting the fact that, on average, somewhat more than one person dies in each fatal crash. Since fatality counts appear to be redundant with crash counts, they are not analyzed further in this report. Khattak (2003) previously reported a similarly increasing trend (about 5.23 crashes/year) for the years 1991 to 2000. In a related analysis, the author normalized the crash trend to annual estimates of vehicle miles traveled (VMT) and reported no change in the fatal AVC rates over the ten-year period reviewed. In the present study, a similar analysis was conducted over a longer period of time (18 years). The new results suggest that there is an increase in fatal AVCs per VMT (see Figure 2). There appears to be a rise in crash rate of about 1.3 crashes per trillion VMT per year (t=5.73, $p < .0001$; CI: .82, 1.8). Not only have there been more AVCs per year over the last two decades, but the rate of such crashes per distance driven appears to be rising.

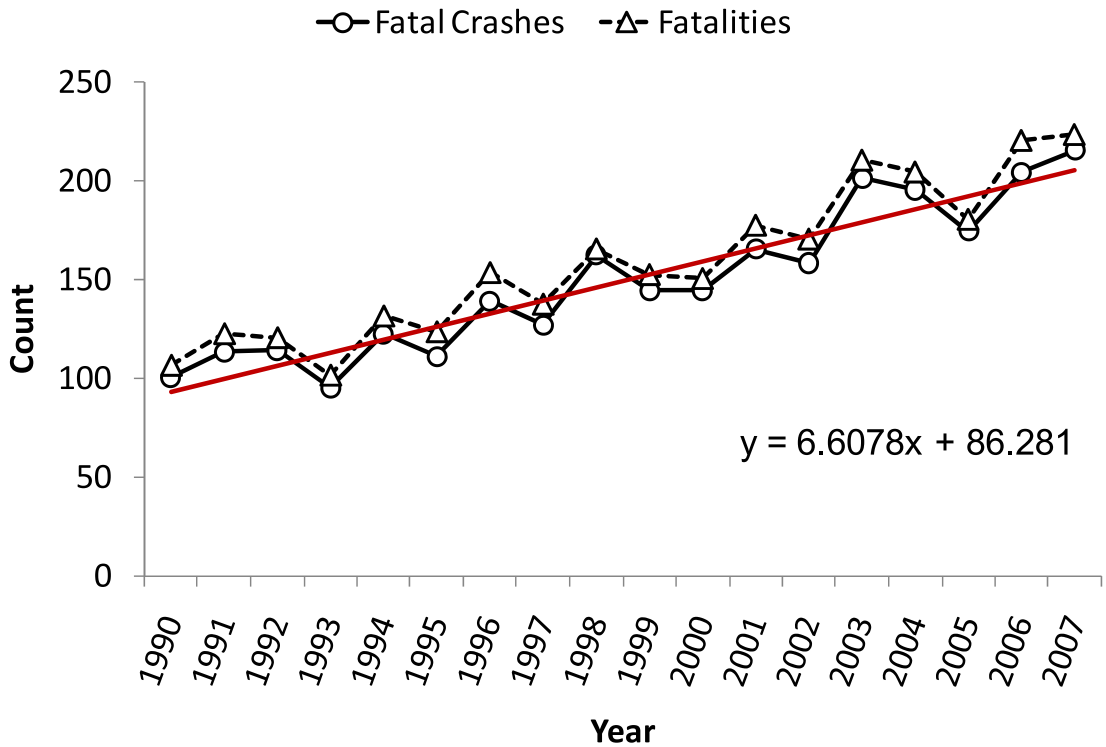

Figure 1. Fatal crash and fatality trends for animal-vehicle collisions reported by FARS 1990 to 2007.

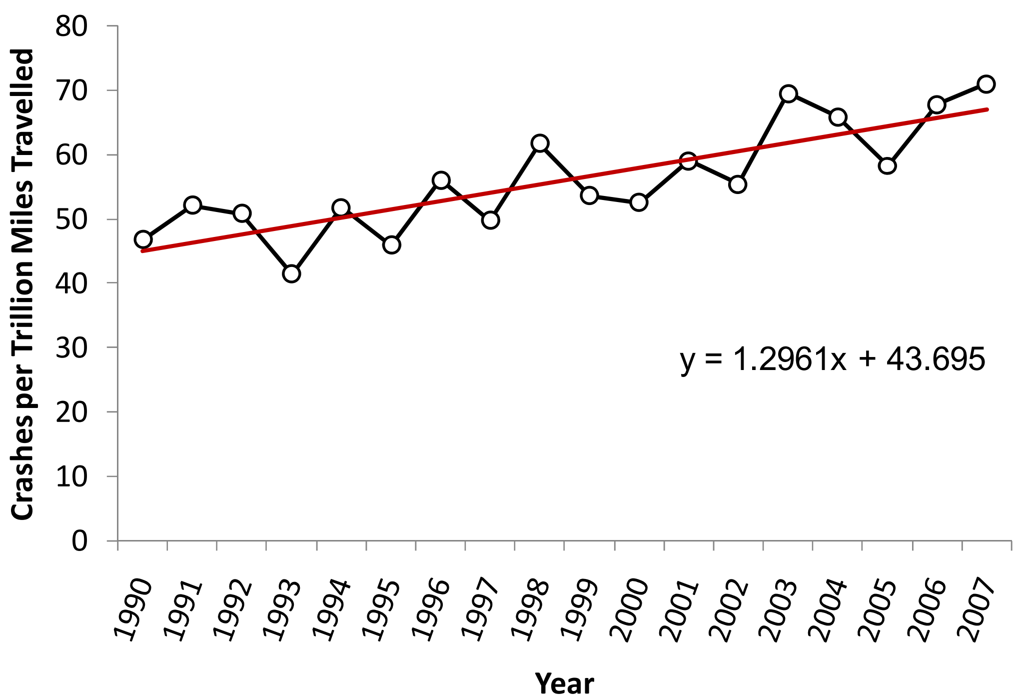

Figure 2. Fatal animal-vehicle collisions per trillion vehicle miles travelled.

An alternative way of normalizing AVC risk is to compare the year-by-year counts of AVCs to the count of all fatal crashes, estimating the percent of AVCs. This is shown in Figure 3. Again, a regression analysis suggests that there is an increasing risk of a fatal AVC of about .017% per year (t = 9.82, p < .0001). A similar analysis was also performed using the General Estimates System (GES) data over the same time period in order to include estimates of nonfatal crashes. In the analysis, the year-by-year percent of all police-reported crashes involving an AVC was examined. As in the fatal crash analyses, an increasing trend was found (t = 8.53, p < .001). This is shown in Figure 4. There is a proportional increase in the AVC share of all crashes (fatal and nonfatal) of about 0.1% per year.

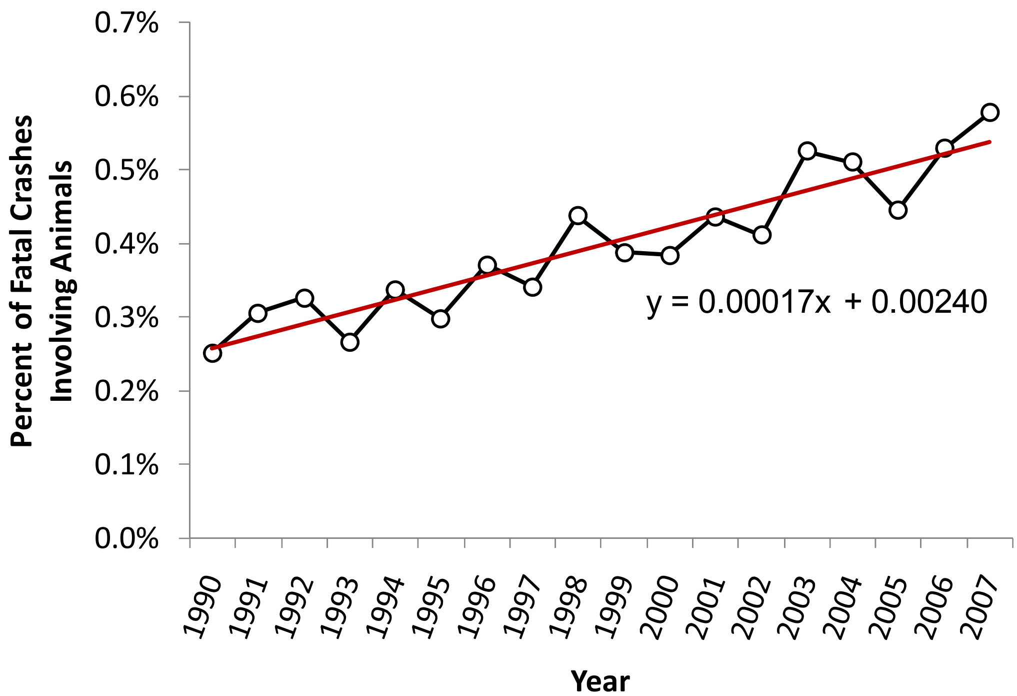

Figure 3. Percent of fatal crashes involving animal-vehicle collisions by year.

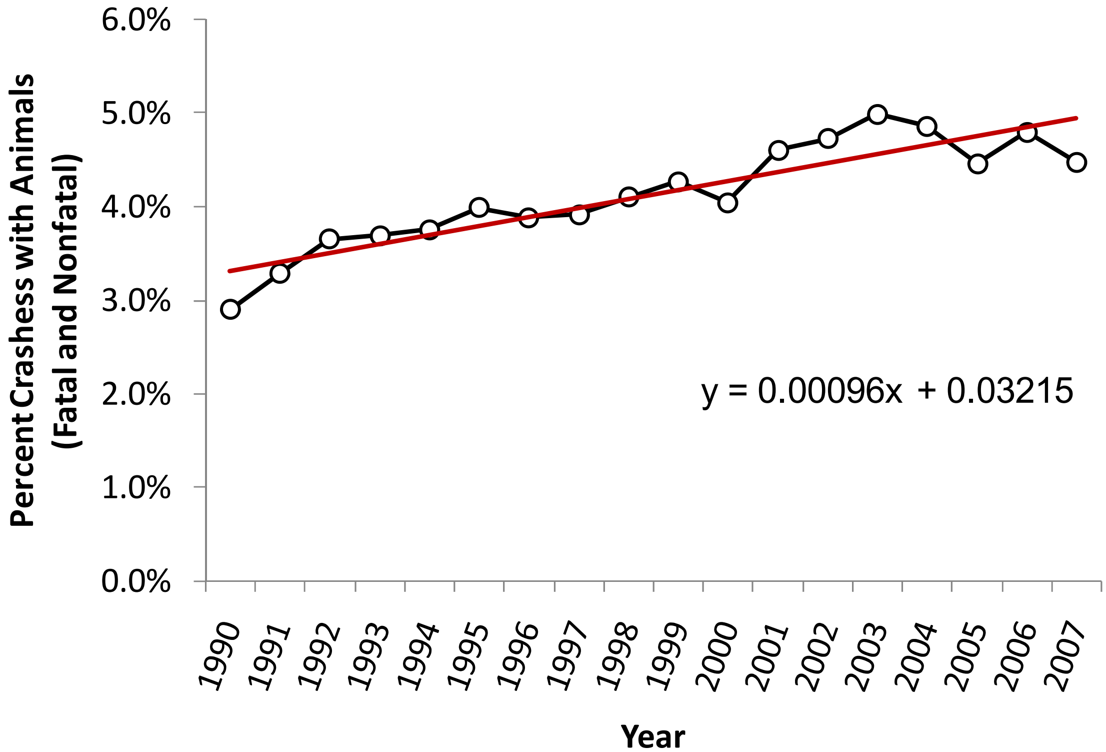

Figure 4. Estimated percent of all crashes involving a collision with an animal, from GES 1990 to 2007.

It thus appears that the increases in AVCs cannot be solely attributed to an increase in vehicle miles travelled or to a general rise in either fatal or nonfatal crashes. Instead, AVC risk appears to be increasing per vehicle mile driven. Several factors could be responsible for such an increase. For example, wildlife exposure to traffic may be increasing, perhaps because of changes in animal populations or movement patterns; animal habitats may have been changed by suburban development; or commuting patterns of drivers may have changed in ways that have increased traffic on rural roadways. This latter hypothesis, however, is not supported by FHWA statistics that partition VMT data into rural and urban components. The shift in VMT appears to be in the direction of more vehicle miles travelled in urban areas: the proportion of rural VMT was about 40% in 1990, and about 34% in 2007 (Federal Highway Administration, 2007).

Daily and Seasonal Variation in Animal-Vehicle Collisions

The frequency of AVCs varies seasonally and is likely related to variations in the exposure levels of both animals and motor vehicles. In the United States, deer appear to dominate fatal AVCs, accounting for 77% of the fatal AVCs in the three years spanning 2000-2002 (Williams & Wells, 2005). Deer are crepuscular animals—their daily peak activity levels coincide with dawn and dusk (Beier & McCullough, 1990) and they are less active in the daytime and nighttime. Deer activity levels also vary seasonally.

Seasonal activity levels among Michigan white-tailed deer have been characterized as rising in late winter through May, followed by a modest decline in June and July. As fall approaches, activity levels rise again, peaking in October and November (during mating season) and declining to their lowest point in January and February (Beier & McCullough, 1990). This pattern is also affected by seasonal variations in weather that affect population levels and the areas in which forage is available. In the deep winter of the northern states, when forage is scarce, deer activity level (and population) may decline. In the southern states such as Texas, where AVCs are also common, seasonal variation in deer activity is likewise driven by weather—specifically summer drought—which may limit the food supply, forage activity, and population. Thus, seasonal variation in deer activity levels may differ by region within the United States.

The distributions of AVCs and nonanimal collisions by hour of the day are shown in Figure 5. As noted, there appear to be two peaks in the AVC crash distribution—roughly coinciding with sunrise and sunset, the commonly reported peak periods of activity (Allen & McCullough, 1976). The AVC hourly pattern also seems to confirm reports that the highest risk occurs an hour after sunset (Haikonen & Summala, 2001), when ambient light level has significantly declined. Thus, crash risk appears to be driven by both an increase in animal exposure and a decline in ambient light levels.

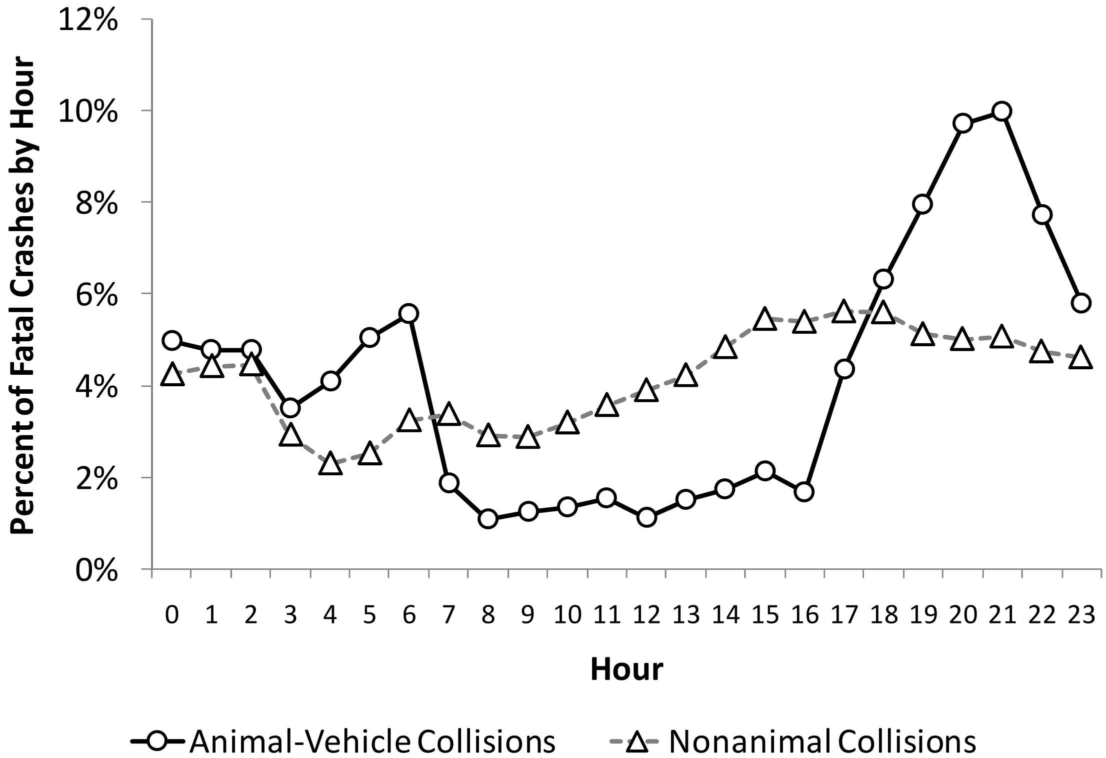

Figure 5. Percent of AVCs and nonanimal collisions occurring by each hour of the day, FARS 1990-2007.

Seasonal variation in AVCs is shown in Figure 6. This pattern mirrors the seasonal pattern of deer activity described above. It features an increase during mating season in October and November, a sharp decline through winter (December to February), and an increase in spring through summer.

In Figure 7, the joint variation by season and hour of the day is shown for all fatal AVCs in the United States from 1990 to 2007. A similar pattern is shown in Figure 8 for all AVCs in Michigan (fatal and nonfatal) averaged across 2004-2007. In both figures, there is an overall peak in the evening hours in the fall, and there are shifts in the morning and evening crash frequencies that follow the seasonal variation in sunrise and sunset.

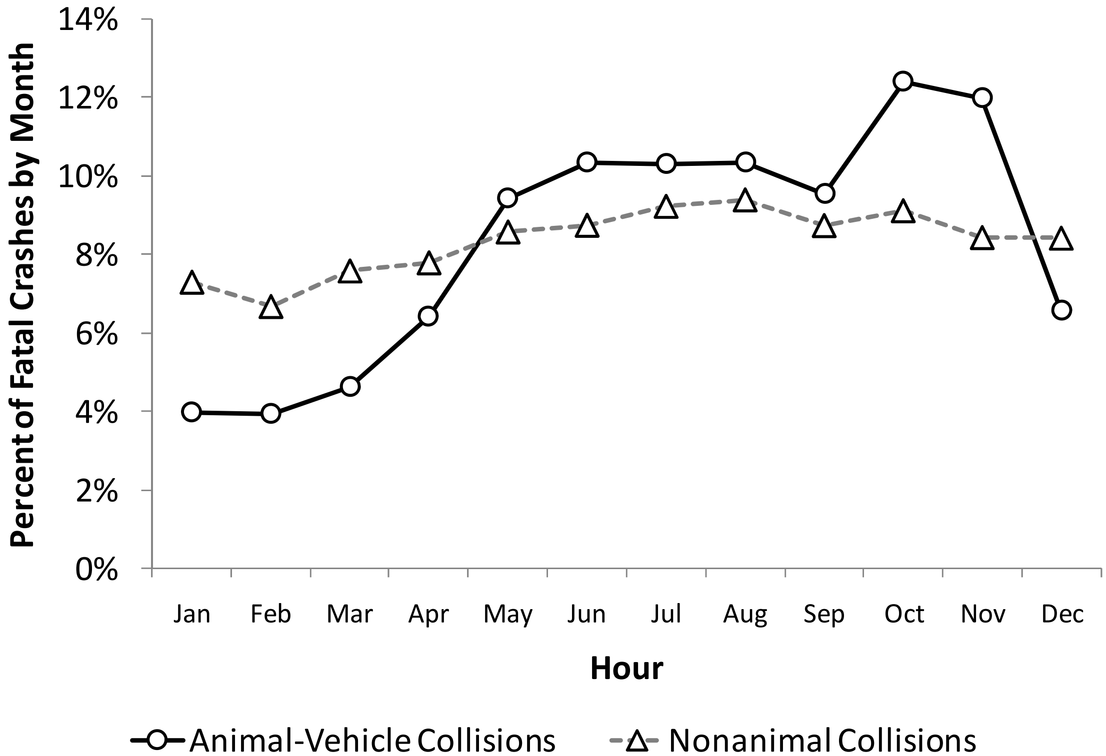

Figure 6. Seasonal variation in AVCs and nonanimal collisions, FARS 1990-2007.

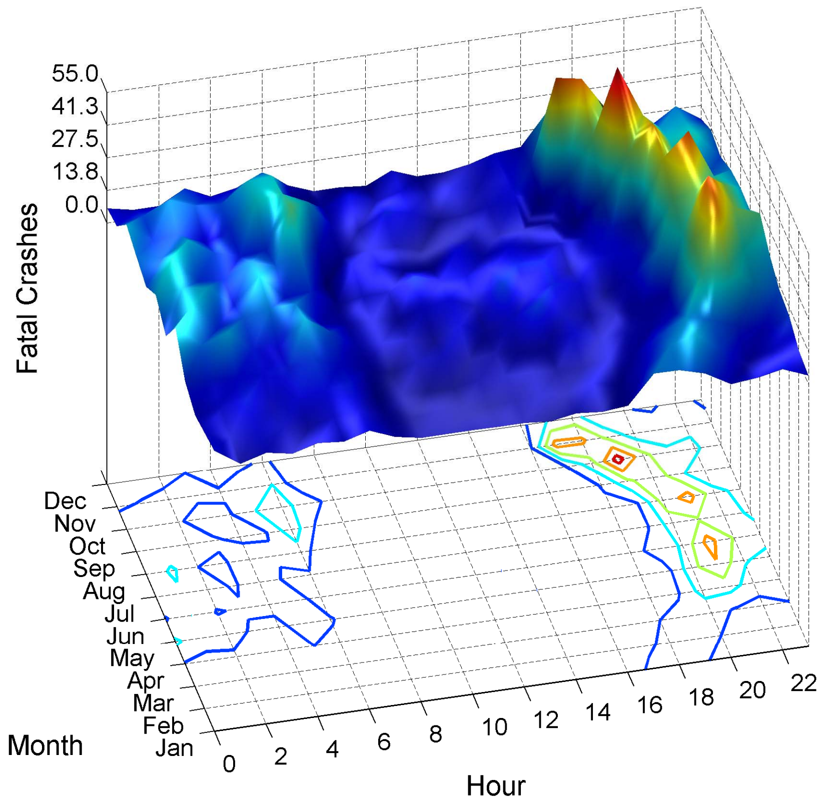

Figure 7. Trends by month and hour for fatal animal-vehicle collisions in the United States, FARS 1990-2007.

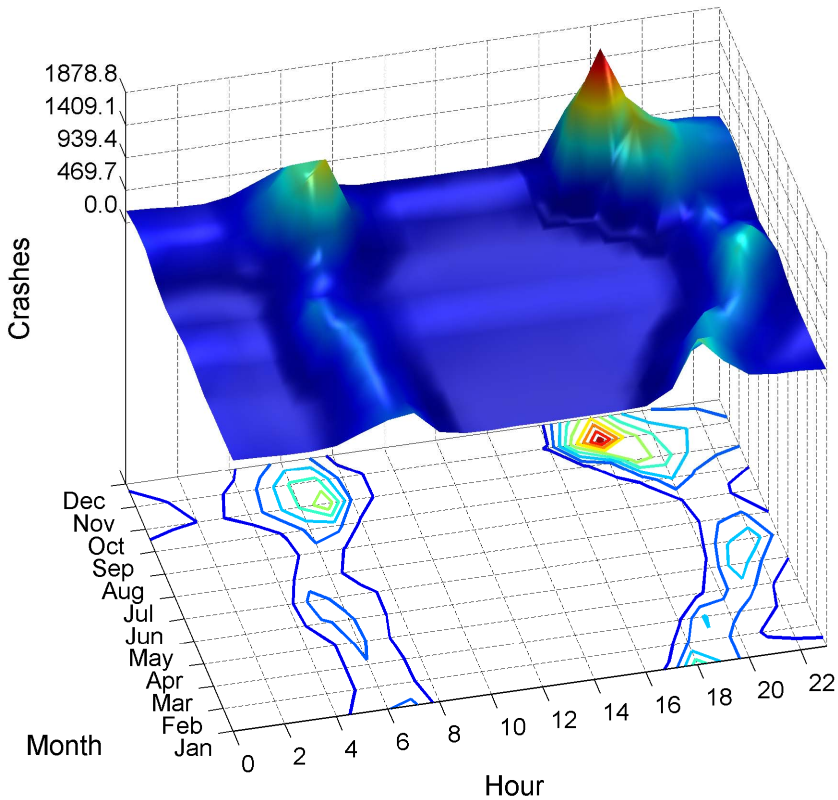

Figure 8. Trends by month and hour for all police-reported animal-vehicle collisions in Michigan (fatal and nonfatal) 2004-2007.

Regional Distribution of Animal-Vehicle Collisions

The number of fatal AVCs between 1990 and 2007 were tallied for each state, along with totals of nonanimal collisions. The results are shown in Table 1. States were ranked according to number of fatal AVCs and the table sorted from highest to lowest.

States were also ranked by number of nonanimal collisions (gray bars, highlighting the top ten) and by the fraction of the total number of crashes that were animal collisions (light blue, highlighting the top ten). Texas, Wisconsin, Pennsylvania, Ohio, and Michigan are the leading states in absolute numbers of fatal AVCs. Many of these states also lead in the number of nonanimal collisions, indicating a general relationship between state population and crash counts. For example, Texas is ranked second in nonanimal collisions; it is also ranked second in population by the U.S. Census Bureau. On the other hand, Florida has the third highest nonanimal collision count, while it is ranked 15th in terms of animal-vehicle collisions. The difference may be related to the degree to which wildlife and human populations are isolated from each other. One way of characterizing this may be in terms of the proportion of AVCs found in each state, as shown in the fourth numerical column of Table 1. We might expect that in states where there is less separation between wildlife and human populations, the proportions would be high. Thus, Alaska, Montana, and Maine show the highest proportions of AVCs in their crash makeup. In states where there is greater separation—most likely a consequence of large urban areas—proportions of AVCs are small. Thus, California, Florida, and Massachusetts have the smallest proportions of AVCs.

Table 1.
Fatal crash counts by state, sorted by number of fatal animal collisions, 1990-2007. Gray highlight denotes top ten states by total nonanimal collisions; blue highlights denote top ten by proportion of animal collisions.

State	**Animal**	**Non-Animal**	**Non-Animal Rank**	**Proportion Animal Crashes**	**Proportion Rank**
TEXAS	235	54381	2	0.0043	30
WISCONSIN	124	10557	23	0.0116	9
PENNSYLVANIA	120	25179	5	0.0047	26
OHIO	103	22613	9	0.0045	28
MICHIGAN	93	21657	10	0.0043	31
ILLINOIS	90	22879	8	0.0039	33
CALIFORNIA	86	66020	1	0.0013	50
NEW YORK	84	26878	4	0.0031	39
OKLAHOMA	80	11080	21	0.0072	18
MINNESOTA	79	9276	26	0.0084	16
MISSOURI	79	16439	13	0.0048	24
GEORGIA	78	24908	6	0.0031	38
INDIANA	73	14988	17	0.0048	23
NORTH CAROLINA	68	24027	7	0.0028	41
FLORIDA	66	47738	3	0.0014	49
IOWA	63	6190	33	0.0101	11
COLORADO	63	9828	25	0.0064	20
MONTANA	60	3194	38	0.0184	2
MISSISSIPPI	59	13406	20	0.0044	29
KANSAS	58	7213	29	0.0080	17
SOUTH CAROLINA	56	15750	15	0.0035	34
TENNESSEE	51	19834	11	0.0026	44
ARIZONA	50	15920	14	0.0031	37
MAINE	49	2649	40	0.0182	3
KENTUCKY	47	13847	19	0.0034	36
ALABAMA	47	17487	12	0.0027	43
VIRGINIA	44	15217	16	0.0029	40
SOUTH DAKOTA	39	2587	41	0.0149	7
NEW MEXICO	39	6195	32	0.0063	21
UTAH	38	4260	34	0.0088	13
ALASKA	36	1321	45	0.0265	1
WEST VIRGINIA	36	6457	31	0.0055	22
ARKANSAS	35	9906	24	0.0035	35
WASHINGTON	34	7953	28	0.0043	32
LOUISIANA	34	14682	18	0.0023	46
WYOMING	33	2059	43	0.0158	5
IDAHO	32	2955	39	0.0107	10
OREGON	32	6682	30	0.0048	25
NEBRASKA	30	3392	37	0.0088	15
NEW HAMPSHIRE	28	1575	44	0.0175	4
NEW JERSEY	26	10797	22	0.0024	45
MARYLAND	23	8204	27	0.0028	42
NEVADA	20	4228	35	0.0047	27
NORTH DAKOTA	18	1196	46	0.0148	8
VERMONT	17	1120	47	0.0150	6
DELAWARE	9	976	48	0.0091	12
MASSACHUSETTS	8	4132	36	0.0019	48
HAWAII	5	731	49	0.0068	19
CONNECTICUT	5	2274	42	0.0022	47
RHODE ISLAND	1	113	50	0.0088	14

Relationship between Posted Speed Limit and Crashes in Darkness

Earlier in this report, it was noted that roadway lighting has not been shown to reliably reduce the risk of collision with animals, and that the evidence for AVC mitigation that depends on driver avoidance behavior is relatively meager (Hedlund et al., 2004). In addition, some computational models of animal-vehicle collision dynamics do not even include the possibility of crash mitigation by drivers (e.g., Jaarsma, van Langevelde, & Botma, 2006). Perhaps crash avoidance by the driver plays a limited role in AVC mitigation because such crashes are often a consequence of sudden animal dart-outs into the roadway, leaving little or no time to execute an evasive maneuver. If this is the case, efforts to extend the forward view of the roadway may not succeed in reducing AVC crash risk. This question can be examined more carefully by determining whether differences in preview time influence the relative risk of AVCs in darkness versus daylight.

Low-beam headlamps provide a fixed preview distance of the road ahead. Based on the travel speed of the vehicle, this preview distance can be translated into an associated preview time. At high speeds, preview time is shortened. For example, if the forward preview distance is 100 m, a vehicle traveling at 100 kph would cover this distance in 3.6 seconds; a vehicle traveling at 50 kph would cover it in 7.2 seconds; and a vehicle traveling at 25 kph would cover it in 14.4 seconds. Thus, preview time increases as travel speed decreases. At some speeds, preview time is insufficient to allow the possibility of an avoidance maneuver—the time to detect the obstacle and respond to it by braking or steering exceeds the time to contact. This is often characterized as overdriving the headlamps. In daylight, where forward visibility is not limited by the reach of forward headlighting, this relationship between preview time and vehicle speed is not present.

If AVCs are predominantly the result of animals suddenly darting out into the roadway in a manner that leaves little opportunity for avoidance, regardless of speed, there may be little chance of successful avoidance above a travel speed of 25 kph (16 mph). For example, if deer-vehicle collisions typically involve dart outs into the roadway at around 10 m in front of the vehicle, a vehicle travelling at 100 kph would cover that distance in 360 msecs, at 50 kph in 720 msecs, and at 25 kph in 1,440 msecs. If a driver takes a minimum of 2 seconds to respond, there is no chance that a collision can be avoided at any of these speeds. On the other hand, if preview time does matter, then higher travel speed should increase the crash risk in darkness for animals, as it has been shown for pedestrian crashes (Sullivan & Flannagan, 2006). If we assume that posted speed limit can serve as a reasonable surrogate for actual vehicle speed, then we might observe the influence of preview time as an increase in the odds of an AVC in darkness (versus daylight) with posted speed limit.

In this analysis, the odds of a crash in darkness were modeled in a logistic regression that examined the influence of posted speed limit on the odds of a fatal collision occurring in darkness. Two ambient lighting conditions, *light* and *dark,* were modeled. Other ambient conditions—*dawn, dusk, dark with lights*, and *unknown*—were excluded from this analysis. The sample included all fatal crashes drawn from the FARS 1990-2007 dataset involving collisions with animals. An effect of posted speed limit was observed such that for every mile-per-hour increment in speed there was an increase in the odds of a crash in darkness of about 2.5% ($\chi^2 = 17.0$, $p < .001$). The observed trend is shown in Figure 9, which recasts the odds measure into the proportion of crashes in darkness for clarity.

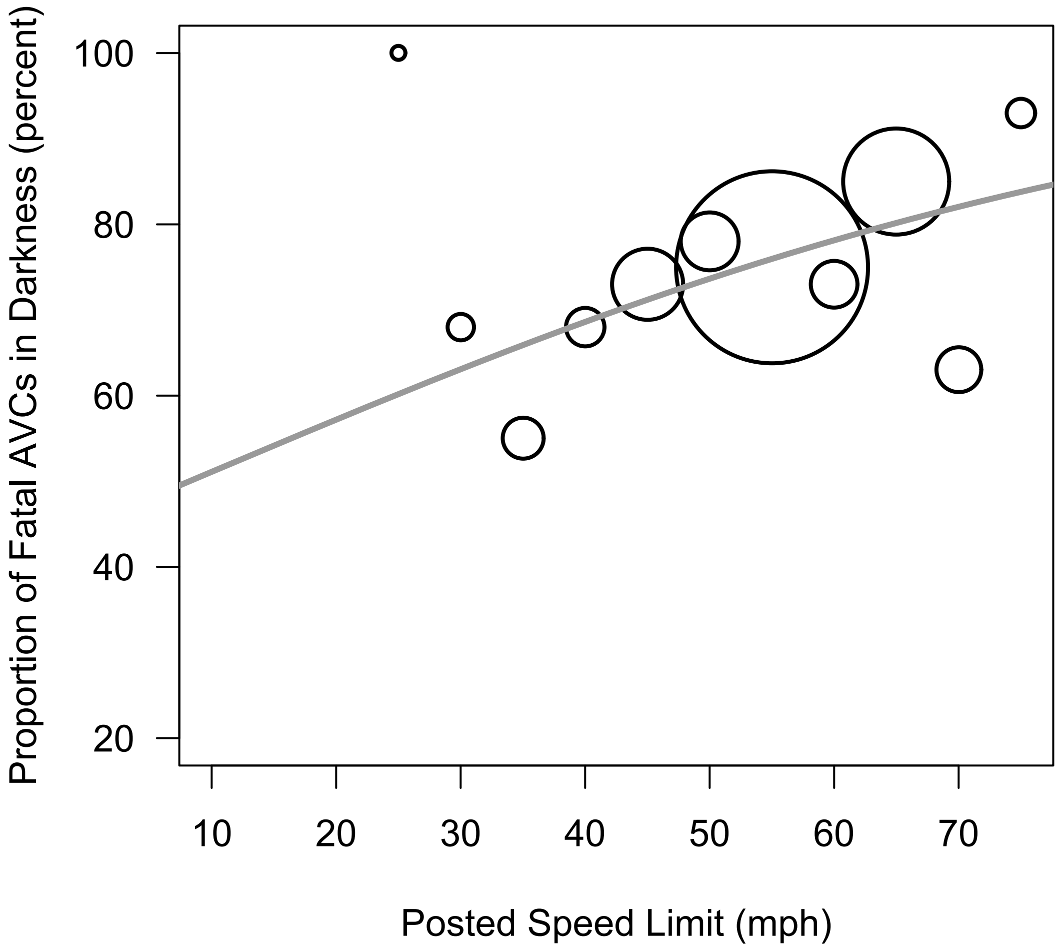

Figure 9. Proportion of fatal AVCs in darkness on roads with different posted speed limits (open circles). Areas of circles are proportional to number of collisions. The solid line represents the modeled relationship between posted speed limit and collision proportion.

As noted earlier, the difference between a fatal and a nonfatal crash is often a matter of impact force. Thus, if a simple caution that animals are present in the roadway environment prompts the driver to reduce speed, a *fatal* collision might be avoided even though the collision cannot. If this is the only mechanism of crash mitigation—reduction of the impact force of the crash, but not crash avoidance—then AVCs that involve less injury or property damage may not benefit with additional preview time. To investigate this issue in more detail, the odds of deer-vehicle crashes in darkness were examined for Michigan from 2004 through 2007. Two levels of crash severity were distinguished: crashes involving any fatality or bodily injury, and crashes in which property damage only (PDO) occurred. A logistic regression modeled the odds of a crash in darkness as a function of severity (PDO, fatal and injury) and posted speed limit. Main effects of posted speed limit (χ^2 = 64.3, p < .001) and crash severity (χ^2 =25.4, p < .001) were observed. This can be seen in Figure 10. An interaction was also observed between crash severity and posted speed limit (χ^2 = 4.3, p < .05), such that posted speed is associated with proportionally greater change in the odds of a deer crash in darkness for the fatal and injury crashes. Specifically, the odds of a PDO collision in darkness increased about 0.7% per mile-per-hour increase in posted speed limit; the odds of a fatal or injury crash in darkness increased about 1.5% for the same increase in posted speed. One interpretation of this result is that PDO crashes are less affected by changes in preview time than higher severity crashes, because it is more difficult to execute a maneuver that completely avoids contact with the animal (and the resulting vehicle damage). Nevertheless, it is important to note that AVCs involving only property damage are, in fact, sensitive to preview time, but to a lesser degree than the fatal and injury AVCs. This suggests that AVC models in which neither vehicle speed nor driver avoidance play a role do not faithfully reflect all characteristics of these collisions. Instead, it appears that attempts to extend a driver's preview time for the road ahead—whether by extension of the forward beam pattern, night vision enhancement, or radar detection—may provide valuable assistance in helping drivers avoid animal-vehicle collisions.

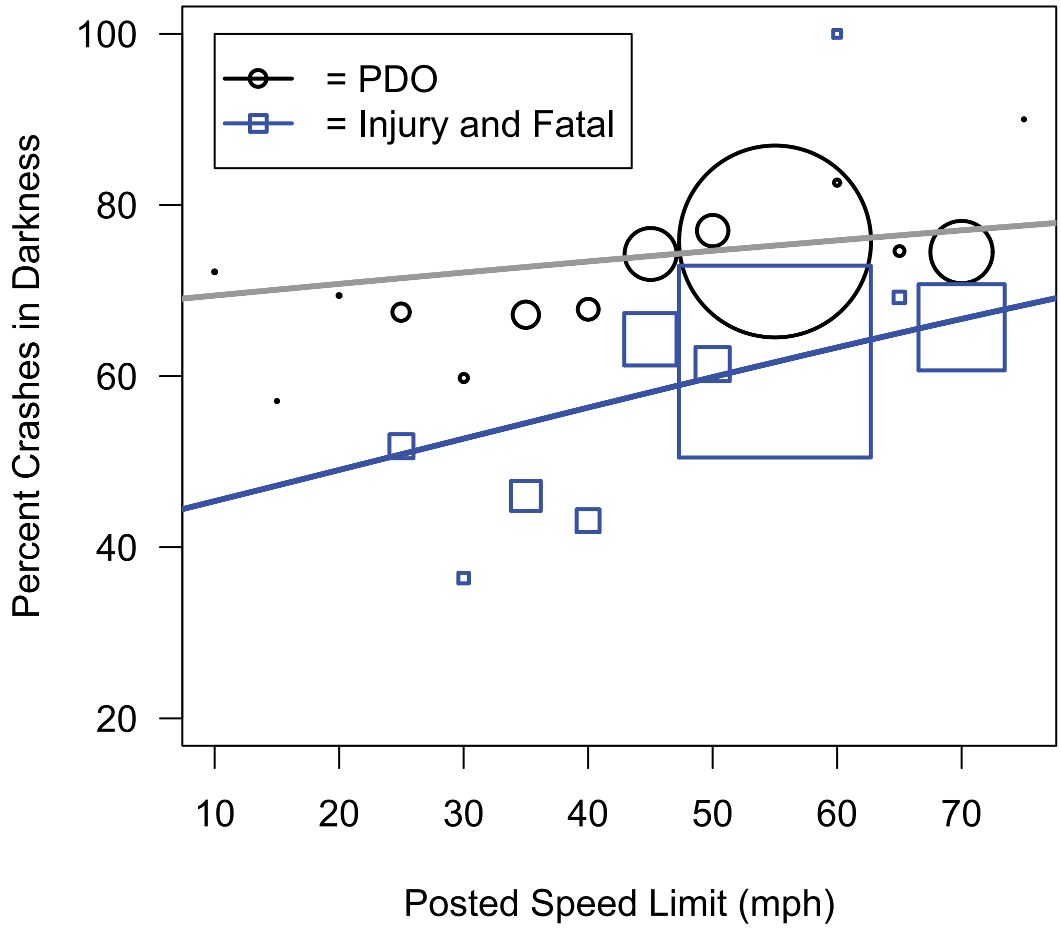

Figure 10. For two severity levels, proportion of deer-vehicle collisions in darkness on roads with different posted speed limits in Michigan 2004-2007. Areas of circles and squares are proportional to number of collisions within severity level. Solid lines represent modeled relationships between posted speed limit and collision proportion.

Conclusions

In 2007, there were 223 fatalities in the United States in crashes for which a collision with an animal was the first harmful event. Compared to the 106 fatalities of that type in 1990, this change represents a 110% increase. The preceding analyses suggest that this increase cannot be fully explained by increases in vehicle miles travelled, nor by changes in the general fatal and nonfatal crash rates. Animal-vehicle collisions (AVCs) represent an increasing share of the overall crash picture.

In the United States, about 77% of AVCs involve collisions with deer. One consequence of the prominence of deer involvement is that temporal patterns of crash occurrence broadly mirror the activity patterns of deer. Peak daily deer activity coincides with dawn and dusk. Similarly, peak crash levels follow this pattern, perhaps with some adjustment related to ambient light level: highest collision risk occurs about an hour after sunset when ambient light level has declined. Peak seasonal deer activity occurs during mating season in October and November, it declines in winter, and rises again in the spring. A similar pattern is found in both the fatal crash record (FARS), and the fatal/nonfatal AVC profile for Michigan.

Perhaps the most significant result for vehicle lighting is that the relative risk of AVCs in darkness versus daylight appears to be associated with posted speed limit. Higher posted speeds result in proportionally greater crash risks in darkness. The effect is observed for fatal collisions compiled from FARS, and for injury and property-damage-only (PDO) crashes compiled from Michigan crash datasets. One implication of this association is that limited forward preview time results in elevated AVC risk, and that methods that extend the forward preview would likely help reduce the risk of such crashes. These methods might include dynamic modification of the forward beam pattern to extend the driver's view of the road, perhaps using advanced frontlighting system technologies. Extension of the forward view could also be accomplished with night vision enhancement and other advanced detection systems that help drivers identify the position of animals in the roadway.

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