DEER-VEHICLE CRASH COUNTERMEASURE TOOLBOX:
A DECISION AND CHOICE RESOURCE

Final Report

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Submitted to the Wisconsin Department of Transportation

Completed as part of the Deer-Vehicle Crash Information Clearinghouse Initiation
Project for the Wisconsin Department of Transportation
SPR Project Number 0092-01-11
Report Number DVCIC – 02

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June 2004

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This research was funded by the Wisconsin Council on Research of the Wisconsin Department of Transportation and the Federal Highway Administration under SPR Project 0092-01-11. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Wisconsin Department of Transportation or the Federal Highway Administration at the time of publication.

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Technical Report Documentation Page

1. Report No. DVCIC – 02	2. Government Accession No	3. Recipient's Catalog No

4. Title and Subtitle Deer-Vehicle Crash Countermeasure Toolbox: A Decision and Choice Resource	5. Report Date June 2004 6. Performing Organization Code
7. Authors Keith K. Knapp, Xin Yi, Tanveer Oakasa, Wesley Thimm, Eric Hudson, and Chad Rathmann	8. Performing Organization Report No. DVCIC – 02
9. Performing Organization Name and Address Midwest Regional University Transportation Center Deer-Vehicle Crash Information Clearinghouse University of Wisconsin-Madison 1415 Engineering Drive Madison, WI 53706-1791	10. Work Unit No. (TRAIS) 11. Contract or Grant No. SPR 0092-01-11
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation Hill Farms State Transportation Building 4802 Sheboygan Avenue Madison, WI 53707-7910	13. Type of Report and Period Covered Final: September 2001-May 2004 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Wisconsin Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Study Title: Deer-Vehicle Crash Information Clearinghouse Initiation Project

16. Abstract

In July 2001 the Deer-Vehicle Crash Information Clearinghouse (DVCIC) was created by the Wisconsin Department of Transportation. During the last two years an extensive review of deer-vehicle crash (DVC) countermeasure documentation has been completed. This toolbox contains what is believed to be the most detailed summary and evaluation of DVC countermeasure information. Three levels of discussion are provided that focus on the current state-of-the knowledge related to 16 potential DVC countermeasures. Specific findings and conclusions for each countermeasure are discussed in Chapter 2 and summarized in the Executive Summary. Each of the summaries in Chapter 2 can be acquired from the DVCIC webpage: www.deercrash.com. More broad-based conclusions and recommendations are provided in Chapter 3. It was generally concluded that it is difficult to define the magnitude of the DVC problem in the United States, and that the collection of roadside deer carcass locations may provide a more accurate measure of the problem. The 16 countermeasures are grouped into five categories based on their apparent use and how much they had been studied. It was not considered appropriate, given the current limited state-of-the-knowledge and lack of definitive studies, to group the countermeasures by their apparent DVC reduction capabilities. The majority of the potential countermeasures are used in the field, but the safety impacts of few have been evaluated rigorously. Only studies of properly installed/maintained exclusionary fencing and wildlife crossing installations have consistently shown DVC reductions. The DVC reduction capabilities of the other 14 countermeasures appear to still be in question. Different types of evaluations are recommended for each of the five categories defined. It is also recommended that a national or regional DVC database be created and that the value of a similar database of roadside carcass locations be evaluated. It is proposed that all DVC countermeasure installations and evaluations be completed by a team of transportation safety and ecology professionals. A national or regional DVC or large ungulate-vehicle crash safety research center should also be created to fund/promote appropriately designed research in the DVC area.

17. Key Words	18. Distribution Statement
Deer-Vehicle Crash, Crash Countermeasures, Animal Mortality, Safety	**No restriction. This document is available to the public through the National Technical Information Service** 5285 Port Royal Road Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	263	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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EXECUTIVE SUMMARY

It has been estimated that more than a million deer-vehicle crashes (DVCs) occur each year in the United States, but that less than half of them are reported. These collisions are believed to cause more than one billion dollars in property damage. In the Upper Midwest, more than 125,000 DVCs are reported each year, and these collisions result in more than 30 fatalities, 4,700 injuries, and an estimated $213 million dollars in property damage. Almost one in six reported crashes in Wisconsin are DVCs, and there are counties where more than 50 percent of the crashes reported in a year are DVCs. The number of DVCs continues to increase, and are a significant safety problem with costly results.

DEER-VEHICLE CRASH INFORMATION CLEARINGHOUSE

In July 2001 the Wisconsin Department of Transportation (WisDOT) initiated the Upper Midwest DVC Information Clearinghouse (DVCIC). Five states (Michigan, Minnesota, Illinois, Iowa, and Wisconsin) are involved with the clearinghouse. Transportation safety professionals from the Department of Transportation and wildlife experts from the Department of Natural Resources from each state are on the technical advisory committee of the DVCIC. The website for the clearinghouse is at www.deercrash.com.

TOOLBOX PURPOSE AND CONTENT

One of the first tasks of the DVCIC was to create this document. Its primary purpose is to summarize the current state-of-the knowledge related to the DVC-reduction effectiveness of 16 potential countermeasures. A significant amount of money is spent on the implementation of these countermeasures each year in the United States and throughout the world.

The toolbox is written from the point-of-view of a traffic operations and transportation safety researcher and analyst, and it is believed that the level of detail it contains is unlike any other general DVC countermeasure review document currently available. If more detailed summaries do exist for specific countermeasures, however, they are identified for the reader. The objective was to provide the detail needed to clearly understand the extent of the DVC reduction knowledge available for each countermeasure, and if possible discuss some of the key choices and concerns that should be considered in their implementation or application.

The information should be useful to professionals that must currently make and defend decisions (given the current state-of-the-knowledge) about whether or not to implement one or more DVC countermeasures. By identifying some pitfalls, it could also be used to design appropriate monitoring plans to evaluate countermeasure effectiveness. Finally, the gaps in the knowledge that are identified can be used to define a future research strategy focused on DVC countermeasures.

This toolbox generally contains three levels of discussion. This executive summary includes a general description of what was found in the literature for each countermeasure. Chapter 2, however, contains a self-contained detailed description and review of the research. Chapter 3 of this toolbox contains a series of conclusions about the status and value of the existing and generally available documented research about DVC countermeasure effectiveness. Recommendations are also provided about how and what might be done to extend and expand upon the current state-of-the-knowledge in this area. The content of all three discussions should be used in combination by the reader to understand the current state-of-the-knowledge for a particular countermeasure, and to determine the transferability, validity, and general applicability of that knowledge to their particular situation. This toolbox should also be a living document, and if possible will be updated as appropriate (See www.deercrash.com).

DVC COUNTERMEASURE SUMMARIES

In-Vehicle Technologies

No published studies were found that evaluated the DVC reduction capabilities of in-vehicle sensors or vision technologies. However, the application of these technologies in the general vehicle population is very recent and the ability to do this type of large-scale study probably has not been possible. An evaluation of the DVC reduction capabilities of these technologies for a wide range of drivers would be of interest. Their potential to reduce the number of DVCs (if properly used) appears to exist. Currently, the cost of in-vehicle vision systems is relatively high, but it may decrease if demand and competition for these devices increase.

Deer Whistles

The DVC reduction effectiveness of air-activated deer whistles has generally been investigated through the use of non-scientific before-and-after studies and some documented research into the hearing capabilities of deer. In general, the relatively poor design and/or documentation of the before-and-after studies (e.g., sample size) have produced dramatically conflicting results. No conclusions can be drawn from these studies as a whole, and better designs and documentation are recommended for future studies of this nature.

A small amount of documented/published research has been completed in the area of deer auditory capabilities and their reaction to air-activated whistles. For the most part, it has been found that the range of hearing sensitivity for deer is two to six kilohertz (kHz), and only some whistles apparently make sound within that range. It has also been generally concluded that deer did not react to vehicle-mounted air-activated deer whistles, and that hearing the sound from these devices might be difficult when combined with typical vehicle roadway noise levels. The ability of whistles to produce the advertised level of sound at an adequate distance within the typical environment of a roadway has also been questioned. Additional scientifically defined and designed research focused on the effectiveness of air-activated deer whistles and similar non-air-activated devices is recommended. A current concern is also the impact the installation of these devices (which may or may not work) on vehicles may have on the alertness of drivers (i.e., Do they provide an unproven sense of security?).

Roadway Lighting

One study was found that attempted to directly relate the existence of roadway lighting to a reduction in DVCs. This study also investigated the changes in deer crossing patterns and average vehicle speeds that might occur with the addition of lighting. The study researchers concluded that the addition of lighting did not appear to have an impact on DVCs, deer crossing patterns, or average vehicle speeds. However, they made this conclusion despite the fact that the number of crashes per deer crossing appeared to decrease by about 18 percent with the addition of lighting along the roadway test segment. It is assumed, but it was not documented, that the investigators believed that this reduction was within the normal variability of the data evaluated. The addition of a taxidermy-mounted full-size deer in the emergency lane of the roadway segment did produce a reduction in average speed of about 8 mph when the lights were activated. However, not enough speed data were available to validate these results. Additional research should probably be completed to evaluate the focused effectiveness of lighting as a DVC-reduction tool (versus a speed reduction tool).

Speed Limit Reduction

Two studies that evaluated speed limit reduction as a potential DVC countermeasure were reviewed. In both cases the researchers suggested that there was a relationship between animal-vehicle collisions and posted speed limits. In certain instances, but not all, their research results appear to show a less then expected number of animal-vehicle collisions along roadway segments with lower posted speed limits. To reach this conclusion, one study statistically compared the proportion of roadway mileage with a particular posted speed limit to the proportion of animals killed along those segments. The other study compared the frequency and rate per roadway length of animal-vehicle collisions before and after a posted speed limit change. No studies were found that specifically focused on the number of white-tailed DVCs and posted speed limit.

Several limitations need to be recognized with respect to the results of the two "speed limit reduction" studies reviewed. Overall, like the analysis of many other animal-vehicle crash countermeasures, these two studies did not address, and/or attempt to control for, a number of factors that could impact the validity and usefulness of their conclusions. For example, neither study quantitatively considered the differences in traffic volume or the adjacent animal population along the segments considered. A comparison of the proportion of animal-vehicle collisions to the proportion of roadway mileage (with a particular posted speed limit) also assumes a uniform distribution of animal population, and ignores any positive or negative relationships that might exist between roadway design, topography, posted speed limit, operating speed, and animal habitat. Effectively determining and defining a relationship (if any) between reduced posted speed limits (or operating speeds) and the number of animal-vehicle collisions along a roadway segment will require additional research studies that attempt to address, control for, and/or quantify the impact and potential interaction of these and other factors.

One of the studies summarized also concluded that the choice of vehicle operating speed appeared to be primarily affected by the roadway and roadside design features (versus the posted speed limit). This is a conclusion that is generally accepted in the transportation profession, and primarily supports the idea that a reduction in posted speed limit that is not considered reasonable by the driving public will generally be ignored (without significant enforcement presence). This type of situation has also been shown to increase the general possibility of a crash between two vehicles along a roadway because some drivers will slow and others will not.

Deicing Salt Alternatives

Animals are naturally attracted to salt sources, and there is speculation that the use of roadway salt for winter maintenance purposes may increase DVCs. In the past, however, suggestions and/or studies of sodium chloride and its alternatives have typically focused on the water quality environmental impacts of these chemicals (e.g., surface runoff) rather than their potential DVC impact. Research into how much of an impact the use of roadway salt may have on the number of DVCs occurring at a particular location is needed.

Only one study was found that attempted to consider the quantitative impacts of roadway salt on animal-vehicle collisions, and it focused on the patterns of moose-vehicle collisions near roadside pools with significant concentrations of salt. The runoff from the roadways apparently produced these pools in an otherwise sodium deficient area. It was found that moose were highly attracted to roadside pools with levels of high salt concentration. The moose-vehicle crash data also showed that approximately 43 percent of the moose-vehicle collisions in the study area occurred within 328.1 feet (100 meters) of a saltwater pool. However, about the same amount occurred more than 984.3 feet (300 meters) away from the pools. The researchers concluded that the distribution of the observed moose-vehicle crashes near the roadside pools was much higher than what might randomly be expected. The assumption used in this comparison (i.e., all locations have an equal chance for a crash) is questionable and no comparisons were completed about how many moose-vehicle crashes might not have occurred if the saltwater pools (or the use of roadway salt) were eliminated or reduced. This is a key question that needs to be answered. Future studies that focus on DVCs and roadway salt use should also evaluate the effectiveness of the roadway salt alternatives at clearing the roadway pavement (which increases general safety) and the other benefits and costs of their use.

Deer-Flagging Models

White-tailed deer raise their tails to expose their white undersurface (i.e., deer-flagging) as a warning signal. In one study wood silhouettes of models of this deer-flagging warning stance were installed along a roadside to warn deer away from the roadway. However, none of the deer-flagging model designs considered in the study appeared to yield conclusive results that their addition to the roadside reduced the number of white-tailed deer that were observed and/or crossed the study roadway right-of-way. In some cases fewer deer were seen along the treatment segments than the control segments, but in others the number of deer observed increased after the models were installed. The general fluctuations in deer movements and the variability in data observation approaches (and time periods) also appeared to confound attempts, at least in some of the experiments, to connect deer behavior to the presence or absence of the flagging models. The researchers involved with the study generally concluded that they had failed to demonstrate that the use of deer-flagging models was an effective method of reducing the number of deer observed along the highway right-of-way. They did not recommend their use. A similar well-designed study in the future might be considered to validate or refute the results of this study.

Intercept Feeding

Intercept feeding involves the provision of feeding stations outside the roadway area. The objective is to divert animals to the feeding areas before they cross the roadway. One study was found that attempted to evaluate the impact of this DVC countermeasure. The researchers generally concluded that intercept feeding might be an effective short-term mitigation measure that could reduce DVCs by 50 percent or less. However, the study results actually described in the study document appeared to be contradictory. In addition, there was no documentation of the number of DVCs that occurred along the roadway segments evaluated before the intercept feeding stations were in operation, and it was generally acknowledged by the researchers that the amount of deer roadkill counted along the segments were not proportional to the estimated deer population near each segment. In general, the study investigators were also of the opinion that the potential for a short-term reduction in DVCs of 50 percent or less was not sufficient enough to justify the amount of work and funding necessary for the implementation of an intercept feeding program. It was suggested that intercept feeding might be combined with other countermeasures to increase its effectiveness. Two problems that might occur with the implementation of this countermeasure are that deer may become dependent on the food supply and more deer than typical might be drawn to the general vicinity of the roadway and the area. A well-designed study to support or refute the results of this study may also be appropriate.

Deer Crossing Signs and Technologies

Several studies were reviewed that evaluated the potential impacts of specially designed deer crossing signs on roadside deer carcasses and/or vehicle operating speed. Two studies of a lighted deer crossing sign believed that it did produce vehicle speed reductions. However, the outcome of a more in-depth study (by some of the same researchers) of a lighted and animated sign design did not appear to indicate that the resultant vehicle speed reduction had actually produced a reduction of the number of roadside deer carcasses (i.e., DVCs). Unfortunately, these study results are also based on only 15 weeks of data and the variability in DVCs and the factors that impact their occurrence limits their validity and transferability.

The seasonal use of specially designed deer crossing signs was also considered in two states. Researchers in Utah installed signs during the mule deer migratory season, and observed reductions in vehicle speed and DVCs. However, researchers in Michigan investigated the impact of a different deer crossing sign design that was installed during the fall months (a “high” DVC and white-tailed deer movement time period), and generally found no significant reduction in DVCs or vehicle speed. The differences in these two studies include sign design, animal species, and apparently the general ability of drivers to appropriately assess the risk of a collision at a particular time and location. In Utah the familiarity of the drivers with the distinct migratory seasons and locations of the mule deer were believed to have had an impact on the sign effectiveness. It is proposed that more consistent and incremental studies may be needed to support or refute the speed- and DVC-reduction impacts of properly installed (i.e., at “high” DVC locations) deer crossing signs for both the existing and any proposed designs.

There are also a number of systems that combine dynamic signs and sensors that are being considered or have been installed throughout the world. Several of these systems were briefly described in this toolbox. The recent development of these systems requires an initial evaluation and improvement of their activation reliability. One key to the successful application of these systems is the minimization of false activations. The operation and effectiveness of some of the systems described in this summary are currently being studied, but only the Nugget Canyon, Wyoming systems analysis appears to have been documented in the United States at this time.

The researchers doing this evaluation concluded that when the system worked properly it produced a small, but statistically significant, reduction in average vehicle speeds. The impacts of the other systems that exist still need to be determined. It is recommended that properly designed monitoring and evaluation studies be included as part of the installation of all new systems.

Roadside Reflectors and Mirrors

The roadside reflector/mirror studies and literature reviewed for this toolbox were grouped into four categories. Past roadside reflector/mirror research typically used either a cover/uncover, before-and-after, or control/treatment study approach to evaluate their impact. Researchers have also either observed deer movements as they evaluated the impact of roadside reflectors/mirrors on deer roadkill and/or DVCs, or specifically considered deer behavior toward reflected light. The studies summarized (which represent only a sample of the reflector documents available), whether they focused on deer roadkill and DVC impacts or deer behavior, had conflicting results. Overall, 5 of the 10 studies summarized for this toolbox had conclusions that indicted roadside reflectors did not appear to impact deer roadkill or DVCs, and 2 of the 10 concluded that they did. Three of the 10 studies summarized appeared to reach inconclusive or mixed results. Most of the studies that evaluated deer behavior (many dealing with captive deer) were also inconclusive or concluded that the deer either did not appear to react to the light from the reflectors and/or quickly became habituated to the light patterns. Unfortunately, the experimental designs and details of all the studies varied (their details are included in this toolbox), and comparisons of their results are probably not appropriate. The significant amount of speculative and anecdotal information that exists about roadside reflector/mirror DVC-reduction effectiveness was not included in this summary.

At this point in time it is difficult to conclude the level of roadkill- or DVC-reduction effectiveness roadside reflector/mirror devices may have due to the conflicting results of the studies summarized. It is recommended that the completion of a definitive roadside reflector/mirror DVC-reduction effectiveness study be considered. A well-designed widespread long-term statistically valid study of comparable and well-defined roadside reflector treatment and control roadway segments (with consideration given to local deer travel patterns) is suggested.

Repellents

A large number of studies, with varied approaches, have attempted to evaluate the effectiveness of numerous repellents (of varying composition) on the feeding patterns of several different types of captive animals. The studies summarized in this toolbox investigated repellent impacts on white-tailed deer, mule deer, caribou, and elk. No studies were found that documented an attempt to test repellent effectiveness on deterring wild animals from approaching a roadside and roadway to feed.

Some of the factors evaluated in the repellent studies included the type and number of repellents (e.g., predator urine, brand, odor, taste, etc.), status or application of repellent (e.g., spray, paste, etc.), concentration of repellent, animal hunger level, food type, and the amount of rain or water that occurred after repellent application. All of the studies did find some type of feeding reduction with one or more of the repellents considered, but the variability and/or non-repeatability of the studies makes a direct comparison of their results difficult.

Two published reviews of a large number of repellent studies did attempt to discover some overall trends in their results. In 1995, the repellent effectiveness results of twelve studies were ranked (i.e., 0 = ineffective to 4 = highly effective) and analyzed by two experts. It was concluded that Big Game Repellent™ and predator odors were typically found to be the most effective. In addition, no significant difference was found in the reactions to repellents between deer and elk (although white-tailed and mule deer appeared to react differently to predator odor). In 2003, a detailed literature review and qualitative summary of a large number of repellent studies was also completed to investigate the potential for an area repellent system to keep ungulates away from roadways. It was determined that the area-based repellents with the most potential were putrescent egg and natural predator odors. However, their potential still needs to be tested in the field. It was also noted that there should not be an expectation that one repellent will result in complete deterrence, or that the choice of which specific repellent (e.g., type of predator odor or repellent brand name) to use for roadside purposes is obvious. The results from these studies are summarized in this toolbox and may be useful when choosing a repellent, but should also be used with the understanding that the comparisons required a subjective, but expert, ranking or analysis to be completed.

The effective and economical application of repellents to potentially reduce roadside browsing of white-tailed deer would need to consider several factors. Some of these factors include how the repellent is applied, at what time intervals, cost, animal habituation, overall ecological impacts, and the locations to which is it applied. Like most of the other countermeasures already summarized, the application of repellents as a DVC reduction tool would most likely need to be focused on "high" DVC locations rather than widespread. However, white-tailed deer (or other animals) may also just shift their browsing location if repellents are not applied in a widespread manner. The application of repellents in combination with other DVC reduction tools at "high" crash locations might be most appropriate.

Hunting or Herd Reduction

The relationship between specific hunting policies or activities and their impact on white-tailed deer population is generally acknowledged. However, the impact of these same policies or activities on the number of DVCs that occur along roadways within the managed area has not been studied in a quantitatively proper and comprehensive manner. The primary objective of most hunting or herd reduction studies is not DVC reductions. Researchers have typically investigated the impact of these activities on the white-tailed deer population, and then suggested that the reduction in deer population or density produced by these activities should lead to a reduction in DVCs. The number of DVCs in an area is sometimes used as a factor in large-area herd management decisions, and in urban areas the reduction in DVCs is often the reason herd reduction activities are initiated.

The suggestion that a reduction in the white-tailed deer herd should lead to fewer DVCs appears to be at least partially supported by the input variables included in DVC prediction models. The models described in this toolbox all appear to include some direct or indirect measure(s) of deer population, habitat, and/or movement. The cause-and-effect relationship between these measures, herd reduction and/or hunting activities/policies, and the occurrence/pattern of DVCs, however, has not been quantified in a proper manner. The multiple regression statistical approach typically used describes correlations rather than cause-and-effect relationships, and several, if not all, of the proposed models developed appear to include intercorrelated input factors (which by definition are supposed to be "independent"). This approach often leads to model factor coefficients that seem illogical (e.g., reductions in DVCs with an increase in posted speed limit), and this subsequently limits or negates their value of the value of the models. These concerns should to be considered as the models described in this summary are used with caution.

There is a need for a focused study of the causal connections between hunting or herd reduction management policies and their potential impact on DVCs. The small area studies hunting/herd reduction activities have suggested some promising results, but the DVC analysis in these studies was typically lacking in its rigor. When complete, the results from a properly designed small area study might be expanded to a larger area. It is also suggested that the creation of predictive models for DVC frequencies and/or "high" DVC probabilities continue to be developed with the recognition and/or control of those input variables that may be intercorrelated. These intercorrelations need to be better defined.

Public Information and Education

Public information and education, combined with engineering and herd reduction activities, is generally acknowledged as a key component to a comprehensive DVC reduction program. Unfortunately, similar to other driver education programs, proving the crash reduction impact of particular informational campaigns is difficult. No experimental research that attempted to directly connect specific public information and education campaigns with a resultant DVC reduction or potential reduction was found. An annual or semi-annual reminder of the DVC problem, however, could potentially change some driver behaviors during critical time periods. The limited amount of information available about the DVC-reduction capabilities of almost all the countermeasures reviewed in this toolbox also make a public information and education campaign important. It also does not appear that any one of the DVC countermeasures reviewed would ever be completely effective, and public information and education campaigns will always be necessary.

The information typically included in a DVC reduction and/or avoidance public information and education campaign is described in this toolbox. Messages are often provided about the significance of the DVC problem (both temporally and spatially) along with suggestions about how to avoid a DVC and what to do if a DVC does occur. This information is typically released in the Fall (a peak DVC time period), and sometimes in the Spring. The DVC-reduction impact of this information has not been studied, but an evaluation may be warranted.

Roadside Vegetation Management

It has been generally speculated that certain roadside vegetation management policies or plantings may attract white-tailed deer and subsequently increase DVCs. No studies were found, however, that specifically considered the DVC impact of changes in roadside vegetation management policies/plantings. Three studies are summarized in this toolbox that generally focused on the plant preferences of white-tailed deer and other animals. One study found that white-tailed preferred Crownvetch in comparison to Sericea Lespedeza and Fescue. The second study concluded that the addition of woody shrubs in the right-of-way appeared to encourage wildlife usage, but did not appear to increase the numbers of animals killed along the roadway. However, no white-tailed deer or deer carcasses were observed near the test or control plots during the six months of this study. The third study considered the browsing preferences of white-tailed deer within a garden estate in Morris County, New Jersey, and produced a list of “deer resistant” plants. The applicability of these results should be decided on a case-by-case (i.e., location-by-location and plant-by-plant) basis.

Two studies were also found, however, that may at least show the DVC reduction potential of vegetation clearing. These studies focused on moose and their interaction with motor vehicles and trains. In the first study the clearing of low vegetation within 65.6 feet (20 meters) of the roadway appeared to reduce moose-vehicle crashes by almost

20 percent, but this reduction was too close to the natural variability of this data. The cost of this approach was also noted. The second study evaluated a similar but more extensive removal of vegetation along railroads in Norway, and showed more than a 50 percent reduction in moose-train collisions. However, the amount of data was limited and the individual segment results were highly variable. It was also recognized by the researchers that their experimental design could have resulted in an overstatement of the crash reductions from vegetation clearing. In general, there is still a need to properly study and document the safety (i.e., DVC reduction), ecological, and cost impacts of vegetation clearing along roadway segments.

Exclusionary Fencing

A series of studies have examined the various impacts of exclusionary ROW fencing. Other studies have considered the similar impacts of fencing installations with one-way gates, earthen escape ramps, and/or wildlife crossings. This toolbox describes study results from both types of studies, and also those that discuss DVC predictive models with fencing as a variable, electric fencing, and the benefit-cost of fencing.

Overall, the fencing installations evaluated have resulted in white-tailed/mule deer carcass (i.e., mortality) reductions of 60 to 97 percent. Some of these installations included exclusionary fencing only, but others combined fencing and one-way gates, and a sample of sites included fencing, one-way gates, and wildlife crossings. Almost all of the studies that considered DVC reductions were for fencing that was approximately 8-feet (2.44-meter) in height. Several studies attempted to evaluate the impacts of different fencing heights, but they either did not have enough data to make valid conclusions, found conflicting results, and/or failed to control for confounding variables (e.g., existing fence holes and gaps). It is recommended that future fencing evaluations consider more detailed design questions related to exclusionary fencing (e.g., what height is needed), and also include a DVC reduction analysis that incorporates currently accepted evaluation approaches.

The variability in the roadside carcass or DVC reductions that appear to result from similar fencing installations, however, is relatively high, and these results should be used with caution. Three factors that may have produced this wide range of results include variations in fencing installation quality, maintenance/repair activities, and a focus on the immediate removal of animals that do enter the fenced ROW. In addition, the combination of exclusionary fencing with other complementary infrastructure (e.g., one-way gates, earthen escape ramps, and/or wildlife crossings) may increase the amount of the observed DVC reduction along a roadway segment.

Several other conclusions were also reached about exclusionary fencing. One, more information is needed about the importance and need for a particular fencing height. Fencing heights other than 8-feet (2.44-meters) need to be evaluated. Two, the location of the fencing with respect to specific types of land cover may have an impact on its effectiveness. Three, the length of the exclusionary fencing is clearly important. Several of the researchers had problems with deer going around the ends of their installations. One study suggested that fencing should be installed 1/2-mile (0.8-kilometers) beyond the areas of "high" deer activity and/or DVCs. Four, one-way gates that allow trapped animals to escape the roadway right-of-way are important, but the animal use of these gates seems to vary, and one study found that earthen escape ramps (e.g., mounds immediately inside the right-of-way fence) were used 8 to 11 times more than one-way gates. Five, several studies have shown that the installation of electric fencing can reduce crop damage, but its use along a ROW has not been studied. Finally, based on series of assumptions (see Toolbox content) it has also been suggested that the installation of a 8-foot (2.44-meter) fence on one side of the roadway, both sides of the roadway, and on both sides combined with a wildlife crossings, would produce a benefit-cost ratio of 1.35 when the roadside deer carcass numbers were 8, 16, and 24 deer killed per mile (1.6 kilometer) per year, respectively.

Roadway Maintenance, Design, and Planning Policies

Decisions that might have an impact on DVCs and roadside animal mortality are made throughout the "life" of a roadway. The summary for this countermeasure includes an introduction and discussions of some of the decisions connected to roadway maintenance, design, and planning that might have this type of impact. The maintenance activities described are related to the use of salt mixtures for snow and ice control, the installation and maintenance of roadside vegetation, and the procedures followed for roadside carcass removal. The potential DVC impact of the first two activities are considered in other summaries within this toolbox, but the roadside carcass removal procedures rarely consider its potential for increasing collisions with animals that might feed on the carcasses. The design decisions that are discussed include the posted speed limit, curvature, and cross section of a roadway, and bridge height and length. It has been proposed that narrower lanes and more curvilinear roadways (where possible) should reduce vehicle operating speeds and subsequently reduce DVCs. The expected DVC impact of reduced speed limits are the focus of another summary in this toolbox, and the studies that have investigated the DVC impact of wider roadway cross sections have produced conflicting results. Choices related to the height and length of reconstructed bridges could consider the use of these facilities by animals. The roadway planning discussion introduced the idea of considering wildlife impacts (including DVCs) as a factor in the comparison of alignment alternatives within the project prioritization process.

Overall, it would appear that the consideration of existing or potential DVC impacts throughout the development of a roadway might help mitigate the DVC problem to some degree. The individual or cumulative DVC impacts of all or some of these decisions, however, have not been studied to any large extent. In addition, each of these decisions must also take into account the costs and benefits of the change in operating procedure or roadway design that may result.

Wildlife Crossings

There appears to be a significant amount of information available on the use and general effectiveness (typically measured by animal use) of *specific* wildlife crossing/fencing installations. The roadside animal mortality reductions that have resulted from several of these installations are described in the “Exclusionary Fencing” portion of this toolbox. It is generally accepted that a properly located, designed, and maintained crossing/fencing combination can significantly reduce animal mortality along a roadway segment.

A general review of wildlife crossing research that was summarized in this toolbox concluded that most studies focused on a particular wildlife crossing(s) and the species use of that structure (versus its potential animal mortality reduction impacts). Very few wildlife crossing studies have been designed and/or documented for the possible general application of their results. In general, however, it has been found that the location of a wildlife crossing is key to its success, and it is preferable that it matches the natural movement patterns of the target species. Ungulates (including white-tailed deer) also typically prefer overpasses or large open underpasses. Their initial use of a wildlife crossing appears to be more strongly correlated with structural design variables than adjacent landscape and human activity. In the long term, however, natural groundcover on and/or within a structure, natural vegetation leading to its entrances, and minimal human activity and nearby development are preferred crossing characteristics.

Significant gaps exist in the current state-of-the-knowledge (or its documentation) for crossing design decision-making (e.g., "best" crossing geometry and location). Currently, it would appear that heights as low as 7 to 8 feet and widths as narrow as 20 to 25 feet are considered minimum design criteria for the use of an underpass by deer. In addition, suggested minimum openness indices (a combination measure of crossing width, height, and length) have ranged from 0.6 (metric) for mule deer and 0.75 (metric) for roe deer to 1.5 (metric) for red and fallow deer. However, designing for the "minimum" is not a typical approach to most roadway component or bridge designs, and it would typically not be the preferred or recommended approach in the case of wildlife crossings. Overpasses are either square or hourglass shaped and it has been suggested that they be constructed with widths (at their narrowest point) of 100 feet or more. These types of designs have been used successfully in Europe for many years. It is expected that the results of two ongoing/proposed research projects may reduce some of the gaps in the current state-of-the-knowledge that exist for wildlife crossings, but additional evaluation of the details related to the effective implementation of wildlife crossings will most likely still be needed.

CONCLUSIONS AND RECOMMENDATIONS

Specific conclusions/findings (and some recommendations) for each countermeasure are summarized in the previous paragraphs. The conclusions and recommendations presented below, however, are more broad-based in their focus. They are discussed in more detail within Chapter 3. In general, the conclusions summarize the current status of defining the DVC problem and evaluating the effectiveness of existing and proposed DVC countermeasures are discussed. Five DVC countermeasure categories are also suggested. The recommendations respond to the issues identified in the conclusions, and suggestions are made about how some of the gaps in the current state-of-the-knowledge might be addressed.

Conclusions

- DVCs are a transportation safety concern throughout most of the United States and many parts of the world. The actual magnitude of this problem, however, can only be grossly estimated. The collection and trend analysis of the best available reported DVC (or animal-vehicle crash) data from all 50 states is needed. Other information related to the subject of DVCs could also be included in this database (e.g., vehicle travel and roadside deer carcasses estimates), and the documentation of the criteria and/procedures used to collect and/or estimate the data is essential.

- It is generally recognized that reported DVC data represents only a fraction of the collisions that do occur (up to 50 percent is likely). But, deer carcass data by specific collection location is not generally available. Large amounts of long-term reported crash data are available, but the similar creation of a deer carcass database may more specifically define the DVC problem.

- Many factors appear to impact the number of DVCs at a particular roadway location. These factors are generally related to the characteristics of the roadway and traffic flow, the deer population, and the adjacent land use and cover. Specific examples include traffic flow volumes, deer densities or crossings, and the existence of adjacent crops or woodland. Many of these factors are highly variable and also interrelated.

- The variability of the factors believed to impact the occurrence of a DVC, combined with their complex interrelationships, make it a difficult problem to evaluate, predict, and solve. Overall, these facts, combined with available resources, have limited the usefulness of the results from past DVC countermeasure studies. Although informative, few studies have rigorously evaluated and/or documented DVC countermeasure impacts from a safety analysis point of view.

- A number of potential DVC countermeasures are discussed in this toolbox. However, the current state-of-the-knowledge related to their DVC reduction capabilities is limited. It is not appropriate to group most of the countermeasures based on the inconclusive information currently "known" about their DVC impacts. Five DVC countermeasure categories are suggested that are based on whether or not the measure is currently used in the roadway environment, and how much they have been studied. The categories and their assigned countermeasures are listed below.

  - Used with Conflicting Study Results:
    - Deer Whistles
    - Roadside Reflectors/Mirrors

  - Used with Generally Positive Study Results:
    - Exclusionary Fencing
    - Wildlife Crossings

  - Used but Rarely Studied:
    - Speed Limit Reduction
    - Deer Crossing Signs and Technologies
    - Hunting or Herd Reduction
    - Roadside Vegetation Management

- Used but Not Studied:
  - In-Vehicle Technologies (on Roadways)
  - Deicing Salt Alternatives
  - Public Information and Education
  - Roadway Maintenance, Design, and Planning Policies

- Not Generally Used but Rarely Studied:
  - Roadway Lighting
  - Deer-Flagging Models
  - Intercept Feeding
  - Repellents (on Roadways)

- At the current time, the variability and complexity of the DVC problem makes it unlikely that there is one solution that exists which could be cost effectively applied to every roadway location. Similar to other roadway safety problems, a number of measures and activities will most likely need to be implemented to result in any significant reduction in DVCs. A combined and coordinated application of engineering, education, enforcement, and ecological measures seems appropriate.

Recommendations

- The ability to define the extent and temporal/spatial trends of the DVC problem is currently limited. It is recommended that a national or regional database of the best available and properly defined DVC and/or animal-vehicle collisions be created. This database should also include vehicle volume/travel estimates as a separate input variable, and potentially contain with deer population estimates and roadside deer carcass data at the most detailed level available. Typical DVC frequencies and rates should be calculated from this information, and then used to identify and possibly plot roadway locations with a higher than typical DVC safety concern (at the local and state jurisdictional levels).

- The collection of roadside deer carcasses reveals that the actual number of DVCs may be more than twice that reported. It is recommended that a pilot study be completed that investigates the collection of roadside carcass locations and its potential value to defining the DVC problem. The collection of this data could produce a more accurate measure of the DVC problem and possibly help identify problem locations that would have been missed if only reported DVCs are used. An investigation of the weaknesses and strengths of reported DVC and roadside carcass data is also recommended.

- There are many factors, some more quantifiable than others, which can lead to a DVC. There is a need to more adequately quantify the relationships between these factors, and to more properly define their individual or combined impacts on the occurrence of a DVC. Using this information, the development of a valid DVC frequency and/or rate prediction model is recommended. The most useable DVC prediction model would include the fewest number of easily collected or estimated independent input variables that appear to produce adequately calculated answers.

- The DVC problem has both ecological and transportation safety impacts. Therefore, an effective and acceptable DVC countermeasure should reduce vehicle-animal interactions while still allowing necessary animal behavior and movements (given an existing roadway). It is recommended that the installation and evaluation of all DVC countermeasures be completed with teams of transportation safety and ecology professionals. It is expected that this approach will result in a more all-encompassing approach to DVC countermeasure use, and produce monitoring plans that consistently apply the most current state-of-the-knowledge in the fields of transportation safety and ecology.

- From a transportation safety analysis point of view there is a general need for more well-defined and documented research related to the impacts of DVC countermeasures. The interdisciplinary team approach recommended above should address this need by involving transportation safety analysts/engineers and ecologists in the data collection, experimental design, results evaluation, and report development stages of DVC countermeasure projects.

- The potential DVC countermeasures reviewed for this toolbox have been grouped into five categories (see the Conclusions summary). Recommendations to address some of the gaps in the current state-of-the-knowledge for each category are described below.

    - Used with Conflicting Study Results: It is recommended that a properly funded, designed, and documented evaluation of these countermeasures (i.e., deer whistles and roadside reflectors/mirrors) within the roadway environment be completed to definitively determine their DVC reduction effectiveness.

    - Used with Generally Positive Results: It is recommended that the DVC and ecological impacts of exclusionary fencing/wildlife crossing installations continue to be evaluated, and that these studies use the most generally accepted analysis procedures. In addition, because past research has shown consistent DVC reductions due to the installation of these measures, questions about the details of their application and design in the field should be investigated further. The National Cooperative Highway Research Program (NCHRP) recently funded a project that focuses on the use and effectiveness of wildlife crossings.

    - Used but Rarely Studied: These measures have all been suggested as DVC countermeasures, and in some cases been used somewhat extensively. The past evaluations of the DVC reduction capabilities of these countermeasures, however, have been limited to very few studies. Additional evaluations are recommended (using the interdisciplinary approach previously recommended) to determine the actual impact of these measures on DVCs. Replicating and improving upon the studies previously completed to refute or support their results is necessary.

  - Used but Not Studied: A number of the countermeasures discussed in this toolbox are being used (sometimes sporadically), but their DVC impacts have never actually been studied. It is recommended that the efficient and effective application of these potential countermeasures be investigated, and their DVC impacts properly quantified.

  - Not Generally Used but Rarely Studied: Four countermeasures summarized in this toolbox have rarely been studied. It is recommended that it may be appropriate to further evaluate these measures and support or refute the results of thee studies that have been completed before thee use of these countermeasures is completely discouraged.

- The complexity and variability of the DVC problem, the factors that impact it, and its potential solutions require long-term (i.e., multi-year) and large-scale (i.e., multi-jurisdictional) evaluation projects. Two organizational activities are recommended to address this issue. First, it is recommended that a properly funded regional or national roadway deer-vehicle (or large ungulate-vehicle) crash reduction research center be created. This type of center would begin to address the more consistent and long-term approach needed to properly evaluate the effectiveness of DVC countermeasures, serve as a focal point for those interested in the subject, promote standardized and generally accepted research, and encourage interdisciplinary DVC countermeasure installation/evaluation teams. Second, it is also recommended that an annual DVC or large ungulate-vehicle crash symposium be established, and that these meetings include interdisciplinary evaluation workshops and information sharing sessions. The organization of this meeting could be one of the first activities for the proposed research center.

CHAPTER 1
INTRODUCTION

Collisions between white-tailed deer and vehicles are a significant safety and increasingly costly concern for Wisconsin, the Upper Midwest region, and throughout most of the United States. The range (i.e., habitat area) of the white-tailed deer includes almost the entire United States (excluding only Alaska, Hawaii, and portions of three other states). Nationally, it has been estimated that more than a million deer-vehicle crashes (DVCs) may occur each year, and that the cost of these DVCs is more than a billion dollars (*1*).

REGIONAL AND STATE PROBLEM

Total Crashes

Table 1 shows the total number and an estimated cost of the DVCs reported in five states within the Upper Midwest. Data from Wisconsin, Minnesota, Michigan, Illinois, and Iowa are shown. These five states are members of the Deer-Vehicle Crash Information Clearinghouse (DVCIC) based at the University of Wisconsin – Madison.

DVCs in the Upper Midwest can represent a significant percentage of the total number of reported crashes. For example, more than 21,500 DVCs were reported in Wisconsin in 2003 (See Table 1) and this represents about 16.5 percent of all the crashes reported in the state. In fact, DVCs were more than 50 percent of all reported crashes in two Wisconsin counties during 2003. The total number of reported DVCs in the Upper Midwest (See Table 1) is believed to represent more than 15 percent of those estimated to occur DVCs nationally (*1*).

In addition, it is also generally accepted that the number of *reported* DVCs under represents the *actual* number of DVCs that occur. Nationally, it has been estimated that only about 50 percent of all DVCs are reported (*1*). In Wisconsin, for example, the number of deer carcasses normally removed from the roadways by contractors of the

Department of Natural Resources is typically more than twice the number of DVCs reported to the Department of Transportation each year. This under-reporting can occur for a number of reasons (e.g., minimum reporting criteria, motorists leaving the scene,

TABLE 1 Recent Upper Midwest Deer-Vehicle Crashes

State	Pre-Hunt Numbers in Deer Herd	Deer-Vehicle Crashes*	Deaths	Injuries	Vehicle Damage**
Michigan (Year: 2003)	1,800,000 (Year: 2002)	67,760	11	1,913	$115.2 mil
Wisconsin (Year: 2003)	1,663,000	21,666	13	792	$36.8 mil
Minnesota (Year: 2002)	1,140,000 (Year: 2003)	5,550	5	520	$9.4 mil
Illinois (Year: 2002)	750,000 (Year: 2002)	23,645	2	976	$40.2 mil
Iowa (Year: 2002)	210,000 (Year: 2000)	6,987	2	523	$11.9 mil
Total	5,563,000	125,608	33	4,724	$213.5 mil

*It has been estimated that the total number actual deer-vehicle crashes may be at least twice as large as those reported. In Minnesota it is believed to be three to four times as large as those reported. As expected, the number of unreported deer-vehicle crashes probably varies from state to state due to different reporting procedures, etc., and few states track the number of carcass collections. Minimum property damage crash reporting thresholds can also be different: $1,000 in IA, MN, and WI; $500 in IL, and $400 in MI. The number of reported crashes in Iowa is for animal collisions.
**Vehicle damage cost estimate based on just $1,700 per reported crash.

and enforcement priorities). Of course, there are also DVCs in which a deer leaves the roadway right-of-way, dies, and the carcass is never found.

Injuries, Fatalities, and Property Damage

DVCs do result in some injuries and rarely have a fatality as an outcome (although in 2003 Wisconsin experienced a double fatality DVC), but almost always produce vehicle damage. In 2003, 13 fatalities and 792 occupant injuries resulted from the 21,666 DVCs reported in Wisconsin. Eight of the 13 fatalities were motorcyclists. The number of fatalities and injuries related to DVCs in Wisconsin during the last 20 years is shown in Figure 1. Total vehicle property damage costs (ignoring medical treatment costs, lost work time, police officer time, environmental and hunting impacts, and several other intangibles) of the DVCs reported in Upper Midwest was roughly estimated at 213.5 million dollars. A value of $1,700 was used to calculate this estimate, and this is considered relatively conservative. Property damage costs for individual DVCs are often

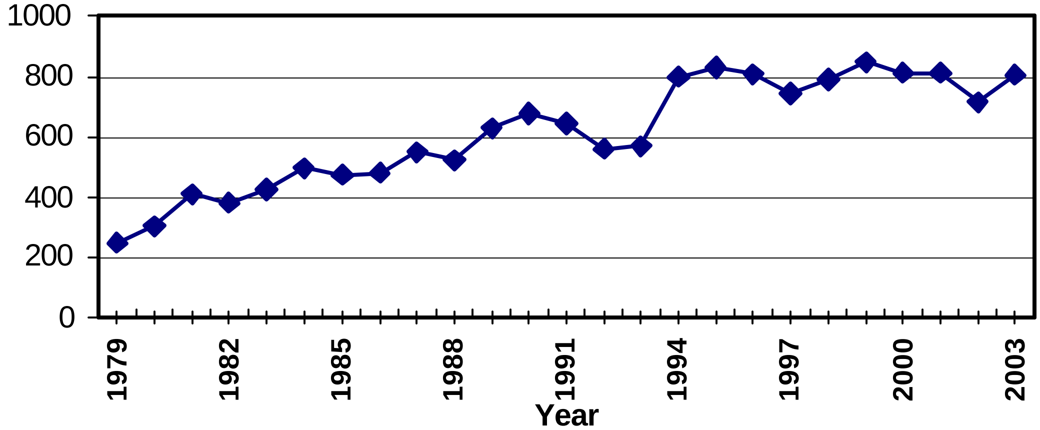

FIGURE 1 Wisconsin deer-vehicle crash fatalities and injuries (*2*).

much higher. The human, environmental, and economic impacts of DVCs are significant, and they are not expected to decrease as both vehicle-travel and the white-tailed deer population continue to increase.

TOOLBOX PURPOSE AND CONTENT

A number of DVC countermeasures or reduction methods have been proposed or implemented throughout the world. A primary objective of these countermeasures is to reduce the probability or likelihood of a DVC occurring along a roadway by influencing either the behavior of the driver or the animal. A significant amount of money is spent on the implementation of these countermeasures each year.

The purpose of this toolbox is to describe and discuss the current state-of-the knowledge related to 16 potential DVC countermeasures. Its content has several unique characteristics, and unlike previous summaries it is written from the point-of-view of a traffic operations and transportation safety researcher and analyst. It is also the opinion of the author that the level of detail provided is unlike any other general DVC countermeasure review document currently available. In addition, if a more detailed summary does exist for a specific countermeasure (e.g., repellents and wildlife crossings) their key findings are discussed and the document is appropriately referenced for the reader.

This toolbox provides the detail needed by the reader to clearly understand what level of knowledge exists with respect to the DVC reduction effectiveness of each countermeasure discussed. In possible, some of the key choices and concerns related to the implementation or application of particular countermeasures are also identified. This information should be useful to professionals that must currently make and defend decisions (given the current state-of-the-knowledge) about whether or not to implement one or more DVC countermeasures. The toolbox can also be used to identify the characteristics that should be the focus if and when a countermeasure is applied, and to better understand the complexities of the proper monitoring and evaluation plans needed for those that do implement DVC countermeasures. Finally, researchers can use this toolbox (and other DVCIC documents) to identify the gaps in the current state-of-the-knowledge that need to be addressed in order to effectively implement a countermeasure and properly understand its expected DVC reduction impacts.

This toolbox contains three levels of discussion. The executive summary contains a general description of what was found in the literature for a particular countermeasure. Chapter 2, on the other hand, includes a detailed description and review of the research that has focused on the countermeasures. Each of the countermeasure summaries in the chapter is written as a self-contained document with its own conclusions and references. Some of the countermeasures have been studied much more extensively than others. Chapter 3 contains conclusions about the status and value of existing and generally available research documentation about DVC countermeasure effectiveness.

Recommendations are also provided about how and what might be done to extend and expand the current state-of-the-knowledge in this area. The content of all three discussions should be used in combination by the reader to understand the current state-of-the-knowledge for a particular countermeasure, and to determine the transferability, validity, and general applicability of that knowledge to their particular situation. This toolbox should also be considered a living document, and if possible will be updated as appropriate (See www.deercrash.com).

DVC COUNTERMEASURE LITERATURE CATEGORIES

A significant amount of literature about DVC countermeasures and other DVC-related subjects was reviewed to create this toolbox. However, only a small amount of this documentation would be considered valid and repeatable research that might produce transferable countermeasure effectiveness results. This type of information was summarized in this toolbox if it was generally available for a particular countermeasure. In some cases, however, the level of knowledge, documentation, and literature for a particular countermeasure is much less valid (but may seem to be the current state-of-the-knowledge because it has been repeated numerous times during the last two to three decades).

In general, three types of literature on DVC countermeasures were identified as part of the activities related to the creation of this document. First, a large number of the documents and webpages related to DVC countermeasures are primarily anecdotal in nature when DVC reduction effectiveness is addressed (e.g., multiple oral testimonials). These sources of information typically did not include any formal scientific studies or surveys, experimental design, or data to support their conclusions. Another type of DVC countermeasure report or document that exists includes those that describe an organized study of one or more DVC countermeasures. For these types of studies, the characteristics of the experimental design (e.g., length of study period, statistical approach, and definition of the control and treatment study areas) are key to determining whether the approach has the appropriate rigor for the results to have widespread applicability. For this toolbox, it was found that many DVC countermeasure studies of this type had limitations on their usefulness and/or transferability, and their results needed to be understood in their defined context. It also requires the detailed documentation of the countermeasure study, and this may or may not exist. The study approach may also explain why studies of similar countermeasures produce contradictory results. As previously mentioned, this toolbox provides enough detail and discussion that the context of the results from many studies can be understood and used properly. The third type of report reviewed for this toolbox consisted of those well-documented (and sometimes peer-reviewed) studies of DVC countermeasure effectiveness. This countermeasure toolbox, to the greatest extent possible, focuses on the content of original documentation that is non-anecdotally based reports.

Many of the published studies of DVC countermeasure effectiveness were either completed several decades ago or relatively recently (in North America in any case). In fact, there are also several major ongoing and planned projects that won't be completed before this toolbox is completed. Interest in the proper investigation of DVC countermeasure effectiveness also appears to be gaining momentum. The results presented in this report also support the significant need for a more scientifically valid and quantitative evaluation of this type. Updates to the toolbox will be done as appropriate.

DVCIC BACKGROUND

In April 2000 a Deer Vehicle Collision Reduction Working Group Conference was held in Milwaukee, Wisconsin. The objective of this meeting was to develop a strategy for the reduction of DVCs and their severity within the Upper Midwest. The creation of a DVCIC was one of the recommendations proposed by the Working Group Conference attendees.

The DVCIC was initiated in July 2001 and is currently funded by the Wisconsin Department of Transportation. This countermeasure toolbox is one of the primary products of the DVCIC. The general focus of the DVCIC is the exchange, evaluation, and/or summary of the current state-of-the-information in the area of white-tailed deer and vehicle crashes (i.e., DVCs) in the Upper Midwest (i.e., Wisconsin, Illinois, Minnesota, Iowa, and Michigan). The stated objectives of the DVCIC include:

- The compilation of current DVC-related knowledge (e.g., a countermeasure toolbox);
- The development and promotion of standard DVC-related research, and DVC data collection and information management approaches;
- The collection, evaluation, and analysis of regional DVC-related data;
- The creation and/or update of a DVC-related data information system (e.g., the DVCIC webpage – http://www.deercrash.com);
- The distribution of useful DVC-related information/findings (e.g., a countermeasure toolbox; research reviews, conclusions, and recommendations; DVC-related data collection and estimation procedures, presentations, workshops, seminars, and a regional data summary); and
- A long-term contribution to the decrease in the frequency/severity of DVCs by providing useful information and monitoring.

Each of the five states included in the DVCIC has representation on its Technical Advisory Committee and Board of Directors. In addition, because the DVC issue has both transportation and ecology components, the technical committee includes representatives from the Department of Natural Resources and the Department of Transportation from each state. The webpage for the project is located at www.deercrash.com, and it includes this and other reports, links, and any updates that might be completed for the documents after they are printed.

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CHAPTER 2
COUNTERMEASURE SUMMARIES

The DVCIC staff has reviewed and summarized a significant amount of deer-vehicle crash (DVC) countermeasure literature (see toolbox bibliography) to complete the detailed summaries in this chapter. Documents also continue to be retrieved and reviewed as their existence becomes apparent. When necessary, and if possible, updates and addendums to this toolbox will be posted at www.deercrash.com. This website also contains a much longer list of DVC and DVC-related documents. The different categories of DVC countermeasure literature found during the creation of this toolbox were described in Chapter 1. If available for a particular countermeasure the content of this toolbox focuses on the evaluation results documented in governmental reports, peer-reviewed journals articles, and/or papers from professional society conference proceedings.

This chapter provides a detailed and realistic summary of the current state-of-the-knowledge with respect to the effectiveness of 16 individual DVC countermeasures. However, the amount and quality of the literature that exists for each potential DVC countermeasure varies dramatically. Each countermeasure discussion in this chapter has been written as an individual summary with its own introduction, detailed literature review, and conclusions. The length of each summary is related to the amount of information currently available and the complexity of the evaluations completed. DVC summaries for the following countermeasures are presented in this chapter:

- In-Vehicle Technologies;
- Deer Whistles;
- Roadway Lighting;
- Speed Limit Reduction;
- Deicing Salt Alternatives;
- Deer-Flagging Models;
- Intercept Feeding;

- Deer Crossing Signs and Technologies;
- Roadside Reflectors and Mirrors;
- Repellants;
- Hunting or Herd Reduction;
- Public Information and Education;
- Roadside Vegetation Management;
- Exclusionary Fencing;
- Roadway Maintenance, Design, and Planning Policies; and
- Wildlife Crossings.

The experimental design, results, and/or documentation of the studies summarized are evaluated with respect to accepted research practices, and their general usefulness, validity and transferability. In addition, if relevant and appropriate, information about the installation (e.g., physical characteristics) and maintenance of a countermeasure is discussed. The state-of-the-knowledge related to the DVC-reduction effectiveness of each countermeasure continues to evolve and slowly increase. Additional countermeasures are also constantly being suggested, and it is expected that the length of this list will increase as the use and evaluation of these measures is documented.

IN-VEHICLE TECHNOLOGIES

The availability of in-vehicle technologies that might help drivers avoid a deer-vehicle crash (DVC) has grown in recent years. The design details of these technologies vary, but the documentation reviewed indicates that most appear to combine sensing devices and displays. Their primary objective is to show the driver where an animal is located (i.e., enhance their vision), typically at night, far enough away to avoid a DVC. Some concerns do exist about the effect and usefulness of these devices as they are currently designed. There is the potential for false or multiple indications that could impact their effectiveness (e.g., much like false alarms from radar detectors). In addition, with the introduction of any new technologies that interface with the driver of a vehicle there are always concerns about driver compliancy, information overload, and/or distraction.

Literature Summary

Two in-vehicle "vision" systems have been deployed and others are being developed. Documented studies that evaluate the DVC reduction effectiveness of these specific devices and/or their interaction with the driver were not found. However, these technologies are new and limited in their use, and it is unlikely that a properly designed DVC reduction study have even been possible. It is expected that the viability of offering these technologies in vehicles (i.e., whether they would appeal to the consumer) has been studied by the manufacturers. For example, Honeywell™ and Raytheon Commercial Infrared™ have partnered to develop and market Bendix XVision™ (*1*). This infrared system is designed specifically for trucks and buses to improve driver night visibility (*1*). The Cadillac Night Vision™ system also uses infrared technologies to increase the night vision of drivers that have purchased the technology option (*2*). The cost of this option in a new Cadillac DeVille™ is currently about $2,250 (*2*).

Conclusions

No published studies were found that evaluated the usefulness or DVC reduction capabilities of these technologies. However, as previously mentioned, the application of these technologies in the general vehicle population is very recent and the ability to do this type of large-scale study probably has not been possible. The results from a DVC reduction evaluation of these technologies as they are used by a range of drivers would be of interest. Their potential to reduce the number of DVCs (if properly used) does exist. Currently, the cost of in-vehicle vision systems is high, but it may decrease if demand and competition increases.

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DEER WHISTLES

There are a number of deer-vehicle crash (DVC) countermeasure devices sold to the general public that indicate they use "ultrasonic" noise to alert deer to the approach of a vehicle. These devices are commonly referred to as "deer whistles". Deer whistles have existed for a relatively long time (they were introduced in the late 1970s) and have even been distributed to drivers by some insurance companies for a reduced fee rate.

The primary objective of deer whistle devices is to alert a deer by producing a noise that draws their attention and reduces the risk of a DVC occurring (e.g., the deer freezes or flees). The manufacturers of these devices, for the most part, indicate that they produce ultrasonic noise in the range of 16 to 20 kilohertz (kHz). The devices reportedly produce this noise (which is outside the range of human hearing) as air passes through them. Typically, the manufacturers indicate the device operates on vehicles traveling 30 miles per hour (mph) or faster, and that the ultrasonic noise can be heard up to about a 1/4-mile. More recently, some noise-related devices have also been introduced, but are not air-activated. These devices are electronically powered and can be designed to produce the manufacturer specified level of noise at any vehicle speed. No studies or independent analysis of just electronic devices was found in the literature. A few studies, however, were discovered that considered the effectiveness of air-activated deer whistles and the hearing capabilities of deer (*1*, *2*, *3*, *4*, *5*, *6*, *7*). One of these studies also included electronic whistles, but the possible difference in effectiveness between them and air-activated whistles was not the focus of the investigation (*3*). These studies are discussed in the following paragraphs.

Literature Summary

The DVC reduction effectiveness of deer whistles has not been vigorously studied. Much of the literature reviewed consisted of non-scientifically defined anecdotal evidence as its basis for an effectiveness discussion. However, there have been some very specific declarations made about the DVC reduction effectiveness of deer whistles based on this type of approach. The scientific validity of this type of claim was considered questionable by the authors of this toolbox and they are not repeated.

Another method that has been used to evaluate the effectiveness of deer whistles appears to include the comparison of safety or crash data for a group of governmental agency vehicles (typically one to several hundred) before and after the device was installed. Typically, the time period considered before and after the devices were installed was months, years, or not documented. A general discussion of the results from these types of studies is briefly described in the following text. The primary weakness of this research is typically the small sample size, length of time period considered, and general lack of control comparison.

Published documents that focus on the effectiveness of deer whistles and also describe the study design and results were found in only a few instances. These studies are discussed in this summary. An analysis that considers the hearing capabilities of white-tailed deer is also summarized.

Before-and-After Evaluations

Some before-and-after studies have attempted to evaluate the effectiveness of air-activated deer whistles. The details of few of these studies have been properly documented. One study in Onodaga County, New York was documented (*1*). The Sheriff's Department in the county mounted deer whistles on 55 patrol cars (*1*). The documentation for the devices indicated that they were supposed to activate at vehicle speeds above 30 mph and be heard by animals at a distance of 400 yards (*1*). In an October/November 1988 newsletter article about the devices it was reported that only two patrol cars had struck deer since 1986 and that five others had sustained minor damage avoiding collisions with deer (*1*). Before the installation of the devices the county sheriff's department experienced about 10 DVCs each year (*1*). It was suggested by the author of the newsletter article that the whistles need to be checked often so that they did not become plugged, and that extra caution needs to be used in areas with vertical and horizontal roadway curvature because the noise might not propagate well in these areas.

The results from an analysis of the fleet vehicle whistle experience at the Idaho National Engineering and Environmental Laboratory have also been documented (*2*). This article indicated that the laboratory fleet experienced no crashes during the five years after the device installation, but had an average of 17 per year before the devices were installed (*2*). The authors of this study also acknowledged that conflicting results had been produced by studies that focused on the effectiveness of these devices (*2*). The typical variability in the number of DVCs experienced by the governmental agencies and/or the general public was not addressed in either document.

On a larger scale, several different types of air-activated and electronic deer whistles were provided free of charge to 1,648 drivers of Modoc County, California (*3*). The whistles were distributed to people that responded to the newspaper advertisement, and their license plate numbers recorded (*3*). The drivers were responsible for whistle installation and maintenance, but the adequacy of these activities was not confirmed (*3*). From 1998 to 2000 it was indicated that about 23 percent of the reported collisions in this county were animal related (primarily mule deer) (*3*).

A statistical analysis was used to compare the 2001 and 2002 actual and expected number of DVCs for the 1,648 vehicles with whistles (*3*). Assuming that every vehicle in the county had an equal chance of being involved in a DVC, it was determined that the vehicles with whistles should have experienced a total of six DVCs (*3*). However, no DVCs actually occurred (*3*). This difference was determined to be statistically significant by the authors of this report, and they believe the whistles were the reason for this reduction (*3*). No discussion of the natural variability in DVCs in the area was addressed. A similar approach was taken to compare the DVC involvement rate of vehicles with and without whistles to the crash patterns that occurred before the whistles were distributed. Not surprisingly, the same conclusion was reached with respect to the effectiveness of the whistles (*3*).

The authors of the Modoc County study document, however, recognized that several factors weakened the validity of these results (*3*). These factors include the small number of DVCs that occurred during the two years of the study and the impact of characteristics outside the control of the researchers (e.g., severity of the winter and number of mountain lions) (*3*). Additional concerns with the results include the inherent assumption that all vehicles have the same probability of being involved in a DVC, and that the whistles were all installed and maintained adequately throughout the study time period. It might also be argued that drivers who take advantage free whistles are especially aware of the DVC problem, and this could impact the results of this study. These confounding factors limit the validity, transferability, and usability of the results from this study (despite the large number of vehicles involved).

In contrast, the Insurance Institute for Highway Safety also published a status report in which it reviewed at least two studies that appeared to produce the opposite result of those indicated above (*4*). First, an article from the mid-February 1993 *Farm Journal* was reviewed that stated the Ohio State Police, after installing deer whistles on their patrol vehicles, did not experience a DVC reduction (*4*). In addition, it was also stated that the Georgia Game and Fish Department had not observed, during hundreds of encounters, any deer response to vehicles with deer whistles installed (*4*).

Device Effectiveness

During January/February 1990, Romin and Dalton studied the response of mule deer to vehicle-mounted deer whistles (*5*). Two brands of air-activated whistles were separately mounted to the front of a truck and their impact evaluated on wild mule deer. These whistles had what were considered to be typical manufacturer specifications (i.e. it was expected they would produce an ultrasonic sound of 16 to 20 kHz at vehicle speeds greater than 30 mph, and that could be heard by deer at or closer than 1/4-mile or 400 yards). The study was conducted along a 6 mile segment of dirt roadway in the Gordon Creek Wildlife Management Area of Carbon County, Utah (a winter range for mule deer). The impact of each whistle was tested by driving the test truck in both directions at 40 mph past groups of deer within 62 feet of the roadway. The first pass drive by of the vehicle was completed without whistles to acclimate the deer to the truck noise, and to get a better idea of how the responses changed with the addition of the whistle. The second drive by of the vehicle, in the opposite direction, was competed with the whistles. The response of the deer, and their distance to the vehicle was recorded for each pass. A response by a group of deer was considered equal to one of them lifting its head, changing its orientation, running away from the truck, or running toward the truck (*5*).

A total of 300 observations were made on 150 deer groups as part of this study (*5*). As indicated, half of these observations were for the vehicle with no whistle, and the other 150 observations were split almost equally between the two whistle brands being evaluated (i.e., one was tested 76 times and the other 74 times). Table 1 shows the observed deer response to the truck with and without the whistles. Overall, approximately 61 and 69 percent of the deer did not respond to the vehicle either with or without the whistle mounted, respectively. In other words, fewer deer responded to the vehicle with the whistle (31 percent of the total) than to the vehicle without the whistle (39 percent of the total). The expectation would be that the deer would acclimate themselves to the vehicles and the difference in reaction would be the result of the whistle if the deer could hear it.

TABLE 1 Whistle and No Whistle Responses of Free-Roaming Mule Deer Groups (*5*)

	Behavior				
	No Response	**Lifted Head**	**Changed Orientation**	**Ran Away**	**Ran Toward**
No Whistle	91	31	5	18	5
Whistle	103	28	3	9	7

The number of responses from deer groups within 6 feet of the roadway is shown in Table 2 (*5*). The authors more closely considered these deer groups because it was speculated that they would have the most probability of causing a collision. The response/no response results for the vehicle passes with and without the whistle follow a pattern similar to those shown in Table 1 for the entire sample. In general there were fewer responses to the vehicle with the whistle than without.

The authors of this study concluded that the mule deer response to a vehicle without a whistle was not statistically different than those with a whistle (*5*). However, the study

TABLE 2 Mule Deer Response Observation within 6 Feet of the Vehicle (*5*)

	BEHAVIOR	
	Response	**No Response**
Without whistle	18	12
With Whistle	14	14

did not test whether the mule deer can hear within the specified noise range of the devices, or if the devices were actually making that specified noise.

Deer Auditory Capability Study

The effect of deer whistles on the number of DVCs is dependent upon the ability of deer to physically hear and respond to the sound produced by the devices. As previously mentioned, the advertised range of the sound produced by air-activated deer whistles is typically 16 to 20 kHz at speeds at or above 30 mph. In 1993, the Insurance Institute for Highway Safety (IIHS) summarized a number of studies that considered the auditory capabilities of deer (*4*). The article stated that wildlife biologists at the University of Georgia had found that neither deer nor humans could hear these ultrasonic sounds, and that whistles blown by mouth produced no response from penned deer. The IIHS summary also indicated that University of Wisconsin researchers had found that the whistles produced low-pitch and ultrasonic sounds at 30 to 70 mph, but that no response from deer was observed. Published documentation of these studies that describes their experimental design and how the deer response was measured were not found.

Fortunately, a document was also found that included a description of some work that compared deer hearing capabilities to the sound made by typical deer whistles (*6*). The physical characteristics and impact on sound projection of the roadway environment (e.g., vehicle noise and lessening of sound through air) were also investigated (*6*). Scheifele, et al. tested six deer whistle devices in the laboratory and/or the field. All the devices were generally advertised as "ultrasonic" (i.e., producing a sound with a frequency greater than 20 khz) devices, but the packages of two devices also indicate that they produced sound frequencies between 16 and 20 kHz sound when mounted on vehicles driven at 30 mph or more (*6*). The sound made by the other whistles was only described as high frequency (*6*). It was stated that the devices could be heard by deer that were anywhere from 62 feet to 1.2 miles (100 meters to 2 kilometers) away from the roadway. The objective of the study was to determine the most commonly produced frequency of the deer whistles and compare them to the reported hearing capabilities of deer. The relationship between the roadway environment and the noise produced by the devices at certain distances was also investigated (*6*).

All six whistles were tested in the laboratory and the two that produced the highest intensity sound in the laboratory were then tested in the field (*6*). The laboratory tests included the forcing of air through the six whistles until a strong sound was "heard" and measured (*6*). In the field, the two devices that produced the highest intensity sound were then mounted on two cars that were driven at 30 mph, 35 mph, 40 mph, and 45 mph. The sound intensity of the whistles was recorded 10 times for each speed from a single point on the closed roadway. In both cases, the ambient room and roadway (without the vehicle) noises were first measured. The measurement results included the most common sound frequency and intensity, and the variation in the signal at each speed (*6*). Typical vehicle and roadway noise levels were estimated from previous research.

Overall, the hearing capabilities of deer have not been studied to any great extent. However, past research used by Scheifele, et al. for comparison purposes indicated that the "range of greatest hearing sensitivity" for deer is between two and six kHz (*6, 7*). In the Scheifele, et al. study deer whistle effectiveness was determined by comparing the most commonly measured frequency and intensity with this deer threshold hearing range. Overall, it was found that the primary operational frequency produced by the different whistle designs was 3.3 kHz (closed end design) and 12 kHz (open end design) (*6*). In the latter case, the results were found to vary and also depend on how hard the air was forced through the device. Clearly, the results of the laboratory tests do not match the frequencies typically advertised as those produced by the deer whistles. The 16 to 20 kHz sound range advertised for two of the air-activated whistles is also outside the "best" range of deer hearing capabilities.

Scheifele, et al. concluded that the harmonics of the devices they studied were not likely to be heard by deer unless they were broadcast at very high intensities (*6*). The 12 khz whistles produce a sound that is outside the "best" hearing range of deer, and the average sound pressure levels for the 3.3 kHz whistles was also "totally lost" within the noise past research has indicated is produced by a vehicle on the roadway at 40 mph (*6*). In addition, a frequency of 3.3 kHz should also be heard by both the deer and humans, but in these tests the drivers did not notice the whistle noise. The sound from the devices also has to be heard far enough away from the vehicle to allow a proper reaction by the deer.

The results from Scheifele, et al. show that the range (based on research-based assumptions of transmission loss and ambient roadway noise levels) of a device operating at 3.3 kHz would probably reach a "significant warning distance" equal to the maximum they considered (i.e., 1.3 miles). This assumes, however, that the deer can hear and differentiate the device alert sound from the others that exist (e.g., vehicle roadway noise (see above) and wind). It was indicated, for example, that deer favor low frequency signals more than ultrasonic noise, and that the wavelength of signals that impact animals should be at least two to four times their body size (*6*). The 3.3 kHz signal measured had a wavelength of only about 4 inches (*6*). Deer will also typically focus on the closest sound, but Scheifele, et al. indicate that very little noise normally exists in the one to four kHz range in the wild, so the use of a 3.3 kHz device could be a good level to be heard by deer. Overall, it appears that the physical characteristics of the roadways limit the capabilities of deer whistles as alert devices. In addition, the researchers also indicate that there is a likelihood that the deer that feed near roadways will habituate to both the sound of the vehicles and that of the alert devices if they are heard (*6*).

Conclusions

The DVC reduction effectiveness of air-activated deer whistles has been investigated through the use of non-scientific before-and-after studies and some documented research into the hearing capabilities of deer. In general, the relatively poor design and/or documentation of the before-and-after studies (e.g., sample size) have produced dramatically conflicting results. No conclusions can be drawn from these studies as a whole, and better designs and documentation are recommended for future studies of this nature. A small amount of documented/published research has been completed in the area of deer auditory capabilities and their reaction to air-activated whistles. For the most part, it has been found that the range of hearing sensitivity for deer is two to six kHz, and only some whistles apparently make sound within that range. It has also been generally concluded that deer did not react to vehicle-mounted air-activated deer whistles, and that hearing the sound from these devices might be difficult when combined with typical vehicle roadway noise levels. The ability of whistles to produce the advertised level of sound at an adequate distance within the typical environment of a roadway has been questioned. Additional scientifically defined and designed research focused on the effectiveness of air-activated deer whistles and similar non-air-activated devices is recommended. A current concern is also the impact the installation of these devices (which may or may not work) on vehicles may have on the alertness of drivers (i.e., Do they provide an unproven sense of security?).

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ROADWAY LIGHTING

There have been a number of studies done about the effect of roadway lighting, but little research has focused on its deer-vehicle crash (DVC)-reduction potential. Most DVCs occur in the evening, night, and early morning hours, and it has been proposed that roadway lighting would improve driver visibility and their ability to avoid a DVC. In fact, literature reviewed by Reed, et al. revealed that 92 percent of 1,441 deer kills on Colorado roadways occurred between 5:00 PM and 9:00 AM (*1*). The most active time for white-tailed deer (to forage and feed) overlaps with the time of minimum driver visibility.

Literature Summary

Only one study was found that evaluated the DVC-reduction effectiveness of roadway lighting (*1*, *2*). The researchers involved with this study had reviewed previous research and found that urban roadway lighting appeared to reduce the occurrence of vehicle-pedestrian crashes, and that the factors in that type of crash were similar to those of a DVC (*1*). Based on that review, Reed, et al. decided to evaluate the effect roadway lighting might have on the number of DVCs, deer crossing patterns, and on motorist behavior (*1*, *2*).

Study Design

The roadway test section for the Reed, et al. study was a 0.75-mile (1.2 kilometer (km)) section of State Highway 82 south of Glenwood Springs, Colorado (*1*). Along this section of highway, 13 clear mercury vapor lamps (37,000 lumens, 700 watt) were installed on poles 12.2 meters (40-feet) high. Nine of the lights were evenly spaced along a 0.3 mile (0.5 km) section of the highway test area, and two of the remaining four lights were each placed on the ends of the 0.75 mile (1.2 km) segment (outside the full lighted 0.3 mile (0.5 km) section) to act as transition lighting (*2*). After the installation of the lights, horizontal illumination levels were measured to determine uniformity in the lighting pattern along the roadway segment of interest (*1*).

The impact of the lighting was studied by turning them on and off for one-week periods from January to April between 1974 and 1979, and collecting DVC information, an estimated number and location of deer crossings, and vehicle speed data (*2*). The length of the test period was chosen to help reduce the impact of the annual and monthly variations observed in the data collected (*2*). During the study time period the location of each DVC was recorded along the study segment, and the number of deer crossings estimated by nightly spotlight counts, observations, and track counts (*2*). Deer were also captured and tagged to supplement and improve the crossing estimates (*2*). The effect of lighting on the pattern of deer crossings was studied by comparing their location along the roadway section during one to two hour evening time periods (i.e., a time of peak deer crossing and traffic volume) with and without the lights (*2*).

The effect of roadway lighting on motorist behavior was also studied by comparing the average of 80 vehicle speeds from 35 nights for similarly lighted and unlighted time periods and locations (within the defined study roadway segment). In addition, vehicle speeds were collected and compared from March 3, 1975 and March 17, 1975. The highway lighting was on for both data collection time periods, but in one case a taxidermy-mounted mule deer was placed in the emergency lane of the roadway (*2*).

Study Results

The number of estimated deer crossings, observed DVCs, and calculated crossings per DVC are shown in Table 1. However, no DVCs occurred along the roadway test section during the 1976 and 1977 study time periods, and these two years were removed from the Reed, et al. evaluation (*1, 2*). During the remaining four years there were 2,480 estimated deer crossings with the lights off and 2,611 with the lights on along the roadway test section (*2*). Table 2 also shows that 384 and 269 of these crossings, respectively, occurred in the transition area of lighting. In addition, despite the increase in deer crossings there were a total of 45 DVCs that occurred when the lights were off and only 39 when the lights were activated. The number of crossings per crash, therefore, decreased from 66.9 to 55.1 (See Table 1) (*2*). In other words, the number of crashes per

TABLE 1 Estimated Deer Crossings, Number of Crashes, and Deer Crossings per Crash (*2*)

	Estimated Deer Crossings		Number of Crashes		Crossings per Crash	
Year	**Lighting Off**	**Lighting On**	**Lighting Off**	**Lighting On**	**Lighting Off**	**Lighting On**
1974	600	502	9	4	66.7	125.5
1975	963	1,118	9	13	107.0	86.0
1978	177	250	5	4	35.4	62.5
1979	740	741	22	18	33.6	41.2
Total	2,480	2,611	45	39	55.1	66.9

TABLE 2 Estimated Number and Location of Deer Crossings (*2*)

	Number of Deer Crossings		
Year or Lighting Status	**Transition Ends***	**Within Full Light Segment**	**Transition/Within Crossing Ratio**
1974 to 79	653	5,091	0.13
Lights Off	384	2,480	0.15
Lights On	269	2,611	0.10

*Transition roadway length at each end of lighted area.

crossing was about 18 percent lower when the lights were activated along the roadway test section. Reed, et al. concluded that this difference was slight (*2*).

Reed, et al. also concluded that the roadway lighting did not appear to have an effect on the location of the deer crossings along the roadway segment (See Table 2) (*2*). The ratio of transition lighted to fully lighted deer crossings with and without the roadway lights activated ranged from 0.10 to 0.15 (See Table 2) (*2*). Reed, et al. concluded that the difference in the ratios was not significant (*1*, *2*). It is assumed by the authors of this document that this conclusion may be based on the fact that it was believed that these results fell within the natural variability of deer crossing numbers and locations. For example, the ratio described was twice as large during the two years before the study. The apparent variability in this type of data makes an interpretation of these results difficult. In general, however, the pattern of the crossing within the transition and fully lighted segments were similar whether the lights are on or off.

The study of mean vehicle speeds showed an average speed of 49.2 miles per hour (mph) (79.3 kilometers per hour (kph)) southbound and 49.5 mph (79.8 kph) northbound with the lights off (*2*). The mean vehicle speeds with the lighting activated were 49.4 mph (79.7 kph) southbound and 49.1 mph (79.2 kph) northbound. Not surprisingly, Reed, et al. concluded that mean vehicle speeds were not affected by the existence of lighting along a roadway (*1*, *2*). When a taxidermy-mounted deer was placed in the emergency lane of the roadway, however, there was an 8.3 mph (13.9 kph) reduction observed in the average vehicle speed (*1*, *2*). But, recall that this reduction information is based on the average speed from only one night. The addition of the mounted deer on the roadway was considered too much of a risk to vehicle safety for the continuation of this part of the study (*2*).

Conclusions

The Reed, et al. study was the only one found that attempted to directly relate the existence of roadway lighting to a reduction in DVCs. This study also investigated any changes in deer crossing patterns and average vehicle speeds that might occur with the addition of lighting. Reed, et al. concluded that the addition of lighting did not have an impact on DVCs, deer crossing patterns, or average vehicle speeds (*1*, *2*). They made this conclusion despite the fact that a reduction in the number of crashes per deer crossing appeared to decrease by about 18 percent with the addition of lighting along the roadway test segment. It is assumed by the authors of this review that Reed, et al. believed this to be within the normal variability of the data evaluated. The addition of a taxidermy-mounted full-size deer in the emergency lane did produce a reduction in average speed of about 8 mph (13 kph) when the lights were activated. However, not enough speed data was available to validate these results or determine whether this approach would have speed choice impacts in the long term. This approach to vehicle speed reduction (which may or may not equate to DVC reductions) in areas with a DVC problem shows some potential, but would need to be considered further in a more controlled environment. The addition of deer silhouettes on the roadside has been considered elsewhere and is discussed in another countermeasure packet.

Overall, the use of lighting as a DVC reduction measure would be extremely expensive if applied uniformly and not focused on specific locations. Additional research is needed to evaluate its effectiveness as a DVC-reduction tool. Future research in this area should also consider how the magnitude and variability of a moving target (e.g., deer) luminance appears to and impacts driver visibility of that target. The foreground and background lighting situation should also be consistent with actual normal roadway lighting. Non-uniform lighting might, in theory, have less of an impact on the number of DVCs along a roadway segment than shown in this study.

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SPEED LIMIT REDUCTION

A reduction in the operating speed of a vehicle can provide a driver with additional time and distance to react to observed conflicts. The benefits provided by additional reaction time/distance (due to vehicle speed reductions) are relatively clear for a driver approaching a stationary object in the roadway. There is more time and distance to see the object and stop or adjust the speed of the vehicle. Additional time to observe and judge the speed of a conflicting object traveling at a relatively uniform speed (e.g., other vehicles) is also beneficial. The advantages produced by a general decrease in posted speed limits on the number of deer-vehicle crashes (DVCs), and/or the ability of a driver to avoid a less predictable moving object (e.g., a deer), however, are much less clear.

A number of jurisdictions and projects have implemented, considered, and/or proposed reductions in posted speed limits as a potential DVC reduction method. The following paragraphs include a summary of the documented results from two studies that focused on the apparent relationship between lower posted speed limits and collisions between vehicles and animals.

Literature Summary

Several project and research reports have suggested a reduction of posted speed limits as a mitigation measure for animal-vehicle crashes (*1, 2, 3, 4, 5, 6*). In many cases, however, a reduction in the posted speed limit was suggested or proposed as one of several measures. Then, if a crash reduction was observed, the general conclusion was that the reduced speed limit had contributed in some manner. The implementation of multiple reduction measures, however, typically did not allow the direct impact of a speed limit reduction to be quantified.

Few research projects have specifically considered an evaluation of how much (if any) vehicle-animal crash reduction might result from a lower speed limit. Only two studies were found that attempted to investigate the direct impact of reduced posted speed limits on animal-vehicle collisions (*7, 8*). These two studies primarily focused on the correlation between posted speed limits and the collisions between vehicles and bighorn sheep and/or elk (*7*, *8*). No studies were found that focused on the impact of the reduction in posted speed limits on the number of crashes between vehicles and white-tailed deer.

Yellowstone National Park Study

In 1997, researchers in Yellowstone National Park (YNP) studied a number of factors that they believed had an impact on the number of vehicle-wildlife collisions (*7*). Two of the factors studied were posted speed limit and average operating vehicle speed (*7*). At that time, YNP had approximately 268 miles of paved roadway with six posted speed limits (*7*). The length of roadway with each posted speed limit included:

- 1.1 miles at 15 mph,
- 18.6 miles at 25 mph,
- 24.9 miles at 35 mph,
- 24.5 miles at 40 mph,
- 178.3 miles at 45 mph, and
- 20.2 miles posted at 55 mph.

From July to October 1997 the operating speeds along the 15 primary paved roadway segments in YNP were collected. These speeds were collected with a radar gun at different times of the day, and by timing vehicles over a known distance (*7*). The timing methodology for the collection of vehicle speeds was primarily used along straight segments of roadway. About 450 of the more than 1,400 vehicle speeds collected were calculated from the results of the timing method (*7*).

Each large mammal roadkill location was also collected along the roadways in YNP, and then categorized by the posted speed limit of the segment. From 1989 to 1996 there were 939 large mammal roadkill locations identified (*7*). The roadkills observed included 14 species of animals. About 40 percent of the roadkill was elk and 30 percent were mule deer (*7*). The number of bison, moose, and coyote killed on the roadway during this time period each represented about 7 to 8 percent of the total (summing to around 23 percent) for the eight years considered (*7*). The other species that were killed by vehicles all individually represented less than 2 percent of the total killed between 1989 and 1996 (*7*). This group of animal species included white-tailed deer. About 85 percent of the vehicle-animal crashes were split about equally between the roadway segments with 45 mph and 55 mph posted speed limits (See Table 1) (*7*). The researchers also collected information about vegetation cover adjacent to the roadway and the large mammal populations within YNP.

Table 1. Proportion of Total Roadkill and Roadway Mileage (1989-1996) (*7*)

Speed Limit (mph)	Miles of Roadway	Percent of Total Roadway Mileage	Number of Roadkills	Percent of Total Roadkills
15	1.1	0.4	3	0.3
25	18.6	7.0	42	4.5
35	24.9	9.3	59	6.3
40	24.5	9.2	35	3.7
45	178.3	66.6	418	44.5
55	20.2	7.5	382	40.7
Total	267.2	100.0	939	100.0

Overall, the YNP researchers concluded that vehicle speed was significantly related to collisions between vehicles and wildlife (*7*). This conclusion was based on a statistical comparison of the proportion of vehicle-animal collisions that occurred along roadway segments with specific posted speed limits, and the proportion of roadway mileage represented by this speed limit within YNP (See both in Table 1).

The researchers analysis of these proportions indicated that there were statistically more than the expected number of vehicle-animal collisions within the roadway segments posted with a 55 mph speed limit, and a statistically less than expected number within those segments at 45 mph or less (*7*). These conclusions were statistically significant at a 90 percent level of confidence. Overall, about 41 percent of the roadkill recorded did occur along the roadway segments with a 55 mph posted speed limit, but these segments only represented about 8 percent of the roadway miles in YNP (See Table 1) (*7*).

The average operating speed measured along the roadway segments with a 55 mph posted speed limit were about 9 to 16 mph higher than that posted (*7*). The operating speed measured along those segments with a 35 and 45 mph posted speed limit, however, were within one to three mph of that posted (*7*). The researchers concluded that the design of the roadway (versus the posted speed) had the largest impact on speed (*7*). This result is generally supported by past transportation research, and is related to driver expectations, topography, and a number of other factors. The vehicle speeds measured for this study, however, also imply a relatively large difference in the designs for the 55 mph roadway segments and those segments with lower posted speed limits within YNP. No speed results were documented for the segments with 15 or 25 mph posted speed limits.

The researchers involved with this project also concluded that pavement condition had a great impact on vehicle speed choice (*7*). They supported this and their roadway design conclusions by measuring the apparent speed impacts of one reconstruction project, and comparing the animal-vehicle crashes before and after two other reconstruction projects.

An increase in the average operating speed of about 5 mph was found when one roadway segment cross section in YNP was improved from 22 to 24 feet wide (with abrupt edges, no shoulders, and very poor pavement) to 30 feet wide with shoulders and new pavement. Assuming this type of increase would occur with all similar roadway improvements, the researchers considered the roadkill numbers along two other segments that were reconstructed. The results of this analysis produced some conflicting results. One roadway segment was repaved and there was an annual average of 7 vehicle-animal collisions in the three years before the project, but 13 collisions on average for each of the four years following (*7*). This change was found to be a statistically significant. The other repaved roadway segment, however, showed no statistically significant change in animal-vehicle crashes (*7*). There was no documentation or speculation about why these two roadways segments (and surrounding ground cover) may have produced these results.

Based on their data collection and analysis the YNP researchers recommended that roadway designs be used that encourage vehicle speeds of 45 mph or lower (e.g., narrow pavement width, tighter curves) (*7*). They believed these designs would reduce operating speeds and ultimately the number of vehicle-animal collisions. They also felt this approach was consistent with the mission and mandate within YNP. In areas where faster speeds were considered necessary the researchers suggested that fencing and underpasses might be an option.

From the other information collected as part of this study the researchers also concluded that antelope, bison, coyote, and elk were killed significantly more than expected (when comparing roadkill proportions to the proportion of adjacent forest and non-forested land) in non-forested land (*7*). Not surprisingly, this is also where the food for these animals also exists. Mule deer, on the other hand, were hit at less than expected levels in non-forested areas and more than expected in forested areas (*7*). Moose were killed along the roadways in the same proportion as the existing forested and non-forested land use (*7*). It was also found that those species with the largest populations were also involved in the most vehicle-animal collisions (*7*).

Jasper National Park Study (Alberta, Canada)

The animal collision reduction impact of reduced speed limits was also studied along the Yellowhead Highway in Jasper National Park – Alberta, Canada (*8*). The highway consists of two 13.3-foot (3.7 meter) lanes and 10.8-foot (3 meter) paved shoulders. In 1991 the posted speed limits were reduced along three sections of this highway from 55 mph (90 kilometers per hour (kph)) to about 42 mph (70 kph). The number of vehicle collisions with bighorn sheep and/or elk was then compared for specific time periods before and after the posted speed limit change (*8*). The three segments selected for this study were chosen because of the number of bighorn sheep, elk, and/or mule deer collisions that had occurred along them, and their traffic and/or pedestrian flow. Overall, however, it was found that the traffic flow along each of the segments was similar, and that the design of the roadway provided good driver visibility (i.e., most of the roadway has passing sight distance available). The three sections of roadway selected (approximate length of 2.5 miles (4 km), 1.5 miles (2.5 km), and 5.6 miles (9 km)) were posted as "Slow Down for Wildlife" speed zones with wildlife crossing warning signs and a lower posted speed limit (*8*). There are similar signs along the Yellowhead Highway, but the posted speed limit is not normally reduced. The vehicle operating speeds measured along two of these selected speed reduction roadway segments indicated that between 73 percent and 89 percent of the vehicles traveled at 55 mph (90 kph) or less in the posted 42 mph (70 kph) speed limit segment (*8*).

The number of bighorn sheep-vehicle and elk-vehicle collisions that occurred along the three speed reduction roadway segments was collected for 8 years before and after (1983 to 1998) the posted speed limit reduction. In addition, the elk population adjacent to the Yellowhead Highway was estimated from aerial and roadside counts. From 1983 to 1998 the population of the elk increased by approximately 132 percent (*8*). The greatest increase (about 178 percent) appeared to occur adjacent to the 5.6 mile (9 km) "Slow Down for Wildlife" speed zone considered in this study (*8*). This zone experienced an elk presence on a seasonal basis, and was adjacent to an area where a permanent elk herd presence existed. The bighorn sheep population in the park area was believed to be relatively stable or experiencing a small increase (*8*). In general, the researchers indicated that these bighorn sheep were randomly distributed on five rock outcroppings adjacent to the park roadways throughout the day. Three of these rock outcropping were within the two of the roadway segments selected for study.

The Jasper National Park researchers found that the number of bighorn sheep-vehicle collisions increased only slightly (82 before the change and 83 after) in the two speed reduced (42 mph (70 kph)) segments considered for this type of collision (*8*). This small increase occurred despite the fact that vehicular flow increased by 50 percent during the study time period, and the number of bighorn sheep-vehicle collisions decreased by 33 percent (30 before the change to 20 after) along the 55 mph (90 kph) posted speed limit segments adjacent to the "Slow Down for Wildlife" zones (*8*). The study documentation, however, did not indicate the length of the 55 mph (90 kph) roadway segments considered. An analysis of variance calculation by the researchers caused them to conclude that there appeared to be a relationship between *increases* in bighorn sheep-vehicle collisions and the reduction in posted speed limit (*8*). A more general and non-statistical evaluation of the overall study time period bighorn sheep-vehicle crash data trends, however, indicated (according to the researchers) that the number of bighorn sheep-vehicle collisions in the 42 mph (70 kph) zones appeared to be increasing before the posted speed limit reduction, but generally decreased after the change (*8*). The collision trends in the 55 mph (90 kph) zones appeared to be relatively stable throughout the study time period (*8*).

The Jasper National Park researchers believed that the behavior of the bighorn sheep may have negated the impact of the slower speed limits (*8*). They found that most of the bighorn sheep-vehicle crashes recorded in the area occurred during the day, that the sheep became habituated to the traffic, and that they would remain in the roadway as a small herd even as vehicles tried to move along the roadway. It was speculated that bighorn sheep could be easily seen and avoided in the day, and that the reduction in vehicle speed (and increased congestion) which occurred because of the herds in and adjacent to the roadway, may have resulted in the observed patterns of the bighorn sheep-vehicle collisions in the time period considered.

Data restrictions allowed the evaluation of elk-vehicle collisions within only one of the speed reduction segments selected. Based on the documentation reviewed, it appears that the effectiveness of the speed reduction was measured by a statistical comparison of the number of elk-vehicle collisions that did occur to the number of expected collisions (*8*). The number of expected elk-vehicle collisions was calculated from crash data collected within a 13-mile (21 km) 55-mph (90 kph) segment of roadway surrounding the reduced speed study segment. This 13-mile (21 km) roadway segment, along with the 5.6-mile (9 km) speed reduction segment of interest, experienced about 79 percent (315 of 398) of the vehicle-elk collisions observed between 1983 and 1998. Elk-vehicle collisions per mile (km) increased by 84 percent within the 13-mile (21 km) roadway segment posted at 55 mph (90 kph), but by only 24 percent along the 5.6-mile speed reduction segment posted at 42 mph (70 kph) (*8*). The authors observed that the general trend in elk-vehicle collisions also appeared to show an increase in the number of crashes along the entire segment before the posted speed limit reduction, but a general decrease in 42 mph (70 kph) segment after the change (*8*). The authors concluded that a statistical association existed between the 42 mph (70 kph) speed reduction zone and a reduction in elk-vehicle crashes along the segment considered (*8*). In other words, decreasing the posted speed limit had a significantly negative effect on the number of elk-vehicle collisions that occurred (*8*).

Conclusions

It has been suggested by the researchers of the two studies summarized in this document that there is a relationship between animal-vehicle collisions and posted speed limits. In some cases, but not all, their research appears to show a less then expected number of animal-vehicle collisions along roadway segments with lower posted speed limits. One study statistically compared the proportion of roadway mileage with a particular posted speed limit to the proportion of animals killed along those segments. The other study compared the frequency of animal-vehicle collisions and animal-vehicle crashes per roadway length before and after a posted speed limit change. No studies were found that focused on the number of white-tailed deer-vehicle crashes and posted speed limit. However, the results of the two studies summarized indicate that the potential impact of speed reductions on animal-vehicle crashes could depend on the species considered. Several other limitations to the results presented in this summary are discussed below.

Overall, like the analysis of many other animal-vehicle crash countermeasures, the two studies summarized in this document don't address a number of factors that could impact the validity and usefulness of their conclusions. For example, neither study quantitatively considered the differences in traffic volume or adjacent animal population along the segments considered. In other words, crash numbers normalized by actual exposure were not compared. The comparison of the proportion of animal-vehicle collisions to the proportion of roadway mileage also assumes a uniform distribution of animal population throughout the segments considered, and ignores any relationships that might exist between roadway design, topography, posted speed limit, operating speed, and animal habitat. For example, it is possible that more animals exist near straight roadway segments with high posted speed limits because these roadways are built within wide river valleys. Alternatively, roadways with higher speed limits (typically in rural areas with larger animal populations) may also have better design features (wider clear zones, lanes, etc.) that provide the driver better visibility of the roadside and the increase or assist with the possibility of avoiding a crossing animal. Consideration of these types of interrelationships are essential to repeatable and verifiable evaluations of the specific impact of speed limit reductions on the number of animal-vehicle crashes. Effectively determining and defining a relationship (if any) between reduced posted speed limits (or operating speeds) and the number of animal-vehicle collisions along a roadway segment will require additional research studies that attempt to address, control for, and/or quantify the impact and potential interaction of these and other factors.

Finally, there are also some less theoretical issues that must be addressed for the effective application of this type of countermeasure (if it was found to be effective). One of the studies summarized did conclude that the choice of operating speed appeared to be primarily impacted by the roadway and roadside design features. This conclusion is also generally accepted in the transportation profession. In other words, a reduction in posted speed limit that is not considered reasonable by the driving public will generally be ignored. This type of situation has been shown to increase the possibility of a crash between two vehicles along roadways (some drivers will slow and many others will not). Therefore, any consideration or study of the impacts of a speed reduction in posted speed limit must first determine whether the posted speed limit is or will be followed. In addition, it must also be acknowledged that roadway designs which require slower speeds will also have operational, cost, and some other safety impacts that need to be considered before the roadway design is implemented.

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DEICING SALT ALTERNATIVES

One of the most common chemicals used for roadway deicing is sodium chloride (i.e., salt). White-tailed deer, like most animals, are attracted to natural and artificial salt deposit locations in their normal course of feeding. It has been speculated that the use of salt for roadway deicing may attract white-tailed deer to the pavement and/or roadside, and that this could result in more deer-vehicle crashes (DVCs) when deicing salts are in use.

No research literature was found that specifically or scientifically documented any attempts to prove whether white-tailed deer were attracted in larger numbers to a roadway right-of-way due to the use of sodium chloride for pavement deicing. The increase in DVCs that might occur due to the use of roadway deicing salts also does not appear to have been studied. However, some research in Canada did consider the potential moose-vehicle crash impacts of roadside pools with high concentrations of dissolved roadway salt (*1*). That study is discussed below. A study that focused on the effectiveness of chemical deer repellents also proposed that it might be mixed with roadway salt, but that study is discussed in the repellents summary of this document.

Literature Summary

Documentation about the possible impact of roadway salt use on white-tailed deer movement, and the number and location of DVCs does exist, but these discussions are only anecdotal in nature. For example, it has been observed that the largest number of DVCs in a state often occurs in October and November, but these months are not typically those with a high level of roadway salt usage. However, this observation does not address what percentage of DVCs might be due to deicing salt during the months when it is used. Two journal articles also offered the expert opinion that the use of roadway salt did contribute to DVCs, but these appear to be based on field observations and/or a knowledge of animal behavior rather than scientifically organized research results (*2*, *3*).

A related study in Canada focused on moose movement and moose-vehicle crash impacts of roadside pools with high levels of dissolved roadway salt (*1*). The study considered a 96.9-mile (156-kilometer) segment of the Trans-Canada Highway in Ontario, and in the late 1970s the locations of the salty roadside pools along this segment were identified (primarily by the existence of significant moose tracks) (*1*). Within the study area 169 salty pools (i.e., a specific conductance of greater than 500 μ) were identified, and the amount of moose trampling was scored from zero (not used) to five (heavily trampled) at 162 of these pools (*1*). Most of the pools were given a ranking of two or higher, and those with rankings of three or more typically also had wildlife trails leading to them (*1*). The pools actively used by moose were high in sodium (Na) and chloride (Cl) in comparison to the nearby lakes (*1*). A strong relationship was also found between the specific conductance of a pool and its sodium content (*1*).

The study also compared the use by moose of the saltwater and freshwater pools, and investigated the locations of moose-vehicle crashes (occurring from May to September 1979 and 1980) with respect to the nearest saltwater pool (*1*). Not surprising, a sample of 13 natural lakes and streams did not show signs of concentrated moose activity, but 14 small pools with a high specific conductance (i.e., greater than 1,000 μ) had a statistically higher trampling ranking than the other 23 in the sample considered (*1*). Overall, 39 moose-vehicle crashes occurred in the study area during the time periods considered (*1*). Approximately 43 percent of the crashes occurred within 328.1 feet (100 meters) of a heavily used (i.e., a ranking of three or more) roadside pool (*1*). Approximately the same number of crashes, however, occurred more than 984.3 feet (300 meters) from a heavily used pool (*1*). If it were assumed that moose-vehicle crashes could occur randomly and equally along the study segment approximately 8 percent of the crashes should have occurred within 328.1 feet (100 meters) of a heavily used pool and 72 percent further than 984.3 (300 meters) from this type of pool (*1*). The validity of these assumptions for analysis purposes, however, is open to debate.

The researchers make several conclusions and suggestions (*1*). Their general conclusions were that saltwater pools are a significant attraction to moose and that approximately half of the moose-vehicle crashes that occurred along the study segment were at or near these pools (*1*). They suggest that a reduction in the use of roadway salt (e.g., sodium chloride) may have a number of benefits but should not be expected to eliminate moose-vehicle collisions. In fact, in some areas with little natural salt only a small amount is needed to attract animals (e.g., the amount needed to keep the sand spread on some roadways from clumping) (*1*). The researchers discuss some options to the use of sodium chloride and the costs that are related to their use. It is suggested that if some salt substitutes (e.g., calcium chloride in Ontario) could be used in smaller amounts than the sodium chloride they might be economical and also produce a reduction in moose-vehicle collisions (*1*). Finally, the researchers suggest that the elimination of some of the roadside pools might be possible and/or that better drainage might be provided to flush the pools more quickly (*1*). If a roadside saltwater pool must remain a repellent could also be added to it during the highest moose-vehicle crash time periods (*1*). It is proposed, however, that the removal or management of saltwater roadside pools should preferably only be done if other salt sources are provided artificially (*1*). Animals may just move to another location along the roadside if this supplemental salt is not provided (*1*).

Conclusions

Research into how much of an impact the use of roadway salt may have on the number of DVCs occurring at a particular location is needed. In the past, suggestions and/or studies of sodium chloride and its alternatives have typically focused on the water quality environmental impacts of these chemicals (e.g., surface runoff) rather than their potential DVC impact. Only one study was found that attempted to consider the quantitative impacts of roadway salt on animal-vehicle collisions, and it considered the patterns of moose-vehicle collisions near roadside pools with significant concentrations of salt. The runoff from the roadways apparently produced these pools in an otherwise sodium deficient area.

The study of moose-vehicle collisions and roadside saltwater pools was completed from 1979 to1980 within the province of Ontario in Canada. It was found that moose were highly attracted to roadside pools with levels of high salt concentration. The moose-vehicle crash data also showed that approximately 43 percent of the 39 moose-vehicle collisions in the study area occurred within 328.1 feet (100 meters) of a saltwater pool. In addition, about the same amount occurred more than 984.3 feet (300 meters) away from the pools. The researchers compared the distribution of the observed moose-vehicle crashes with what might happen randomly along the study segment. It was found that the percentage of moose-vehicle crashes near the roadside pools was much higher than what might randomly be expected. The assumption involved in this comparison (e.g., all locations have an equal chance for a crash), however, and the general variability of moose-vehicle crashes were not discussed by the researchers. In addition, no comparisons were completed that could result in conclusions about how many of the 39 crashes might not have occurred if the saltwater pools were eliminated. This is a key question that needs to be answered. This research study does appear to show, however, that the use of roadway salt does have the potential to increase animal mortality in some manner, and that more specific consideration of this subject is required.

If the results of future roadway salt usage studies are able to determine the magnitude of its relationship with DVCs, the impact of existing and proposed deicing alternatives should then also be evaluated and considered. However, these evaluations must also consider the effectiveness of the roadway salt alternatives at clearing the roadway pavement (which increases general safety) and the other benefits and costs of their use.

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DEER-FLAGGING MODELS

White-tailed deer raise their tails to expose their white undersurface (i.e., deer flagging) as a warning. One study was found that evaluated the unique idea that deer-vehicle crashes (DVCs) might be reduced if white-tailed deer could be warned away from roadway by the installation of placards that mimic this "flagging" behavior (See Figure 1) (*1*, *2*).

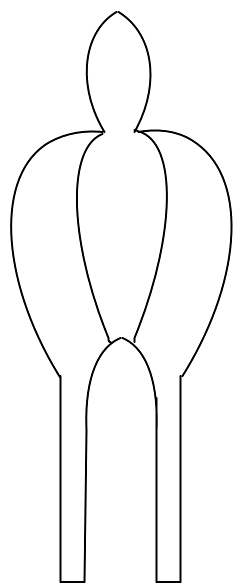

FIGURE 1 Example schematic of flagging model.

Study Design and Results

In 1978, researchers at Pennsylvania State University documented their attempt to verify and expand upon the results from an earlier study that indicated white-tailed deer avoided areas with plywood flagging models (See Figure 1**)** (*1*, *2*). The researchers assessed the effect of these flagging models in four experiments that focused on several fenced sections of Interstate 80 (*1*). During three of these experiments the following data were collected: the number of deer along 200-foot sections of roadway; the type of deer (i.e., adult, fawn, and undetermined); deer behavior (i.e., grazing, lying, walking, running, standing, and other); and the time of the deer sighting (*1*). In two of these three experiments the position of deer in the right-of-way was also recorded, but the document reviewed offered no further explanation. The data were generally collected at night from a vehicle traveling at 15 miles per hour along the shoulder of Interstate 80. Observers used hand-held spotlights to observe the deer. The effectiveness of the flagging models was measured by comparing the number of the deer observed before and after the model installation within a treated segment, or by comparing treatment and control roadway segment observations.

Experiment One

Each of the four experiments had a slightly different approach to the measurement of flagging model effectiveness. In the first experiment, the researchers observed deer along the north side of a 2,400-foot roadway segment of Interstate 80. This segment had a right-of-way fence that was approximately 7.5 feet in height. Similar data were also collected along a comparable 3,000-foot control segment. Both segments were located in open valleys, and surrounded by mixed hardwood forests. Both segments also had a number of gaps in the fence that could be used by deer to enter/exit the right-of-way. The exact size and number of gaps in each segment was not documented for this experiment, but twelve flagging models with real deer tails were placed 6.6 to 9.8 feet in front of the fence gaps within the treatment segment. No models were placed in the control segment. The researchers gathered data for 16 nights before and after the models were placed.

The data collected show that the number of deer observed in the treatment and control segments declined from 120 to 12 (a 90 percent decrease) and 156 to 36 (a 77 percent decrease), respectively (*1*). Assuming that the control segment results are typical (i.e., they show what might be expected in the treatment segment without the models) and a uniformity of deer movement, the expected treatment segment results should have been about 125 and 29 if the models were not installed. In other words, the number of deer observed after the models were installed is about 60 percent lower than expected.

The number of nights the deer were observed along the treatment segment also declined within the treatment segment, but remained the same along the control segment. Deer were observed for 15 of the 16 nights along both segments before the models were erected, but only during five nights along the treatment segment after the models were installed. The number of nights deer were observed along the control segment did not change after the models were installed. The researchers concluded that the results were not robust enough to allow them to make a conclusion about how effective the flagging models were at keeping deer out of the roadway right-of-way (*1*).

Experiment Two

In the second and third experiments, the researchers focused on deer behavior related to flagging model designs, and collected data for a longer period of time. Seven different types of flagging models were erected along Interstate 80 and their impact evaluated in the second experiment. The seven designs considered included painted and unpainted models with upright real and wooden deer tails, painted and unpainted models without an upright tail, and a plain plywood rectangle (*1*).

In the second experiment, six different flagging models (initially excluding the plain plywood rectangle) were randomly placed within the roadway right-of-way 6.6 to 9.8 feet in front of 24 fence openings for two months. Another 24 fence openings had no flagging model for the first month, but then received simple plywood rectangles for the second month. Two-thirds of the fence openings were on the north side of a 4.2-mile segment of Interstate 80. The other 56 openings were along the south side of a 6.0-mile segment. Deer movement data were collected by track counts on 24 days of the two months the models were erected.

The results indicate that during the first month of observation more deer used the fence openings with no model than those that used the other openings combined (65 versus 36 sets of tracks) (*1*). The researchers believed that the models with real or painted deer tails might also repel deer more than the plainer models, but that belief was not confirmed during either month of data collection (*1*).

The openings with the real or painted deer tails mounted on painted plywood models also did not appear to suppress deer crossings any more than the plain rectangle (*1*). In the second month, when the unpainted plywood rectangle models were placed near the control openings, only 19 deer used these gaps (versus 65 in the previous month) (*1*). The total number of deer using those gaps with the six other flagging model designs remained about the same as the previous month (34 sets of tracks versus 36) (*1*). Overall usage of the right-of-way by deer decreased, but this may have been expected by the researchers (*1*).

Experiment Three

The third experiment was longer term in nature, and an attempt to respond to the high variability of deer crossings along Interstate 80 (*1*). In this experiment, three consecutive three-mile segments (i.e., two experimental segments separated by a control) were observed. On the north side of Interstate 80, painted models with wooden tails were placed (halfway between the highway edge and fencing) along one treatment segment at 200-foot intervals. Unpainted plywood rectangles were placed in the same area along the other treatment segment. The control segment had no models. The researchers conducted spotlight observations three to four nights per week in the fall months of the study, but from December to March only a few observations could and were made along both sides of the roadway study segments (*1*). The number and location (both longitudinally and laterally from the roadway) of the deer sighted were recorded (*1*).

The results of this experiment indicate that more deer were seen along the segment with the painted deer models (N = 666) than those with no models (N = 335) or plywood rectangle models (N = 490) (*1*). Almost the same numbers of deer were also seen between the roadway and the painted models as were observed between the roadway and the plywood rectangles (N = 186 and 204, respectively). Only 77 deer were seen within the control segment. An analysis of the relationship between the number of deer observed at different distances from the roadway indicated that there was more deer movement between the models and the right-of-way fence than between the roadway and the models (*1*). However, this pattern occurred in both treatment segments (*1*). From these results, the researchers concluded the installation of either deer model design may have discouraged deer movements, but that that the deer models did not appear to be effective at reducing the total number of deer along the segments within which they were installed (*1*). No documentation was provided about number of deer that used each segment before the experiment began.

Experiment Four

The final experiment was similar to the third, and a three-mile section along eastbound Interstate 80 was divided into three one-mile segments. Within the three-mile segment, one-mile contained painted flagging models and was located between two one-mile control segments that had no models. The number of deer along the right-of-way of each roadway segment were then observed in the same manner as the other experiments, but for a time span of seven months (i.e., one month before installation and up to six months after) (*1*).

In the month before the models were installed, the number of deer observed within the one-mile segment where the models would eventually be installed was higher (N = 531) than that in either control area (N = 91 and 134). However, after models were installed, the number of deer observed in the following month increased along all three segments (*1*). The deer observed in the treatment segment increased by about 13 percent (N = 601), and increased by about 25 and 95 percent along the control segments (N = 114 and 261). The ratio of deer observed along the model segment and along one of the control segments remained about the same, but almost doubled with along the other control segment. The number of deer observed in the second month after the installation were higher than before the model installation in both control segments but lower in the treatment segment (*1*). Total deer observations for the following four winter months only ranged from 7 to 34 (*1*). Based on these results, the researchers concluded that this pattern of deer observations was contrary to their belief that the painted deer models would reduce the number of deer in the roadway right-of-way (*1*).

Conclusions

None of the four experiments summarized here appear to yield conclusive results that the addition of flagging models had an impact on and/or reduced the number of white-tailed deer that would be typically observed and/or cross a roadway right-of-way. In some cases fewer deer were seen along the experimental segments than in the control segments, but in others the number of deer observed increased after the models were installed. The general fluctuations in deer movements and the variability in data observation approaches also appears to confound attempts, at least in some of the experiments, to connect deer behavior to the presence or absence of the flagging models. The experimental designs also added some factors that may have had some impact in the interpretation of the results as documented (e.g., different time periods of observation before and after model erection).

The investigators of the experiments reached the general conclusion that they had failed to demonstrate that deer flagging models were effective at reducing the number of deer observed along the highway right-of-way. They believed that this approach would not be effective at reducing the number of DVCs, and did not recommend the use of deer flagging models as a deterrent to DVCs. A similar study in the future, but with some different design characteristics (e.g., longer observations before and after model installation, and clearly defined comparable control and treatment segments), might be considered to validate or refute the results of the study summarized here.

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INTERCEPT FEEDING

Intercept feeding is the practice of strategically placing food to lure animals into desired areas (e.g., away from roadways), and/or stop animals with food before they cross a roadway. Documentation for one study was found that explored the use of this practice as a possible method to deter deer from the roadway area (*1*). It was hypothesized that intercept feeding could be used to keep deer away from a roadway right-of-way, and consequently reduce deer-vehicle crashes (DVCs).

Literature Summary

Study Design

During the winter months of 1985 and 1986 (January to mid-March) researchers at Utah State University conducted an investigation to test the effectiveness of intercept feeding on diverting mule deer from a highway right-of-way. Counts of roadside deer carcasses and live deer were completed to accomplish this objective.

Three highway segments along three different state highways were considered in the study (*1*). The study site along each roadway was divided into treatment (i.e., intercept feed was provided) and control (i.e., no intercept feed was provided) segments of equal length, and a 3-mile buffer segment between the two (*1*). Two of the study sites had 6-mile treatment and control segments, and at the other site these were 5 miles long (*1*). The buffer areas at each site remained unchanged, and were intended to remove any extraneous effects that the intercept feeding within the treatment segment might have on the defined control segment. After the first year of the experiment the treatment and control locations were interchanged.

Intercept feeding stations were provided in each treatment segment and spaced as evenly as possible within the existing landscape features that funneled mule deer toward the roadway (e.g., canyon entrances). These stations were placed approximately 1,300, 2,600 and 3,900 feet away from Utah State Highways 6, 28 and 89, respectively (*1*). The food provided was primarily alfalfa hay supplemented with balanced-ration deer pellets and apple mash. The quantity of food at each site was adjusted during the experiment to accommodate the number of mule deer apparently using it.

The researchers recorded the date, location, sex, and age class (e.g., fawn, yearling, or adult) of all the deer carcasses along the highway segments during the study months. In addition, they conducted spotlight surveys (i.e., night observations made with hand-held spotlights from a vehicle) along Utah State Highway 28 to investigate the distribution and location of live deer along the highway right-of-way with respect to the control and treatment zones, and the deer carcasses observed.

In general, the researchers also made two assumptions when evaluating the data they had collected (*1*). First, they assumed that without the intercept feeding the deer killed along the treatment and control roadway segments (e.g., the number of DVCs) would be equally distributed (*1*). Actual deer carcass or DVC patterns before the project started were not investigated. Second, the researchers assumed that the number of fatally wounded deer that wandered off the right-of-way before they were able to make their observations were proportionally distributed along the segments of interest, and that the inability to include this data in the analysis did not impact their conclusions (*1*).

Study Results/Discussion

During the first year of the study the investigators found that number of deer carcasses in the three treatment segments was not significantly lower than those observed in the control segments (See Table 1) (*1*). In addition, in 1986 (the second year of the study), after the treatment and control segments were reversed, one of the study sites (Utah State Highway 6) experienced more deer carcasses in its treatment segment than its control segment (See Table 1). Theoretically, the number of deer carcasses observed should be equal (i.e., a ratio of 1:1) in the treatment and control segments if the intercept feeding has no impact. Some of the reasons for the results in Table 1 are explained in the following paragraph.

TABLE 1 January to Mid-March Numbers of Deer Carcasses (*1*)

	Site Segment Deer Carcasses				
Year	**Control***	**Buffer***	**Treatment***	**Total**	**Control:Treatment Ratio**
Utah State Highway 28 Site					
1985	31	13	19	63	1.6:1
1986	89	41	38	168	2.3:1
Utah State Highway 89 Site					
1985	29	12	19	60	1.5:1
1986	59	21	34	114	1.7:1
Utah State Highway 6 Site					
1985	14	5	8	27	1.7:1
1986	13	8	31	52	0.4:1

*Control = Segments where intercept feeding was not provided (about 17 miles), Buffer = Segments separating control and treatment segments (about 9 miles), and Treatment = Segments where intercept feeding was provided (about 17 miles).

The investigators recognized that there were several factors, other than the presence of the intercept feeding, that may have influenced the number of deer killed along the roadway segments considered (*1*). The study site along Utah State Highway 6, for example, produced results that in one case appeared to contradict those from the other sites. Difficult road conditions at that site, however, had precluded the transport of the feed farther than about 1,300 feet from the highway, and the feed stations at the other two sites were 2,600 feet and 3,900 feet away from the roadway. The presence of elk at some of the feeding stations along Utah State Highway 6 may also have reduced and/or negated their use by mule deer. The researchers also suggested that the deer movement along Utah State Highway 6 was more parallel than perpendicular to the roadway, and they surmised that the deer movement patterns along Utah State Highway 6 in 1986 might have been less susceptible to the impact of intercept feeding stations than in 1985 (*1*).

As previously mentioned, live deer counts were also completed by spotlight surveys at the Utah State Highway 28 study site (the other study sites did not offer enough room to allow these counts to be done safely). Overall, 51 spotlight counts were completed at about 25 miles per hour in 1985 and 31 counts in 1986. In general, significantly more deer were observed in the control segment than the treatment segment, and 47 percent more deer were counted in 1986 than 1985. The ratios of deer in the control and treatment segments, however, were approximately equal each year (i.e., 2.2:1 for 1985 and 2.3:1 for 1986). The researchers concluded that these results, combined with the deer carcass numbers, supported their hypothesis that intercept feeding kept deer away from the roadway.

One interesting and possibly confounding result, however, was also introduced by the spotlight counts. From 1985 to 1986 the researchers found a decrease in the difference between the numbers of deer carcasses in the control and treatment segments, but an increase in the difference in the number of live deer counted between these two segments. In theory, it would be expected that the number of carcasses would increase with the number of live deer exposed to the roadway, and that the ratios of carcasses and deer counted should be approximately equal. The results appear to indicate that the number of live deer counted at night along each roadway segment was not proportional to the number of deer hit by vehicles in that segment. The researchers speculated that if counts had been done throughout the night, instead of just after dusk, a comparison of the spatial patterns and movements of the live deer and roadside deer carcasses may have revealed additional information about this relationship.

Conclusions

The researchers of the study summarized here generally concluded that intercept feeding might be an effective short-term mitigation measure that could reduce DVCs by 50 percent or less (*1*). Although the described study results appear contradictory in some cases, this conclusion by the researchers is most likely based on their interpretation of the deer carcass ratios documented in Table 1. There was no documentation, however, of the number of DVCs that actually occurred along these segments before the intercept feeding stations were in operation. In addition, it was acknowledged by the researchers that the number of roadside deer carcasses counted along the segments was not proportional to the deer population, and that these populations were quite different from one segment to the next.

The researchers were of the opinion that the potential for a reduction in DVC of 50 percent or less was not sufficient enough to justify the amount of work and funding necessary for the implementation of intercept feeding. This conclusion was reached by them despite the fact that their cost-benefit analysis results indicated that the potential benefits from the DVC reductions were expected to exceed the feeding (or feed) costs. The researchers did recognize, however, that this was a significant reduction when compared to their opinion of the potential reduction from other DVC countermeasures. It was suggest that intercept feeding might be combined with other countermeasures to increase its effectiveness.

The results of this study, although showing some promise, are also weakened by the number of locations considered, short data collection time period, and the variability in the approach by study site. A true comparison of DVCs, deer population exposures to a roadway, and roadside deer carcass ratios would also require a more comprehensive data collection approach (e.g., time and location). This type of study, however, would be a significant undertaking, and encounter the same physical challenges the researchers encountered in the study summarized. The challenges encountered in the field would be expected to require variability in feeding stations installations at different study sites. Controlling or accounting for this variation is a key to the proper analysis of study results. The challenges encountered by the authors of the study summarized here also indicate that the widespread application of this approach (versus a focused and short-term installation and analysis) may not be possible.

Two other problems that might occur with this type of application is that deer may become dependent on the food supply and more deer than typical might be drawn to the general vicinity of the roadway and the general area. In addition, the appearance of chronic wasting disease in Wisconsin has resulted in a ban on deer feeding (to reduce nose-to-nose contact – a potential transmitter of the disease) and may remove this measure, even in a short-term focused manner, as a DVC mitigation in that state.

Reference

1. Wood, P., and M.L. Wolfe. *Intercept Feeding as a Means of Reducing Deer-Vehicle Collisions*. Department of Fisheries and Wildlife, Utah State University, Logan, UT, 1988.

DEER CROSSING SIGNS AND TECHNOLOGIES

One of the most widely used measures to reduce deer-vehicle crashes (DVCs) is the deer crossing warning sign (See Figure 1). The design of this sign is controlled by the *Manual on Uniform Traffic Control Devices* (MUTCD), and consists of a diamond-shaped panel with a black "Deer Crossing" legend or deer symbol and a yellow background (See Figure 1) (*1*).

It is generally acknowledged and understood by transportation professionals that roadway warning signs are most effective (i.e., they result in an alteration of speed and/or path choice) when they alert the driver to an obvious danger (e.g., a curve ahead). The use of warning signs that alert drivers to sporadic and/or warn of general possibilities, encounters, or situations (e.g., deer crossing and slow children warning signs), on the other hand, do not normally have a consistent impact on driver behavior. The overuse or misuse (i.e., installation at incorrect locations) of warning signs also reduces their overall effectiveness. Unfortunately, deer crossing signs have one or both of these characteristics.

No research literature was found that specifically considered or quantified the DVC reduction and/or vehicle speed reduction impacts of typical deer crossing signs (See Figure 1). The deer crossing sign studies that were reviewed appear to be based on the general assumption that a typical deer crossing warning sign does not generally reduce vehicle speeds (one measure of warning sign effectiveness), and that the effectiveness of these signs needs to be improved in some manner.

Documentation was found for several studies that attempted to increase the effectiveness (as measured by a reduction in vehicle speed) of typical deer crossing signs (*2*, *3*, *4*, *5*, *6*, *7*). These studies considered either permanent or temporary (i.e., only activated when deer are detected nearby) changes in the physical appearance of a typical deer crossing sign installation. In the early 1970s researchers attempted to improve the effectiveness of a deer crossing sign through permanent enhancements to its message (*2*, *3*, *4*). More recently, however, two studies investigated the effectiveness of special deer crossing

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FIGURE 1 Typical deer symbol crossing warning sign (*1*).

signs with a different design that were only installed during time periods of significant animal movement (e.g., the fall months for white-tailed deer) (*5*, *6*). In addition, newer technologies have allowed a more dynamic approach to deer crossing sign improvements, and several sign systems have been designed to activate only when animals are detected near the roadway (*7*, *8*, *9*, *10*, *11*). The evaluation of one system of this type is summarized in this document (*7*). Other systems are also currently being considered, have been installed, and/or are being evaluated in several states (e.g., Indiana, Minnesota, Montana, Pennsylvania, Utah, and Washington). Detailed documentation of these installations, and their potential vehicle speed reduction and/or DVC reduction impacts, is not yet available.

Literature Summary

Deer crossing sign studies that evaluated the vehicle speed and/or DVC reduction impacts of enhanced sign designs and the application of a dynamic sign and sensor installation are described in the following paragraphs (*2*, *3*, *4*, *5*, *6*, *7*). The first two studies consider the vehicle speed reduction impacts of two technologically enhanced deer crossing sign designs (*2*, *3*, *4*). Another two studies evaluated the impacts of using special deer crossing signs along roadway segments during high DVC and/or migratory time periods (*5*, *6*). Then, brief summaries of some recently installed and documented dynamic deer crossing sign and sensor systems are provided. The effectiveness of only one of these systems, however, has been studied and documented in detail (*7*).

Sign Message Enhancement – Initial Study

Pojar, et al. have evaluated the impacts of two enhanced deer crossing sign designs (*2, 3, 4*). These designs are shown in Figures 2 and 3. The first sign evaluated was a typical diamond-shaped yellow and black warning sign with the words "DEER XING" in neon lights (See Figure 2). The other sign was also a diamond-shaped yellow and black warning sign, but included a series of deer shaped lights that activated in sequence and gave the impression of a deer jumping (See Figure 3). A small rectangular supplementary "DEER XING" sign was also added to this installation (See Figure 3). The impact of these signs was measured by comparing average operating vehicle speeds when the signs were turned toward and away from the traffic.

FIGURE 2 Lighted "DEER XING" sign (*3*).

In 1971 the signs in Figure 2 and 3 were installed along Colorado State Highway 82 (*3*). First, the "DEER XING" sign in Figure 2 was installed, but turned away from the traffic for 16 days (*3*). Then, the sign was turned towards traffic and activated for 28 days (*3*). After the "DEER XING" sign was removed it was replaced with the animated sign in Figure 3 for four days (*3*).

FIGURE 3 Animated deer crossing sign (*3*).

Vehicle operating speeds were collected about 800 feet downstream of the sign location from 6:00 PM to 10:00 PM each day for the time period indicated (See Table 1). This was also the only time period during the day when the enhanced signs were in operation. The speed data were collected during dry conditions with automatic recorders that used magnetic loop detectors. The number of vehicle speeds collected and/or whether any data were discarded was not documented (*3*).

TABLE 1 Average Operating Vehicle Speeds (*3*)

	Sign Turned Away from Traffic	"DEER XING" Sign Activated	Animated Deer Sign Activated
Days of Data Collection	16	28	4
Average Operating Vehicle Speed	54.5	53.0	51.6

A statistical analysis of the speed data collected show a significant difference between the average vehicle speed with the sign turned away from traffic and the average vehicle speed with either treatment sign activated (*3*). The number of data collection days for the animated sign treatment, however, was limited, and the potential for residual impacts on vehicle speed from the previous "DEER XING" sign installation should be recognized. The possible relationship between average daily vehicle speed (for the 4 hours considered) and the number of days since a treatment began was also evaluated (*3*). The objective was to investigate whether drivers habituated to the enhanced designs, and adjusted their vehicle speed. The researchers report that they found no relationship between the daily average vehicle speed and the number of days from the beginning of a treatment (*3*).

Sign Message Enhancement– Detailed Study

Pojar, et al. have also documented a more in-depth impact analysis of the animated sign design shown in Figure 3 (*4*). This study was conducted along the same highway segment as the initial study, but vehicle speed data were recorded 0.15, 0.65, and 1.5 miles downstream of the sign installation (*4*). This data was again collected with magnetic loops from 6:00 PM to 10:00 PM when the highway surface was dry (*4*). The researchers also estimated the number of nightly deer crossings in this 1.5-mile segment with spotlight surveys (one hour after sunset) within one area along its length, and recorded the number and location of deer roadkill within the study segment (*4*). The number of nightly deer crossings was estimated by simply doubling the number of deer counted by the researchers that night (*4*). In other words, it was assumed that each deer observed would cross the roadway at least twice that night. Finally, a short preliminary analysis of the vehicle speed impact of placing a deer carcass next to the sign treatment was also completed (*4*).

In 1972 and 1973, Pojar, et al. activated the animated sign in Figure 3 for two and five weeks (*4*). Those weeks when the sign was turned toward traffic (or activated) were alternated with weeks during which the sign was turned away from traffic (*4*). The number of weeks that vehicle speeds, deer crossings, and deer roadkill data were collected and/or estimated, along with the ratio of estimated deer crossings and roadkill are shown in Table 2 (*4*).

TABLE 2 Deer Crossings Per Roadkill Results (*4*)

	Data Collection Year					
	1972		1973		Total	
	Sign Turned Away	Sign Activated	Sign Turned Away	Sign Activated	Sign Turned Away	Sign Activated
Data Collection Weeks	2	2	6	5	8	7
Est. Deer Crossings	227	163	1,016	975	1,243	1,138
Total Deer Roadkill	6	3	16	17	22	20
Deer Crossings/Roadkill	37.8	54.3	63.5	57.4	56.5	56.9

The researchers from this study made several conclusions based on the data in Table 2. First, the total ratio of the estimated number of deer crossings per roadkill was not statistically different (i.e., higher) when the sign was activated (*4*). In fact, in 1972 the ratio of deer crossings per roadkill increased with the sign activated, but in 1973 it decreased. Their conclusion was that other, less readily apparent, variables were impacting this ratio (*4*).

A 0.2 to 2.9 mile per hour reduction in average vehicle speed was also calculated for the three data collection locations during the two- and five-week periods the sign were activated in 1972 and 1973, respectively (See Tables 2 and 3). All of the average vehicle speed reductions calculated (See Table 3) were also determined to be statistically significant except the 1973 observation at the 1.5-mile data collection location (*4*). The number of vehicle speeds collected to determine the average speed reductions shown in Table 3 were not documented.

A preliminary analysis of the change in vehicle speeds was also documented after the researchers placed three deer carcasses next to the warning signs (*4*). These carcasses were placed on the roadside each Tuesday (for an undocumented number of weeks) two

TABLE 3 Average Vehicle Speed Reductions (*Adapted from 4*)

Data Collection Distance Downstream of the Sign (Miles)	Average Vehicle Speed Reduction[1]	
	Study Year 1 1972	Study Year 2 1973
0.15	2.9	1.5
0.65	1.4	1.6
1.50	1.2	0.2

[1]Average Vehicle Speed Reduction = the average of the difference in individual vehicle speeds collected inside and outside the study area.

hours after sunset, and remained on the roadside for two hours before they were removed (*4*). The speed data collected when the carcasses were present indicate an average vehicle speed reduction of about seven miles per hour. No significant difference in average vehicle speed reductions (with the deer carcasses present) was found, however, when the animated sign was turned toward or away from the traffic (*4*).

Seasonal Use of Deer Crossing Signs

At least two studies have also been completed that investigated the seasonal use of deer crossing sign installations (*5*, *6*). In both cases the signs used had a different design than the typical deer crossing sign shown in Figure 1. The first study focused on mule deer in Utah and the animal mortality/DVC impacts of using large square yellow and black signs warning of mule deer “Migration Next X Miles” (See Figure 4) (*5*). This sign was installed at the end of roadway segments two and four miles long, and then supplemented with reminder warning signs every mile (See Figure 4). All the sign installations also included flashing amber lights and reflectorized flags (*5*). Overall, the researchers observed reductions in vehicle speed and animal mortality along the segments when the signs were installed during the mule deer migratory season (*5*). It was concluded that these reductions resulted from the installation of the signs and the fact that the drivers were mostly local commuters and understood the time and impacts of the migration (5). In other words, they knew the collision danger during particular time periods of the year, and the signs were a reminder. The addition of non-local drivers (due to a nearby park

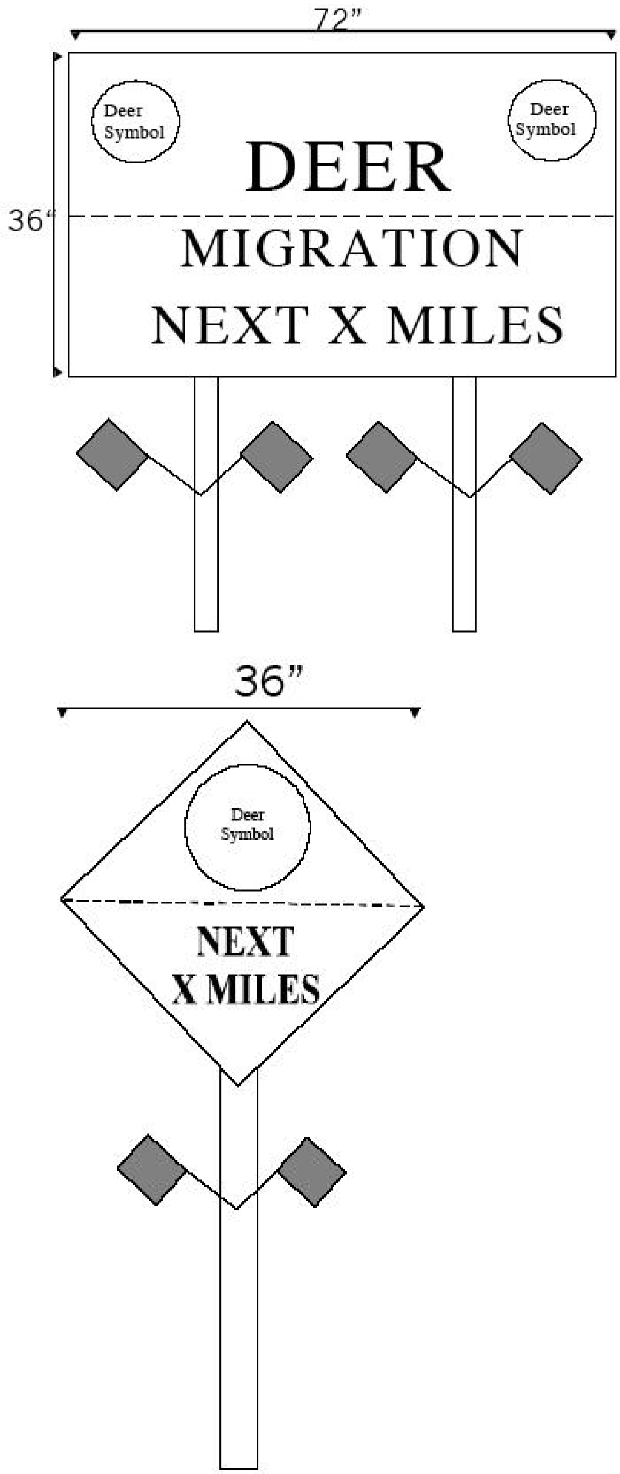

FIGURE 4 Utah primary and secondary temporary deer crossing sign designs (*5*).

opening) may reduce the impact of the signs, and this type of temporary sign use also appears to be most effective with a deer species that has a specific migratory pattern. Recently, a group tried an approach similar to that in Utah, but focused on reducing vehicle collisions with white-tailed deer in Michigan (*6*). Specially designed signs signifying a "High Crash Area" were installed along roadway segments during the fall months of 1998, 1999, and 2000 (See Figure 5) (*6*). In addition, a public education and information campaign that focused on DVCs was in operation at the same time (*6*). The signs were installed along seven roadway segments that did not previously have regular deer crossing signs.

FIGURE 5 Michigan temporary deer crossing sign design (*6*).

The researchers in Michigan collected and compared DVC and vehicle speed data to evaluate the impact of the seven specially signed roadway segments (*6*). A comparison of two years of DVC data, however, showed no reduction in this type of crash after the signs were installed within either the entire township or along the roadway segments with the new signs (*6*). Vehicle speeds before and after sign installation on two roadway segments also showed no significant difference in one case, and a statistically significant, but less than a 0.5 mile per hour reduction, along the other (*6*). The differences in the studies from Utah and Michigan include the design of the signs, species of deer, and the necessary assessment of risk (with subsequent behavioral changes) by drivers based on the predictability of the species movement.

Dynamic Deer Crossing Sign and Sensor Systems – Brief Overview

The research described previously investigated the impacts of enhanced deer crossing sign designs. If used, these enhanced signs are either constantly active or must be turned away from traffic. More recently, a number of dynamic sign and sensor systems have been proposed and/or installed. These systems typically alert the driver, through flashing lights for example, when an animal has been detected near the roadway. An example of some of the equipment used by one dynamic sign and sensor system is shown in Figures 6 and 7.

Several dynamic deer and elk crossing sign and sensor systems have been documented, and are briefly discussed below (*7*, *8*, *9*, *10*, *11*). The operation and/or effectiveness of at least some of these systems are currently being studied.

- In Minnesota, a dynamic sign and system has been installed at one location, and is planned for two other sites (*8*). The choice of locations was based on deer population and DVC data. The system uses an infrared light beam on both sides of the roadway to detect animal movement, and when these sensors are activated a battery-powered transmitter turns on amber warning lights on top of a series of traditional deer crossing signs (*8*).

- In Montana, the Western Transportation Institute has also installed and is testing a dynamic sign and sensor system that operates with radar beam sensor equipment connected to amber lights on traditional elk crossing and "When Flashing" sign installations (*9*). This is the system shown in Figures 6 and 7.

FIGURE 6 Dynamic elk sign and sensor system example (*Photo courtesy of the Western Transportation Institute*).

FIGURE 7 Solar powered animal sensors (*Photo courtesy of the Western Transportation Institute*).

- In Washington, a system has been installed along United States Highway 395 that utilizes laser beam sensors on each side of the roadway (*10*). When the laser beam is interrupted by an animal, a solar-powered red strobe light on top of a traditional deer crossing sign (with a "When Flashing" supplementary sign) is activated (*10*).

  In the same state, along a segment of United States Highway 101, another approach to dynamic signing and sensing is also being studied (*11*). Radio collars have been attached to eight elk (within a herd of about 80 near the roadway). When any of the collars are within a quarter mile of the roadway a series of flashing lights are activated on elk crossing signs (*11*).

- In Finland, a dynamic elk warning sign and sensor system has also been installed (*10*). This approximately 800-foot project uses microwave radar sensor equipment, 16 passive infrared detectors, and a rain detector to reduce the number of false detections. Animal detections activate lighted fiber optic signs (*10*). The speed of the vehicles in the study area is also being measured.

- In Wyoming, the Flashing Light Animal Sensing Host (FLASH) system was installed along United States (U.S.) Highway 30 between Kemmerer and Cokeville (*7*). The reliability and the effectiveness of this system has been studied and documented. The details of this system, along with the results of this study, are described in the following section.

The Nugget Canyon, Wyoming Dynamic Sign and Sensor Study

The Flashing Light Animal Sensing Host (FLASH) system was installed in Nugget Canyon, Wyoming along U.S. Highway 30 (*7*). This segment of roadway crosses a mule deer migration route, and in 1989 a seven-mile eight-foot fence was erected along both sides of the roadway. A 300-foot gap, however, was left in the fence for the mule deer migration (*7*). The FLASH system was installed and tested within this 300-foot gap from December 2000 to May 2001 (*7*).

The Nugget Canyon dynamic sign and sensor system consists of a group of roadside detector sensors connected to amber flashing lights mounted on deer crossing signs (*7*). These signs are located approximately 985 feet from each end of the study area (i.e., the fence gap), and have the legend "Deer on Road when Lights are Flashing" (*7*). A total of three sensor systems have been installed to detect deer activity within the study area (*7*). These systems include a series of active (i.e., break-the-beam) infrared sensors on both sides of the roadway that, when combined with the roadside signs and flashing lights described above, represent the FLASH system (*7*). The other two deer activity sensing systems in the study area include a combination of the infrared scopes on both sides of the roadway and in-ground geophone installed on one side of the roadway (these sensors detect ground vibrations from nearby deer), and a set of microwave sensors (*7*). Infrared and low-light video cameras were also installed in December 2000, and could be used to observe almost the entire study area (*7*).

The evaluation of the FLASH system in Nugget Canyon consisted of three parts. First, the activation reliability and/or accuracy of the active infrared and the infrared scope/Geophone sensor designs were compared to the results of a video camera. Then, vehicle speeds and classifications were collected both inside and outside the study area (with loop detectors) during normal FLASH system operations (*7*). Speed measurement devices were located outside the study area (i.e., before drivers could observe the new warning sign configuration), and between the signs. Finally, the vehicle speed impacts of five different sign, flashing light, and/or deer presence situations were tested during the study time period (December 2000 to May 2001) (*7*).

The sensor accuracy test revealed a number of complications with the application of these types of systems. For example, in 30 hours of observation the FLASH infrared sensors operated correctly, but by the second month of testing the system was beginning to experience a large number of false activations. Overall, during the study time period, more than 50 percent of activations were determined to be false (*7*). These false activations, among other things, appeared to be caused by birds and snow from snowplows breaking the infrared sensor beams (*7*).

The combination of the geophone and infrared scopes appeared to be very reliable (*7*). During 30 hours of observation this system always registered an activation when a deer was present, and never registered an activation when there was no deer present (*7*). A comparison to the video camera results indicates that this level of reliability continued throughout the study time period (*7*). The system tended to overestimate the number of actual deer crossings (because it registered deer as they moved back and forth across the sensors), but it did so in a reliable and somewhat predictable manner (*7*). The researchers concluded that some form of the geophone/infrared scope sensing system had the most potential for future installations (*7*).

The second and third parts of the Nugget Canyon study evaluated the vehicle speed reduction impacts of eight different situations. The first five situations described in the following list were observed during four different two-hour time periods to evaluate the impacts of different sign, flashing light, and deer presence configurations (*7*). The final three situations represent the three combinations found to occur during the normal operation of the FLASH system (*7*). Speed data from two days that were randomly chosen from each month of the study time period were used in this analysis. All eight situations are briefly described in the following list:

1. A baseline or "expected" average vehicle speed reduction was calculated from data collected when the flashing lights on "Attention: Migratory Deer Crossing" signs were continually active.

2. The sign legend was changed to "Deer on Road When Lights are Flashing", but the flashing lights remained continually active. This allowed the quantification of the average vehicle speed reduction that might be due to the sign message change and continually flashing lights without a deer present.

3. A realistic taxidermist deer mount was added to the roadway environment. Everything stayed the same as the second situation, but a deer mount was added about 10 feet from the traveled way. This setup allowed an approximation of the average

vehicle speed reduction impacts of the system with continually flashing lights and a "deer" in the right-of-way.

4. The third situation was repeated, but the flashing lights were deactivated. The speed reduction data collected during this situation could be used to evaluate the impact of the flashing lights.

5. The second situation was repeated, but the flashing lights were remotely activated when the driver could observe that the system was active. This situation was evaluated to measure the vehicle speed impacts if the drivers knew the system was active.

6. The FLASH system was fully operational, and vehicle speeds were summarized and compared for those situations when the flashing lights were activated and an actual deer was present.

7. The FLASH system was fully operational, and vehicle speeds were summarized and compared for those situations when the flashing lights were not active and no actual deer was present.

8. The FLASH system was fully operational, and vehicle speeds were summarized and compared for those situations when the flashing lights were activated, but no actual deer was present (this situation represents a false activation).

The average vehicle speed reductions calculated for the eight situations described are shown in Table 4 (*7*). These results show that when the system worked as it was designed, and the lights were activated with actual deer present (Situation 6 in Table 4), drivers slowed their vehicles by a statistically significant average of 3.6 miles per hour (*7*). The data also show that the average speed reduction calculated for the situation when the lights were not flashing and no deer were present (Situation 7 in Table 4) was less then one mile per hour, but this reduction was also determined to be significant by

TABLE 4 Nugget Canyon Average Vehicle Speed Reductions (*7*)

Situation	Flashing Light Operation	Sign Legend	Actual or Decoy Deer Present?	Average Speed Reduction (miles per hour)[1]	Sample Size[2]
1	Continuous	"Attention: Migratory Deer Crossing"	No	1.2	NA
2	Continuous	"Deer on Road When Lights are Flashing"	No	2.3	NA
3	Continuous	"Deer on Road When Lights are Flashing"	Decoy Deer Present	12.3	NA
4	Deactivated	"Deer on Road When Lights are Flashing"	Decoy Deer Present	8.0	NA
5	Remotely Activated	"Deer on Road When Lights are Flashing"	No	4.7	NA
6	FLASH Sensor Activated	"Deer on Road When Lights are Flashing"	Actual Deer Present	3.6	655
7	Not Activated	"Deer on Road When Lights are Flashing"	No	0.7	8,153
8	FLASH Sensor Activated	"Deer on Road When Lights are Flashing"	No	1.4	1,965

[1]Average speed reduction is the average of the differences in measured vehicle speeds inside and outside of the study area. Average speed reduction for Situations 1 to 5 is for passenger cars only. The average speed reduction for Situations 6 to 8 is for all vehicles.
[2]NA = not available or documented.

the researchers (*7*). Finally, the average vehicle speed reduction produced by the activation of the lights when no deer were present (i.e., a false activation or Situation 8 in Table 4) was only 1.4 miles per hour (*7*). This reduction was also determined to be significantly different than zero, and was 2.2 miles per hour less than when the lights were activated with a deer present (*7*). This 2.2 mile per hour difference could be an approximate measure of the average speed reduction due to the presence of a deer. It is much smaller, however, than the 8.0 miles per hour speed reduction data shown in Table 4 for a deactivated sign and sensor system with a deer decoy (Situation 4 in Table 4) (*7*). A comparison of the speed reduction results for the remote-control activation of the flashing lights (Situation 5 in Table 4) to those for the fully operational system (Situation 6 in Table 4) also show that the remotely activated system might be used quickly to approximate the impact of one that is fully installed and operating. The FLASH system researchers considered it unlikely that the largest vehicle speed reduction observed during the normal operation of the FLASH system (i.e., 3.6 miles per hour) would produce a reduction in DVCs.

When the sign legend and/or the flashing light characteristics were changed manually, or a roadside deer decoy was added to the study area, the data indicated that average vehicle speeds decreased much more dramatically when deer decoys were present on the roadside (*7*). In fact, the data show that the combination of the continually flashing lights and the deer decoy (Situation 3 in Table 4) produced a speed reduction of about 12 miles per hour (*7*). In addition, when the deer decoy was presented without the flashing lights (Situation 4 in Table 4), an average speed reduction of 8.0 miles per hour was calculated (*7*). These results would appear to indicate that the presence of the flashing lights may produce about a four mile per hour passenger car speed reduction impact (*7*). Finally, the change in the sign legend also appeared to approximately double (i.e., 1.2 to 2.3 miles per hour) the average vehicle speed reduction calculated, and the possible reasons for the difference in the data for the flashing lights being continuously operated (Situation 2 in Table 4) and when they were remotely activated (Situation 5 in Table 4) were not explained. All five average speed reductions are significantly different than zero, but the researchers concluded that these reductions in vehicle speed would most likely not reduce the probability of a DVC (*7*).

Conclusions

In the first two studies summarized in this document Pojar, et al. concluded that the lighted sign design improvements they proposed (See Figures 2 and 3) and evaluated did significantly reduce average vehicle speeds. However, the outcome of a more in-depth study of the animated design (See Figure 3) did not appear to indicate that its resultant vehicle speed reduction had actually resulted in a reduction of the number of deer roadkill (i.e., DVCs) in the study area (See Table 2). However, the variability in DVCs and the factors that impact their occurrence limits the validity and transferability of the study results presented here because they are based only on 15 weeks of data.

The seasonal use of specially designed deer crossing signs was also considered in two states (See Figures 4 and 5). Researchers in Utah installed signs during the mule deer migratory season, and observed reductions in vehicle speed and DVCs. However, researchers in Michigan investigated the impact of a different deer crossing sign design that was installed during the fall months (a "high" DVC and white-tailed deer movement time period), and generally found no significant reduction in DVCs or vehicle speed. The differences in these two studies include sign design, animal species, and apparently the general ability of drivers to appropriately assess the risk of a collision at a particular time and location. In Utah the familiarity of the drivers with the distinct migratory seasons and locations of the mule deer were believed to have had an impact on the sign effectiveness. It is proposed that more consistent and incremental studies may be needed to support or refute the speed- and DVC-reduction impacts of properly installed (i.e., at "high" DVC locations) deer crossing signs for both the existing and any proposed designs. An incremental approach (e.g., first add an additional text message, then reflectorized flags, and then amber flashing lights) may be necessary to determine what changes to deer crossing signs are the most effective. The appropriate use of temporary signs is clearly less expensive then some of other potential DVC countermeasures discussed in this toolbox.

A number of dynamic sign and sensor systems are being considered or have been installed throughout the world. Several of these systems were briefly described in this summary. The recent development of these systems requires an initial evaluation and improvement of their activation reliability. One key to the successful analysis and application of these systems is the minimization of false activations. The number of false activations should be noted in the analysis of these systems and not included in the data used to calculated average speed reductions. The presence of false activations could also cause drivers to lose confidence in the validity of the system and its intended purpose (eventually resulting in no speed reduction even when deer are actually present). The operation and effectiveness of some of the systems described in this summary are currently being studied, but only one analysis appears to have been documented at this time (*7*).

The Nugget Canyon FLASH system in Wyoming has been studied and documented (*7*). In this case, the effectiveness of the system was evaluated by comparing the average vehicle speed reduction calculated for eight different situations (See Table 4) (*7*). The researchers doing the evaluation concluded that when the system worked properly it produced a small, but statistically significant, reduction in average vehicle speeds. However, they did not believe the average speed reduction found would reduce DVCs (*7*). Reductions in average vehicle speeds were also found when the lights were continuously flashed and/or a deer decoy was introduced on the roadside. In fact, the largest average vehicle speed reduction calculated (See Table 4) was when the lights were flashing and the deer decoy was present (*7*).

A complete analysis of the benefits and costs of these systems should be considered before installation. Overall, additional evidence is also needed to evaluate whether the costs (e.g., time and money) for an improved sign design or dynamic sign and sensor system is worth the reduction in average vehicle speed that may occur. Additional research and the results from ongoing studies should help in this evaluation. The DVC reduction potential of posted speed limit reductions (which can be related to operating speed) are discussed in another section of this document.

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ROADSIDE REFLECTORS AND MIRRORS

Roadside reflectors and mirrors have been applied as a potential deer-vehicle crash (DVC) countermeasure for several decades (See Figure 1). These devices reflect (or mirror) the light from oncoming vehicle headlights into adjacent roadside areas. Their primary objective is to reduce nighttime DVCs by using reflected/mirrored light to frighten, distract, freeze, and/or alarm animals enough that they will not cross the roadway. Polished steel is the most common roadside mirror material, and several manufacturers and/or distributors sell roadside reflectors with various colors (red is typical) and mounting assemblies.

The use, operation, and/or deer roadkill or DVC reduction effectiveness of roadside reflector/mirror installations has been documented in a variety of formats. These formats range from summaries in peer-reviewed journals to the description of anecdotal case studies. Several individual states have also funded and documented research on the subject, and there are also reflector/mirror manufacturer- and/or distributor-produced promotional materials. The reflector/mirror studies or activities documented in each of these formats are completed to varying degrees of scientific rigor. For the most part, the studies described in this summary are documented in peer-reviewed journals and/or federal and state reports.

Literature Summary

This literature summary is organized into discussions of studies that took four distinct approaches to the evaluation of the deer roadkill and/or DVC reduction effectiveness of roadside reflectors/mirrors. The first group of studies summarized includes those that examined the number of deer roadkill and/or DVCs during time periods when the devices were covered and uncovered along a specific roadway segment (*1*, *2*, *3*, *4*). Another group of studies summarized examined deer roadkill and/or DVCs before-and-after the installation of reflectors/mirrors (*5*, *6*, *7*, *8*). Third, two studies are described that compared deer roadkill and/or DVC data from treatment roadway segments (those with reflectors/mirrors) to similar data from control or non-treatment segments (*9*, *10*). Finally, studies that either included deer behavior observations in their evaluation, or

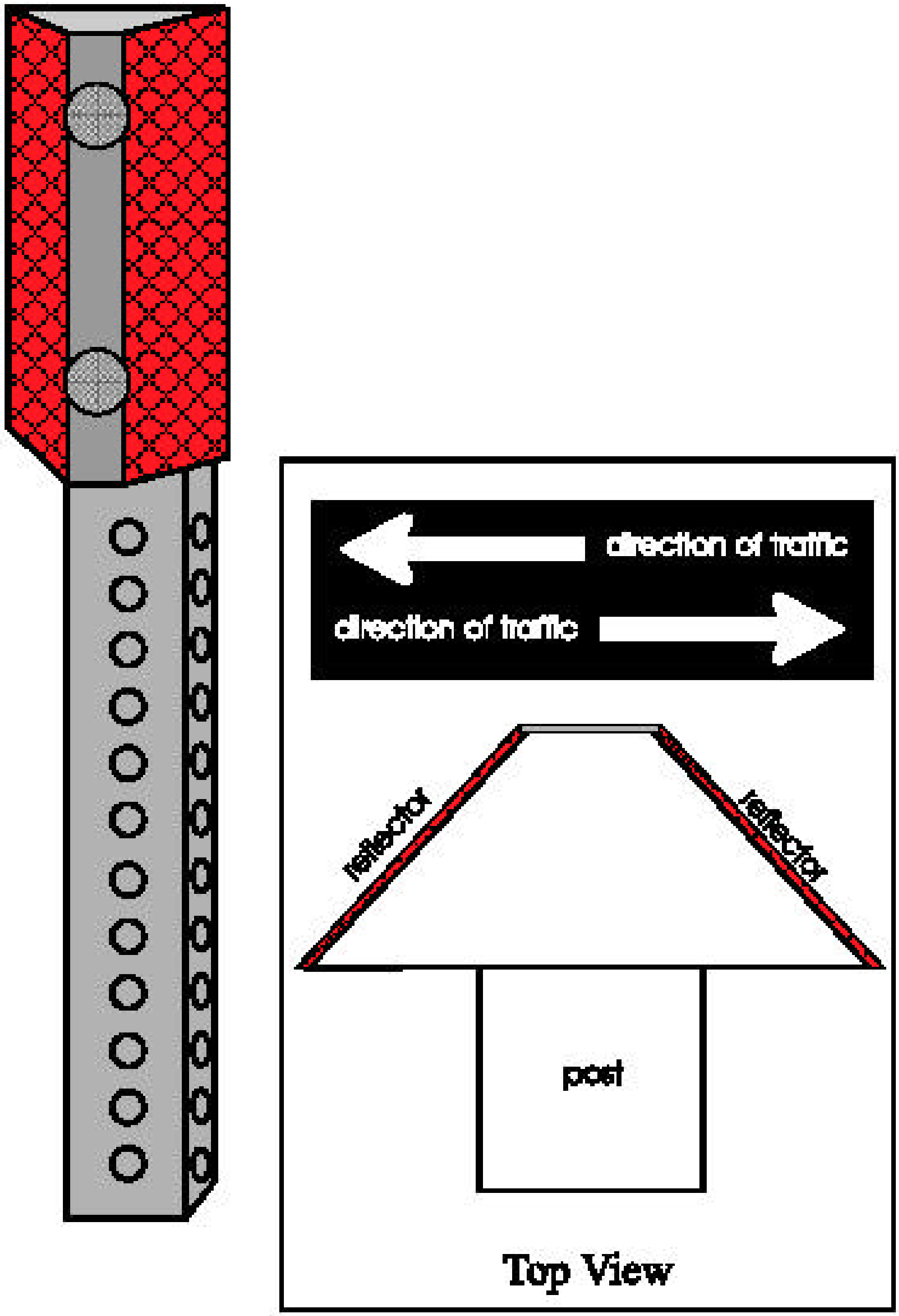

FIGURE 1 Deer reflector example (side and top view) (*11*).

specifically focused on the responses of wild or captive deer to reflector and/or mirror phenomena are described (*4, 8, 12, 13, 14*).

Cover/Uncover Studies

Studies in several states and one Canadian province have used a cover/uncover approach to evaluate the effectiveness of roadside reflectors/mirrors (*1, 2, 3, 4*). For example, in 1990 researchers in California installed roadside reflectors along two non-contiguous four-mile roadway segments of the two-lane State Highway 36 (*1*). For three years between May and September one of the four-mile series of reflectors was alternately covered and uncovered (*1*). During each five month time period, the reflectors were first alternately covered for three weeks and uncovered for three weeks, then covered and uncovered for four alternate two-week time periods, and finally each were covered and uncovered for three weeks again (*1*). The other four-mile series of reflectors remained uncovered. During the study time period, 399 mule deer roadkill were counted (*1*). About 56 percent (or 222) of these mule deer were killed at night (*1*). Fifty-eight percent (or 129) of the deer killed at night when the reflectors were uncovered (*1*). The researchers concluded from a two-sample t-test, however, that the number of mule deer roadkill during the covered/uncovered time periods were not statistically different (*1*). It was also noted that no mule deer roadkill were recorded along the segment where the reflectors were continuously uncovered (*1*). The researchers concluded that no additional analysis or research was needed, and did not recommend additional reflector installations (*1*).

A similar cover/uncover approach was taken by researchers in Washington when they attempted to evaluate the effectiveness of roadside reflectors along four adjacent roadway segments that were 0.45 to 0.68 miles long (*2*). The time period for this study was from October 1981 to April 1984, and deer roadkill data were collected from mid-October to mid-April of each year. The reflectors were alternately uncovered and covered along the four adjacent roadway segments, and the uncover/cover pattern reversed weekly from October 1981 to November 1982 and bi-weekly from December 1982 to April 1984 (*2*). During the study period, 594 deer roadkill were found along State Roadway 395, but only

58 occurred at night and within the study area (*2*). Of the 58 deer kills that occurred, 52 (about 90 percent) occurred along the roadway segments that had their reflectors covered (*2*). The researchers concluded that this value was statistically different than the six deer roadkill found along the segments with the reflectors uncovered. They recommended the installation of additional reflectors (*2*).

In Wyoming the cover/uncover study approach was also employed to test the effectiveness of roadside reflectors on mule deer (*3*). Reflectors were installed along both sides of a two-mile segment of United States Highway 30 from October 1986 to May 1989. This roadway segment crossed a major mule deer winter range. A 3.2-mile roadway control segment, for comparison purposes, was also identified about one mile from the study site. The reflectors were alternately covered and uncovered at one-week intervals along the two-mile study segment. During this 2.5-year study 64 deer roadkill were found while the reflectors were covered, and when the reflectors were uncovered 126 deer roadkill were counted (*3*). During the same time period, only 85 deer roadkill were counted along the 3.2-mile control segment. The researchers concluded that there appeared to be no evidence that the reflectors reduced the incidence of deer roadkill (*3*). However, problems related to the maintenance and durability of the reflectors were also noted (*3*).

In 1990 roadside reflectors were also installed on both sides of a 2.5-mile segment of Highway 21 in Ontario, Canada (*4*). The researchers in this 54-week study covered and uncovered the reflectors along this segment each Friday (*4*). The number and date of the DVCs that occurred along the segment were then collected. In addition, the researchers also attempted to observe and document the reaction of deer to the reflectors when the deer were located at the edge of the roadside woods, the middle of the ditchline, and at the edge of the shoulder (*4*). This deer behavior was observed with binoculars through a closed car window during a portion of the study period, and the eight deer observed had varying reactions to the reflectors. These reactions are documented in the "Captive Deer Studies" section of this summary (*4*). During the study, however, the roadway segment 30 nighttime DVCs were recorded at night (*4*). Sixteen (or about 53 percent) of these 30

DVCs occurred during weeks when the reflectors were covered, and 14 during those weeks when the reflectors were operational (*4*). The researchers concluded that the reflectors did not appear to reduce the occurrence of DVCs along the study segment.

Before- and-After Studies

A number of roadside reflector/mirror studies have also used a more traditional before-and-after study approach to safety analysis (*5*, *6*, *7*, *8*). The before-and-after approach has been used for many years to analyze transportation safety impacts of proposed roadway improvements. This approach has the advantage of being relatively simple, but it does not control for data regression to the mean. Regression to the mean relates to the basic hypothesis that locations with a large number of crashes one year should be expected to "normally" experience fewer crashes the next year with or without any improvements. For obvious reasons, safety improvements (including roadside reflectors/mirrors) are often installed at high crash locations, and if regression to the mean is not considered the results may overstate the actual effectiveness of these improvements. A partial response to this issue is the general recommendation to consider three or more years of safety data in any analysis of this type. Before-and-after studies from Georgia, Minnesota, and Illinois are briefly described in the following paragraphs (*5*, *6*, *7*, *8*).

In 1997 a total of 149 reflectors were installed along both sides of a 1/2-mile segment of State Highway 155 in Georgia (*5*). This segment of roadway was chosen because it represented one of the top ten DVC locations in the state, and was also being resurfaced. The number of DVCs reported along this 1/2-mile study segment was tabulated from 1993 to 1996, and for two years following the reflector installation. Prior to the reflector installation, from 1993 to 1996, there was an average of two reported nighttime DVCs per year. During the two years following the installation of the reflectors no nighttime DVCs were reported. However, due to the small sample size and short "after" analysis period, the researchers indicated that they could not make any conclusive recommendations about the effectiveness of the roadside reflectors (*5*).

Two before-and-after studies of reflector effectiveness have been completed and documented in Minnesota (*6*, *7*). The first study was relatively small, and evaluated the installation of 346 reflectors along a one-mile segment of Interstate 94 near Sauk Centre, Minnesota (*6*). In the year prior to the installation 38 white-tailed deer were found dead along this segment. After the installation, only 13 deer roadkill were observed during the following four years. The researchers did not document whether these deer roadkill numbers included those that occurred during daylight hours (*6*). They did, however, conclude that the results appeared to show a significant reduction in deer roadkill due to the reflector installation (*6*).

The second study in Minnesota was larger and included 16 installation sites throughout the state (12 rural sites and 4 urban) (*7*). Unfortunately, it appears that the before-installation deer roadkill data for this study were estimated with a variety of methods (e.g., crash reports and anecdotal accounts) (*7*). These estimates were then compared to the after-installation annual mean number of reported deer roadkill between 1988 and 1994 (*7*). In general, the 12 rural locations evaluated had a 50 to 97 percent reduction in nighttime deer roadkill, but the urban location data appeared to show an increase in deer roadkill. The researchers concluded that the reflectors appeared to successfully reduce deer roadkill along the rural segments, but no robust statistical analysis was conducted (*7*). They also concluded that the roadside reflectors were less successful along roadway segments with high sideslopes, and that the results from the urban locations might have been due to large traffic volumes or a difficulty with effectively maintaining the reflectors (*7*).

A before-and-after study approach was also taken in Illinois to evaluate the impacts of roadside reflectors on the number of deer roadkill and deer behavior (*8*). Roadside reflectors were installed along two 1/2-mile roadway segments of Illinois State Highway 148 (*8*). Samples of the deer behavior were then observed for a time blocks that, when combined, represented a 24-hour day. These data were collected for six months before (starting in September 1977 and ending in March 1978) and 14 months after the installation of the reflectors (starting in November 1980 and ending in January 1982) (*8*).

Deer roadkill data were also collected. The details of the deer behavior observations are described in the "Deer Reaction Studies" section of this summary. During this three-year study, 11 nighttime deer roadkill were recorded along the reflectorized roadway segment for the two years prior to the installation, and six nighttime deer roadkill were reported in the segment during the year after the installation (*8*). These roadkill results (along with the deer behavior observations described later) were used by the researchers of this study to conclude that the installation of the reflectors did not appear to reduce deer roadkill along the segment (*8*). They also indicated that data had been collected during a time period when the population density of white-tailed deer in the area was increasing (*8*).

Control/Treatment Comparison Studies

A third study approach that has been used to evaluate the effectiveness of roadside reflector/mirror installations is the control/treatment comparison. In these studies deer roadkill and/or DVC data from treatment roadway segments are compared to similar data from a control segment chosen by the researcher. In the 1960s, for example, roadside mirrors were installed along 2.5 miles of United States Highway 6/24 in Colorado (*9*). Vehicle speeds were measured before (N = 133) and after (N = 89) the mirror (and a sign indicating test) installation, and the average speed increased from 54.7 to 57.4 mile per hour (*9).* Overall, it was found that the ratio of the deer roadkill within the treatment segment to that in the remainder of the study area (without the mirrors) was not significantly different for the five years without and the three years with the installation (*9*). In other words, the researchers did not find that there were comparatively fewer deer roadkill in the mirrored segment than those study area segments without them. In addition, a comparison of the average annual roadkill for the entire study area with (i.e., five years) and without (i.e., three years) the mirror installation showed a six percent increase while the mirrors were in operation (*9*). The authors of the study reviewed did not specify whether they only considered nighttime roadkill (*9*). The researchers concluded, however, that their results appeared to show that the roadside mirrors had no impact on average vehicle speed or the number of deer roadkill occurring along the treatment segment (*9*).

A control/treatment comparison was also used in Iowa at five different treatment locations that varied from 1/2 mile to 1 mile in length (*10*). These sites were deliberately distributed throughout the state to account for different driving conditions, deer densities, and road types (*10*). A 1/2-mile control segment was also established at each end of the five test sites. In the year prior to the reflector installations 34 deer were killed in the reflectorized segments, and another four within the control segments. During the following three years 50 deer (16 in Year 1, 11 in Year 2, and 23 in Year 3) were killed along the treatment segments, and 17 deer were killed in the control segments (5 in Year 1, 9 in Year 2, and 3 in Year 3) (*10*). Overall, about 11 percent of the total deer roadkill occurred in the control segments before the installation, but about 25 percent after the installation. The annual percentage of total roadkill in the control segments varied from 12 to 45 percent during the three post-installation years considered, and the results also varied from installation to installation site (*10*). During the time period considered, the DVCs reported statewide increased by 140 percent (*10*). After the reflectors were removed only nine and twelve deer roadkill were reported within the treatment and control segments, respectively (*10*). The significance of these post-reflector removal results, beyond an indication of the normal deer roadkill variability in the segments, was not documented (*10*). Overall, the researchers concluded that the reflectors appeared to be effective at the reduction of deer roadkill along some of the segments but not along others (*10*). They recommended the installation of reflectors along roadway segments with high levels of DVCs (*10*).

Deer Reaction Studies

What deer actually see and react to is also an important question to answer in the study of roadside reflector/mirror effectiveness. For example, many roadside reflectors are red in color, but some researchers speculate that white-tailed deer may not be able to see this color. Several studies have been documented that either included deer observation in their evaluation or specifically focused on the reactions of wild and/or captive deer to reflected light (*4*, *8*, *12*, *13*, *14*). Many of the projects previously described focused on mule deer. However, no studies were found that addressed whether the reactions vary between mule and white-tailed deer, or quantified the potential difference between captive and wild deer reactions. Those deer behavior studies reviewed are described in the following paragraph.

The researchers involved with two of the studies previously described also considered and documented some deer behavior during their evaluation of the impact of roadside reflector installations on deer roadkill and/or DVCs (*4*, *8*). During the Ontario cover/uncover study, for example, researchers observed deer behavior through a car window with binoculars during a portion of their study period (*4*). Eight deer were observed, and had varying reactions to the reflectors (*4*). These reactions ranged from turning their heads with the vehicle movement to running into the adjacent woods (*4*). The researchers concluded that even this small sample of observations appeared to indicate that the deer were not reacting to the reflector before the vehicle passed their location (*4*). They believed the deer were responding to the sound and light of the passing vehicle rather than the reflected light, but no comparison with deer reactions when the reflectors were absent was documented (*4*). More details about this study are also documented in the "Cover/Uncover Study Approach" section of this summary (*4*).

Finally, the researchers involved with the Illinois control/treatment study described in the previous section also observed deer behavior when studying roadside reflectors (*8*). Samples of deer behavior were observed from a parked vehicle for a time block representing a 24-hour day during six months before and 14 months after the installation of reflectors. Before the installation of the reflectors, 70 percent of the observed deer approached and attempted to cross the roadway segment (*8*). After the reflector installation, 87 deer were observed along this same part of the roadway, but only 14 (or 16 percent) of those observed made an attempt to cross the roadway in the presence of a vehicle (i.e., when the reflectors would be operating) (*8*). Eleven (or 79 percent) of these deer approached the pavement and crossed, and three ran back into the woods (possibly due to the reflectors) (*8*). Based on this data, the researchers concluded that the roadside reflectors did not appear to have an impact on deer approaching the roadway (*8*). They also indicated that the results had been collected during a time period when the population density of white-tailed deer in the area was increasing (*8*).

Some studies also specifically focused on the evaluation of deer reactions to reflected light. During a study at Michigan State University various wavelengths of light were shown to a captive female white-tailed deer (*12*). The behavior of this deer and its ability to discriminate between different light wavelengths were then observed. Overall, the researcher found no clear evidence that the captive deer reacted to different colors in any measurably different manner, but it may have been relatively more responsive to lower wavelengths (i.e., not the color red) (*12*). The researcher also concluded that nothing specific was observed about the vision of deer that might help in the construction of a light-based deer deterrent system (*12*). In addition, it is also plausible that the color recognition of this single deer was not representative of the population. In other words, the design and significance of the study did not allow the researchers to make any definite conclusions about *wild or captive* white-tailed deer and their reaction to colored reflectors (*12*).

Researchers at Michigan State University also attempted to evaluate the impact of red, white, and no reflector installations on captive white-tailed deer movements (*13*). The researchers installed five reflectors (facing in one direction) at the 66-foot spacing recommended by the manufacturer. These reflectors were placed across a 3.5-acre enclosure that contained 10 white-tailed deer (*13*). A pair of automobile headlamps was then installed at one end of the reflector series. During 18 twenty-minute sessions the researcher then recorded how many times the white-tailed deer crossed the reflectorized area (*12, 13*). Red, white, and no reflector light was presented to the deer for an equal period of time in the study, and the six different orders in which they could be presented were done three times each but varied from session to session (*12*, *13*). Overall, the researchers concluded that the red reflectors did not appear to discourage white-tailed deer from crossing or approaching the line that they defined (*12*, *13*). The data showed that white-tailed deer crossings were about the same for red and white reflectors, and that the crossings only slightly increased with no reflectors (*12*, *13*). Other researchers have questioned the transferability of these study results to the roadside and wild white-tailed deer (*2*). In other words, it has been speculated that the reaction of the captive deer may not be indicative of wild deer (*2*).

A Danish research team has also documented a 20-night reflector-related behavioral analysis of captive fallow deer (*14*). The researchers installed a reflector assembly on a tree about 2.6 feet above the ground, exposed it to four different light intensities to similar to vehicle headlights at different distances, and noted the deer behavior (*14*). The four light intensities considered were the result of one 0.24-Watt bulb; one 0.24-Watt and one 2-Watt bulb; one 0.24-Watt and two 2-Watt bulbs; and one 0.24-Watt, two 2-Watt, and one 3-Watt bulbs (*14*). Corn was spread in the area of the reflected light so the deer would be attracted to the area for observation (*14*).

Overall, the behavioral responses of the deer were categorized as flight, alarm (i.e., looked up suddenly with tensed muscles), head movement (i.e., looked up for a while and then again lowered its head), and no reaction (*14*). The deer fed normally during the nights with no reflector lights. On the first night of the study, only the lowest level of light was used, and 99 percent (80 of 81) of the deer reacted with flight (*14*). By the fifth night, however, only 16 percent (28 of 174) fled, one percent lifted their heads, nine percent were alarmed, and 74 percent had no response (*14*). The other light intensity designs were then used sequentially, to simulate an approaching vehicle, on nights 6 to 15 (*14*). Overall, observations during the sixth and seventh nights showed a total of 86 percent (19 of 22) and 94 percent (152 of 162) of the deer fled for the three light intensities used (*14*). However, the deer also fled less often and more of them showed no reaction to the lights as the project progressed from the sixth to the fifteenth night (*14*). In general, the researchers concluded that the fallow deer habituated to the reflectors with time, and increasingly showed no reaction to the light (*14*). It was assumed by the researchers that other types of deer might exhibit the same type of behavior to other types of reflectors (*14*).

Conclusions

The studies and literature reviewed in this summary were summarized in four categories. Past reflector/mirror research typically used either a cover/uncover, before-and-after, or control/treatment study approach to evaluate their impact on deer roadkill and/or DVCs. Researchers have also either observed deer movements as they evaluated deer roadkill and/or DVC impacts or specifically considered deer behavior toward reflected light. Many of the studies summarized in this document, whether they focused on deer roadkill and DVC impacts or deer behavior, led to conclusions with conflicting results. Overall, 5 of the 10 studies concluded that roadside reflectors did not appear to impact deer roadkill or DVCs, and 2 of the 10 concluded that they did. Three of the 10 studies summarized also appeared to reach inconclusive or mixed results. Most of the studies that evaluated deer behavior (many dealing with captive deer) were also inconclusive or primarily concluded that the deer either did not appear to react to the light from the reflectors, or quickly became habituated to the light. A key to the validity or strength of the study results in this summary is their experimental design, and many of these details are included. The robustness of the experimental designs used in the studies summarized does vary, but for the most part only those that recorded the necessary information were included. As previously mentioned, there is also a lot of speculative and anecdotal information that exists about roadside reflector/mirror effectiveness. These documents were not summarized.

At this point in time it is difficult to conclude anything about reflector/mirror deer roadkill or DVC-reduction effectiveness due to the conflicting results of the studies summarized. It is recommended that the completion of a definitive roadside reflector/mirror DVC-reduction effectiveness study be considered. A well-designed widespread long-term statistically valid study of comparable and well-defined roadside reflector treatment and control roadway segments (with consideration given to local deer travel patterns) is believed to be necessary to assist in well informed decision-making.

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REPELLENTS

A number of studies have attempted to evaluate the impact of chemical and biological repellents on animal feeding. Some of these studies are summarized in this document (*1*, *2*, *3*, *4*, *5*, *6*, *7*, *8*). It has been speculated that the application of repellents on roadside vegetation might be used to deter deer browsing and possibly reduce the number of deer-vehicle crashes (DVCs). Unfortunately, no research was found that discussed or tested the DVC impact of repellents applied in the field along a roadway, or attempted to evaluate the other impacts or factors that might need to be considered in an application of this type.

Repellents reduce animal feeding by making a source of food taste unpleasant (this is referred to as a contact repellent) and through offensive (typically predator-related) smells (this is referred to as an area repellent). A number of chemical and biological repellents are available that use these approaches. The studies summarized in the following paragraphs evaluate the impact of one or more repellents on the eating habits of captive white-tailed deer, mule deer, caribou, and/or elk. These animals all have similar predators and were expected to have somewhat similar responses to particular repellents. The "Conclusions" section of this summary discusses some of the potentially confounding factors that should be considered in the use and comparison of the studies reviewed, and also describes the results of an analysis and ranking of repellent effectiveness completed by Hani and Conover (*8*). Their analysis and ranking activities included five of the references reviewed in this summary plus seven others (*9*, *10*, *11*, *12*, *13*, *14*, *15*). The results from a recently completed review to determine the potential of an area repellent system to keep ungulates away from roadways are also described (*16*).

Literature Summary

White-Tailed Deer

During the winter season of 1989 and 1990 Swihart, et al. conducted a study that tested the effectiveness of three predator odor repellents on white-tailed deer consumption of shrubs (*1*). The trials evaluated the effectiveness of urine from bobcats, coyotes, and humans (*1*). In general, some of the factors that might impact a response by a white-tailed deer to predator odors could include whether the predator and prey consistently co-exist in the same space, the length of the association between the predator and prey, and to what extent a flee response to a predator can or has been passed on by members of the prey species (*1*). Based on this knowledge, Swihart, et al. hypothesized that the white-tailed deer repellency of the predator urine odors they considered would decrease in the following order: bobcat, coyote, and human (*1*).

During the first trial, a tube containing predator (i.e., bobcat, coyote, and human) urine was attached to transplanted Japanese yew shrubs in a wooded test area (*1*). Distilled water tubes (as a control) and those with the urine treatments were attached to the yew shrubs in a random manner (*1*). The percentage of shoots browsed was then measured. Overall, an increase in browsing was observed with time, but the yew shrubs treated with bobcat and coyote urine were browsed at a significantly lower level than those treated with water or human urine (*1*). In addition, the shrubs treated with bobcat urine were browsed significantly less than those treated with coyote urine (*1*).

During the second trail, Swihart, et al. tested whether a weekly topical spray application of bobcat and coyote urine would be more effective than the hanging of tubes at repelling white-tailed deer (*1*). One yew shrub in each test plot was sprayed with a urine mist, and it was found that this shrub received less white-tailed deer browsing than the control trees (which had experienced browsing similar to that which occurred in trial one) (*1*). Swihart, et al. concluded that the repellency (as measured by percent shoots browsed) of the bobcat and coyote urine was still significantly greater than human urine, and that the repeated topical applications (versus tube hanging) significantly increased repellency (*1*).

A related third trial included yew shrubs and also added several Eastern Hemlock tree branches to the experimental plots. Some of the plots were sprayed with bobcat and coyote urine once or twice weekly (*1*). Other plots served as a control and were sprayed with distilled water. The researchers found that the spraying of bobcat and coyote urine on the Eastern Hemlock decreased the white-tailed deer browsing more than that experienced with the yew experiments (*1*). However, the authors were unable to conclude that the increased frequency of application produced any additional reductions (*1*).

Overall, Swihart, et al. made several conclusions based on their experimental results (*1*). First, human urine appeared to be ineffective as a white-tailed deer repellent (*1*). They speculated that this result might be due to the relatively short period of co-existence between humans and white-tailed deer. In other words, the smell of humans did not result in the same naturalistic flee mechanism that would occur with the apparent presence of a bobcat and coyote. Second, Swihart, et al. concluded that their evidence appeared to show that white-tailed deer could distinguish between predator and non-predator odors, and that the coyote and bobcat urine in tubes became less effective with time (*1*). These results could have been caused by white-tailed deer habituation or the evaporation of the repellent components, but Swihart, et al. believed it was evaporation because their reapplication of the repellents resulted in a larger reduction in browsing (*1*).

Mule Deer

Sullivan, et al. have completed research on the repellency of predator odors on the feeding patterns of mule deer (*2*). They specifically tested the effectiveness of cougar, coyote, bobcat-lynx (mixture), jaguar, and wolf feces odors, and the urine odors of coyote, wolf, lynx, bobcat, fox, and wolverine (*2*). During seven test trials, these materials, as well as human urine, ammonia, and/or other commercial repellents were applied to Salal (a type of shrub) leaves and/or two types of coniferous seedlings using several methods. In some cases the feces were mixed with water and placed on the plant, and the ammonia and human urine were placed in vials located near the leaves. In other cases, fecal extracts were mixed with an adhesive and painted on nearby stakes (*2*).

When the different extracts were applied to the plant or used as an adhesive it was concluded that the predator feces (e.g., cougar, coyote, and wolf) odors significantly suppressed (sometimes completely) the browsing by mule deer (*2*). The vials of human urine resulted in no significant difference (when compared to the control) in the mule deer browsing (*2*). The vials of ammonia reduced browsing for the three days considered, but to a significantly smaller level than the wolf or jaguar feces (*2*). Coyote, wolf, and jaguar fecal odors, whether in vials or used as an adhesive, also significantly reduced Salal browsing. Finally, all the predator urine odors were found to significantly reduce Salal browsing (*2*). The coyote odor had the most consistent Salal browsing reduction results, but also reduced the coniferous browsing (*2*).

Overall, the Sullivan, et al. study indicated that predator orders could be an effective mule deer repellent using any of the three application methods considered (*2*). In 1978 Melchiors, et al. also found that predator fecal odors reduced the feeding of mule deer (*3*). Unlike the later Sullivan, et al. study, however, Melchiors, et al. found that feline odors were more effective than canine odors (*3*).

Andelt, et al. also evaluated the effectiveness of several repellents on mule deer (*6*). The details of the experimental design used in this study are similar to that of another Andelt, et al. study described in the "Elk" section of this summary (*5*). Overall, this study found that McLaughlin Gormley King Company™ Big Game Repellent (BGR), whole chicken eggs, and coyote urine were more effective at repelling mule deer than Hinder™, bars of soap, Ro-pel™, and thiram. However, none of the repellents tested did deter mule deer when they were hungry (*6*). This study also showed a decrease in the effectiveness of *odor* repellents (i.e., BGR, coyote urine, and chicken eggs) with time, and an increase in effectiveness with time of the thiram taste repellent (*6)*. However, Andelt, et al. also concluded that water sprinkled on apple twigs after the application of the repellents somewhat decreased their effectiveness (*6*).

Caribou

In 1998, Brown, et al. studied 14 captive caribou to test the feeding deterrent capabilities of Wolfin™, Deer Away™ BGR, and lithium chloride (LiCl) (*4*). They speculated that these repellents might be combined with roadway sand-salt mixtures and/or applied adjacent to roadways to reduce DVCs (*4*). The Wolfin™ was tested by observing the feeding patterns of caribou when a capsule of the material was placed near their food tubs. Capsules of Wolfin™ with the substance (at concentrations five times the manufacturer's recommendation for roadside use) were placed approximately 6.6 feet from the food tubs (*4*). The BGR and LiCl repellents were tested by combining them with the caribou food.

The reaction of the caribou to each repellent was measured by recording the quantity of food consumed, the time spent feeding, and the number of feeding bouts (i.e., the number of separate instances a caribou lowered its head to the food, turned away, and then moved more than 3.3 feet) (*4*). Observations were made for two days prior to the treatment, during the five days of each treatment, and for two days after the treatment.

Each repellent had a different impact on the feeding patterns of the caribou. Overall, the researchers concluded that the captive caribou did not appear to be affected by the Wolfin™ (*4*). They continued to feed with the Wolfin™ nearby, showed a slight increase in feeding time, and an increase in the number of feeding bouts (*4*). Conversely, on the first day of the BGR treatment the caribou did not consume any of the treated food, and the length of caribou feeding time initially decreased (*4*). During the remainder of study period, however, feeding time and quantity slowly increased and returned to those similar to pre-treatment levels (*4*). This feeding pattern could be the result of habituation or increased hunger by the caribou. Feeding bouts only slightly decreased during the treatment period (*4*). The application of the LiCl resulted in an immediate 25 percent reduction in the quantity of treated food consumed, and the feed was entirely rejected throughout the remainder of the study period (i.e., the caribou ate the LiCl, were sick, and did not return) (*4*). The number of feeding bouts and total feeding time did increase at the start of LiCl treatment, but then continued to decline during the study time period (*4*). The number of feeding bouts appeared to initially increase because the caribou would check the food more often and then leave it alone if it was still treated (*4*). In the post-treatment period, the quantity of food consumed increased immediately. Brown, et al. also noted that the caribou appeared to seek water more often when the LiCl was applied (*4*).

Brown, et al. also suggested that the caribou did not appear to be repelled by the Wolfin™ because their motivation to feed may have been greater than the odor avoidance impact, and/or the animals may not have recognized the odor of a predator (*4*). The pattern of feeding observed with the BGR application also appeared to indicate some habituation to the repellent, and the LiCl was the most effective caribou repellent tested (*4*). Unfortunately, according to the authors of this study, the use of LiCl as a repellent may also initially increase the feeding time of animals (*4*). This side effect may remove this repellent as an option for applications along roadways (*4*). In addition, it may also have some negative effects on other animals (*4*). Past research and field studies have also produced inconsistent results, and although LiCl is not considered hazardous, there have been examples where non-targeted animals have died from ingesting too much of it (*4*). These observations suggest that more research is needed.

Elk

Research similar to that described above was also completed by Andelt, et al. (*5).* They evaluated the repellency of McLaughlin Gormley King Company™ BGR, chicken eggs, coyote urine, Hinder™, Hot Sauce Animal Repellent™, Ro-pel™, and thiram on captive female elk (*5*). In one trial, each of the repellents was sprayed on alfalfa cubes and fed to the elk. Observations were then made of the quantity of food consumed. In a second trial, the food supply was reduced for several days to increase the hunger of the test animals and the treated food was then supplied (*5*). Finally, in a third trial, Andelt, et al. tried to determine the minimum repellent concentration levels that would inhibit elk browsing of apple tree twigs (*5*).

Overall, the effectiveness of the repellents studied by Andelt, et al. was related to the hunger level of the elk, the palatability of what was consumed, and the concentration of the repellent (*5*). For example, the hungry elk ate more treated apple twigs than those that were regularly fed (*5*). In fact, hunger appeared to reduce the effectiveness of all the repellents tested except for a 6.2 percent concentration (at 100 times the recommended for deer) of Hot Sauce Animal Repellent™ (*5*). This concentration of animal repellent deterred all the well-fed elk and the majority of the hungry elk (*5*). The application of the recommended concentration of Hot Sauce Animal Repellent™ for deer, however, failed to deter hungry elk and most of the regularly fed elk (*5*). The coyote urine concentrations that Andelt, et al. tested also failed to deter the hungry elk, and only reduced the feeding levels of some regularly fed elk when it was applied at full strength (*5*). Similar results were found when the recommended concentration of thiram was tested (*5*).

In general, Andelt, et al. concluded that BGR and coyote urine were more effective than the chicken eggs and other repellents at decreasing the feeding activities of elk on alfalfa cubes (*5*). The effectiveness of the repellents based on *odor* (e.g., chicken eggs) also appeared to decrease during the study period and may have been caused by elk habituation (*5*). The *taste* repellent tested (i.e., thiram), however, reduced feeding during the entire study period (i.e., after the initial taste) (*5*).

Conclusions

A number of studies have attempted to evaluate the effectiveness of numerous repellents on the feeding patterns of several different types of captive animals (*1, 2, 3, 4, 5, 6, 7*). The studies summarized here investigated different repellent impacts on white-tailed deer, mule deer, caribou, and elk. Unfortunately, the descriptions in this document reveal, for the most part, that these studies were designed in an inconsistent manner and focused on several specific factors that may impact repellent effectiveness. Some of the different factors evaluated include type and number of repellents (e.g., predator urine, brand, odor, taste, etc.), status or application of repellent (e.g., spray, paste, etc.), concentration of repellent, animal hunger level, food type, and amount of rain or water occurrence after repellent application. All of the studies did find some type of feeding reduction with one or more of the repellents considered, but the variability and/or non-repeatability of the studies makes a direct comparison of their results difficult. Any comparison would require an assumption of equality in the validity and robustness of the results from these multiple studies. An attempt to discover some trends in these and other repellent studies is described below.

Hani and Conover did reach conclusions similar to those stated above when they evaluated five of the studies described in this document and seven others (*1*, *2*, *3*, *5*, *6*, *8*, *9*, *10*, *11*, *12*, *13*, *14*, *15*). They also decided to rank, analyze, and then evaluate the repellent effectiveness results of all twelve studies, and attempt to define some overall trends (*8*). All of these studies evaluated by Hani and Conover focused on the effectiveness of two or more repellents (*8*). First, they summarized the species considered (i.e., white-tailed deer, mule deer, and elk) in each study, the food used, and whether the study was a field test (*8*). Then, they ranked (i.e., 0 = ineffective to 4 = highly effective) the effectiveness results for each repellent considered in the studies they reviewed (*8*). These rankings were then statistically analyzed.

Overall, Hani and Conover concluded that BGR and predator odors were typically shown to be the most effective of all the repellents considered in the studies they evaluated (*8*). In addition, they found no significant difference in the ranking of area (i.e., primarily odor) and contact (i.e., spray or dust) repellents, or in the reactions to repellents between deer and elk (although white-tailed and mule deer appeared to react differently to predator odor) (*8*). Factors found to impact the effectiveness of repellents included the relative palatability of the plant protected, local deer herd populations, availability of other food, weather, amount and concentration of repellents, and study/test duration (*8*). The results of the Hani and Conover evaluation may be useful when choosing a repellent, but should also be used with the understanding that the comparison required a subjective, but expert, ranking to be completed. An assumption that all the studies they evaluated were equally valid and comparable results was also required.

In 2003, Kinley, et al. also completed a detailed literature review and qualitative summary of a large number of studies to investigate the potential for an area repellent system to keep ungulates away from roadways (*16*). Their document contains more than 75 references in its bibliography, and has a table that summarizes the results of more than 265 repellent tests (*16*). After a review of this information they determined that the area-based repellents with the most potential to keep ungulates away from roadways were putrescent egg and natural predator odors (*16*). However, their potential still needs to be tested in the field. It was also noted that there should not be an expectation that one repellent will result in complete deterrence, or that the choice of which specific repellent (e.g., type of predator odor or repellent brand name) to use for roadside purposes is obvious (*16*).

Despite the number of repellent effectiveness studies on captive white-tailed or mule deer, no studies were found that documented an attempt to test repellent effectiveness on deterring wild animals from crossing a roadway. It should also be recognized that the reaction of captive and non-captive animals to some repellents (e.g., predator urine) might vary because captive animals may not associate these odors with danger. The significance of this difference, however, still needs to be measured because it appears that some of the reaction to predator odor could be genetic rather than learned (*7*).

The effective application of repellents (chemical, biological, acoustical, etc.) to reduce roadside browsing of white-tailed deer is based on several factors. These factors include, but are not limited to, how the repellent is applied, at what time intervals, cost, animal habituation, and the locations to which is it applied. Like most of the other countermeasures already summarized, the application of repellents as a DVC reduction tool would also most likely need to be focused on "high" DVC locations rather than widespread. In addition, white-tailed deer (or other animals) may just shift their browsing location if repellents are not applied in a widespread manner (but this would also have its own undesirable ecological impacts). Studies have shown that animals may habituate to repellents, and if they are hungry may even browse plants treated with repellents. In fact, Kinley, et al. suggest that repellents would be most effective if used at specific locations for the short-term (*16*). In addition, the application of repellents in combination with other DVC reduction tools at "high" crash locations might be considered for maximum effect. Finally, other factors that need to be considered in the application of repellents are their impact on non-targeted animals and their possible impacts on the general environment. Clearly, additional and repeatable research needs to be completed in this field to determine the actual impact of repellent application on the number of DVCs.

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HUNTING OR HERD REDUCTION

The number and type of vehicle crashes at a particular location are often directly related to and/or predicted by its exposure characteristics. For example, the Federal Highway Administration recently released a document that included models used to predict the number of intersection crashes per year along two-lane rural roadways (*1*). A primary input for these models are conflicting vehicle flows (an intersection crash exposure characteristic).

In a similar manner, deer-vehicle crashes (DVCs) occur when a vehicle and deer are at the same place at the same time. Two DVC exposure characteristics of a particular roadway location (and time) would seem to include, therefore, measures of vehicle flow and deer crossing the roadway. A plot of deer population and deer carcass data (per hundred million vehicle miles traveled (HMVMT)) for a 30-year time period in Wisconsin is shown in Figure 1 (*2*). In addition, the number of white-tailed deer bucks killed during hunting season has been shown to be highly correlated with the number deer carcasses (one measure of DVCs) collected (*3*). For these reasons, it has been suggested

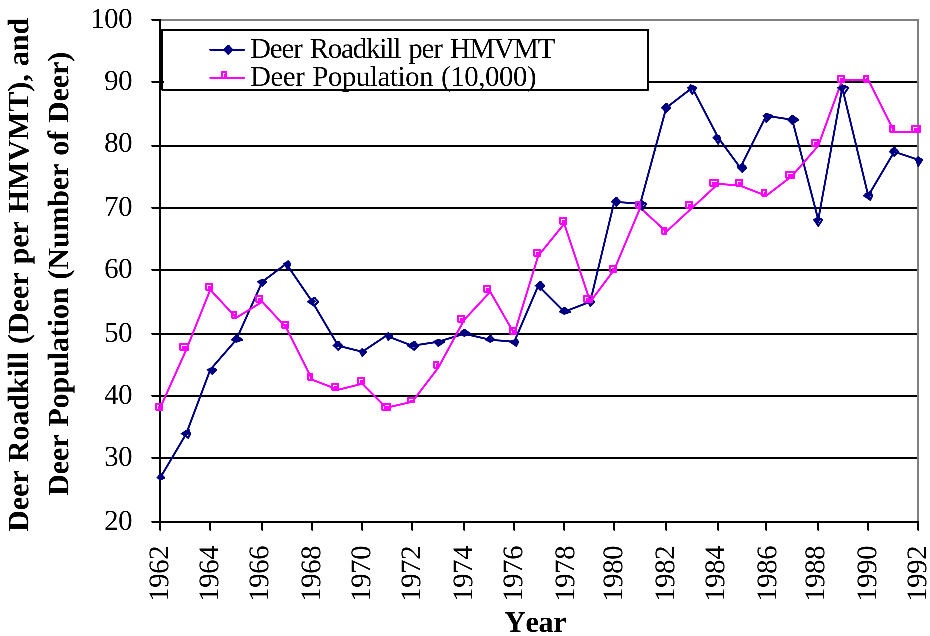

FIGURE 1 Deer roadkill rate and deer population in Wisconsin by year (*2*).

that a reduction in white-tailed deer herd size, through hunting or other means, could be a potential DVC countermeasure.

No studies were found that attempted to quantitatively relate hunting and/or herd reduction activities or policies with a subsequent change in the number of DVCs within a particular large geographic area (e.g., a state). Not surprisingly, the primary objective of the hunting or herd reduction studies reviewed for this toolbox was the impact these activities may have had on the animal population of interest. Several papers and reports were reviewed, however, that did document observed DVC patterns while herd reduction activities were being completed within smaller geographic areas (e.g., a park or city). The findings from these and two other white-tailed deer population dynamics studies are discussed in this summary (*4*, *5*, *6*, *7*, *8*, *9*, *10*, *11*). The researchers from the population dynamics studies speculate that the herd reductions could reduce the number of DVCs in the area (*4*, *5*). Several other researchers, however, have discussed and/or attempted to model the relationships between DVC data and a number of deer and human population, vehicle travel, land use, landscape, and/or roadway/roadside characteristics (*12*, *13*, *14*, *15*, *16*, *17*, *18*, *19*, *20*).

DVC Prediction Models

During the last 30 years a number of researchers have discussed and/or investigated the factors associated with the occurrence and location of DVCs (*12*, *13*, *14*, *15*, *16*, *17*, *18*, *19*, *20*). Some of the factors they have identified include: deer population; human population; vehicle-miles-of-travel (VMT); highway miles; and land cover or acreage classified as woodland, farmland, timberland, urban land, rural land, cropland, and forestland (*12*, *13*, *14*, *15*, *16*, *17*, *18*, *19*). For example, Gunther, et al. noted that within their study area the number of mule deer killed along roadways within forested areas was more than expected (*12*). In addition, Bertwistle also observed relationships between roadkill and the particular habitat and/or behavior or animals (*13*).

In other cases, however, researchers have focused on quantifying the relationships and/or correlations between specific ecological, land use, or roadway factors and the number of

DVCs at a location or within a county or city (*14*, *15*, *16*, *17*, *18*, *19*). Models have been developed (often through a multiple regression approach) to predict the probability a location will be a "high" DVC site and the number of DVCs expected to occur within a county or city (*14*, *15*, *16*, *17*, *18*, *19*). Several examples of these models are described in the following paragraphs. Many of the factors included in these models can be connected to white-tailed deer habitat or movement in some manner.

"High" DVC Location Models

Several projects that examined the potential relationships between "high" DVC locations and their adjacent environmental, roadside, and roadway characteristics were recently summarized and included in a University of Wisconsin thesis (*20*). Models from Illinois, Iowa, Pennsylvania, and Kansas are discussed below (*14*, *15*, *16*, *17*).

The Illinois Model In Illinois, Finder considered the percentage of woodland, forage (i.e., crops, fields, and orchards), developed land, and water within a 0.8 kilometer (0.5 mile) buffer of 1.3 kilometer (0.8 mile) roadway segments with more than 15 reported DVCs between 1989 and 1993 (*14*). She also investigated characteristics related to right-of-way topography (flat, gully, and bank), roadway segment curvature (a ratio of total length to straight length), general buffer area topography (the difference between the highest and lowest contours), the number of fields in the buffer area, the deer travel corridor width (i.e., the typical width of corridor that deer use to travel within their home range) across the roadway, and the distance from the roadway to the nearest forest cover and parks (*14*).

Data from 81 "high" DVC locations and 81 control sites within 43 counties were used to develop two models to calculate the probability a roadway location would be a "high" DVC site (*14*). The first Illinois model included all variables found to be significantly different between the "high" DVC and control sites (*14*). The model indicated that the probability a roadway segment would be a "high" DVC site decreased as its distance from woodlands increased (*14*). This probability increased with the percentage of adjacent gully, nearby recreational areas, and the width of the deer travel corridor across the roadway (*14*). Only landscape variables were incorporated into the second model, and it showed that higher values of Simpson's diversity index (a measure of land cover richness (i.e., number of different landscape patches) and uniformity), and woodlands mean proximity index (a measure of woodlands patch size and density) increased the probability of a roadway segment being a "high" DVC site (*14*). Finder proposed that a site be considered a "high" DVC location if the model output was greater than 0.60 (*14*).

The Iowa Study Hubbard, et al. also studied the relationships between several roadway and roadside factors and the probability a roadway segment could be a "high" DVC location (*15*). They considered the characteristics of 1,284 locations randomly selected within Iowa, and defined any one mile roadway segment with greater than 14 reported DVCs between 1990 and 1997 as a "high" DVC site (*15*). Hubbard, et al. evaluated data that described certain land cover, daily traffic volume, the distance to the nearest town and nearest city with a population greater than 2,000, the number of bridges along the segment, and the number of roadway lanes (*15*). Eight years of data were used, and the proposed "high" DVC location probability model included measures related to grass, crop, and woodland patches; the variability in land cover patches; and the number of bridges and lanes along the roadway segment (*15*).

The number of bridges within the roadway segment and the number of roadway lanes appeared to be two of the more important predictors of "high" DVC sites in Iowa (*15*). The probability of a "high" DVC site occurring increased with both of these variables, and also the size of nearby grass and woodland patches. The probability of a roadway segment being a "high" DVC site, however, appeared to decrease as the variation in nearby patch sizes and the size of crop fields increased (*15*). A validity test of the model correctly classified 160 (or about 65 percent) of 245 randomly selected sites as "high" DVC or control locations (*15*).

The Pennsylvania Study Finally, Bashore, et al. considered the environmental and traffic flow characteristics of "high" DVC locations along two-lane highways in Pennsylvania between July 1979 and October 1980 (*16*). Roadway segments that were

250 meters (825 feet) long were considered "high" DVC locations if they had a minimum of four DVCs reported in the year preceding the study and at least two reported DVCs per year in 5 of the 10 years preceding the study (*16*). Some of the roadway and habitat (within 100 meters (328 feet) of the roadway) variables considered for this model included: number of residences; number of commercial buildings; percent terrain classified as banks, gullies, and level; percent land cover classified as wooded, non-wooded, and barren; distance to woodlands greater than 0.8 square kilometers (0.25 square miles) in area; three percent slopes classifications; sight distances along the roadway and in-line visibility (i.e., the distance at which an observer one meter (3.28 feet) from roadway centreline can no longer see a two meters (6.56 feet) high board on the roadway edge); posted speed limit; fencing within the buffer area as a percent of segment length; and guardrail length as percent of the segment length (*16*).

Data from 51 "high" DVC and 51 control sites were used to develop the Bashore, et al. model, and it included variables that measured the number of homes, commercial, and other (e.g., hunting camps, churches, and barns) buildings within the buffer area of the roadway segment, roadway sight distance and in-line visibility, posted speed limit, the distance to woodlands, and the proportion of fence length and non-wooded herb areas in the buffer zone (*16*). The predicted probability decreases with an increasing number of homes, commercial, and other buildings within the buffer area, and longer sight distance along the roadway (*16*). The model also indicates a decrease in the "high" DVC probability with increases in the percent fencing, the distance to woodlands, the ability to see a roadside object (i.e., in-line visibility), non-wooded herbs in the buffer zone, and posted speed limit (*16*). The researchers speculated that the negative relationship between posted speed limit and the probability of a "high" DVC location might be because fewer deer may cross when vehicles move at higher speeds (*16*). They suggested that a "high" DVC site should have a model output of 0.70 or greater (*16*). Issues related to the potential intercorrelations between input variables included in this and other models are discussed in the conclusions section of this summary.

The Kansas Study Researchers at the University of Kansas also recently completed work that identified variables or parameters that appear to be correlated with the DVC experience of a roadway segment (*17*). They developed a model to predict DVCs per year per mile of roadway, and considered input data from 45 roadway, roadside, and deer population factors (e.g., land use type, deer harvest density, sideslope, traffic volume, posted speed, etc.) (*17*). The results indicate that the variable most strongly correlated with DVCs per year per mile was the existence of wooded land adjacent to the roadway (*17*). DVCs per year per mile were also positively correlated to the number of roadways lanes, traffic volume, posted speed, number of bridges and/or visible culverts, the presence of a deer warning sign, and traditional right-of-way fencing (*17*). Factors negatively correlated with DVCs per year per mile included clear width (i.e., distance to an obstruction at least 3 feet wide and 2.5 feet high), roadside sideslope, and roadside topography in the transverse direction (*17*). In addition, those roadway segments with a grass median had higher DVC rates than those with median barriers, and those with median barriers had higher rates than two-lane undivided roadways (*17*).

County DVC Models

At least two researchers have also developed models to predict the number of DVCs within a county (*15, 18*). In Illinois, Finder studied the relationships between county DVC densities (i.e., the number of DVCs per county land area) and deer habitat, traffic volume, highway length, land ownership, and human habitat factors (*15*). Iverson and Iverson took a similar approach in Ohio, but also examined the relationships between county DVCs and the total land area in the county, and areas classified as urban, rural, cropland, and forestland (*18*).

Illinois Study Finder studied the number of state highway DVCs reported from 1987 to 1994 within each Illinois county (*15*). She used a multiple regression approach to develop a model to predict county DVC density, and considered data related to the following potential input variables:

- County deer density;
- County human density;
- Urban and rural roadway miles per county area;
- Average daily vehicle kilometers of travel per county area;
- Percent county land area closed to hunting;
- Percent county acreage of timberland in federal, state, county and private ownership;
- Percent county acreage of farmland; and
- Percent county acreage of woodland (*15*).

The model proposed by Finder to predict county DVC density included measures of human density, deer density, and farmland, privately-owned timberland, and woodland acreage (*15*). The predicted countywide DVC density increased with both human and deer densities, and the amount of privately-owned timberland. The predicted DVC density decreased with increases in the percentage of woodlands and farmland. Finder speculated that the percentage of woodland acreage in a county might be intercorrelated in some form with roadway mileage, human density, and the amount of farmland. For example, as the amount of woodland increases in a county the amount of roadway mileage, human density, and farmland appeared to decrease. These variables, however, remained in the final model proposed (*15*). This issue is discussed further in the conclusions portion of this summary.

Ohio Study In Ohio, Iverson and Iverson analyzed the number of reported DVCs in 88 counties from 1995 and investigated the relationships between these data and the following variables:

- County deer harvest (number of deer killed in hunt),
- Total county roadway length,
- Total county land area,
- County forest land area,
- County rural land area,
- County urban land area,

- County cropland area, and
- County human population (*18*).

The model developed to predict the annual number of DVCs in a county included the total length of roadway, and the total amount of land area, urban land area, and cropland in the county (*18*). The predicted frequency of annual DVCs increased with all these variables except cropland. A DVC density (i.e., DVCs per 100 hectare) model was also developed, and included measures of cropland, forestland, and urbanized land as input. Intercorrelations between these variables would seem to exist, but the model indicated that DVC density decreased with the amount of cropland and forestland in a county, but increased with the amount of urbanized land (*18*). The intercorrelations between these model inputs were not extensively discussed in the report, but it was speculated that fewer deer would exist with increases in cropland (*18*).

Urban Area Model

Another investigation of the variables related to DVCs was also recently documented, but this study focused on landscape factors within an urban environment (*19*). Clayton, et al. evaluated and quantified the relationship between a series of 66 landscape variables and the DVCs in Bloomington and Maple Grove, Minnesota (two suburbs of Minneapolis) (*19*). The DVC data evaluated was from 1993 to 2000, and eighty 0.5 kilometer (0.62 mile) roadway segments (including 0.1 kilometer (109 feet) on each side of the roadway for the landscape variables) with 2 or more reported deer carcass permits were identified along with 80 random control segments with 1 or fewer reported deer carcass permits (*19*). The variables that best explained the difference between the DVC and control segments were the number of adjacent buildings and public land patches (*19*). The DVC segments contained fewer buildings and more patches of public land (*19*). A validation test of the logistic regression model developed with these two input variables produced a correct classification for 77.5 percent of the 40 validation locations considered (*19*). It is suggested by Clayton, et al. that this type of information could be useful to wildlife biologists and urban planners to manage white-tailed deer habitat within urban areas (*19*). No conclusions were documented that addressed the impact the potential intercorrelation between the number of building and public land patch input variables, and the impact that might have on the usefulness of the model. The researchers did acknowledge that the public lands observed had few buildings and little human presence (*19*).

Hunting and DVCs

The studies previously described show that many factors, including the number and/or density of deer, appear to influence the number of reported DVCs at a particular location or within a particular area. In addition, many of the input variables (e.g., amount of woodlands) in the predictive models developed can often be related to the expected population, behavior, and/or movements of white-tailed deer. In fact, it has also been shown that management of or changes in white-tailed deer habitat can have herd reduction impacts in addition to typical hunting or herd reduction activities (*21*). However, the use of public hunting or other activities/policies to manage a white-tailed deer herd to proper and supportable densities is a generally accepted approach and widespread application throughout the United States. The white-tailed deer population and DVC impacts from the introduction of a hunting season and other herd reduction activities within small geographic areas (e.g., parks, reserves, and cities) are described below (*4*, *5*, *6*, *7*, *8*, *9*, *10*, *11*). Unfortunately, no studies were found that attempted to define the relationship between large-area (e.g., statewide) hunting policies that may result in lower white-tailed deer densities and a subsequent reduction in DVCs. This type of large-scale causal chain would be difficult to quantify, and most likely require a long-term evaluation in one state and/or a comparison of impacts in multiple states with differing herd management approaches. DVC and/or deer carcass numbers, however, are considered as input by several state agencies to their herd management decisions or population goals.

Population Dynamics Studies

The focus of two studies reviewed for this summary was the impact an introduction of hunting might have on the white-tailed deer population (*4, 5*). The documents that summarized this impact also described the impact or interactions these actions appear to have on the number of nearby DVCs. For example, Lamoureux, et al. studied white-tailed deer population dynamics and found that DVCs were a principal cause of deer mortality during periods of no hunting, but that the level of DVCs occurring did not appear to be a concern with respect to herd population (*4*).

In 1993 the hunting season in two large white-tailed deer wintering areas was closed due to population concerns (*4*). In 1996, the hunting season was then reopened because it was felt that the white-tailed deer population had recovered. From 1996 to 1998 the primary causes of deer mortality in the area were hunting (39 percent), undetermined (22 percent), poaching (16 percent,), starvation (13 percent), DVCs (6 percent), and predation (3 percent) (*4*). But, the estimated deer population growth rate during these years was equal to or lower than the rate reported during the hunting moratorium. It was concluded that male-only hunting regulations did not protect female deer from hunting mortality, and hunting apparently had a greater impact on mortality than starvation, predation, DVCs, and other undetermined causes (*4*). The impact of hunting on the pattern of DVCs in the area, however, was not quantitatively considered.

A similar study of white-tailed deer population dynamics was also done in the Oak Ridge Reservation in Tennessee (*5*). Hunting in the reservation (which is surrounded by a 3 meter (9.8 foot) fence) was not allowed for 45 years, but was introduced in 1985 (*5*). The study period for this hunting impact evaluation was from 1985 to 1994, and the number of deer killed by vehicles during this time period decreased from 273 to 143 (*5*). The number of deer harvested in the area also decreased from 923 to 470 (*5*). It was concluded that the almost 50 percent reduction in DVCs was an indication that the white-tailed deer population in the area had been intensely hunted (*5*). In addition, the researchers also believed that the number of DVCs before hunting was allowed in the area had been the primary reason the white-tailed deer population had reached equilibrium below its ecological carrying capacity (*5*).

Herd Reduction Activity Studies

One goal of herd reduction activities within smaller geographic areas (e.g., a metropolitan city or park) is often the reduction of DVCs. In fact, in addition to vegetation damage, DVCs appear to one of the primary reasons herd reduction activities are proposed and/or started in urban areas. A number of urban herd reduction activities (e.g., additional hunting, professional sharpshooters, live trapping and release, and sterilization) have been documented, but only a few of the summaries include data related to the monitoring or evaluation of their potential DVC impacts (*6*, *7*, *8*, *9*, *10*, *11*).

For example, the potential DVC impact of introducing hunting in Princeton Township, New Jersey was recently documented (*6*). It was concluded that gun hunting could be used to control deer populations in the area and that this reduction should reduce DVCs (*6*). However, little quantitative evidence was offered to support the latter portion of this conclusion (*6*). Another author, describing the same area in an earlier document, had shown that the DVCs in Princeton Township (which has a no-firearms-discharge ordinance) increased 436 percent from 1972 to 1982, but that DVCs in the two adjacent townships (which had firearms hunting) had not experienced a statistically significant change (*7*).

Similarly, herd reduction activities have been documented within county forest preserve land in Northeast Illinois, the Town of Irondequoit, New York, the City of River Hills, Wisconsin, and Bloomington, Minnesota (*8*, *9*, *10*, *11*). White-tailed deer population reduction was completed during the mid- to late-1980s within the Ned Brown Forest Preserve or Busse Woods (*8*). The reductions were accomplished by sharpshooters, rocket-netting, and drive-netting (*8*). The objectives of the reduction were to increase vegetation, reduce DVCs on adjacent roadways, and improve the condition of the herd (*8*). It was found that the DVCs on adjacent roadways decreased from 37 in 1982 to 13 or fewer per year after 1987 (the year the herd density goal was reached), but no statistical analysis or DVC data variability discussion was included in the document (*8*).

Herd reduction activities in the Town of Irondequoit, New York included a selective culling program, and a live-capture and translocation process was used in River Hills, Wisconsin (*9*, *10*). Sharpshooters have been used within Irondequoit's Durand Eastman Park and adjacent public lands since 1993 and the town introduced a controlled archery hunt in 1996 (*9*). The sharpshooters have culled 845 deer and the archery season 240 deer (*9*). The total number of DVCs from 1993 to 2000 was 534, but in 1992 (before the culling program) the number of DVCs was 227 (*9*). In 2000 it was estimated that the number of DVCs was around 100 (*9*). However, the general variability of the DVC data was not discussed (*9*). The authors of the summary concluded that the DVC data could represent another measure of the white-tailed deer herd size (*9*). The live-capture and translocation activities in River Hills began in the winter of 1987 and 1988 (*10*). These activities were approved in the city because of concerns related to vegetation damage and DVCs (*10*). A total of 438 deer were captured in River Hills and relocated between 1987 and 1992 (*10*). The number of DVCs in River Hills had generally increased from 1980 to 1989, but has experienced a decline since 1989 (despite an increase in traffic flow) (*10*). The peak number of annual DVCs within River Hills between 1980 and 1992 occurred in 1989 (*10*). It is estimated that the cost per white-tailed deer captured within the program was between $300-$400, and that the success of the program was at least partially due to the insular nature of the River Hills herd (*10*).

From 1991 to 1993 four methods of herd reduction were also used on the white-tailed deer population in Bloomington, Minnesota (*11*). The methods used were controlled hunts, opportunistic sharpshooting by conservation officers, sharpshooting over bait in a county park, and sharpshooting over bait in small public land areas (*11*). It was concluded that these four programs reduced the white-tailed deer density by 46 percent and DVCs (measured by carcass possession permits issued) by 30 percent in the area (*11*). The herd density goal was reached in 1993, but the 30 percent reduction in DVCs only occurred between1992 and 1993 (*11*). The number of DVCs actually increased the first two years of the program, and the annual number of DVCs in 1989 was also lower than that occurring during 1993 (*11*). This natural variability in DVCs or DVC-related data was not addressed in the document reviewed.

Conclusions

The relationship between specific hunting policies or activities and their impact on white-tailed deer population is generally acknowledged. However, the impact of these same policies or activities on the number of DVCs that occur along roadways within the managed area has not been studied in a quantitatively proper and comprehensive manner. This is not surprising because the primary objective of many herd reduction or hunting studies is not DVC reductions. Researchers that have investigated herd reduction and/or hunting activities have focused on their impacts on the white-tailed deer population, and then suggested that the reduction in deer population or density caused by these activities should lead to a reduction in DVCs. The number of DVCs is sometimes used as an input to large-area herd management decisions, and the reduction in DVCs is always a desirable outcome of these decisions. In urban areas, a reduction in DVCs is often the reason herd reduction activities are initiated.

The suggestion that a reduction in the white-tailed deer herd should lead to fewer DVCs appears to be at least partially supported by the input variables included in the DVC predictive models discussed in this summary. The "high" DVC probability and county DVC frequency or density models described all appear to include some direct or indirect measure(s) of deer population, habitat, and/or movement. The cause-and-effect relationship between these measures, herd reduction and/or hunting activities/policies, and the occurrence/pattern of DVCs, however, has not been quantified in a proper manner. In general it should be recognized that models developed through a multiple regression approach define a statistical data correlation, but may not describe a cause-and-effect relationship (*1*). In addition, caution is advised when a proposed model appears to include intercorrelated input factors (which by definition are supposed to be "independent") and/or modeled coefficients that seem to be illogical (e.g., reductions in DVCs with an increase in posted speed limit). The intercorrelation of input factors in a model makes it difficult (or impossible) to interpret the actual magnitude and direction of individual variable impacts on model output (*1*). This interpretation problem can occur even if the model appears to produce "reasonable" results (*1*). These types of issues should to be considered as the models described in this summary are used.

There is a need for a focused study of the causal connections between hunting or herd reduction management policies and their potential impact on DVCs. The small area studies described in this summary suggest promising results, but the DVC data from these studies (and future studies) should be more properly evaluated. The natural variability of DVC data needs to be properly considered for valid conclusions to be made about the DVC reduction impact of specific herd reduction activities. The results from a properly designed small area study might also be expanded to provide an adequate indication of what could occur over a larger area. It is suggested that the creation of predictive models for DVC frequencies and "high" DVC probabilities continue to be developed with the recognition and/or control of those input variables that may be intercorrelated. The intercorrelations that exist between variables that may impact the occurrence and number of DVCs at a location need to be better defined.

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PUBLIC INFORMATION AND EDUCATION

Public information and education, combined with engineering and herd reduction activities, is generally acknowledged as a key component to a comprehensive DVC reduction program. Unfortunately, similar to other driver education programs, proving the crash reduction impact of particular informational campaigns is difficult. No experimental research that attempted to directly connect specific public information and education campaigns with a resultant DVC reduction or potential reduction was found. These results can be approximated with driver behavior surveys, but educational programs are often evaluated by the long-term tracking of the crash experience of comparable individuals. The following paragraphs summarize the typical content of DVC-related public information and education materials, and several links to examples are provided.

DVC Reduction Public Information and Education Campaigns

A number of public and non-governmental organizations distribute DVC and DVC-avoidance educational material to the general public. Sometimes there is even more than one organization within a particular jurisdiction that releases this type of information. The material is typically distributed and made available to the media and public in the form of press releases, brochures, posters, videos, and/or webpages.

DVC Significance

Typically, there are two objectives to DVC reduction public information and education material. First, the significance of the DVC problem in the jurisdiction of interest is described and clearly shown. This type of information can be communicated through a number of forms:

- Charts of total annual DVCs for a number of years, and possibly facts related to DVCs per second;
- Map-based plots of DVC locations (for particular segments);
- Plots of when DVCs occur during the day and year;

- Total and average estimated DVC cost, property damage crashes, injury crashes, and fatal crashes; and
- A graphic that indicates the typical size of a human, car, and deer.

The map-based color-coded plots of DVC locations (crash total, rate, etc.) anecdotally appear to be of particular value. These plots have different colors at particular locations or along roadway segments that indicate a different number or rate of DVCs. For example, the color red might indicate a higher range of DVCs occurring along a one-mile roadway segment than the color yellow. These plots are typically based on one or three years of data. The plots appear to be used by the general public to identify general areas in which extra care in driving might be needed. However, not all states or jurisdictions are capable of easily creating this type of graphic.

DVC Avoidance

The second portion of most DVC-related public information and education material involves a series of suggestions typically referred to as "driver tips". The objective of this information is to assist the driver with their actions if a deer should appear on the side of the roadway. The "driver tips" for DVC avoidance typical include all or some of the following:

- Be alert for white-tailed deer all the time, but especially during dusk/dawn and/or Fall/Spring;
- Drive within your headlights and/or reduce your speed at night;
- If you see one white-tailed deer you should expect others;
- Stay on the road and hit the animal rather than leaving the roadway and colliding with a roadside object or crossing the centerline;
- Expect more white-tailed deer near deer crossing warning signs because they should be installed where this is true;
- Some suggest beeping your horn and/or flashing your headlights, but others suggest that focusing on other driving tasks at that time is more important; and

- Other suggestions: search and scan the roadway/roadside ahead, keep your windshield clean, buckle up, stay sober, and keep your headlights adjusted, and use your high beams where possible.

Some of the public information and education material reviewed also included information and/or graphics about how long it takes for a vehicle to stop at different speeds. This information was typically included to show the impact that speed choice may have on the possibility of being involved with a DVC. As indicated above, DVC reduction information campaigns often suggest a reduction in vehicle speed to allow more reaction time to a roadside white-tailed deer. Research about the quantitative impacts of reductions in posted speed limits (which may be related to operating speed) is discussed in the "Speed Limit Reduction" summary portion of this toolbox.

What a driver should do after a DVC has occurred is also sometimes addressed in the "driver tips" portion of a DVC reduction public information and education campaign. Some of the suggestions that are provided by the Michigan Deer Crash Coalition include the following:

- Don't swerve, brake firmly, stay in your lane, hold onto the steering wheel, and bring your vehicle to a controlled stop.
- Pull off the roadway. Turn on the vehicle hazard flashers, and be careful of other traffic when you leave your car.
- Don't attempt to remove white-tailed deer from roadway unless your convinced it's dead. An injured white-tailed deer can cause serious injury.
- Report the crash to nearest police agency and your insurance company (DVCs are usually covered under the comprehensive portion of your policy and shouldn't increase your rates)
- If feasible, a possession permit from a police or DNR conservation officer may be issued if you want to keep the white-tailed deer. If not, there are a number of charities to which it might be donated.

Conclusions

A combination of some or all of the information described above is typically included in a DVC reduction and/or avoidance public information and education campaign. This information is typically released in the Fall (a peak DVC time period), and sometimes in the Spring (the second highest peak DVC time period during a year). The DVC-reduction impact of this information has not been studied, but it is generally acknowledged that education, along with engineering methodologies and herd size reduction activities, are key components to a comprehensive program addressing the DVC issue. The limited amount of information available about the DVC-reduction capabilities of almost all the countermeasures reviewed in this toolbox also make a public information and education campaign important. It also does not appear that any one of the DVC countermeasures reviewed would ever be completely effective, and public information and education campaigns will always be necessary.

As indicated, a large number of jurisdictions distribute DVC-related information. Four webpage addresses are listed below for examples of what can be accomplished:

- http://www.deercrash.com/releases.htm
- http://www.dps.state.ia.us/deercrashes/
- http://www.state.me.us/mdot/safety-programs/maine-crash-data.php
- http://www.semcog.org/TranPlan/TrafficSafety/MDCC/index.htm

ROADSIDE VEGETATION MANAGEMENT

In most jurisdictions roadside (within roadway right-of-way) vegetation management is completed by public works agencies, departments of transportation, or the contractors of these entities. One of the primary objectives of these planting and mowing activities is roadway safety. Roadside vegetation management policies and practice are often designed to provide a clear line of sight along the roadside and to minimize woody vegetation that may grow into a hazardous object to vehicles that leave the road. The suggested distance from a roadway lane that should be free of hazardous objects (e.g., individual trees greater than 4 inches in diameter, or groups of trees with an effective diameter of 4 inches) is called the clear zone and varies with traffic volume, vehicle speed, and roadside sideslope (*1*).

Other objectives of roadside vegetation management policies and practices include the encouragement of quick plant growth after construction (to avoid soil erosion), the control of invasive species, and roadway aesthetics. Plantings that are easily managed and appropriate to the locality are also important because the cost to the public of roadside vegetation management activities needs to be minimized. Mowing timing (i.e., when it occurs during the year), frequency (i.e., how often the mowing occurs), and intensity (a measure related to vegetation height) have both ecological and cost impacts (*2*).

It has been generally suggested that the results of some typical roadside vegetation management activities may attract white-tailed deer and increase the number of deer-vehicle crashes (DVCs). The type of vegetation planted along roadsides and roadside mowing practices (i.e., when and how often) of transportation agencies are typically the focus of these discussions. The suggestions that there is a potential connection between roadside vegetation management and DVCs appear to be primarily based on opinions about the type and growth level (e.g., freshly cut) of vegetation that appeals to white-tailed deer.

No studies were found that quantitatively related specific roadside vegetation management policies or practices to the number of DVCs occurring along a roadway segment. However, a few studies are described in this summary that specifically considered the relationship between white-tailed deer activities (e.g., apparent feeding or browsing) and certain types of vegetation (*3*, *4*, *5*). In addition, two European studies are summarized that considered the impacts of vegetation clearing on vehicle-moose and train-moose collisions (*6*, *7*). Related studies that examined white-tailed deer repellents or attempted to model or investigate the relationship between land cover (e.g., woodland or crops) adjacent to the roadway right-of-way and the number or probability of DVCs are described in the repellent, hunting or herd size reduction, and speed limit reduction summaries within this toolbox.

Most of the documents or webpages that discuss vegetation and white-tailed deer focus on residential planting choices rather than roadside management (*8*, *9*, *10*, *11*, *12*, *13*, *14*, *15*, *16*, *17*, *18*). The information contained in these information sources is typically based on expert opinion. An example of a "deer resistant" plant list based on expert opinion (from New Jersey) is included at the end of this summary (*5*). The applicability of these expert opinions to roadside vegetation management decisions was not addressed in any of the documents reviewed. In October 2003, however, the Minnesota Department of Transportation released a "Plant Selector" program to the public (*17*). The program is designed to help decision-makers make better roadside plant choices, and it includes a wildlife rating and animal damage choice as inputs to be considered in the roadside plants it suggests. This program is described briefly at the end of this summary.

Deer Activity and Vegetation Studies

A few studies were found that summarized the activities of white-tailed deer and other animals with respect to certain types of vegetation (*3*, *4*, *5*). More specifically, these studies were typically designed to investigate the vegetation impacts and/or preferences of different animals species. Two of the studies focused on right-of-way plantings, and another included a garden estate evaluation of plantings that might also be applicable to the roadside vegetation decisions (*3*, *4*, *5*).

In 1980 a study commissioned by the West Virginia Department of Highways investigated animal activity near three types of highway right-of-way plots (*3*). The plantings in each plot were Crownvetch, Sericea Lespedeza, and Fescue (*3*). Animal signs (e.g., tracks and fecal droppings) near these plantings were recorded from October 1977 to July 1979 along one segment of interstate highway. It was concluded by the researchers that white-tailed deer appeared to prefer the Crownvetch while smaller mammals preferred the Fescue (*3*). A statistical analysis of the animal signs indicated that the plant preference by white-tailed deer was significant (*3*).

Researchers at Ball State University also attempted to evaluate wildlife use and the potential animal-vehicle collision impacts of shrubs (i.e., woody plantings) placed by the Indiana Department of Natural Resources along four segments of four-lane highway (*4*). Fourteen species of shrubs and trees were planted (e.g., Flowering Dogwood, American Hazelnut, Redbud, etc.) and a total of 156 plots (79 roadside shrub sites and 77 roadside control grass sites) studied. These plots were 328 feet long.

The Ball State University researchers recorded animal activity (i.e., bird and mammal sightings, bird nests, tracks, feces, and gnawings) and wildlife carcasses within all of the plots during four study periods (i.e., June, July, and September of 1983, and mid-December 1983 to mid-January 1984) (*4*). No live white-tailed deer or white-tailed deer carcasses were observed during the data collection activities, but signs of deer activity and plant usage were noted. However, the researchers did conclude that there was no statistically significant difference between the numbers of other animal carcasses they did observe in the control (i.e., grassy roadside) and test (i.e., woody plantings) plots (*4*). In addition, the number of live rabbits and birds in the shrub test plots was greater than those observed in the grassy control plots (*4*). Based on these findings, the researchers concluded that right-of-way plantings could be managed to encourage wildlife use without increasing the number of animal-vehicle collisions. They recommended that a similar study be completed to evaluate roadway segments that have had natural vegetative growth (*4*). They felt that similar results, without the cost of planting, spraying, or mowing may indicate an even more efficient method of enhancing wildlife activity without increasing animal-vehicle collisions (*4*).

Finally, the plant species preferences of white-tailed deer were studied at the Tracy Estate Research Garden in Morris County, New Jersey (*5*). In March 1991 six test plots within the garden were created. Initially, the plants were in containers, and these containers were then surrounded by wood mulch in May 1991. In December 1991 the plants were set in the ground and again surrounded by wood mulch. A number of the different "deer resistant" plants in the list at the end of this summary were evaluated (*5*). The plants introduced in March 1991 were generally trees species (e.g., Common Boxwood, Colorado Spruce, Inkberry Holly, etc.). Several grasses were also planted in July 1991 (e.g., Plume Grass, Silver Grass, Maiden Grass, etc.), and in January 1992 a series of grass types were also planted. These grasses included Sweet Flag, Bulbous Oat, Feather Stricta Reed, Northern Sea, Wood Rush, and Pigmy Bamboo (*5*). Some of these plant types may be relevant to right-of-way vegetation decision-making.

The browsing of each plant species within each plot was ranked every few days after the planting was first installed and then once a week during the summers from March 1991 and December 1992 (*5*). A ranking of zero indicated no browsing, and a ranking of three indicated that 76 to 100 percent of the leaves and twigs were browsed (*5*). The plants investigated that showed no sign of browsing (i.e., a ranking of zero) included the following:

- Catmint,
- Silver Grass,
- Plume Grass,
- Fountain Grass,
- Silver Mound Artemesia,
- Bulbous Oat Grass,
- Feather Reed Grass, and
- Epimedium.

Plants that were already on the Tracy Estate Research Garden site, but also did not exhibit any browsing included:

- Pachysandra,
- American Holly,
- Hay Scented Fern,
- Narcissus,
- Scilla (Not in Attached “Deer Resistant” Appendix),
- Foxglove,
- Siberian Iris,
- White Snakeroot (Not in Attached “Deer Resistant” Appendix),
- Japanese Barberry, and
- Fragrant Sumac.

The shrub species that were planted and received a browsing rank of one (i.e., a leaf and twig browsing level from 1 to 25 percent) included:

- Japanese Boxwood,
- Colorado Blue Spruce,
- Common Boxwood,
- Dwarf Alberta Spruce,
- Japanese Andromeda, and
- William Penn Barberry.

Ornamental grasses and perennial plant species that received a ranking of one included: Lamb’s Ear, Weeping Love, and Maiden Grass (*5*).

The applicability of the Morris County, New Jersey results to roadside management decisions was not addressed, and needs to be considered on case-by-case and plant-by-plant basis. The researchers in New Jersey also suggested that certain plant species (e.g., the William Penn Barberry) could be used as a barrier to white-tailed deer browsing by using them to surround more sensitive or palatable plants (*5*). The type of plant species that white-tailed deer feed on also depends on the preferences of particular herds and the competition for alternative food (*5*).

Vegetation Clearing and Moose Mortality

Two studies from Europe were found that considered the impacts of clearing vegetation on collisions between moose and motor vehicles/trains (*6*, *7*). The first study was completed in Sweden, and Lavsund and Sandegren summarized its original documentation (which was in Swedish) as part of their discussion of moose-vehicle interactions within that country (*6*). They indicate that the study collected and compared three years of moose-vehicle collision data for roadway segments without and without roadside clearing (*6*). In this case, roadside clearing was defined as the removal of all vegetation below 9.8 feet (3 meters) within 65.6 feet (20 meters) of the roadway (*6*). A comparison of the crash data for the treatment and control segments indicated that roadside vegetation clearing resulted in almost a 20 percent reduction in moose-vehicle crashes (*6*). However, it was recognized that this reduction was very close to the natural variability of the moose-vehicle crash data, and that the roadway clearing was considered expensive to apply and maintain (*6*). The details and validity of this crash analysis could not be confirmed, but the results seem to indicate that roadside vegetative clearing may hold some promise as a focused DVC reduction measure.

In addition to the study in Sweden, the impact of vegetation clearing on moose-train collisions in Norway has also been studied (*7*). In this study "high" moose-train collision segments 13.7 miles (22 kilometers) long were identified and cleared, and 24.1 miles (38.8 kilometers) of adjacent roadway segments were used for comparison purposes (*7*). Railside clearing in this case was defined by the removal of all bushes and trees within 65.6 feet (20 meters) of the railroad and anything less than 9.8 to 13.1 feet (3 to 4 meters) was cleared between 65.6 to 98.4 feet (20 to 30 meters) from the railroad (*7*). In addition, vegetation was removed within 196.9 feet (60 meters) of the railroad at critical locations (e.g., curves).

Four years of crash data before and after the vegetation was removed were compared, and the differences in the data for the treatment and control sections were also evaluated (*7*). However, a large amount of variation in the total number of moose-train collisions was observed along all of the segments, and the number of collisions observed was relatively small (i.e., no more than 37 moose were killed along any segment within the four years considered) for evaluation purposes. It was concluded that the vegetation removal reduced moose deaths by about 56 percent, but that the uncertainty of this estimation was relatively high (*7*). It was also recognized that the crash results from the treatment and adjacent control sites were probably not independent (i.e., the removal of vegetation may have lead to more crashes in the segments that were not cleared), and that the choice of removing vegetation only from segments with a "high" number of moose-train collisions may have impacted the results (*7*). Both factors would result in overstating the crash reduction impacts of the vegetation clearing. Study site independence and location choices are a concern in most of the studies reviewed for this toolbox, but there few in which they are actually documented. Overall, these concerns and the moose-train focus of this study also limit the applicability of its positive results to the roadway environment. There is a need to properly investigate the potential reduction impacts and cost-effectiveness of the roadside vegetation removal.

"Deer Resistant" Plant Advice

A large number of documents and webpages focus on the relationship between vegetation and the eating habits of white-tailed deer (*8*, *9*, *10*, *11*, *12*, *13*, *14*, *15*, *16*, *17*, *18*). These information sources focus on residential plantings, and many include a list of plants and shrubs that experts believe white-tailed deer are less likely to eat. An example of a "deer-resistant" plant list, based on the list creator's opinion, is included at the end of this summary (*5*). Unlike the studies previously described, however, no data is typically provided in these documents to support the choice of the plant species in their lists (*8*, *9*, *10*, *11*, *12*, *13*, *14*, *15*, *16*, *17*, *18*). Most of the lists are based on expert judgment and experience.

The audience for these documents and webpages is typically gardeners and/or homeowners (*8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18*). The applicability and cost-effectiveness of "deer resistant" plant advice to vegetation choices along the roadside will need to be determined by staff in the agencies responsible for these decisions. All of these documents also warn that their lists should only be used as guidelines and that the "resistance" of these plants to white-tailed deer browsing depends on the availability of other more desirable food and the needs of the animal. Other factors that impact the desirability of plants to white-tailed deer include the type and maturity of plants, and the past experience of a white-tailed deer with a plant. Most of the documents also indicate that white-tailed deer will eat almost any plant if they are hungry enough. This type of behavior was also observed in the repellent studies summarized in another part of this toolbox.

Several of the documents and webpages reviewed for this summary that focus on gardening or residential vegetation choices are listed below.

- *Outwitting Deer*: A gardening guide in which the author identifies a series of vegetation species that are relatively deer resistant, and stresses using plants that have deterrent odors or thorns (*8*).

- *Deer Proofing Your Yard & Garden*: In this book there is a "deer-o-scaping" chapter that lists plants which appeal to and may be more relatively resistant to white-tailed deer (*9*).

- *Gardening in Deer Country*: This book contains a significant list of plants resistant to deer browsing. It includes more than 60 pages of trees, shrubs, groundcover, vines, perennials, annuals, bulbs, and herbs in its "deer resistant" plant list (*10*).

- *Solving Deer Problems – How to Keep them out of the Garden, Avoid them on the Road, and Deal with them Everywhere!*: Chapters in this book focus on fencing, repellents, and plants unpopular with deer. More than 80 pages of plants that are typically avoided by white-tailed deer are listed. Suggestions are also often provided about the locations in which particular plants might thrive. Lists of "deer resistant" annuals and biennials, herbs, vegetables, fruits, perennials, bulbs, ferns, shrubs and trees are included (*11*).

- A few of the many internet webpages that may be of interest:
  - http://www1.uwex.edu/ces/pubs/ (The University of Wisconsin Extension service offers UW Extension Bulletin A372 – *Plants not Favored by Deer.* This type of document is also provided by a number of extension programs throughout the United States.) (*16*).
  - http://home.ptd.net/~jchorba/deerlist.htm (Private Landscaper Page) (*17*).
  - http://lonestar.texas.net/~jleblanc/deerplants.html (Native Plant Society of Texas) (*18*).

New Plant Selection Tool

In October 2003 the Minnesota Department of Transportation introduced a "Plant Selector" program (*17*). The objective of this program is to help decision-makers make better roadside plant selections. The program includes lists of plant species for trees and shrubs, grasses and sedges, flowering perennials and annuals, ferns, and for windbreak suitability (*17*). For each type of plant or the windbreak suitability objective the user of the program can also identify and select criteria or characteristics for the site and the plants wanted. There are more then 25 site characteristics to choose from and about 20 plant characteristics. Criteria and characteristics that may be relevant to this summary is the ability of the user to indicate a low, medium, or high wildlife ranking as a plant characteristic, and to characterize the site as experiencing animal damage from deer, mice/voles, rabbits/hares, and gophers (*17*). Signs of deer plant damage can be identified by the appearance of bark removal (from rubbing) and 90 degree browsing (*17*). The "Plant Selector" program is available for use at http://plantselector.dot.state.mn.us/. How a plant in the list of plants included in the program is determined to be more or less susceptible to white-tailed deer browsing does not appear to be documented on the webpage.

Conclusions

No studies were found that specifically considered the impact of changes in roadside vegetation management policies and their subsequent impact on the number of DVCs. The three studies summarized here generally focused on the plant preferences of white-tailed deer and other animals. One study found that white-tailed preferred Crownvetch in comparison to Sericea Lespedeza and Fescue. Another concluded that the addition of woody shrubs in the right-of-way appeared to encourage wildlife usage, but did not increase the numbers of animals killed along the roadway. However, this study lasted only about six months and no white-tailed deer or deer carcasses were observed near the test or control plots. A third study considered the browsing preference of white-tailed deer on a series of plants within a garden estate in Morris County, New Jersey. Lists of the most "deer resistant" plants tested are included in this summary and the entire plant list from that study is in the attached appendix. The applicability of the results from this experiment will need to be determined on a case-by-case (i.e., location-by-location and plant-by-plant) basis.

Two studies were found, however, that may at least show the DVC reduction potential of vegetation clearing. These studies focused on collisions between moose and motor vehicles or trains. In the first study roadside vegetation less than 9.8 feet (3 meters) high was removed within 65.6 feet (20 meters) of the roadway, and a reduction in moose-vehicle crashes of almost 20 percent was observed. This reduction, however, was close to the natural variability of this data, and the approach was considered to be relatively expensive. The second study evaluated the removal vegetation along railroads in Norway, and in this case all vegetation was removed within 65.6 feet (20 meters) of the railroad and anything less than 9.8 to 13.1 feet (3 to 4 meters) was cleared out to 98.4 feet (30 meters). A crash comparison showed more than a 50 percent reduction in moose-train collisions due to the clearing, but the results were highly variable. In addition, the researchers did recognize that their experimental design could have resulted in an overstatement of the crash reductions from vegetation clearing. Both studies show the DVC reductions that might result from a localized application of vegetation removal, but there is still a need to properly study and document the safety, ecological, and cost impacts of this approach along roadway segments.

The majority of the information sources available on this subject are documents that focus on helping the homeowner and/or gardener choose plants that are more "deer resistant". The "deer resistant" plant lists contained in these documents are typically based on expert opinion and experience. They also commonly include the warnings that the "deer resistance" of a particular plant depends on the location and the local white-tailed deer herd preferences/experiences, and that white-tailed deer will eat almost anything if necessary. The Minnesota Department of Transportation also recently introduced a new tool entitled the "Plant Selector". The objective of this program is to help decision-makers choose roadside plants. An animal damage and wildlife rating are two inputs to the program. The comprehensive list of plants included in the model does not include invasive varieties to Minnesota, and how an individual plants was determined to be more or less susceptible to white-tailed deer browsing does not appear to be documented.

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Appendix A
Table A.1. Example List of "Deer Resistant" Plant Species (*5*).

Botanical name	Common Name
Abies spp.	Fir
Acanthopanax Siemboldianus	Five leaf aralia
Acer negundo	Boxelder
Achillea millefolium	Yarrow
Aconitum uncinatum	Monkshood
Acorus calamus	Sweet flag
Ageratum Houstonianum	Flossflower, ageratum
Ailanthus altissirna	Tree of heaven
Allium spp.	Garlic, chives, wild onion
Alnus serrulata	Smooth alder
Alnus glutinosa	Black alder
Althaea rosea	Hollyhock
Anaphallis margaritacea	Pearly everlasting
Anchusa azurea	Italian bugloss
Anemone japonica	Anemone
Anemone vitifolia robustissima	Anemone
Aquilegia spp.	Columbine
Aralia spinosa	Devils walkingstick
Aralia elata	Japanese angelica tree
Arctostaphylos uva-ursi	Bearberry
Arctotis stoechadifolia	African daisy
Arrhenatherum elatius bulbosom	Bulbous oat grass
Artemesia spp.	Artemesia
Asclepias tuberosa	Butterfly weed
Asimina triloba	Pawpaw
Astilbe spp.	Astilbe
Aruncus dioicus	Goatsbeard
Berberis spp.	Barberry

Table A.1. Continued.

Betula spp.	Birches
Buddleia alternifolia	Fountain butterfly-bush
Buddleia davidii	Orange-eye butterfly-bush
Buxus spp.	Boxwood
Cactaceae spp.	Cactus
Calamagrostis acutiflora stricta	Feather reed grass
Clendula officinalis	Pot marigold
Callicarpa dichotoma	Purple beautyberry
Callicarpa japonica	Japanese beautyberry
Calluna vulgaris	Heather
Calycanthus fertilis	Pale sweetshrub
Cassia spp.	Senna, cassia
Catalpa bignonioides	Common catalpa
Centaurea montana	Mountain bluet
Cephalotaxus harringtonia	Japanese plum-yew
Cercis occidentalis	Red bud
Chamaecyparis obtusa	Hinoki false cypress
Chamaedaphne calyculata	Leatherleaf
Chasmanthium latifolium	No. sea oats
Chelone spp.	Turtlehead
Chionanthus virginicus	American fringetree
Chrysanthemum maximum	Shasta daisy
Cimicifuga racemosa	Bugbane
Clematis spp.	Clematis
Clerodendron trichotomum	Harlequin glory-bower
Clethra alnifolia	Sweet clethra, summersweet
Colchicum spp.	Autumn crocus
Comptonia peregrina	Sweet-fern
Convallaria majalis	Lily of the Valley
Cotinus coggygria	Smoke tree

Table A.1. Continued.

Cornus spp.	Dogwood
Cotoneaster spp.	Cotoneaster
Crataegus laevigata	Hawthorne
Cryptomeria japonica	Cryptomeria
Cunninghamia lanceolata	China fir
Cytisus scoparius	Scotch Broom
Davidia involucrata	Davidia
Delphinium spp	Larkspur
Dicentra spectabilis	Bleeding heart
Digitalis spp.	Foxglove
Elaeagnus angustifolia	Russian-olive
Eleagnus commututa	Silverberry
Enkianthus campanulatus	Redvein enkianthus
Epimedium spp.	Epimedium
Erianthus ravennae	Plume grass
Erica camea	Winter heath
Erigeron philadelphicus	Fleabane
Euonymus alatus	Winged euonymus
Euonymus atropuroureus	Wahoo
Euphorbia cyparissias	Spurge
Festuca cinnerea	Blue fescue
Ficus spp.	Fig
Forsythia intermedia	Forsythia
Galanthus nivalis	Snowdrops
Gaultheria procumbens	Checkerberry
Gayllussacia baccata	Black buckleberry
Geranium spp.	Cranesbill
Gingko biloba	Gingko, maidenhair tree
Gleditsia triacanthos	Honey locust
Glmnocladus dioica	Kentucky coffee tree

Table A.1. Continued.

Gypsophila paniculata	Baby's breath
Hamamelis virginiana	Common witch hazel
Hedera helix	English ivy
Helianthus spp.	Sunflower
Helichrysum spp.	Strawflower
Helleborus spp.	Hellebore
Hydrangea paniculata	Hydrangea
Ilex aquifolium	English holly
Ilex cornuta	Chinese holly
Ilex crenata	Japanese holly
Ilex glabra	Inkberry
Ilex opaca	American holly
Ilex vertcillata	Black-alder
Iris spp.	Iris
Juglans regia	English walnut
Juglans nigra	Black walnut
Juglans cinerea	Butternut
Juniperus chinensis	Chinese juniper
Juniperus rigida	Needle juniper
Juniperus communis	Common juniper
Knophofia uvaria	Devlis or red hot poker
Kolkwitzia amabilis	Beautybush
Lantana montevidensis	Trailing lantana
Larix decidua	European larch
Lavandula officinalis	Lavender
Leucothoe fontanesiana	Drooping leucothoe
Leucothoe racemosa	Sweetbells
Ligustrum obtusifolium	Myama privet
Ligustrum ovalifolium	California privet
Lindera benzoin	Spicebush

Table A.1. Continued.

Liquidambar styraciflua	American sweetgum
Lonicera fragrantissima	Winter honeysuckle
Lonicera maackii	Amur honeysuckle
Lonicera tatarica	Tartarian honeysuckle
Lupinus spp.	Lupine
Lusimachia nummularia	Moneywort
Luzula nivea	Wood rush
Lychnis chalcedonica	Maltese cross
Lyonia ligustrina	Male-berry
Lyonia mariana	Staggerbush
Maclura domfera	Osage orange
Magnolia spp.	Magnolia
Mimulus spp.	Mimulus, Monkey flower
Miscanthus sinensis	Chlnese silver grass
Miscanthus sinensis 'gracillimus'	Maiden grass
Monarda didyma	Bee balm
Myosotis spp.	Forget-me-not
Myrica californica	Wax myrtle
Myrica pensylvanica	Northern bayberry
Myrtus communis	Myrtle
Narcissus spp.	Daffodil, Jonquil
Nepeta faassenii	Catmint
Nyssa sylvatica	Tupelo, pepperidge
Oxalis oregana	Oxalis, redwood sorrel
Oxydendrum arhoreum	Sorrel tree
Pachysandra terminalis	Japanese pachysandra
Paeonia spp.	Peony
Paulownia tomentosa	Empress-tree
Panayer orientale	Oriental poppy
Parkinsonia aculeata	Jerusalem thorn

Table A.1. Continued.

Pennisetum alopuroides	Fountain grass
Phaedranthus buccinatorius	Blood red trumpet vine
Philadelphus spp.	Mockorange
Phyllostachys aurea	Golden bamboo
Phyllostachys aureosulcata	Gold-furrowed bamboo
Physocarpus opulifolius	Common ninebark
Physosstegia virginiana	Obedience plant
Picea abies	Norway spruce
Picea glauca	White spruce
Picea glauca conica	Dwarf Alberta spruce
Picea pungens glauca	Colorado blue spruce
Picea pungens	Blue spruce
Picea rubens	Red spruce
Picea mariana	Black spruce
Pieris japonica	Japanese andromeda
Pinus spp.	Pine
Poncirus trifoliata	Hardy orange
Pseodosas japonica	Metake
Pulmonaria officinalis	Lungwort
Rhamnus catharticus	Common buckthorn
Rhamnus frangula	Glossy buckthorn
Rheum rhaponticum	Rhubarb, Pie plant
Rhododendron nudiflorum	Pinxter azalea
Rhododendron roseum	Honeysuckle azalea
Rhododendron viscosum	Swamp azalea
Rhus aromatica	Fragrant sumac
Ribes odoratum	Clove currant
Ribes sativum	Red garden currant
Ribes uva crispa	European gooseberry
Robinia pseudoacacia	Black locust

Table A.1. Continued.

Rudbeckia gloriosa	Gloriosa daisy
Salvia spp.	Sage and salvia
Sambucus racemosa	Red elderberry
Santolina spp.	Santolina
Sasa palmata	Chimaki sasa
Sasa pygmaea	Pigmy bamboo
Sassafras albidum	Sassafras
Scilla siberica	Siberian squill
Sedum spsectabile	Showy sedum
Solanum spp.	Nightshade
Stachys byzantina	Lamb's ear
Stokesia laevis	Stokes aster
Styrax japonica	Japanese styrax
Symphoricarpos albus	Snowberry
Syringa chinensis	Rouen lilac
Syringa reticulata	Japanese tree lilac
Syringia vulgaris	Garden lilac
Tagetes spp.	Marigolds
Taxodium distichum	Bald cypress
Thalictrum spp.	Meadow rue
Thuja spp.	Arborvitae
Thymus serphyllum	Mother of thyme
Thyme vulgaris	Common thyme
Torreya nucifera	Japanese torreya
Tradescantia virginiana	Spiderwort
Trillium spp.	Trillium, Wake-robin
Trollius laxus	Globeflower
Tulipa spp.	Tulip
Vaccinium stamineum	Deerberry
Vaccinium corymbosum	Northern highbush blueberry

Table A.1. Continued.

Vaccinium vacillans	Dwarf dryland blueberry
Vaccinium ngustifolium	Low sugar blueberry
Vaccinium macrocarpon	Large cranberry
Valeriana spp.	Valerian
Viburnum spp.	Viburnum
Vinca major	Periwinkle
Vitex negundo	Negundo chaste-tree
Yucca spp.	Yucca, Spanish bayonet
Zantedeschia spp.	Calla lily
Zanthoxylum americanum	Prickly-ash

EXCLUSIONARY FENCING

Exclusionary woven wire fencing has been used to alter the behavior of white-tailed and mule deer for many years. This approach to deer-vehicle crash (DVC) reduction attempts to physically separate animals and vehicles, but will also have impacts on the natural and necessary movement of the animal population. A number of studies have attempted to evaluate the impacts of regular fencing or exclusionary fencing with and without additional complementary infrastructure (e.g., one-way gates, earthen escape ramps, and/or wildlife crossing) on deer activities and/or DVCs (*1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19*). A description of the results from both types of studies is included in this summary.

A range of fencing-related subjects is discussed in the following paragraphs. First, the results of studies that considered the apparent relationships between roadway/roadside characteristics (including fencing) and the occurrence of DVCs are briefly summarized (*10, 16, 17*). However, these studies are discussed in more detail within the hunting and herd reduction summary of this toolbox. Second, studies that investigated the impacts of fencing on white-tailed deer activities and/or DVCs are described (*4, 5, 6, 7, 11*). The number and location of white-tailed deer, DVCs, or deer carcasses observed with respect to the roadway right-of-way (ROW) and/or exclusionary fencing, fencing height, and fencing location are often the focus of these studies. Third, several studies that document the activities of deer and/or the DVC-reduction impacts of exclusionary fencing when combined with other complementary infrastructure (e.g., one-way gates, earthen escape ramps, and/or wildlife crossings) are summarized (*8, 12, 13, 14, 15, 18, 19*). Finally, several studies that consider electric fencing area briefly summarized, and a study that considers the DVC-reduction effectiveness of exclusionary fencing and proposes a benefit-cost installation guideline is presented (*9, 20, 21, 22, 23*).

DVC Modeling and Fencing

Several studies have investigated the apparent relationships between factors that define the roadway/roadside environment and the occurrence of a white-tailed deer carcass or DVC along a section of roadway (*10, 16, 17*). At least two of these studies included the existence of some type of roadside fencing in their evaluation (*10*, *17*). The results of these two studies are described in detail within the hunting or herd reduction summary of this toolbox, and the conclusions they make about fencing and DVCs are somewhat contradictory. The data from the Kansas study indicates that the number of DVCs reported along a segment increases with the existence of traditional ROW fencing, but the Pennsylvania study showed a reduction in the probability of a segment being a "high" DVC site as the amount of fencing (and at least 3.0 feet (0.91 meters) in height) increased within 328.1 feet (100 meters) of the roadway (*10*, *17*). This contradiction is most likely the result of, among other things, the differences in the experimental design and statistical approaches taken, and the fact that correlations in data do not necessarily define a cause-and-effect relationship. The Kansas study also did not include the fencing variable in their model (*17*). The Pennsylvania researchers concluded and recommended that increasing the maintenance and repair of deer fencing would reduce the probability of a section being classified as a "high" crash site (*10*, *17*).

Fencing, Deer, and/or Deer Carcass Location

A series of studies was completed in the 1960s and 1970s that focused on the impacts of the initial roadway construction and fencing of Interstate 80 in Pennsylvania (*1*, *2*, *3*, *4*, *5*, *6*, *11*). The general focus of these studies was the changes in white-tailed deer activity on and near the new roadway. The study area location of these evaluations was centered on an 8-mile (12.9-kilometer) segment of Interstate 80 near Snow Shoe, Pennsylvania. Some of the studies also considered other segments of Interstate 80.

The location and activities of the white-tailed deer observed near Interstate 80 was measured in a similar manner for each study (*1*, *2*, *3*, *4*, *5*, *6*, *11*). A vehicle with a spotlight traveled along the shoulder of the roadway segment (typically at 10 to 20 miles per hour (16.1 to 32.2 kilometers per hour)), and the number of the data collection run, date, time, location, approximate white-tailed deer distance from the paved highway, number of white-tailed deer, sex, and apparent age were recorded. The activity and/or behavior (e.g., feeding, etc.) of the white-tailed deer were also sometimes identified within segment increments about 200 feet long (*1*, *2*, *3*, *4*, *5*, *6*, *11*). Each of the

Pennsylvania studies focused on a different characteristic of the new roadway. The impact of the interstate highway, topography, vegetation, and fencing along the roadway were evaluated (*1*, *2*, *3*, *4*, *5*, *6*, *11*).

The first two studies of white-tailed deer activity along Interstate 80 were completed immediately before the roadway was opened, and before/after it was opened to about 45 miles of local traffic (*1*, *2*). The objectives of these studies were to evaluate the white-tailed deer activity in the area and determine how this activity related to the local vegetation and topography. During both studies, however, there were only short segments of 4- and 5.5-foot fencing within the interchange area and along one side of a one-mile section of the study area (*1*, *2*, *3*). It was assumed that the results from these studies generally represented a "no fencing" or "before roadway opening" situation (*1*, *2*, *3*). Their results were used for comparison purposes in the some of the studies that followed.

From 1969 to 1970, a 7.4-foot (2.26-meter) exclusionary fence was installed along the Interstate 80 study area, and the roadway was opened across Pennsylvania in September 1970 (*4*, *6*). White-tailed deer activities and locations were observed from July 1970 to July 1971 (i.e., before and after the roadway was fully opened) (*6*). The objective of the study was to evaluate the impact of the fencing and increased traffic volume on the behavior of white-tailed deer. The fencing was installed on both sides of Interstate 80, and consisted of 47 inches (119.4 centimeters) of woven mesh (which started five inches (12.7 centimeters) from the ground), three strands of nine-gauge galvanized steel wires 7 to 8 inches (17.8 to 20.3 centimeters) apart, and an extension bar placed at a 45 degree angle (away from the roadway) with another three wires six inches (15.2 centimeters) apart (*6*).

Spotlight observations of the white-tailed deer activities began in October 1970 and lasted until July 1971 (*6*). A total of 97 data collection runs (51 westbound and 46 eastbound) were completed during a seven-hour period from just before dusk until just after midnight (*6*). A total of 744 white-tailed deer were observed (*6*). Seventy-five percent of the white-tailed deer were within the right-of-way and grazing (*6*). Very few (n = 2) of the white-tailed deer were observed on or between the interstate pavement surfaces (*6*).

The researchers concluded that the reason for these results was the large number of gaps remaining below the fencing after its installation. During the study about 11 white-tailed deer were observed going under the fence, and it was shown that a gap of only 9 inches (22.9 centimeters) was needed for this to be accomplished (*6*). However, track evidence (and deer hair in the fence wire) throughout the study segment also indicated that fence jumping had occurred. No attempt was made to account for or repair the gaps below the fencing during this study (*6*).

Only 22 deer were reported killed by vehicles along the study segment between September 20, 1970 and July 31, 1971 (*6*). Tubbs, however, statistically evaluated the fencing by comparing the observed proportion of white-tailed deer on each side of the fencing to the same information observed in a previous study by Carbaugh, et al. (when only local traffic was using the roadway) (*1*, *6*). This comparison showed that, although most of the white-tailed deer were within the roadway ROW, there was a statistically smaller number observed on in the area on both sides of the fencing after it was installed and the roadway was in full operation (*6*).

The researchers also concluded that during the nine months in which the white-tailed deer were observed there appeared to be a relationship (from linear regression analysis) between the number white-tailed deer observed and the number of roadside carcasses removed (*6*). It was concluded by Tubbs that DVCs had significantly decreased from the time of the previous studies, but he did not make any conclusions about whether this apparent reduction was connected to the fencing (*1*, *6*). He did conclude, however, that since most of the white-tailed deer were still within the right-of-way, this “reduction” was probably due to the white-tailed deer becoming “ . . .conditioned to the increased volume of traffic and the roadway, and not crossing it if food were readily available on one side of the roadway (*6*)”. He recommends that the reason for the reduction in roadside white-tailed deer carcasses be further investigated. There was no discussion in the study report about the general and expected natural variability of DVCs along new roadways.

In 1975, Falk also compared the number of white-tailed deer carcasses collected along the same 8-mile (12.9-kilometer) fenced segment with those along a similar, but unfenced, 8-mile (12.9-kilometer) segment about 135 miles west in Monroe County (*5*). Carcass data collected from 1970 to 1974 was used in the comparison. It was found that during this five-year time period the average number of white-tailed deer carcasses per mile (1.6 kilometer) per year on these two segments did not appear to be significantly different (*5*). The conclusion was that the overall existence of the fencing (given its condition of disrepair) in the initial segment did not appear to have an impact on DVCs (*5*). There was no discussion about whether this conclusion was statistically significant.

Fencing Height, Deer Carcasses, and/or DVCs

Approximately two years after the Tubbs study, Bellis and Graves did a similar evaluation along approximately the same Pennsylvania segment (*4*, *6*). The majority of the data collection completed for this study was along six miles (9.7 kilometers) of Interstate 80 near Snow Shoe, Pennsylvania, but a survey of the fence quality and observations of white-tailed deer were completed for 8.42 miles (13.6 kilometers), and the overall segment length in which there were study activities was about 10.19 miles (16.4 kilometers). This study area included the Interstate 80 segment considered previously (*1*, *2*, *6*). Two types of fencing are the in study area: 1) short segments (1.1 to 1.4 miles (1.8 to 2.3 kilometers) of 5.25-foot (1.6-meter) chain link fence (near the interchange and rest area), and 7.0 to 7.3 miles (11.3 to 11.7 kilometers) of 7.4-foot (2.26-meter) white-tailed deer exclusion fence (*4*).

Data related to white-tailed deer location and activities were collected from December 1974 to March 1976 (*4*). The specific segment of Interstate 80 observed was the same study area as the previous research, but also included an additional 2,000 feet (609.6 meters) (*4*). The primary objective of the study was to more clearly evaluate the DVC- or carcass-reduction effectiveness of the fencing along the segment (*4*). However, only six white-tailed deer were killed along the segment during the study time period, and the researchers were generally forced to evaluate the fencing based on their white-tailed deer observations (*4*). Speculation is also offered about the reasons why the number of white-tailed deer killed along this section of roadway had decreased from the time the roadway was opened (1968) and the time of this study (1974 and 1975).

As previously mentioned, the fencing along this segment of Interstate 80 was in general disrepair (*4*). Overall, 486 gaps (i.e., spaces greater then 9 inches (22.9 centimeters) in height at the bottom of the fence) and 7 flaps (holes made by humans) were found along the ROW exclusionary fencing, and tracks and hair evidence showed that 118 were used by white-tailed deer (*4*). Eighty-three downbends of 3 to 5 inches (7.6 to 12.7 centimeters) at the top of the fence were found, and broken wires (from falling branches or trees) at the top of the fencing observed at 96 locations (*4*). The damage at 12 locations was considered to be excessive (e.g., entire sections of the fencing being removed by humans or the fence height being reduced to 40 inches or lower) by the researchers (*4*). Overall, track evidence appeared to indicate that the 5.25-foot (1.6-meter) chain link fence was easily jumped by white-tailed deer, but they apparently preferred to go under the 7.4-foot (2.26-meter) fence.

From December 1974 to August 1975, before modifications to the fencing, seventy observation runs were made along a six-mile (9.7 kilometer) segment of Interstate 80 near Snow Shoe, Pennsylvania (*4*). The results were the same as Tubb's study and approximately 75 percent of the white-tailed deer observed were inside the roadway right-of-way fencing (*4*, *6*). In September 1975, however, to test the fencing as a white-tailed deer deterrent, it was modified on the south side of the six-mile (9.7 kilometer) study segment (*4*). These modifications included:

- Two miles of gaps at the bottom of the fencing were plugged with logs, but the total height of the fence was also reduced to 4.3 feet (1.3 meters).

- Two miles of fencing was reduced to 4.3 feet (1.3 meters) in height but none of the bottom gaps were filled with logs.

- Two miles of fencing remained at 7.4 feet (2.26 meters), had its bottom gaps filled with logs, and the damage to the top wires was repaired.

The 7.4-foot (2.26-meter) fencing on the north side of the roadway was not modified in any manner, and was used as a control (*4*). The white-tailed deer along the segment were then observed for the next seven months (September 1975 to March 1976), and this "after fence modification" data was compared to the data from the nine-month (December 1974 to August 1975) "before fence modification" study period (*4*).

Overall, the researchers concluded that the monthly fluctuations in the number of white-tailed deer observed during the study period were due to normal seasonal variations in population and/or movement (*4*). The number of white-tailed deer observed along the control side of the roadway, for example, increased by 333 percent (*4*). However, the results from the modified fence segments contained conflicting results. There was a 156 percent decrease in number of white-tailed deer in the ROW along the segment that had a 4.3-foot (1.3-meter) fence with its gaps fixed, but a 157 percent increase along the segment with a fence height of 7.4 feet (2.26 meter) and its gaps fixed (*4*). Both changes were significantly smaller than the increase observed in the control area. The researchers concluded that filling the gaps at the bottom of the fence appeared to be more important than fencing height (*4*). The two-mile segment with the 4.3-foot (1.3-meter) fence height and no gaps fixed experienced an increase in white-tailed deer within the ROW that was not significantly different than the control side of the roadway (*4*).

Based on these results, and the constraints of this study design, the researchers could not make any conclusions about the efficiency or effectiveness (or DVC-reduction impact) of the different fencing designs/heights considered (*4*). The confusing results are a good example of the temporal and spatial complexities and variability connected with the study white-tailed deer behavior (which are impacted by many factors) and/or the DVC-reduction impacts of a countermeasure. Controlling for or quantifying this variability from the impact of a particular DVC countermeasure is required to determine how it will affect the probability a DVC will occur along a specific segment of roadway.

Bellis and Graves did believe and conclude, however, that the traffic volumes in 1974 and 1975 appeared to produce a situation that prevented white-tailed deer from crossing or entering the roadway proper (versus the ROW) and producing a DVC (*4*). This conclusion appears to be based on the researchers observation that no white-tailed deer were observed on the roadway surface, that this number had decreased through this series of Interstate 80 studies, and that only six were killed along the segment of interest throughout this 16-month study (*1, 2, 4, 6*). However, this is opposite of the general relationship between traffic volume, white-tailed deer densities, and DVC patterns that is currently observed today, and described in the hunting or herd reduction summary of this toolbox. They recommended that fencing not be installed as a white-tailed deer deterrent along high-volume roadways, but that if it was installed the focus should be on the strength of the bottom of the fencing and proper installation/maintenance (*4*). It was also suggested that the installation of fencing closer to the roadway (possibly just on one side of the roadway) might allow white-tailed deer to feed and not attempt to cross the roadway.

In 1975, Falk also attempted to measure the effectiveness of exclusionary fencing as DVC reduction device Pennsylvania, but he used a slightly different approach (*5*). Three segments of Interstate 80 were studied. The first segment was the previously described 8-mile (12.9-kilometer) site near Snow Shoe, Pennsylvania in Centre County. The second segment was an adjacent 2-mile (3.2-kilometer) section of Interstate 80, and the third segment was an 8-mile (12.9-kilometer) section of Interstate 80 about 135 miles to the west in Monroe County (*5*). The focus of this discussion will be the fencing analysis completed in the 2-mile (3.2-kilometer) Centre County segment (*5*). The results of a comparison of the fenced and unfenced 8-mile (12.9-kilometer) segments were previously described.

The two Centre County study segments had 7.4-foot (2.26-meter) exclusionary fencing along both sides of Interstate 80. The 2-mile (3.2-kilometer) segment was the focus of this study, and its fencing was initially inspected for damage and gaps (*5*). Then, for analysis purposes, the 2-mile (3.2-kilometer) segment was divided into three sections. The first 1/2-mile (0.8-kilometer) of fencing was unmodified, but the next mile (1.6 kilometers) of fencing was completely repaired). The fencing along the next 1/2-mile (0.8-kilometer) also remained unmodified (*5*).

The location and number of white-tailed deer observed in each of the three segments described above were compared to each other in an effort to evaluate the effectiveness of the 7.4-foot (2.26-meter) fencing (*5*). This information was gathered during Spring and Winter study time periods six to seven weeks long. Five observations were made before the one mile (1.6 kilometer) fence in the test section was repaired, five after it had been repaired (e.g., top wires repairs, trees removed, and bottom gaps 9 inches (22.9 centimeters) or more plugged), and five more after the researchers returned the fencing in the test section to its original state of disrepair (although the trees on the fencing were not replaced) (*5*). Falk concluded that the total number of white-tailed deer crossing into the ROW with the repaired fence was significantly less than the two adjacent control sections (*5*). During the Winter observations ROW penetrations by white-tailed deer were smaller overall, but higher in the control sections than the test section. During the Spring, the control sections experienced an increase in white-tailed deer activity but the test section (with the repaired fencing) showed a reduction (*5*). More white-tailed deer were observed going under the fence rather than over. Falk concluded that the 7.4-foot (2.26-meter) height of the fencing may not be as important as plugging the fence gaps (i.e., proper installation and maintenance) (*5*).

Fencing Height/Location and Deer Carcasses/DVCs

Interstate 80 Study

From August 1970 to January 1972 white-tailed deer carcasses were counted along the entire 313-mile (503.7-kilometer) length of Interstate 80 in Pennsylvania (*11*). The objective of this study was to investigate the apparent relationships between roadway/roadside characteristics and the locations of these carcasses (*11*). The data collected at each white-tailed deer carcass location and at all 16,777 roadway markers (typically every 200 feet) included (on both sides of the roadway): vegetation (i.e., wooded, non-crop fields, crops, pasture, or other), topography (i.e., the cut and fill combinations of each side of the roadway), the height of the ROW fencing, and the distance from the fence to the highway and the nearest wooded area (*11*).

Four types of fencing existed along Interstate 80 at the time of this study: 1) 5-foot (1.5-meter) woven mesh fencing, 4-foot (1.2-meter) rectangular mesh fencing, a 5.5-foot (1.7-meter) woven wire mesh fencing topped with three smooth wires, and a 7.4-foot (2.26-meter) fencing with three smooth at the top and another two strands on an 45-degree (away from the roadway) extension (*4*, *5*, *6*, *11*). The 5-foot (1.5-meter) fence was only used in interchanges areas, and the 4- and 5.5-foot (1.2- and 1.7-meter) fencing was mostly located in agricultural and semi-agricultural areas (*11*). The 7.4-foot (2.26-meter) fencing was primarily located in the forested mountains (*11*). On average, the fencing in the mountains was twice as far way (i.e., 90 feet (27.4 meters) from the roadway as the fencing in the agricultural land (i.e., 45 feet (13.7 meters)) (*11*).

A total of 874 deer were killed within the study area during the 15-month time period considered (*11*). Overall, the researchers found more white-tailed deer carcasses adjacent to the 7.4-foot (2.26-meter) fence than the 4.0- to 5.5-foot (1.2- to 1.7-foot) fencing (*11*). They concluded that this was probably due to the fact that the 7.5-foot fencing was only installed in "high" DVC areas (*11*). The correlations between the adjacent land characteristics and the fencing locations may also be part of the explanation. Appropriately, they did not believe the data available allowed a proper analysis of the fencing height impacts on the location of DVCs or deer carcasses. Of course, the data collected in this study may also show that the 7.4-foot (2.26-meter) fencing was not effective at reducing DVCs or deer carcasses, and this would agree with at (which agrees with the results from the previously described Pennsylvania studies of Interstate 80 (*4*, *5*, *6*, *11*). No data summary of the observed white-tailed carcasses by adjacent ROW fence height was provided (*11*).

An examination of the vegetation and topography information collected, however, did lead the researchers to some more general conclusions (*11*). They concluded that fencing location (with respect to the woods), of the roadway/roadside characteristics considered, appeared to have the strongest relationship with the location of white-tailed deer carcasses. The highest carcass numbers were found along segments where the fence was located at the edge of the woods or within 75 feet (22.9 meters) of the woods (*11*). These sites generally had good cover for the white-tailed deer near the fence, but grazing opportunities inside the fence (*11*). The lowest number of carcasses was found when the fence was more than 75 feet (22.9 meters) away from the woods (*11*). These areas were characterized by a small amount of cover for the white-tailed deer near the fence and grazing opportunities outside the ROW (*11*). The number of carcasses was also low when the fence was within the woods. The researchers concluded that the carcass location patterns seemed to be more related to the amount of land with grazing opportunities available than the proximity of the woods to the roadway (*11*). No clear relationship was found between the topography of the adjacent roadside and the carcass locations (*11*).

Interstate 84 Study

In the 1980s the relationships between the height and ROW location of exclusionary fencing (See Table 1) and the observed location of white-tailed deer along Interstate 84 in Pennsylvania was also studied (*7*). Fencing 9 feet (2.7 meters) and 7.2 feet (2.2 meters) in height were considered (See Table 1). A data collection methodology similar to those in the Interstate 80 studies was used, but information from the tracking of some radio-collared white-tailed deer data was also used to determine their behavior and activities (*7*). Data was also collected about white-tailed deer locations for each mile (1.6 kilometer) of the study segments (See Table 1), and information about the adjacent vegetation (i.e., open or wooded), topography (i.e., cut, fill, or level), and location of the ROW fence (i.e., within the woods, at the woods edge, 82 feet (25 meters) or less from the woods, 82 to 328 feet (25 to 100 meters) from the woods, and greater than 328 feet (100 meters) from the woods) was summarized (*7*).

TABLE 1 Fencing Descriptions and Location (*Adapted from 7*)

Fence Height	Description
9.0 feet (2.7 meters)	• Woven-wire mesh with an opening width that progressively increased from 3 to 7.5 inches (7.6 to 19.1 centimeters) from ground level to 4.0 feet (1.2 meters) in height, and then decreased again to 3 inches (7.6 centimeters) within the remaining 5.0 feet (1.5 meters). • 14.3 miles (23.0 kilometers) of this fencing was installed on each side of Interstate 84 from State Route 507 to just beyond the State Route 739
7.2 feet (2.2 meters)	• Woven-wire mesh with a gap width that increased from 3 to 8 inches as it increased in height from 0 to 4.6 feet (0 to 1.4 meters) above ground. Three strands of wire above the square mesh extended the height an additional 1.5 feet (0.46 meters) and a 45-degree angle away from the highway with two additional wires. • 11.4 miles (18.3 kilometers) of this fencing was installed along Interstate 84 for just east of State Route 739 interchange.

The white-tailed deer location data revealed a number of patterns. Overall, the spotlight data showed that the number of white-tailed deer groups in the ROW adjacent to the 9-foot (2.7-meter) fencing was smaller than those adjacent to the existing 7.2-foot (2.2-meter) fencing (*7*). This difference, however, only seemed to hold for wooded (versus non-wooded) segments, segments with adjacent cuts/fills (versus level ground), and segments with a fencing location in the woods (versus at the edge of the woods or greater than 82 feet (25 meters) from the woods) (*7*). The amount of data available for these comparisons was not documented.

An evaluation of the white-tailed deer carcasses along the Interstate 84 study area produced different patterns. No statistically significant differences were found between the number of white-tailed deer carcasses observed along the roadway segments with the two fence heights, or for differences in adjacent vegetation cover, topography, and fence location (*7*). Overall, 100 incidents occurred during the two-year time period considered for this study (*7*). However, recall that Puglisi, et al. (described earlier) did find a relationship between the number of white-tailed deer carcasses they observed on the roadway and the fencing location (*11*).

Fencing with Complementary Infrastructure

A number of studies have also been completed that focus on the impacts of installing exclusionary fencing with complementary infrastructure (*8*, *12*, *13*, *14*, *15*, *19*). These additional facilities are typically related to the movement rather than the exclusion of the animal. For example, in at least two studies the evaluation considered the impacts of one-way gates and exclusionary fencing (*13*, *14*). These gates provide a method of escape to white-tailed deer and other animals that may enter a fenced ROW. Another study compared the use of one-way gates and alternative earthen escape ramps (*19*). Similarly, exclusionary fencing is almost always, and appropriately, installed when roadway wildlife crossings (e.g., overpasses, underpasses, and at-grade) are constructed (*8*, *12*, *15*). In this case, the objective of the fencing is to funnel the animals to the crossings that allow movement across the roadway (versus the complete barrier of fencing and its subsequent migratory impacts). In many cases, all three measures are installed along a roadway segment (*8*, *12*, *15*, *18*, *19*).

The focus of studies summarized in the following paragraphs is typically, but not always, the use of the escape gates, earthen escape ramps, or crossings by the animals. The potential DVC or roadway carcass reductions attributed to the entire installation is also sometimes provided. In the case of combined DVC-reduction measures (e.g., fencing and overpass), however, the reduction impacts due to each component are not typically presented or possible to determine. But, it is generally assumed, for example, that wildlife crossings are typically ineffective without the addition of exclusionary fencing. This assumption sometimes leads to the suggestion that the DVC or carcass reductions observed after the installation of a combination of measures is entirely due to the fencing. The following paragraphs, however, are based on the assumption that the existence of the wildlife crossings and/or one-way gates or earthen escape ramps (or other DVC-reduction actions taken by the implementing agency) may increase the potential DVC or carcass reduction of an exclusionary fencing installation.

Fencing with One-Way Gates

Exclusionary fencing is sometimes combined with one-way gates. These gates are designed to provide a ROW exit to animals that may become trapped between the exclusionary fencing (See Figure 1). Two studies are described in the following paragraphs that focus on the use of one-way gates with exclusionary fencing (*13*, *14*). One the studies considered the use of one-way gates by mule deer in both a controlled and field environment (*14*). A number of one-way gate designs were evaluated by observing whether they were properly used (i.e., they did not allow passage in the unintended direction) and the individual preference of captive mule deer (*14*).

Based on the results of the evaluation mentioned above a one-way gate design with only a 6 percent failure rate (i.e., deer using the gate to go into the ROW) was installed within 1.5 miles (2.4 kilometers) of 8-foot (2.44 meters) fencing (*14*). This fencing was adjacent to a wildlife underpass along Interstate 70 near Vail, Colorado (*14*). In this field experiment, the individual use of the eight gates installed did vary, but their overall failure rate was only 3.8 percent (*14*). The variation in the use of the gates was attributed to their location (e.g., near good ground cover or not), and the negative movements were primarily the result of fawn use (with their small size) and human interference ((i.e., people leaving the gates open). The researchers recommended that the use of one-way gates should be considered when 8-foot (2.44-meter) fencing was installed along roadways (*14*). However, since the time of this study it appears that the use of these gates has declined (apparently because the animals have adapted to the use of the underpass) (*8*).

No DVC or deer carcass observations were documented for the Interstate 70 one-way gate evaluation, but this data was considered in a Minnesota study (*13*, *14*). The same one-way gate design was installed along two new sections of Interstate 90 and Interstate 94 (*13*). The two roadway sections of interest consisted of a 13.2-mile (4-kilometer)

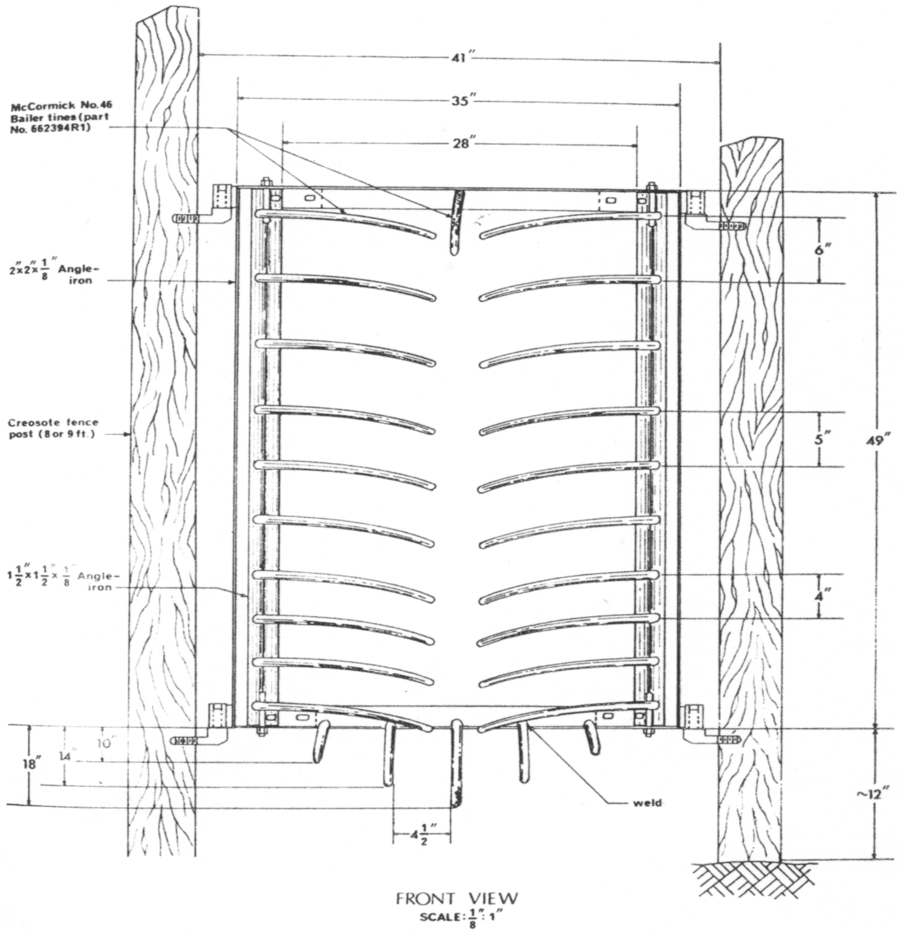

FIGURE 1 One-way gate design (*14*).

segment along Interstate 94 and a 16.8-mile (5.1 kilometer) section along Interstate 90 (*13*). Each segment had 7.9-foot (2.4 meter) ROW fencing and 18 to 20 one-way gates (*13*). A typical 3.9-foot (1.2-meter) ROW fencing installation, however, was attached to each end. The gates were placed near the end of each 7.9-foot (2.4-meter) fencing section, and also at locations where it was believed white-tailed deer might want to enter or exit the ROW.

Data on the white-tailed deer use of the one-way gates was collected with counters and track beds (i.e., section of sand that allow tracks to be counted and then smoothed). Track beds were also installed at each end of the 7.9-foot (2.4-meter) fencing (*13*). The one-way gate movement counters were checked biweekly, and it was impossible for the researchers to know when during the two-week period a malfunction in the counter may have occurred. The equipment along Interstate 90 was also vandalized several times. In addition, six of the nine gates along the Interstate 90 segment never had counters or track beds installed because they were in three feet (0.91 meters) of water for most of the study time period (*13*). These factors may have all at least partially contributed to the study results that show only 69 percent of the wildlife gate passages were in the correct direction (*13*).

The researchers did provide several suggestions for future one-way gate installations. They suggested that the gates and fencing must be maintained properly and in good working order to be effective, and that the fences/gates should be located at the top of the ROW backslope (to avoid possible standing water) and long enough to avoid white-tailed deer movement around the ends (*13*).

The researchers also concluded, however, that the combination of 7.9-foot (2.4-meter) fencing and one-way gates theoretically reduced the number of white-tailed deer carcasses along the roadway segments by 60 and 93 percent (for Interstate 90 and 94, respectively) (*13*). They apparently compared the number of white-tailed deer killed along the segments in the year following the installation of the one-way gates and the 7.9-foot (2.4 meter) fencing to an assumed number of expected kills. Unfortunately, this reduction calculation appears to be based on some extrapolation of the number of observed along older adjacent roadways during the year before the interstates were opened (*13*). In addition, the rationale for how the expected number of carcasses was calculated is only implied and not properly documented (*13*).

Based on their results, however, the researchers did conclude that the 7.9-foot (2.4-meter) fencing along Interstate 94 did keep white-tailed deer off the roadway ROW, but that the same fencing along Interstate 90 was not long enough (i.e., white-tailed deer entered around the ends) and the water in the ditch on this segment caused white-tailed deer to walk on the roadway (*13*). An analysis of both installations in 1978 dollars, assuming the carcass reduction estimates are correct, and using a series of assumptions related to vehicle repair costs, the value of a white-tailed deer, and interest/inflation rates resulted in an average benefit-cost ratio of 2.28 (*13*). The researchers believed that this analysis was a "…fair, but conservative evaluation…" but did not include fencing or gate maintenance costs in the calculation (*13*).

One-Way Gates and Earthen Escape Ramp Use

In the late 1990s the use of one-way gates by deer was compared to that of an earthen escape ramp design (See figure 2) (*19*). There was some concern that the one-way gates (See Figure 1) were not really designed well for deer, and that they were reluctant to use them (*19*). Earthen escape ramps are simply piles of dirt covered with natural vegetation against a wall that is installed along the exclusionary fence. It is suggested the ramp height be 4.9 feet (1.5 meters), and that the exclusionary fence be lowered to that level when adjacent to the ramp (*19*). The deer use these ramps to escape the roadway right-of-way, and do not appear to have a problem jumping down from this 4.9-foot height (*19*).

FIGURE 2 Example earthen escape ramp (*19*).

A study in Utah compared the use of 16 earthen ramps to 18 one-way gates (*19*). In 1997, nine ramps were installed along United States 91, and in 1998 seven ramps were properly constructed along United States 40 (*19*). There were also 10 and 8 one-way gates, respectively, within each of these 1.5-mile roadway segments (*19*). Only about 33 and 49 percent of the deer approaching the gates on each roadway segment, respectively, actually used them (*19*). In addition, a standardized index of ramp and gate use was developed and it was found that overall the earthen escape ramps were used 8 to 11 times more than the one-way gates (*19*). The observed amount of deer mortality also decreased along United States 91 after the ramps were installed (*19*).

The researchers had several recommendations based on their findings (*19*). First, it was recommended that exclusionary fence maintenance and repair programs be institutionalized in Utah (*19*). The regular maintenance of these installations maximizes their effectiveness. They also recommended the use of earthen ramps, and suggested that their location be chosen by qualified personnel or that they be installed no less than 0.25 miles apart (*19*). A 0.5-mile spacing was recommended, however, where the level of the deer collision problem was not known or was less persistent (*19*). The closer 0.25-mile spacing was still recommended within one mile of the ends of the fencing (*19*). Other recommendations included locating the ramps near natural points of movement (e.g., drainage areas), placing them at 0.25-mile spacing near desirable forage, surfacing them with natural vegetation for appearance and to reduce erosion, and shielding them from roadway noise and view if possible (*19*).

Fencing with One-Way Gates and/or Grade-Separated Wildlife Crossings

A sample of five studies that considered the combined installation of exclusionary fencing and grade-separated wildlife crossings are summarized in the next few paragraphs (*8*, *12*, *15*, *18*). In some cases these installations also included one-way gates, but these were not the focus of the studies described.

Colorado Interstate 70 and Highway 82 In 1979 a study in Colorado attempted to determine the DVC-reduction impact of several countermeasures (*8*). The countermeasures evaluated in this research included 8-foot (2.44-meter) fencing, overpasses and underpasses, prototype deerguards (i.e., cattleguards that work on deer) designs, highway lighting, and animated deer signs (*8*). The researchers found that none of the deerguard designs they considered were effective, and the results that focused on lighting and signs are discussed in other sections of this toolbox.

The impacts of 8-foot (2.44-meter) exclusionary fencing were studied at six locations. These locations include the

- Vail Study Area: 1.5 miles (2.4 kilometers) of fencing (with one-way gates) along each side of a wildlife crossing and on both sides of the interstate.

- Avon Study Area: 2.3 miles (3.6 kilometers) of fencing (with one-way gates) between the Avon interchange and the Eagle River bridge on the north side of the interstate.

- Edwards Study Area: 2.3 miles (3.6 kilometers) of fencing (with one-way gates) west of the Edwards interchange on the north side of the interstate.

- Eagle Study Area: 4.8 miles (7.7 kilometers) of fencing (with one-way gates) east of the Eagle interchange on the north side of the interstate.

- Diamond S Study Area: 1.1 miles (1.8 kilometers) of fencing along the divided four-lane Highway 82 approximately one mile (1.6 kilometers) northwest of its junction with Highway 133 (on one side the roadway).

- Carbondale Study Area: 1.1 miles (1.8 kilometers) of fencing along Highway 82 on the north side of the roadway.

The Vail fencing installation in this study was closely associated with an underpass specifically designed for wildlife usage (the use of the underpass was also studied) (*8*).

The other locations may encompass and/or be adjacent to crossing structures (some of which may have been studied), but these combinations were not documented (*8*).

Deer densities along each fenced segment, except Vail, were estimated (*8*). The locations of mule deer carcasses, however, were recorded for all six study areas (*8*). The researchers considered the change in the number of carcasses within each segment from year to year. The percent reduction in the mean annual number of carcasses counted at the six locations ranged from 67.8 to 86.5 percent (*8*). The average annual reduction was about 78.5 percent (*8*). The number of years of data used to calculate the mean annual number of carcasses before and after the fencing installations ranged from 1 to 5 years and 5 to 10 years, respectively (*8*).

It was concluded that the variation in the reductions observed from year to year were probably related to weather conditions (e.g., the severity of the winter), fence length, and the number/behavior of the mule deer near the fenced area (e.g., where they could graze) (*8*). It was also recommended that the cause-and-effect of the fencing (with the associated crossings) on the number mule deer carcasses should be applied with caution because the reductions (and their variability) calculated were based on data from different areas and time periods (*8*). It was also emphasized that the 8-foot (2.44-meter) fencing must be properly constructed and maintained to achieve the effectiveness seen in this study (*8*). Finally, they recommended that exclusionary fencing be installed at least 0.5 miles (0.8 kilometers) past concentrated areas of mule deer activity, and that wildlife crossings be provided every mile (1.6 kilometer) (*8*). These recommendations were based on their observations of lateral deer movement adjacent to the six fencing locations (*8*).

Wyoming Interstate 80 A Wyoming study also considered the behavior of mule deer and DVC impacts related to a fencing and underpass installation (*15*). Initially, an 8-foot (2.44 meter) "game-proof" fence was built along a 6.7-mile (10.8 kilometers) segment of Interstate 80, and then a year later another 1.1 miles (1.8 kilometer) of fencing was installed because the mule deer were going around at least one end of the fence (*15*). The

7.8-mile (12.6-kilometer) segment of roadway also included four wildlife underpasses and three machinery underpasses (*15*). These structures varied in length from 110 to 393 feet (33.5 to 119.8 meters), were 10 to 50 feet (3.0 to 15.2 meters) wide, and 10 to 17 feet (3.0 to 5.2 meters) high (*15*). A typical 46-inch (116.8 centimeter) ROW fence remained across most of the openings to these crossings, but mule deer easily jumped this height (*15*). A total of 30 one–way gates were also installed (*15*).

Each year this segment of Interstate 80 was crossed twice by about 1,000 mule deer, and 37 to 60 DVCs occurred (*15*). The researchers collected information about the behavior of the mule deer (from visual observation, track counts, radio collars, and cameras) and also counted the number of mule deer carcasses along and adjacent to the fenced study segment (*15*). This data was used to evaluate the impacts of the fencing and crossings (*15*).

Before the initial fencing, 53 mule deer were killed within the segment being considered (*15*). Another eight mule deer were killed just to the west of the planned fencing location (*15*). Another 59 mule deer were killed in the first year (i.e., two migration periods) after the initial fencing construction (*15*). About 55 percent of these carcass locations, however, occurred just outside the ends of the fencing. Repairs were done to the fencing, and it was also extended 1.1 miles (1.8 kilometers). During the next six migration periods only one was found in the fenced area and three near the extended end of the fencing (*15*). The number of carcasses found near the fence end that was not extended, however, continued to be found at about the same rate (*15*). It was concluded that the fencing/crossing combination resulted in a mule deer carcass reduction, within the fenced area, of more than 90 percent (*15*). Similar to the other research projects, it was again suggested that having the correct length of fencing was very important, and that proper fence construction and vigilant repair/maintenance are needed (*15*).

Trans-Canada Highway One of the most studied exclusionary fencing and wildlife crossing installations exists along a 16.2-mile (26.1-kilometer) segment of the Trans-Canada Highway (TCH) (*12*). This section of roadway was reconstructed from a two-lane undivided to a four-lane divided cross section between 1983 and 1985, and in December 1984 an 7.9-foot (2.4-meter) ROW fence was installed along 6.8 miles (11 kilometers) of the widened portion of the TCH (*12*). The bottom of this fencing was kept within 5.9 inches (15 centimeters) of the ground. A similar fence was installed on the adjacent 9.4 miles (15.1 kilometers) in September 1987 (*12*). No widening or fencing installation had occurred on the adjacent 33.6-mile (54.1-kilometer) section of the TCH at the time of this study, and data from this segment was used for comparison purposes (*12*).

In addition to the fencing, eight underpasses specifically designed for use by animals crossed this study segment of the TCH (*12*). In addition, four wildlife crossing opportunities also existed at three water underpasses and one railway overpass (*12*). Several one-way gates were also installed in the fencing, but the exact number was not documented (See Figure 1).

An evaluation of the ungulate (i.e., elk, bighorn sheep, mule deer, moose, and white-tailed) carcass numbers along the two fenced sections of the TCH was completed (*12*). Two approaches were taken to measure the potential difference in carcasses before and after the fencing installation. The "after fence" expected number of ungulate carcasses along the 6.8-mile (11-kilometer) segment was calculated by considering how its carcass numbers had historically compared with the control segment (assuming that this relationship would continue with the widening) (*12*). The number of years used to define the historical relationship was not documented, but could have been as many as 14 years (*12*). Overall, a 94 percent reduction in ungulate carcasses was estimated for this 6.8-mile (11-kilometer) segment. The reduction in ungulate carcasses along the 9.4-mile (15.1-kilometer) segment was calculated by comparing the before and after fencing (installed in September 1987) data from 1985 to 1989 (*12*). An overall ungulate carcass reduction of about 97 percent was estimated (*12*).

The post-fencing reduction of just white-tailed and mule deer carcasses along the 16.2-mile (26.1-kilometer) study segment was estimated at about 95 percent (*12*). However, of the 645 ungulates killed by man (e.g., train hits, vehicle hits, and other sources) in the study area from 1985 to 1989, only 61 were white-tailed deer (12 on the roadway segments of interest) and 103 mule deer (22 on the roadway segments of interest) (*12*). In fact, only one mule deer and one white-tailed deer were killed along the 6.8-mile (11-kilometer) segment during the entire study period (all fenced). Along the 9.4-mile (15.1-kilometer) segment it appears that 17 and 10 mule deer and white-tailed deer were killed before the fencing, and four and one, respectively, after the fencing (*12*). Overall, this is a measured deer mortality reduction of about 82 percent (*12*).

The TCH researchers concluded that there was a significant reduction in the number of white-tailed and mule deer on both segments of roadway, but it was also concluded that there was no significant increase in the number of white-tailed and mule deer killed along the second segment of roadway after it was widened to a four-lane undivided cross section but before it was fenced (*12*). These results may be due to the small sample size or the fact that animals moving in small groups (rather than large herds) may be impacted less by roadway widening (*12*). The number of elk and bighorn sheep killed did increase within the widened segment (*12*). It was concluded that the large reduction in ungulates killed along the roadway segments was primarily due to the fencing and the active removal of animals (within the fenced segments) by park wardens (*12*). The additional reduction that might be due to the one-way gates, cattleguards at fence openings, and the wildlife crossings were not discussed or summarized (*12*).

Another study of the reduction in ungulates killed along the TCH was completed after an additional 11.2 miles (18 kilometers) was widened (for a total of 27.4 miles (44.1 kilometers)), and a 7.9-foot (2.4-meter) exclusionary fencing was installed on both sides of the roadway (*18*). Data related to collisions between wildlife and vehicles were collected between May 1981 and December 1999, and overlapped with the data used in the previous study (*12*, *18*). It does not appear, however, that any additional wildlife crossings were constructed along the construction of the additional 11.2 miles (18 kilometers).

Only two years of data before and after the various fencing installation dates along the TCH were evaluated (*18*). This short period of time was chosen to minimize the impacts of ungulate population changes on the results, but also limits its strength as a safety analysis (*18*). A chi-square analysis indicated that the first two segments of roadway (see the previous discussion) had three of four "high" wildlife carcass locations near the ends of their fencing (*18*). As expected, however, the number of wildlife carcasses or wildlife-vehicle collisions along the roadway segments decreased after the fencing was implemented (even with annual increases in traffic flow) (*18*). Overall, a statistically significant reduction in ungulate mortality of 80 percent was calculated after the fencing (along with the crossing previously mentioned) was installed (*18*). The individual reductions in elk and deer carcasses were also significant (*18*).

Electrified Fencing

Several studies have considered the exclusionary effectiveness of "electric fencing" on white-tailed deer movements (*20, 21, 22, 23*). These studies were not done along roadway ROW, and their results have been somewhat mixed. It should also be recognized that the fencing materials and technologies used in even the most recent studies summarized have most likely been updated and improved. No studies were found that attempted to evaluate the impacts or feasibility of installing electric fencing along portions of a roadway ROW.

The focus of one study was the use of electric fencing to exclude white-tailed deer from 255 acres of hardwood forest in the Adirondack Mountains (*20*). The researchers that completed this 1969 study concluded that the fence repelled white-tailed deer, and partially controlled their use of the study area (based on a significant reduction in browsing) (*20*). However, it was also determined that the amount of control offered by the fencing (a six-foot (1.8-meter), five-strand (three with charge), copper-clad steel wire design) was too marginal and the cost too high for them to recommend its use (*20*).

Another study investigated the use of a baited electric fence around one and five hectare areas of apple seedlings (*22*). This study used a single strand electric livestock fence, and the strand was 3.3 feet (one meter) above the ground and had aluminum foil flags attached to it at 32.8 feet (10 meter) intervals (*22*). The underside of this foil tent was covered in peanut butter (*22*). Both the visual effect of the foil and the smell of the peanut butter attract white-tailed deer. The fencing was intended to be somewhat of a physical barrier, but more of a physiological aversion barrier to the white-tailed deer. The fencing surrounded apple seedlings, and the results indicated that the fence was highly effective at repelling white-tailed deer (*22*). Browsing was almost eliminated and new growth greater than that occurring in the nearby comparison, but unfenced, plots (*22*). These results continued for three growing seasons. However, the fencing did stop working for several short periods of time because overgrown vegetation touched it (*22*). In addition, maintenance costs because about one day per month was spent trimming vegetation, replacing foil, and recoating the foil (*22*). The researchers believe, however, that it is an economical alternative to the non-electric 8-foot (2.44-meter) woven wire fence (*22*).

In 1985 evaluated the effectiveness of five different designs for electric fence (*21*). Testing with captive deer within the Penn State Deer Research Facility revealed that all but the 57.9-inch (147-centimeter) vertical five-strand high-tensile smooth-steel wire (spaced at about 12 inches (30.5 centimeters) with the bottom strand 10 inches (25.4 centimeters) from the ground) fence design was penetrated by the white-tailed deer *(21*). Testing of this design was then completed around 10 fields (with varying crops) that had areas between 1.6 and 53 hectares (*21*). The benefit-cost ratio analysis, which included increases in crop yield but not installation or maintenance labor costs, were believed to be acceptable for all 10 sites (i.e., alfalfa, black cherry, corn, fruit trees, small grains, and vegetables) (*21*). It was concluded that this high-tensile wire design offers a low-cost alternative to the non-electric 8-foot (2.44-meter) woven wire fence (*21*).

Finally, researchers considered the use of three different 2-foot (0.6-meter) single-strand electric fencing designs to reduce deer damage to cornfields (*23*). Two types of chemical repellents were also tested (*23*). The study was conducted from 1984 to 1985 on 51 pairs of cornfields that ranged in size from 0.34 to 5.15 hectare (*23*). Each pair consisted of similar test and control plots, and the fencing treatment was randomly assigned to a sample of these pairs. Eleven fences of 17-gauge steel wire were coated with peanut butter and vegetable oil (*23*). Fifteen fences were constructed with a highly visible 0.4-inch (1.0-centimeter) wide yellow polyethylene ribbon with five interwoven strands of stainless steel (*23*). Ten fences were made with a highly visible plastic-backed 0.2-inch (0.5-centimeter) wide aluminum foil ribbon (*23*). The results indicated that white-tailed deer damage was less in the fields surrounded by these single-strand electric fences, and there was no difference in the impact of the three designs (*23*). Each design also had favorable benefit-cost ratios up to five years after their installation (*23*). The researchers recommended only the peanut-butter-coated and the polyethylene ribbon designs because they were easier to install, more durable, and the least expensive (*23*).

The feasibility of installing electric fence at any location (especially along a ROW) would appear to be related to, among other things, fencing installation needs, costs and benefits, animal and human safety, the provision of power, and fencing maintenance. The installation of these fences needs to be correct and also becomes easier as the ground becomes more level. Electric fencing maintenance needs to be vigilant to keep it operating, and requires nearby vegetation to be removed or cut regularly. Enough power is also needed to shock a white-tailed deer, and this will shock other animals and humans. Questions about whether white-tailed deer will somehow adapt to, or at times ignore, the fencing have not been evaluated. Finally, the fence and the wire also need to be strong enough to handle the impact of a white-tailed deer. No studies have considered the impact and/or feasibility of electric fencing in the roadway ROW, but all these factors would need to be evaluated before installation is considered. There may also be newer fencing technologies that may make the feasibility of this type of fencing installation more realistic.

Fencing, DVCs, and Benefit – Cost Analysis

One study was found that focused on the benefit-cost feasibility of installing exclusionary fencing along a roadway environment (*9*). As part of the study, however, an estimation of the DVC-reduction connected to the installation of 8.0-foot (2.44-meter) fencing had to be derived (*8, 9*). The benefits related to this reduction that were used in this study include the vehicle repair cost savings and the benefit of a saving a deer (*9*). The value of a deer used in this study was $350 (1976 dollars), and the range of vehicle repair costs was $324 to $564 (1970 to 1975 dollars) (*9*). The costs considered were the difference between installing an 8.0-foot (2.44-meter) fence versus a regular 3.6-foot (1.1-meter) ROW fence, and fencing maintenance (arbitrarily assumed to be one percent of the installation cost annually) (*8, 9*).

Overall, six fencing installations were used in this benefit-cost evaluation (*9*). In fact, these six installations are the same Colorado Interstate 70 and Highway 82 locations described in the "Fencing with One-Way Gates and/or Grade-Separated Wildlife Crossings" section of this summary. Five of the location calculations included costs for 8.0-foot (2.44-meter) fencing on one side of roadway, and three of these also included the installation/maintenance costs of one-way gates (*8, 9*). One location also included 8.0-foot (2.44-meter) fencing on both sides of the roadway, one-way gates, and a 10-foot by 10-foot (3.05-meter by 3.05-meter) underpass (*8, 9*). The length of the fencing locations ranged from 1.1 to 4.8 miles (1.8 to 7.7 kilometers).

The documented effectiveness of these six locations varied. The mean annual percent reduction in DVCs (as measured by carcasses) for the two installations with just fencing was 70.0 and 82.0 percent, the reduction for those with fencing and one-way gates ranged from 78.9 to 86.5 percent, and the reduction calculated for the fencing installation with the one-way gates and the underpass was only 67.8 percent (*9*). The number of years used to calculate these reductions was not documented (*9*).

Benefit-cost ratios were calculated for all six locations (*9*). The benefit-cost ratios for the five locations without the underpass ranged from 2.83:1.0 to 12.37:1.0 (*9*). The location with the underpass had a benefit-cost ratio of 2.59:1.0 (*9*). This low benefit-cost value was attributed to the high cost of fencing on both sides of the roadway and the underpass, and the relatively low estimated effectiveness of this facility (*9*). All of these factors are related to the topography within which this installation was erected, rockslides, and purposeful human damage to the fence (*9*).

The researchers involved in this study also completed a sensitivity analysis of the benefit-cost calculation inputs (*9*). Not surprisingly, they found that the results were sensitive to errors in vehicle repair cost and the value of the deer saved (*9*). Of course, it was also shown that when costs were held constant, there was more benefit to installing exclusionary fence along roadway segments with high mortalities (*9*). They also calculated the minimum number of deer that would need to be killed each year along a one mile (1.6 kilometer) segment to produce a benefit-cost greater than one (*9*). They assumed a fencing DVC reduction of 75 percent, a $500 cost for vehicle repairs, a $350 deer value, a 6.0 percent discount rate, a fencing cost of about $85,000 per mile, and an underpass cost of approximately $250,000 (all 1978 values) (*9*). It was found that the benefits from 8-foot (2.44-meter) fencing on one side of roadway was close to its cost when six deer were killed per mile (1.6 kilometer) (*8*, *9*). Similarly, a benefit-cost ratio near one was achieved for fencing on both sides of the roadway when eight deer were killed per mile (1.6 kilometers), and for 12 deer per mile (1.6 kilometer) with fencing on both sides of the roadway was combined with an underpass (*9*). The one-way gates were apparently not included in this evaluation. The researchers recommended, however that a benefit-cost ratio closer to 1.35 be used to determine installation levels, and for this ratio the number of deer killed per mile (1.6 kilometer) for the three designs 8, 16, and 24 respectively. The researchers recognized a number of inputs in their study were arbitrarily set, but they think the range of values they presented were reasonable (*9*).

Conclusions

This summary described the results from a series of studies that examined the various impacts of exclusionary ROW fencing. Examples of studies that considered the similar impacts of fencing installations with one-way gates, earthen escape ramps, and/or wildlife crossings were also discussed. Research conclusions related to DVC location modeling, electric fencing, and benefit-cost analyses were also presented.

Overall, the fencing installation evaluated in the studies summarized had documented white-tailed/mule deer carcass (i.e., mortality) reductions of 60 to 97 percent. Some of installations evaluated included exclusionary fencing only, others combined fencing and one-way gates, and a sample of the sites included fencing, one-way gates, and wildlife crossings. Almost all of the studies with a documented reduction, however, had fencing that was approximately 8-feet (2.44-meter) in height. Several studies attempted to evaluate or compare the impacts of different fencing heights, but they either did not have enough data to make a valid conclusion, found conflicting results, and/or failed to control for variables that would confound the observed effectiveness of the fencing (e.g., existing holes and gaps).

Unlike most of the DVC countermeasure research summarized in this toolbox, however, the results from the exclusionary fencing studies all consistently showed a reduction in the number of white-tailed or mule deer carcasses observed adjacent to the fencing installation implemented. Unfortunately, the design and validity of some of these studies are still questionable, and their results should be used with caution. For example, the highest and some of the lowest reductions (a range of about 30 percent) in roadside carcasses were observed in studies that evaluated installations with fencing, one-way gates, and one or more wildlife crossings. Some of the factors that may have produced this wide range of results for similar installations are discussed in the following paragraphs.

Three of the primary factors that appeared to impact the effectiveness of the fencing installations summarized were proper fencing installation, active maintenance/repair, and the vigilant removal of animals that do enter the fenced ROW. For example, it was found that white-tailed deer prefer to breach a fence rather than jump it, and they only need a gap as small as 9 inches (22.9 centimeters) at the bottom of a fence to enter the ROW. In addition, the combination of exclusionary fencing with other complementary infrastructure (e.g., one-way gates, earthen escape ramps, and/or wildlife crossings) may increase the amount of the observed DVC reduction along a segment (trapped animals are provided an escape and other animals can cross the roadway without the possibility of a vehicle conflict). The installations that combine all of these factors are expected to produce the best fencing DVC-reduction effectiveness.

Other more general conclusions can also be reached from the similarities in the study results. One, more information is needed about the importance and need of a particular fencing height. Fencing heights other than 8-feet (2.44-meters) (if cost effective) needs to be evaluated. Two, the location of the fencing may have an impact on its effectiveness. In one study it was found that the number of roadside white-tailed deer carcasses was the highest when the fencing was on the edge or within 75 feet (22.9 meters) of the woods. This pattern was especially obvious if there were grazing opportunities within the ROW. Three, the length of the exclusionary fencing is important. Several of the researchers had problems with deer going around the ends of their installations. One study suggested that the areas of "high" deer activity and/or DVCs be determined (through observation of animals and/or carcasses), and that the fencing should be installed at least 1/2-mile (0.8- kilometers) beyond that area. It was also suggested that wildlife crossings should be installed in these areas, if possible, every one mile (1.6 kilometers). These suggestions are based on their observations of how deer move parallel to the exclusionary fencing. Finally, the topography adjacent to the fencing must be considered, and the locations where it effectively makes the fencing shorter should be adjusted.

The other subjects discussed in this summary included DVC modeling, one-way gates, earthen escape ramps, electric fencing, and the benefit-cost of fencing installations. Two studies were found that showed a relationship between the existence of fencing and whether that segment would be a "high" DVC section or not. The results, however, contradicted each other. The use of the one-way gates in the study installations also seemed to vary, and in one study earthen escape ramps were used 8 to 11 times more than the one-way gates along the same roadway segments. However, several studies have shown that the installation of electric fencing can reduce crop damage. The installations were also considered to be cost effective in some cases. The electric fencing considered was often shorter than 8 feet (2.44 meters) in height, and sometimes only consisted of one strand of wire. Concerns related to the installation of electric fencing typically include cost, vegetation management around the fence, power, and maintenance. The use of electric fence along a ROW has not been studied, but its feasibility could be the subject of future research. Finally, a study was summarized that attempted to determine the number of deer that needed to be killed along a roadway segment to make the benefit-cost ratio of a fencing installation greater than one. It was suggested that for a conservative benefit-cost ratio of 1.35, 8-foot (2.44-meter) fencing on one side of the roadway, both sides of the roadway, and on both sides combined with a wildlife crossings, the roadside deer carcass numbers would need to be 8, 16, and 24 deer killed per mile (1.6 kilometer) per year, respectively.

Ultimately, the study results described in this summary are the outcome of different methods of data collection, amounts of data, and analysis approaches. Few, if any, of the studies are statistically rigorous (as measured by current safety data analysis standards), and the documentation necessary to completely understand the strengths and weaknesses of the declared results are often not available. However, and again unlike most of the DVC countermeasure research considered in this toolbox, there were two fencing studies that did recognize and document the weaknesses of their evaluative approach (e.g., the problems with typical before-and-after and control/treatment site DVC comparisons). There were also some attempts to control for and/or quantify the variability inherent in the data and comparison sites. A proper experimental design and statistically rigorous approach to DVC reduction evaluations would reveal an estimate of the actual impact of particular fencing designs. In other words, the observed impacts of the exclusionary fencing studies described in this summary might decrease by some amount. It is recommended that future fencing evaluations incorporate currently accepted safety data analysis approaches.

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ROADWAY MAINTENANCE, DESIGN, AND PLANNING POLICIES

A focused consideration of the wildlife habitat and movement impacts of a roadway or roadway system during its operation and development could reduce animal mortality (e.g., deer-vehicle crashes (DVCs). However, this level of consideration would generally need to expand upon the current requirements related to endangered or otherwise threatened species, and attempt to address the overall ecological impact of roadways on wildlife.

The most direct and obvious interaction between roadways and wildlife is animal mortality or DVCs. The purpose of this summary is to introduce and discuss a sample of the roadway maintenance, design, and planning decisions that might impact the number of DVCs. For a discussion of the wider range of the ecological impacts due to roadways (e.g., habitat fragmentation, reduced air quality, and increased noise and water runoff) the reader is referred to the recently published *Roadway Ecology: Science and Solutions* (*1*).

There are a number of roadway maintenance, design, and planning choices that might have an impact on the number of DVCs. The focus of the choices discussed in this summary are listed below:

1. Roadway Maintenance
    - Winter Maintenance
    - Roadside Vegetation Installation and Maintenance
    - Carcass Removal
2. Roadway Design
    - Posted Speed Limit
    - Curvature
    - Cross Section
    - Bridge Height and Length
3. Roadway Planning
    - Roadway Alignment Location
    - Project Programming

The "points of wildlife consideration" listed above range from very specific maintenance operational procedures and design choices to more general planning-level alignment and project programming decisions. In fact, the final section of this summary includes some general suggestions about how agencies might develop more ecologically sensitive roadways and roadway systems. Overall, the quantitative DVC-reduction that results from the specific activities and choices discussed here has rarely been studied, but if it has been it is discussed in more detail within the other countermeasures discussions within this toolbox.

Roadway Maintenance

Once a roadway has been constructed there are several maintenance-related decisions that could impact the number of DVCs. It has been generally suggested, for example, that the deicing and/or anti-icing salt mixtures used to keep roadways clear of ice and snow may also attract white-tailed deer and subsequently increase DVCs. This subject is the focus of the "Deicing Salt Alternatives" summary within this toolbox, and no research has been completed that quantifies the number of DVCs that might occur due to the application of roadway salt mixtures. The potential DVC impact does exist, however, and this factor could be considered in winter maintenance decisions. Alternatives to salt for winter maintenance do exist, but general safety (not just DVCs) and cost impacts would need to be evaluated to determine their feasibility.

It has also been generally suggested that choices related to the selection (usually decided during roadway design) and maintenance of roadside vegetation may also impact DVCs. In other words, certain types of vegetation and methods of roadside mowing (e.g., how much and how often) may attract white-tailed deer to the roadway. This subject is discussed in the "Roadside Vegetation Management" summary within this toolbox, but again almost no studies have been done to quantify which roadside vegetation choices and practices impact DVCs. Experts have created lists of plant species that are believe to be more attractive to white-tailed deer, and one of these lists is included in the "Roadside Vegetation Management" summary. Of course, the proper maintenance of roadside vegetation is also required for the safety of run-off-the-road vehicles, and impact how much roadside sight distance drivers would have to white-tailed deer.

Finally, another maintenance-related decision that may have an impact on general roadway safety (versus just DVCs) is the timing of white-tailed deer carcass removal. From a safety point-of-view the rapid removal of white-tailed deer carcasses from the roadway and roadside is the preferred approach for two reasons. One, white-tailed deer carcasses on the roadway and/or roadside of a high-speed roadway could (at least temporarily) be hazardous objects if hit by an errant run-off-the-road vehicle. The result of this type of collision could be the vehicle vaulting or rolling over. Two, white-tailed deer carcasses on the roadway can attract scavengers to the roadside to feed and this could result in a secondary animal-vehicle collision. Of course, decisions related to carcass removal also need to take into account, among other things, the probability of these types of events occurring and the general costs. The impact the carcasses may have on roadside maintenance equipment (e.g., mowers) should also be considered along with aesthetic.

Roadway Design

Several decisions can be made during the geometric design and signing of new or reconstructed roadways that could impact DVCs. However, the majority of the roadway design that occurs in the United States is within existing rather than new right-of-way (ROW). The decisions summarized in the following paragraphs are those related to posted speed limit, roadway curvature, cross-section, and bridge design. The DVC impacts of installing (and maintaining) exclusionary ROW fencing and deer crossing warning signs are discussed in their respective summaries within this toolbox. The choices or decisions related to the newer roadway alignment locations and project programming, on the other hand, are briefly discussed in the next section of this summary. Overall, each of these decisions will require a comparison of their potential cost and the benefits they offer to wildlife and safety.

Several researchers have investigated the apparent relationships between DVC or roadside carcass locations and several roadway/roadside factors (*2*, *3*, *4*, *5*, *6*, *7*, *8*, *9*, *10*, *11*, *12*). Some models have also been developed to predict the probability a particular roadway segment might be a "high" DVC site (*2*, *3*, *4*, *5*). These models are discussed in more detail within the "Hunting or Herd Reduction" and "Speed Limit Reduction" summaries of this toolbox. The focus here is those factors related to posted speed limit, roadway curvature, and cross section. Gunther, et al. found that more DVCs occur along roadway segments with a high posted speed limit, and the results of this study are presented in the "Speed Limit Reduction" summary of this toolbox (*6*). They did not discuss the potential correlations between posted speed limit and white-tailed deer habitat or density, but they did find that the vehicle operating speed along a roadway seemed to be impacted more by the alignment design (e.g., curvilinear versus straight) of the roadway than the posted speed limit (*6*). They suggest that a curvilinear design (and narrower lanes) to reduce vehicle operating speeds could reduce animal mortality (e.g., DVCs) along roadway segments where the posted speed limit cannot be reduced (*6*). It should be recognized, however, that it is common knowledge in the transportation profession that unreasonable posted speed limits will generally be ignored by drivers (unless highly enforced), and the inappropriate introduction of a curvilinear alignment and narrow lane designs could increase other types of crashes and/or impact roadside sight distance. Geometric roadway designs cho ices are also a tradeoff of, among other things, operational efficiency, driver expectations, natural topography, aesthetics, safety, and ROW needs. DVCs could be accounted for in the safety comparison of roadway alignment alternatives.

The relationships found between the location of DVCs or roadside carcasses and the cross section of a roadway have been somewhat mixed (*5*, *6*, *7*, *9*, *10*). For example, as previously mentioned, Gunther, et al. suggested that narrow lanes could reduce vehicle speeds and subsequently animal mortality (*6*). A study in Canada, however, did not find any difference in the number of DVCs when a roadway was increased from an undivided two-lane to a divided four-lane cross section, but the number of elk and big horn sheep collisions did increase (*7*). However, they also did not find a larger numbers of elk-vehicle collisions along the unfenced segments that had a concrete median barrier (*7*). In addition, Allen and McCullough found more roadside carcasses on two-lane than four-lane roadways, but Reilly and Green found an increase in roadside carcass after one roadway was widened (*9*, *10*). Finally, a Kansas study found that roadways with grass medians had higher reported DVC rates than those with median barriers, and those with median barrier had a higher reported DVC rates than two-lane undivided roadways (*5*). It would seem that roadway cross section design decisions could have a DVC impact, but more evaluation is necessary and it may be site specific. The results from three of the studies mentioned above are discussed in more detail in other summaries within this toolbox (*5*, *6*, *7*).

Bridge design decisions could also impact the number of DVCs that occur along a roadway. Animals will sometimes use roadway structures (i.e., underpasses and overpasses) if they are adequately sized, appropriately located, and not heavily used by vehicles and/or humans (See the "Wildlife Crossings" summary in this toolbox). In fact, crossings that are specifically designed (and combined with exclusionary fencing) for wildlife use exist throughout the world. The DVC-reduction effectiveness of these structures and/or the factors that impact their use by animals is the focus of the "Exclusionary Fencing" and "Wildlife Crossings" summaries in this toolbox. The focus here is those crossings along existing roadways (over valleys, ravines, and/or watercourses) that might also represent locations where animals might naturally travel. During roadway reconstruction the height and/or length of these bridges might be altered for their possible use by wildlife. For example, the slope walls or abutments of a bridge over a watercourse are often placed to minimize its length (and cost), but this type of design may also force the animals following the watercourse to cross the roadway surface at the overpass rather than under the bridge. A sufficient bridge length and height that provides level ground adjacent to a stream or river might reduce the occurrence of this movement across the roadway surface. Of course, bridge design decisions like these will also impact the cost of the bridge.

Roadway Planning

In some cases a new location must be chosen for all or part of a roadway alignment. At this stage in the development of a roadway or roadway system the alignment alternatives are still being evaluated, and the prioritization of improvement projects is still being determined. The characteristics of proposed project alignment alternatives are compared, shared with the public, and a preferred location chosen. In addition, the prioritization of improvement projects is often based on a measure of the problem significance. Existing and expected DVC or animal mortality impacts could be added to these planning-level evaluations. However, adequate information and predictive capabilities would need to be available to identify existing and potential problem locations for DVCs or animal mortality. Several researchers, as previously mentioned, have investigated and/or modeled the roadway and adjacent land use characteristics that seem to be correlated to a "high" number of DVCs or roadside carcasses (*2*, *3*, *4*, *5*, *6*, *7*, *8*, *9*, *10*, *11*, *12*). Some of the relationships that have been modeled are described in the "Hunting or Herd Reduction" summary in this toolbox. Others have also electronically combined, among other things, DVC and/or carcass data with landscape descriptors, species data, land uses, highway locations, expert opinions, and wildlife habitat/connectivity/linkage information within a geographic information system (GIS) (*13*, *14*, *15*). These systems have been used to identify existing or proposed "wildlife critical" roadway segments that bisect species habitat or habitat linkages (See "Wildlife Crossing" summary). This information could be considered in the roadway alignment comparison and project prioritization process. A few states have also begun or finished wildlife habitat or connectivity plans (See "Wildlife Crossing" summary).

In a more general sense it has been proposed that the planning of a roadway alignment should recognize its "road effect zone" (*16*). This "road effect zone" is an area that could experience some type of adverse ecological impact due to the construction of the roadway. The size of this zone is much larger than the roadway ROW, and is a function of what impacts (e.g., air and noise quality) and animal species (e.g., sparrows, salmon, and/or and white-tailed deer) are considered in the evaluation. Forman and Deblinger have estimated that 19 percent of the land area in the United States is within a "road-effect zone" (*16*). Based on a wide range of ecological impacts (e.g., the influence of vehicle noise on birds, and water erosion) they have proposed that the average "road effect zone" includes everything within about 984 feet (300 meters) of the roadway edge, but that this value varies greatly even along one roadway (*16*). Another group of authors has also proposed the idea of designating certain roadways as "ecological highways" (*17*). This system would identify those roadways that have met certain wildlife-friendly criteria during their planning, design, operation, and maintenance (*17*). One criterion might be that the roadway is permeable and provides appropriate connectivity (e.g., wildlife crossings) between habitats (*17*).

Forman, et al. agree that the ecological impact of roadways can be large, and that it should be examined at a regional or state level rather than on a segment-by-segment basis (*1*). They proposed the following steps should be applied to develop a more ecologically sensitive roadway system (*1*). First, roadway alignments or systems that prevent or avoid an increase in ecological impacts should be encouraged. This is a "do-nothing" option. Second, if doing nothing is not possible or feasible, the ecological impact of each existing or proposed roadway alignment should be mitigated if possible (e.g., wildlife crossings/fencing, berms to reduce roadway noise, and stormwater management) (*1*). Some of the mitigation measures that might be possible for DVCs are discussed throughout this toolbox. The third step to developing an ecologically sensitive roadway system is to compensate for those impacts that cannot be avoided. This compensation would be similar to the process currently followed for wetland replacement, but be more encompassing. For example, the compensation might include enlarging specific areas of certain vegetation, restoring streams, and/or introducing habitats for bio-diversity or rare species (*1*).

Conclusions

Decisions that might have an impact on DVCs and animal mortality are made throughout the "life" of a roadway. This summary introduced and discussed some of the decisions connected to roadway maintenance, design, and planning. The maintenance activities described were related to the use of salt mixtures for snow and ice control, the installation and maintenance of roadside vegetation, and roadside carcass removal. Unfortunately, very little is known about the actual DVC impact of these activities.

The design decisions discussed in this summary were related to the posted speed limit, curvature, and cross section of the roadway, and bridge height and length. It has been proposed that narrower lanes and more curvilinear roadways (where possible) should reduce vehicle operating speeds and subsequently reduce DVCs. However, the general safety impacts of these designs and their cost also need to be considered. In addition, the studies that have investigated the potential DVC impact of wider roadway cross sections have produced conflicting results and more evaluation is necessary. The choices that must be made related to the height and length of reconstructed bridges could also consider the use of these facilities by animals.

The roadway planning discussion in this summary introduced the idea of considering wildlife impacts (including DVCs) as a factor in the comparison of alignment alternatives within the project prioritization process. Information about existing and potential DVC problems along specific roadway alignments would need to be available to accomplish this task, and some models and systems to assist decision-makers have been developed. For example, several roadway segments or systems have been investigated by combining, among other things, DVC or animal carcass information with highway and species habitat data within a GIS. This information is used to identify “wildlife critical” roadway locations. General suggestions were also made in this summary about the methods that could be used to develop a more ecologically sensitive roadway system.

It would appear that the consideration of existing or potential DVC impacts throughout the development of a roadway might help mitigate the DVC problem to some degree. The individual or cumulative DVC impacts of all or some of these decisions, however, have not been studied to any large extent. In addition, each of these decisions must also take into account the costs and benefits of the change in operating procedure or roadway design that may result. Clearly, some of these costs and benefits are much easier to quantify than others. In general, however, including the possible animal mortality impacts of a maintenance procedure or design/planning decision in the roadway development process appears to be an appropriate approach.

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WILDLIFE CROSSINGS

Roadway crossings (i.e., overpasses and underpasses) specifically constructed or retrofitted for wildlife use are located throughout the United States and the world. Several examples are shown in Figure 1 (*1*, *2*). A wide range of wildlife crossings has been implemented for different types and sizes of animals (e.g., frogs, badgers, deer, elk, and bear). The focus of this summary will be on the study, use, and designs of larger structures specifically implemented for large mammals like the white-tailed deer.

Wildlife crossings are typically constructed to increase the permeability of a roadway and decrease the fragmentation of habitat. These structures, however, are typically only installed with exclusionary fencing or some other type of barrier system that funnels the animals to the crossing(s). A properly located crossing/fencing facility used by white-tailed deer can reduce deer-vehicle crashes (DVCs). The significant reductions in roadway animal mortality that resulted from the implementation of several crossing/fencing installations are discussed in the “Exclusionary Fencing” section of this toolbox (*3*, *4*, *5*, *6*). It is generally accepted that a properly located, designed, and maintained exclusionary fence/wildlife crossing(s) project is currently the most effective means of reducing animal-vehicle collisions while still providing a linkage for animal movement. The benefits and costs of this type of installation, however, need to be evaluated on a case-by-case basis.

The animal mortality reductions produced by exclusionary fencing/wildlife crossing(s) combinations are presented in the “Exclusionary Fencing” section and are not repeated here. This summary will discuss the type and application prevalence of wildlife crossings, summarize a recently published review of wildlife crossing research, and describe a list of factors believed to impact the use of wildlife crossings by ungulates (e.g., white-tailed deer) (*7*). Finally, the results of a study that evaluated the potential of a low-cost at-grade wildlife crossing installation design are summarized, and a list of wildlife crossing resources presented. The resources listed contain much more detailed information about wildlife crossing case studies, choosing crossing location(s), and structural design. A discussion of the science or technologies used to properly determine

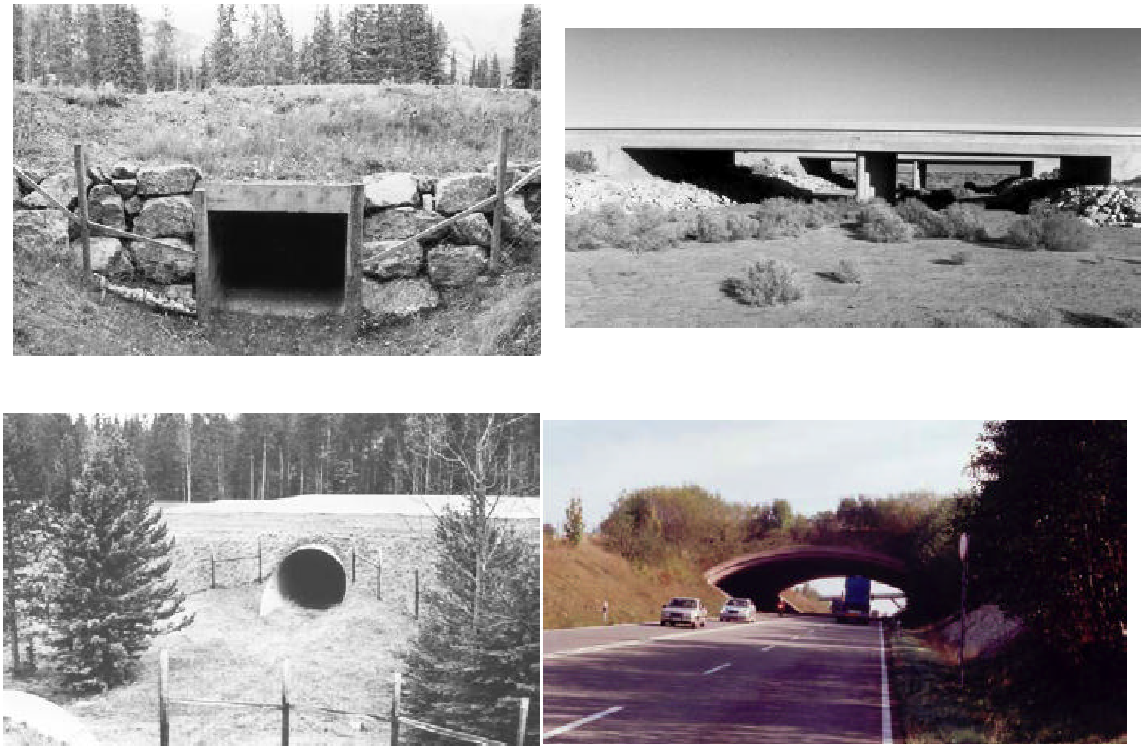

FIGURE 1 Example underpasses and overpasses (*2*).

the location and design specifications of wildlife crossings is beyond the scope of this summary.

Type of Wildlife Crossings

Wildlife crossings are typically categorized by their characteristics. The general categories of wildlife crossings include underpasses (e.g., culverts and tunnels) and overpasses (i.e., bridges) (See Figure 1). Crossings have also been segmented by their height. Small and large underpasses are differentiated by a height or diameters of 5 feet (*7*). Other characteristics that can also be used to differentiate wildlife crossings include structure materials (e.g., concrete or metal) and shape (e.g., box, circular, elliptical, or open-span underpasses; and hourglass or box overpasses). The design choices for a particular wildlife crossing are significant, and the answers are often unique from location to location. Additional information about crossing design choices and white-tailed deer/large ungulate preferences is shared in this summary.

Other types of underpasses can also be implemented for wildlife. These underpass designs include bridge extensions and viaducts. Bridge extensions, for example, are completed to include space for animals to travel along a waterway and under a roadway. This type of improvement can be implemented as part of a bridge rehabilitation project. A viaduct is typically constructed to span a natural valley and is considered the least costly approach to completing the chosen roadway alignment. Animals can pass under a viaduct and this might be another variable to consider when their installation is being evaluated as part of an alignment.

Wildlife Crossing Applications

At least two documents in the last 15 years have attempted to summarize the use of wildlife crossings in the United States (*2*, *8*). In 1992, Romin and Bissonette sent a survey to all 50 state wildlife agencies (*8*). Forty-three agencies responded and eight of them indicated that underpasses or overpasses had been built or modified to reduce deer mortality on their state roadways (*8*). These states included California, Colorado, Idaho, Minnesota, New Jersey, New York, Utah, and Wyoming (*8*). A recently published book also indicates that the first documented wildlife passage was constructed in Florida sometime in the 1950s (*7*). It is likely that this passage was not designed specifically for deer, but the state of Florida is now considered one of the leaders in the area of wildlife crossings within the United States.

A more recent survey of state departments of transportation was also recently completed (*2*). The results of this survey are summarized in *National Cooperative Highway Research Program (NCHRP) Synthesis 305 – Interaction Between Roadways and Wildlife Ecology* (*2*). Thirty-five agencies responded to the question "Has your department used structural measures as mitigation or part of a project to conserve wildlife?" (*2*). About two-thirds of the states indicated that they had used bridge extensions and/or wildlife underpasses (*2*). Overpasses, however, were only being used or planned by seven states (*2*). California, Connecticut, and Montana were planning wildlife overpass structures at the time of the survey, and Florida, Hawaii, New Jersey, and Utah already had them (*2*). The implementation of wildlife crossings in many locations appeared to be in response to problems with deer (*2*). *NCHRP Synthesis 305* includes a short summary of a number of wildlife crossings (*2*).

The consideration of wildlife crossings during roadway construction and reconstruction is prevalent in Europe (*1*, *2*). In fact, the use of overpasses (i.e., "landscape" or "green" bridges) for wildlife is much more widespread in Europe than in North America (*1*, *2*). In 2001, a team of ten experts visited five European countries to discuss their wildlife habitat connectivity activities (*1*). The countries visited were Slovenia, Switzerland, France, Germany, and the Netherlands (*1*). France indicated that it was the first country in Europe to use overpasses and had as many as 125 structures in the early 1990s (*1*). Germany had over 30 overpasses and is constructing or planning almost 30 more (*1*). Switzerland also had more than 20 overpasses and continues their construction (*1*). In North America there are also at least two overpasses within the Banff National Park of Alberta, Canada (*2*).

General Wildlife Crossing Research Review

The type and number of animal species using individual wildlife crossings has been the subject of a large number of studies. A representative sample of these studies was recently summarized by Forman, et al. in *Road Ecology: Science and Solutions* (*4*, *7*, *9*, *10*, *11*, *12*, *13*, *14*, *15*, *16*, *17*, *18*, *19*, *20*, *21*, *22*, *23*, *24*). These studies were reviewed by Forman, et al. for the existence of a stated hypothesis, objective, and criteria for crossing success (*7*). Data collection and analysis methodologies were also evaluated (*7*). In general, the value of any study is primarily related to the validity of their experimental design and general transferability of its results. A summary table created by Forman, et al. of the information they collected is repeated in Appendix B at the end of this summary (*7*).

A summary of the conclusions reached from the information in Appendix B is presented below (*7*). The relevance of these conclusions to our knowledge of wildlife crossing use and/or DVC-reduction capabilities is specifically noted where appropriate.

- Very few of the documents that describe wildlife crossing studies have included a stated hypothesis and/or predefined study criteria for measuring crossing success (*7*). This approach to experimental design limits the value of the conclusions from these studies. Stated objectives and measures of effectiveness are necessary to determine whether a crossing has been successful. Typical measures of success are related to wildlife movements (i.e., crossing use) and animal mortality or DVC reduction. Only three of the 17 studies considered had a stated hypothesis or criteria, but the majority did have stated objectives (See Appendix B or *7*).

- All but three studies focused on one species (*7*). The interaction of species and multiple species requirements of wildlife crossings may limit the applicability of these studies. It has been suggested that the target species for crossing design be the one most likely to use the crossing, but is also believed to have the most species-specific requirements for using a crossing. The structure design based on this target species should then be able to serve other species with less sensitivity to crossing variables. Most of the current crossings designed to serve medium to large mammals are used by white-tailed deer.

- Most studies base their measure of wildlife crossing success on the total frequency of its use by one or more species (*7*). This measure of success tends to ignore the fact that the frequency of crossings is not only related to the number and distribution of a species in the area, but also the time of the year. A more appropriate measure of success would be to compare the observed crossing usage by a species to its expected crossing frequency. A similar approach might also be taken to properly evaluate the DVC or animal mortality reduction impact of wildlife crossings. In this case, however, the expected probability of an individual animal being hit by a vehicle would need to be calculated, taking into account measures of species and vehicle exposure variability, and compared to what is observed.

The use of total crossing frequency as a measure of wildlife crossing success may also not be specific enough to determine whether it has adequately reduced the barrier effect of a roadway. The frequency of crossing use should be compared to the stated objectives of the crossing for each specific species. For example, although related, the “successful” frequency of crossings for the maintenance of genetic variation in a species is different than that needed to maintain a species population.

- Few studies focus on large carnivores, reptiles, and amphibians, and very few studies have included human activity on and near a wildlife crossing as a variable to its use (*7*). Studies have shown that the movements of particular types of animals are significantly impacted by the presence of humans (*22*, *24*). If a crossing has nearby development or is regularly used by humans it can impact its permeability impacts and crash reduction effectiveness.

- Most studies have not indicated that predator species use wildlife crossing as traps to catch prey (*7*). Forman, et al. believe that the basis of this idea is primarily anecdotal, possibly based on the observation of opportunistic predator encounters with prey species, but not a generally observed pattern (*7*, *25*).

- Almost none of the studies have properly compared the animal usage impacts of different wildlife crossing types (e.g., underpasses and overpasses) and other crossing design variables (*7*). In addition, information about how to locate and space wildlife crossings is minimal. For example, an important question that still needs to be answered is whether the installation of several closely spaced inexpensive crossing is more effective than one costly structure in a suboptimal location (*7*). The answers to these types of questions would allow more effective and efficient use of limited funds to construct wildlife crossings.

Factors that Impact Wildlife Crossing Use

Despite some of the general shortcomings of past research on wildlife crossings, a combination of their results (focusing on those more properly designed and documented) with current practice general ecological principles can and have been used to identify some of the factors believed to impact the use of wildlife crossings. There have also been a few studies that specifically focused on wildlife crossing design decisions and their impact on use (*13*, *14*, *16*, *21*, *22*, *24*). Several wildlife crossing are discussed in the following paragraphs. If possible, specific suggestions about the factors have been provided, and their impact on ungulate (e.g., white-tailed deer) crossing use is noted. All of the factors discussed also generally interact, and tradeoffs in design decisions are often necessary.

Animal Species

Certain species tend to prefer particular crossing designs. For example, a grizzly bear may prefer a very large and open crossing, but a cougar may be more comfortable using a more restricted crossing (*7*). Ungulates have been shown to prefer crossings that appear more open (*24*). It is in the nature of deer to avoid confining spaces where a means of escape does not appear to be clear (*5*, *7*, *9*). Clevenger and Waltho have statistically confirmed that ungulate and carnivore species groups do respond to underpass structure designs differently (*22*, *24*).

A good objective for a wildlife crossing is to serve as many species as possible with the design implemented. Ungulates currently use many crossing designs that were implemented for other target species (e.g., the Florida panther) or not even initially constructed for wildlife use. Specific suggestions about the type (e.g., overpass or underpass) and dimensions of a crossing are discussed in the next section.

Crossing Type and Dimensions

Two variables that are closely related to the animal species use of a crossing are its type (e.g., overpass or underpass) and dimensions (e.g., height, width, and length). However, because of the variability in species requirements and the physical constraints of each potential crossing location the application of one design at every site is unlikely. Wildlife crossing designs need to be considered on a case-by-case basis.

Crossing Type A combination of the research and a knowledge of animal behavior indicate and support the idea that different species are more likely to prefer an underpass or an overpass (assuming there is a choice and the options are properly designed). . The variability in wildlife crossing locations and design, however, makes the direct and proper comparison of underpass and overpass preferences difficult. But, a comparison in Banff National Park (located in Alberta, Canada) of two overpasses within about 650 feet of an underpass was completed, and it was found that ungulates (including deer) tended to prefer overpasses (*7*, *26*, *27*). Other animals such as black bear, for example did not appear to have crossing type preference, and cougars seemed to prefer the underpass (*7*, *26*, *27*). However, these results do not mean that ungulates do not use underpasses. They are often the species group that uses many of the existing underpasses with the most frequency (where the choice of an overpass or underpass is not available).

Underpass Dimensions The dimensions that are used or have been suggested for underpasses that may be used by white-tailed deer or other large animals have varied (*7*, *9*, *22*, *24*, *28*). The typical height of existing underpasses used by large wildlife is about 6.5 feet, but range up to 13 to 16 feet (*7*). However, a height of at least 8 feet and widths of at least 23 feet have been recommended for underpasses used by ungulates (*7*, *13*, *28*, *29*). Foster and Humphrey, however, found white-tailed deer in Florida using underpasses that were only 6.9 feet in height (*13*). In addition, deer have used underpasses as narrow as 20 feet (*13*, *30*). Finally, in the 1970s Reed, et al. suggested that a height and width of about 14 feet was needed to provide the necessary feeling of openness for deer (*9*). Overall, it would appear that heights of as low as 7 to 8 feet and widths as narrow as 20 to 25 feet may be considered minimum design criteria for deer use of underpasses. However, similar to all other roadway geometric design components, designing for the "minimum" is often not appropriate.

There does seem to be general agreement that underpasses should be as short as possible, and an unobstructed view through or across wildlife crossings also seems to be important design feature for certain species or species groups (*13*, *31*). For example, as previously indicated, deer appear to prefer larger and more open underpasses (*5*, *9*). In the past, an "openness" index that combined underpass width, height, and length was proposed as a valid measure for properly designed underpasses (*9*, *32*, *33*, *34*). The openness index = ((underpass width)(underpass height))/(underpass length) (*9*, *32*).

In Colorado underpasses designed for deer had an openness index of 0.31 (metric), and mule deer were reluctant to use it (*9*, *35*). Additional studies have found that mule deer were not as reluctant to use structures with openness indices between about 4.6 and 5.6 (metric) (*3*, *36*). Reed and Ward suggest a minimum openness index of 0.6 (metric) for mule deer that are highly motivated to cross a roadway (*32*). Putman, summarizing a large German study by Olbrich, however, indicated that red deer (a relative of the North American elk) and fallow deer did not use underpasses with an openness index less than 1.5, (metric) and roe deer had the same reaction to openness indices less than 0.75 (metric) (*33*, *34*). It has been suggested that the equal treatment of height and width in the openness index may not be appropriate, and the strength of the potential relationship between this measure and underpass use may be species specific and time dependent (*13*).

The wide range of underpass dimensions (whether measured directly or by an openness index) that are used and have been suggested supports the previous conclusion that there is a need for more species-specific crossing design variable analysis (*7*). Fortunately, several studies have been completed in Banff National Park that started to focus on the species and/or species group crossing use impacts of structural, landscape, and human activity variables (*7*, *22*, *24*, *33*, *34*). The structural variables considered were height, width, length, the openness index, and noise level (*22*, *24*).

In 1998, Clevenger found that monthly ungulate use at underpasses was negatively correlated with crossing length and positively correlated with the openness index (*22*).

More specifically, in 2000 Clevenger and Waltho found that three of the structural variables they considered (i.e., openness index, noise level, and width) were the most significant underpass characteristics related to ungulate (e.g., white-tailed and mule deer) use (*24*). However, the intercorrelations between the openness index and underpass length, noise level, and the variable for the distance to the nearest town limited the usefulness of these results if they were not evaluated along with known ungulate behavior (*24*). It was also generally concluded that structural design variables (e.g., openness) were more important to ungulates than carnivores, and that the impacts of specific design decisions was greater when the structure was new and animals had not yet adjusted to its existence (*7*, *24*). Overall, the openness index, of the 14 variables considered, had the strongest relationship to ungulate use and when all the species were considered together, but it had a weaker relationship with carnivore use than a series of landscape and human activity variables (*24*).

Overpass Dimensions As previously indicated, the use of overpasses in the United States is relatively limited, but they are also either currently planned or being designed in several states (*2*). The widths of six existing overpasses in North America range from about 16 feet to 171 feet (*7*). Most overpasses around the world, however, are about 100 to 165 feet wide (*7*). A European study summarized by Forman, et al. indicated that overpass width was one of the most important factors to large mammal use, and that an overpass width of less than 66 feet (20 meters) had significantly less mammal crossing activity (*7*, *20*). It was suggested that the width of an overpass be based on its purpose and the target species, but that widths of 164 to 197 feet (50 to 60 meters) seemed to be adequate (*7*, *20*). The Dutch use an hourglass design that is about 98 feet (30 meters) wide in the center and about 262 feet (80 meters) wide at its ends (*7*). They consider this design the best for large mammals in The Netherlands (*7*).

A "bridge effect" index has also been suggested for overpasses, but its use as a measure that might impact crossing use by deer has not been evaluated (*3*, *32*). The theory is that an overpass can be high, long, and narrow enough that a deer would be reluctant to use it (*32*). The "bridge effect" index is equal to ((overpass width)(overpass height)$^{1/2}$))/(overpass length) (*32*). Little guidance is available about what "bridge effect" index amount might be preferable for deer, but it was found that deer were only slightly to moderately reluctant to cross overpasses in Colorado with "bridge effect" indices of 0.34 and 0.65 (metric) (*3*, *32*). Overpasses in Utah with a "bridge effect" of 0.26 (metric) were also considered successful (*32*). The potential impacts on the species use of an overpass due to the geometrics represented by this index are unknown.

Crossing Location

Location is generally considered the most critical factor that impacts the use of a wildlife crossing (*7*, *13*, *17*, *20*, *22*, *24*, *31*). Upfront and proper planning to determine the most optimally feasible crossing location is key. Unfortunately, as indicated in the general review of wildlife crossing research, the information available on properly choosing a crossing location is scarce (*7*). Locations are often chosen through combinations of expert judgment, the identification of "high" DVC or animal mortality locations, and an evaluation of information about significant animal movements, migratory or movement patterns, and habitat. It has been suggested, however, that a location that removes a barrier or reestablishes a habitat connection or migratory route may be most successful (*7*). The location of a crossing must be considered at both the local and systematic landscape level (*7*).

Ward, et al. did make a recommendation that the spacing of crossings in an area of Colorado should be in one mile increments, but the variability of potential locations makes the general transferability of this specific dimension questionable (*3*). In fact, in 2003 the Colorado Department of Transportation published a report that focused on identifying the best locations for wildlife crossings (*37*). It recommends that crossing locations be evaluated on a case-by-case basis, and that habitat suitability (plus its interaction with the landscape and highway design) be used as the primary indicator of crossing activity (*37*).

Clearly, the proper determination of a crossing site requires a systematic location-specific analysis of crash and/or carcass data, and the magnitude and variability of species, land cover, vegetation, and habitat information. Other data of interest also includes species densities and movement patterns, the number of vehicles traveling on a roadway, and other human activity indicators. Several agencies or researchers have combined expert opinion with this type of information to assist with locating wildlife crossings (*38*, *39*, *40*). The Colorado Department of Transportation report previously mentioned, for example, suggested the systematic mapping of landscape and roadway features/conditions to assist in the identification of the most likely animal crossing locations (*37*). In addition, Florida has developed a system that incorporates many of these pieces of data through a geographic information system (GIS), and they use this coordinated information in the planning of roadways and the identification of potential crossing locations (*40*). Several other states also have created or are creating statewide habitat connectivity maps (e.g., New Mexico).

Human Activity

Measures of nearby human activity (e.g., number of hikers, bikers, or horseback riders using the structure, and distance to the nearest town) have been found to significantly reduce the use of wildlife crossings (*24*). Not surprisingly, these types of measures were found to have a greater impact on the use of crossings for carnivores than ungulates (*24*). Overall, structural openness and the distance to the nearest town were the first and second variables most significantly related to the overall use (i.e., carnivores and ungulates combined) of the crossings studied in Banff National Park in Alberta, Canada (*24*). It was recommended that crossings be designed and located to minimize the influence of nearby human activity (e.g., direct use of the crossing and nearby development) (*22*, *24*). Structure entrance barriers that allow animal movement, but restrict non-pedestrian flow (e.g., big rocks) and the purchase of adjacent land are two potential methods of reducing human activity at a crossing.

Crossing Floor Covering and Adjacent Landscaping

Several studies have shown that most large animals prefer wildlife crossings with a floor, whether an underpass or overpass, be covered with soil and natural vegetation (*33*, *34*, *36*). An example of a "green" bridge in Europe is shown in Figure 1 (*1*). The ability to implement this type of floor covering (and keep it intact) is based on the type and dimensions of the crossing used. A natural crossing floor with vegetative cover and a clear escape route (as well as browsing material) appears to be the preference of white-tailed deer. "Green" overpasses also need to be designed to support the dead and live weights expected.

The use of proper landscaping or vegetative cover at both entrances of an underpass or overpass is also important to its use by particular species (e.g., ungulates) (*24*, *33*, *34*). This vegetation may attract and calm an approaching animal, and it can also be used to help direct animals to a crossing along with fencing. Clevenger and Waltho did find that the use of a crossing by carnivores was more strongly related to its distance to the nearest major drainage than most of the structural variables they considered, but still had a weaker relationship than that between carnivore use and several measures of nearby human activity (*24*). For ungulate use, the strength of the relationship between the distance from the crossing to the nearest major drainage is about the same, but opposite, of that for carnivore use (*24*). However, it was suggested that this might be an indicator of the predator-prey relationship rather than the impact of the direct impact of these landscape variables (*24*). Greater distances from the crossing to the nearest forest cover were also related to smaller crossing use by ungulates, but the strength of the relationship was still lower than several of the structural variables considered (*24*). The need to locate crossing in habitat that support the target species for the structure is generally discussed in the crossing location section of this summary.

Others: Fencing and Structure Age

The installation of a crossing without exclusionary fencing or something that directs animals to and across the crossing is not recommended. However, it should be remembered that many crossing structures are used by animals that were not initially designed for wildlife, and these installations are only normally bordered by typical right-of-way fencing. As indicated previously, crossing location is very important, but then adaptation by wildlife to just about all crossings appears to occur in some manner.

In fact, it has been shown that the use of a crossing often increases with the age of the structure (*9*, *15*, *24*). For example, Reed, et al. concluded that the data describing the use of an underpass in Colorado showed mule deer adapted to it sometime between the second and third year of migration (*9*). There is a time of adjustment for animals to new passages and during that time the species prefer those structures that match their natural behavior and crossing needs (*7*). It has been suggested that once individual animals adapt to a particular crossing the role of its structural dimensions is reduced in comparison to adjacent landscape features or human activities (*24*, *41*). It has also been suggested that with fencing and a near optimal location a crossing will most likely experience some use despite its shortcomings (*7*).

At-Grade Crossings

A unique at-grade crosswalk design has also been tested as a lower cost DVC-reduction alternative to grade separation (*42*). In Utah, four at-grade crosswalks were installed along United States 40 (a four-lane divided roadway) and five were installed along State Route 248 (a two-lane undivided roadway) (*42*). The number of deer carcasses was collected before and after the installation of the crosswalks along study site and control segments (*42*). The control segment for the United States 40 installations was adjacent to its study segment, and the control segment for the State Route 248 installations was along a comparable nearby roadway. Data were collected for 36 months before and 15 months after the installation of the crosswalks (*42*).

The general design of the crosswalk installation consisted of 7.5-foot (2.3 meter) exclusionary fencing that led animals to an opening (*42*). This opening was approximately 30 feet (9.1 meter) from the roadway, and a short three-foot fence was retained in the exclusionary fence gap. The animals needed to jump this short fence to use the crosswalk. The 30 feet (9.1 meter) between the opening and the roadway pavement was a dirt path bordered by round cobblestones (*42*). The objective was to funnel the mule deer on to the roadway crosswalk. The crosswalk was edged by cattleguard lines on the pavement to help motorists identify its location. The location of the crosswalks was chosen based on the number of observed deer crossings (*42*).

The mule deer carcass data collected were then analyzed (*42*). First, the location of the carcasses was investigated. Most of the carcasses that were found in the study area were just beyond the exclusionary fencing (*42*). About 59 percent of the carcasses were found outside the fenced area along United States Route 40, and 75 percent along State Route 248 (*42*). Then, the change in the number of mule deer carcasses along the segments with and without the crossing/fencing installations was compared (*42*). The number of mule deer killed in the test segments was about 37 to 42 percent below what was expected, but it could not be statistically concluded that this change was anything more than normal variability in the data (*42*). The researchers did believe that the introduction of the exclusionary fencing reduced the number of mule deer -vehicle collisions, but no conclusions could be reached that the at-grade crossing installation had a statistically significant impact (*42*). One problem was that some mule deer entered the right-of-way through the gap in exclusionary fencing, and then grazed on the vegetation along the roadside rather than crossing the roadway (*42*).

Overall, the researchers believed that an updated design of an at-grade crossing might be more effective (*42*). They recommended that the exclusionary fencing be placed closer to the roadway, and that the roadside vegetation in the area be made less attractive to mule deer (*42*). The application of this design would most likely only be effective along lightly traveled roadways with drivers that understood or had been educated about the mule deer migratory time period (*42*). The crossing location of the mule deer could then be defined for drivers with the crosswalk infrastructure.

Additional Wildlife Crossing Resources

The following paragraphs briefly describe some of the general reference documents used in this summary, websites that may be of interest to the reader, and two ongoing/planned wildlife crossing research projects.

A large number of documents have been referenced in this summary. However, there were three that contained a wide range of information and were used extensively (*1*, *2*, *7*). These documents included:

- *Wildlife Habitat Connectivity Across European Highways* (*1*). This summary was published as part of the American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Administration (FHWA) international scan tour program. It is a discussion of habitat connectivity activities in five European countries with recommendations about how some of these activities might be transferred to the United States. This document can be found at: international.fhwa.dot.gov/.

- *NCHRP Synthesis 305 – Interaction Between Roadways and Wildlife Ecology* (*2*). This synthesis was completed as part of the National Cooperative Highway Research Program (NCHRP) and published in 2002. In general, *NCHRP Synthesis 305* summarizes information available about roadway planning, design, construction, operation, and maintenance decisions, and how they interact with ecological systems and wildlife. It also contains the results of a survey of state departments of transportation that focused on activities related to wildlife mitigation along roadways. *NCHRP Synthesis 305* can be found at: www4.trb.org/trb/onlinepubs.nsf.

- *Road Ecology Science and Solutions* (*7*). Richard Forman and 13 other authors recently published this book. It consists of 14 chapters that focus on a wide range of interactions between roadways and ecology. Some of the individual chapters focus on roadsides and vegetation, wildlife populations, wildlife impact mitigation, water and sediment, wind and air, and roadway chemical impacts. It is generally believed that this book may be the first focused consideration of the "road ecology" issue.

A series of documents that described the results of the long-term and ongoing study of overpasses and underpasses in Banff National Park (in Alberta, Canada) have also been used to a great extent in this summary (*4*, *6*, *22*, *24*, *25*, *26*, *27*).

There are also two web-based resources that the reader is encouraged to visit. They contain more detail and information about wildlife crossings (and links to additional webpages) than could be included in this summary. These sites include:

- *Critter Crossings: Linking Habitats and Reducing Roadkill.* This site was developed by the United States Department of Transportation Federal Highway Administration Office of Natural Environment. It describes the impact of transportation on wildlife and shares some potential physical and procedural solutions to the problem. The critter crossings link can be found at: www.fhwa.dot.gov/environment/. Additional examples of measures that can be used to help reduce the impact of roadways on wildlife can also be found at another related Federal Highway Administration website: *Keeping it Simple: Easy Ways to Help Wildlife along Roads*. A link to this website is located at the same address as critter crossings.

- *Wildlife Crossing Toolkit.* This website was initiated by United States Department of Agriculture (USDA) Forest Service and created at the Jack H. Berryman Institute of Utah State University. Its audience is professional biologists and engineers. The website contains a searchable database of mitigation measure case studies, and articles about reducing animal mortality and increasing habitat connectivity along roadways. It also includes graphical examples of crossing types, a glossary of biological and engineering terms, and the information initially contained in the ARTEMIS Clearinghouse from the Western Transportation Institute of Montana State University. The *Wildlife Crossing Toolkit* can be found at www.widlifecrossings.info. The ATREMIS Clearinghouse can be found at: www.coe.montana.edu/wti/default.htm.

There are also at least two ongoing or planned research projects in the area of wildlife crossings that should produce useful information. The Western Transportation Institute at Montana State University is working for the Federal Highway Administration to develop *Guidelines for Designing and Evaluating North American Wildlife Crossing Systems.* They plan to review and synthesize the information available about the design, monitoring, and performance of wildlife crossings. In addition, protocols for monitoring wildlife crossings will be developed and research gaps identified. A second wildlife crossing project has also started as part of the National Cooperative Highway Research Program (NCHRP). The objective of this project is to develop guidelines for the selection, configuration, location, monitoring, evaluation, and maintenance of wildlife crossings. The results from both of these efforts are expected to address some of the gaps in the state-of-the-knowledge with respect to wildlife crossings, and also assist in their proper application.

Conclusions

There appears to be a significant amount of information available on the use and general effectiveness (typically measured by animal use) of *specific* wildlife crossing/fencing installations. The animal mortality reductions that have resulted from several of these installations are described in the "Exclusionary Fencing" summary of this toolbox. It is generally accepted that a properly located, designed, and maintained crossing/fencing combination can significantly reduce animal mortality along a roadway segment.

The documentation reviewed for this summary contained some very useful information. An evaluation of the results from two national surveys revealed that wildlife crossings are used in more than 20 of the United States, and that the great majority of these crossings were underpasses. Other options for wildlife crossings include overpasses, bridge extensions, and viaducts. A general review of wildlife crossing research concluded that most were completed for particular wildlife crossing(s) and focused on the species use of the structure (versus its potential animal mortality reduction impacts). Very few studies were designed and/or documented for the possible general application of their results. In addition, only some of the more recent studies have begun to formerly evaluate the impact of design decisions (e.g., crossing type, location, and dimensions) on wildlife crossing use (and their subsequent impact on DVCs). Significant gaps in the current state-of-the-knowledge (or its documentation) exist in the crossing design decision-making area. The two ongoing/proposed research projects described previously should contribute additional wildlife crossing decision-making material, and reduce the gaps in the current state-of-the-knowledge.

A number of factors were also identified that are believed to impact the use of a wildlife crossing. The factors described in this summary included animal species, crossing type (e.g., underpasses and overpasses) and dimensions, crossing location, human activities, crossing floor covering and landscaping, fencing, and structure age. In general, it has been found that the location of a wildlife crossing is key to its success, and it is preferable that it matches the natural movement patterns of the target species. Ungulates (including white-tailed deer) generally prefer overpasses or large open underpasses. A method of escape (i.e., the ability to see through or across the structure) is important to their movement. However, their initial use of a wildlife crossing appears to be most strongly correlated with structural design variables rather than adjacent landscape and human activity. These other features (i.e., adjacent landscape characteristics and human activity) become more important as individual animals adapt to the existence of a crossing. In the long term, natural groundcover on and/or within a structure, natural vegetation leading to its entrances, and minimal human activity and nearby development are also preferred crossing characteristics.

A wide range of underpass and overpass designs has been implemented and is used by ungulates. Underpasses can be square, circular, or elliptical and made from either concrete or steel. It would appear that heights as low as 7 to 8 feet and widths as narrow as 20 to 25 feet may be considered minimum design criteria for the use of an underpass by deer. Suggested minimum openness indices have ranged from 0.6 (metric) for mule deer and 0.75 (metric) for roe deer to 1.5 (metric) for red and fallow deer. However, designing for the “minimum” is not a typical approach to many roadway component or bridge designs, and it would typically not be the preferred or recommended approach in the case of wildlife crossings. Overpasses are either square or hourglass shaped and it has been suggested that they be constructed with widths (at their narrowest point) of 100 feet or more. These types of designs have been used successfully in Europe for many years.

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APPENDIX B

Table B-1. Sample Wildlife Crossing Study Characteristics (*Adapted from 7*).

		Design		Data Collection				Analysis			
Source	**Location**	**Hypothesis Stated?**	**Objectives Stated?**	**Number of Structures**	**Method[a]**	**Duration (Months)**	**Monitoring Frequency**	**Level[b]**	**Species[c]**	**Criteria for Success?**	**Observed/ Expected[d]**
Reed, et al. (*9*)	WY, USA	No	Yes	1	Counters Transects	48	Weekly	S (S)	Mammal (u)	No	Observed
Ballon (*10*)	Upper Rhine, France	No	No	4	Transects	9	Weekly	S (M)	Mammal (u)	No	Observed
Hunt, et al. (*11*)	NSW, Australia	No	Yes	5	Traps Transects	2	1 per 8 Days	S (M)	Mammal (s, m)	No	Observed
Jackson and Tyning (*12*)	MA, USA	No	Yes	2	Observation	< 1	Daily	S (S)	Amphibian	Yes	Observed
Woods (*4*)	Alberta, Canada	No	Yes	8	Transects Telemetry	36	1 per 3 Days	S (M)	Mammal (u)	Yes	Observed
Foster and Humphrey (*13*)	FL, USA	No	Yes	4	35mm Camera	2-16	Continuous	S (M)	Mammal (m, lc, u) Bird Reptile Human	No	Observed
Yanes, et al. (*14*)	Central Spain	No	Yes	17	Transects	12	16 Days per Year	G (M)	Mammal (s, m) Reptile	No	Observed
Land and Lotz (*15*)	FL, USA	No	Yes	4	35mm Camera	24	na	S (M)	Mammal (m, lc, u) Reptile	No	Observed
Rodriguez et al. (*16*)	South-central Spain	Yes	Yes	17	Transects	11	1 per 3 Days	G (M)	Mammal (s, m, u) Reptile Amphibian Human	No	Observed
Roof and Wooding (*17*)	FL, USA	No	No	1	Transects 35mm Camera Telemetry	12	1 per 3 Days	S (M)	Mammal (s, m, lc)	No	Observed
AMBS Consulting (*18*)	NSW, Australia	No	Yes	3	35mm Camera	9	Continuous	S (M)	Mammal (s, m)	No	Observed

Table B-1. Continued.

Pfister, et al. (*19*)	Switzerland, Germany, France, Netherlands	No	Yes	16	Video Camera	24	na	S (M)	Mammal (s, m, u) Bird Reptile Amphibian Invertebrate	Yes	Observed
Rodriguez, et al. (*20*)	South-central Spain	Yes	Yes	17	Transects	10	1 per 3 Days	S (M)	Mammal (m) Human	No	Observed
Rosell, et al. (*21*)	Catalonia, Spain	No	Yes	56	Transects	11	16 Days per Year	G (M)	Mammal (s, m, u) Reptile Amphibian	No	Observed
Clevenger (*22*)	Alberta, Canada	No	Yes	11	Transects	12	1 per 3 Days	S (M)	Mammal (lc, u) Human	No	Observed
Veenbaas and Brandjes (*23*)	Netherlands	No	Yes	31	Transects	5	na	S (M)	Mammal (s, m, u)	No	Observed
Clevenger and Waltho (*24*)	Alberta, Canada	Yes	Yes	11	Transects	35	1 per 3 Days	S (M), G, C	Mammal (lc, u) Human	No	Expected

[a]Method: Transect = sand traps. Traps – live-trapping. Observation = direct observation. 35mm Camera = remote camera monitoring. Telemetry = radio-telemetry. Counters = motion-sensitive game/trail counters. Video camera = remote-operated video camera monitoring.
[b]Level = level of analysis: Individual species (S) [single-species S (S), or multiple species S (M)]. Species groups or guilds (G). Community level (C).
[c]Species types: s = small mammals. m = medium-sized mammals. lc = large carnivore. u = ungulate. Human = human impact on passage analyzed.
[d]Observed/Expected: Obs = observed passage frequency counts. Exp = expected passage frequency based on probability of occurrence in vicinity of passage.
[e]na = not available in publication or report.

CHAPTER 3
CONCLUSIONS AND RECOMMENDATIONS

A significant amount of information was reviewed and summarized for the creation of this deer-vehicle crash (DVC) countermeasure toolbox. Each of the summaries in Chapter 2 contains specific conclusions/findings (and some recommendations) about each countermeasure, and these conclusions/findings were summarized in the Executive Summary. This chapter includes more general conclusions about the current status of defining the DVC problem and evaluating the DVC reduction capabilities of existing and proposed countermeasures. The DVC countermeasures summarized in this toolbox are also grouped into five suggested categories. Recommendations are also provided as a response to each of the conclusions. Suggestions are made about how some of the gaps in the current state-of-the-knowledge for DVC countermeasure safety impacts might be addressed.

CONCLUSIONS

- DVCs are a transportation safety problem throughout most of the United States. The actual magnitude of this problem, however, can only be grossly estimated. The collection and trend analysis of the best available reported DVC (or animal-vehicle crash) data for all 50 states is needed. At a minimum, this database should also include documentation of the criteria used to define and/or differentiate a reportable DVC or animal-vehicle collision in each state. A summation and comparison of this data could then be done in a proper manner. The DVCIC has begun this task for the Upper Midwest with a goal to collect the last 10 years of DVC-related data (e.g., vehicle travel, deer populations, reported DVCs, and roadside carcass numbers). More specifically, this information should also improve the ability to identify those roadway segments with higher than expected levels of DVCs for many jurisdictions.

- It is generally recognized that reported DVC data represents only a fraction of the collisions that do occur (up to 50 percent is likely). But, deer carcass data, by location of pick-up, is not generally available. Reported DVC data are the only widespread, long-term (e.g., more than the time period of a study), easily defined, and generally available approximation of the DVC problem along roadway segment in the United States. These are the reasons reported crashes of all types, despite the recognized weaknesses of this data, are generally used to evaluate roadway safety improvements. Some of the DVC countermeasure research reviewed for this toolbox collected roadside animal carcass data during the study time period (usually less than two years) to evaluate the safety impacts of a countermeasure. Not surprisingly, it appears that roadside carcass data for a particular roadway segment, although greater in number, has some of the same type of variability characteristics as reported DVC data. A minimum of three years of reported crash data preceding and following the implementation of a measure is generally accepted in transportation safety analysis if a simple before-and-after approach is used.

- Many factors appear to impact the number of DVCs at a particular roadway location. These factors are generally related to the characteristics of the roadway and traffic flow, the deer population, and the adjacent land use and cover. Specific examples include traffic flow volumes, deer densities or crossings, and the existence of adjacent crops or woodland. Multiple pieces of often highly variable and interrelated data usually need to be considered to properly determine why there is a DVC problem at a particular location. Several regression based DVC prediction models have been suggested with a series of input variables. However, the general applicability of a multiple regression approach to predict crashes, and/or the inclusion of factors with interrelationships in the same prediction model is typically not considered appropriate without a detailed explanation of how these may confound its results.

- The variability of the factors believed to impact the occurrence of a DVC, combined with their complex interrelationships, make it a difficult problem to evaluate, predict, and solve. The variability and generally accepted characteristics of DVC data also add to the complexity of this issue. For example, the weaknesses of simple short-term before-and-after study results, given the variability of safety data, have long been recognized. The need to specifically define and describe how control and treatment segments are comparable and independent is also important. The complexity, interaction, and number of factors that may impact the occurrence of a DVC make this task difficult, but these characteristics of the problem also support the need to properly document the experimental design details and potential concerns about study results.

Overall, although informative, very few studies have rigorously evaluated and/or documented DVC countermeasure impacts from a safety analysis point of view. Many DVC countermeasure studies have followed the before-and-after and/or control-treatment analysis approaches mentioned above, but the impact of these experimental designs on the strength of their results or conclusions were rarely documented. These methods are the same as those used by roadway safety researchers in the past to evaluate the impacts of other improvements (e.g., addition of a left-turn lane), but the inherent statistical weaknesses (assuming a proper experimental design) of these more basic statistical analysis approaches are also now recognized.

The analysis of safety data has recently experienced a number of advancements and in the transportation profession can be considered a relatively specialized focus area. The most generally accepted and comprehensive methodology to measure the impact of safety improvements at this point in time is the Empirical Bayes approach to evaluation. It is expected that most studies in the past were limited in their evaluation due to funding levels (which impacts the possible experimental designs, project team content, and the time period of evaluation) that did not match the analysis needs for the complexity of the DVC problem.

- A number of potential DVC countermeasures are discussed in this toolbox. Many of these countermeasures have been used for decades with a limited knowledge of their DVC reduction capabilities. These limitations are described for each specific countermeasure in Chapter 2, and restrict the ability to conclusively group almost all of the countermeasures reviewed solely by their DVC reduction capabilities. For this reason, the author has grouped the countermeasures discussed in this toolbox into five categories. These categories are defined by the apparent use of a countermeasure in the roadway environment, and the general level of research that has been completed with respect to its DVC or roadway animal mortality reduction capabilities. The five categories and their assigned countermeasures are identified below.

- Used with Conflicting Study Results:
  - Deer Whistles
  - Roadside Reflectors/Mirrors

- Used with Generally Positive Study Results:
  - Exclusionary Fencing
  - Wildlife Crossings

- Used but Rarely Studied:
  - Speed Limit Reduction
  - Deer Crossing Signs and Technologies
  - Hunting or Herd Reduction
  - Roadside Vegetation Management

- Used but Not Studied:
  - In-Vehicle Technologies (on Roadways)
  - Deicing Salt Alternatives
  - Public Information and Education
  - Roadway Maintenance, Design, and Planning Policies

- Not Generally Used but Rarely Studied:
  - Roadway Lighting
  - Deer-Flagging Models
  - Intercept Feeding
  - Repellents (on Roadways)

Recommendations for future activities related to the countermeasures in each of these categories are presented in the next section of this chapter. However, given the current state-of-the-knowledge, the DVC reduction capabilities of very few countermeasures can be stated with any confidence. The application of adequately high fences (properly installed and maintained) with properly located and designed wildlife crossings have consistently produced positive safety results while minimizing the ecological impacts of a roadway. In the case of these two countermeasures the gaps in the state-of-the-knowledge are more application oriented. The basic DVC reduction capabilities of the remainder of the countermeasures, however, must still be determined.

- At the current time, the variability and complexity of the DVC problem makes it unlikely that there is one solution that exists which could be cost effectively applied to every roadway location. Fortunately, new potential countermeasures are also always being introduced for further evaluation. More likely, and similar to other roadway safety programs, a number of measures and activities will need to be implemented to result in any significant reduction in DVCs. Some examples of these activities include the proper installation and maintenance of countermeasures and public information and education campaigns. A combined and coordinated application of engineering, education, enforcement, and ecological measures seems appropriate.

RECOMMENDATIONS

- The ability to define the extent and temporal/spatial trends of the DVC problem is an important element to determining its solution(s). It is recommended that a national or regional database of the best available and properly defined DVC and/or animal-vehicle collision data be created. This database should also include vehicle volume/travel estimates as a separate input variable, and potentially contain deer population estimates and roadside deer carcass data at the most detailed level available. Land use and/or land cover within a particular distance of roadway segments, and average DVC costs are also of interest. Typical DVC frequencies and rates should be calculated from this information, and could be used to identify and possibly plot roadway locations with a higher than typical DVC safety concern (at the local and state jurisdictional levels). The ability to accomplish this task is important to the effective implementation of countermeasures. The information can also be used to assist with the development of the DVC prediction models recommended below.

- The collection of roadside deer carcasses reveals that the actual number of DVCs may be more than twice that reported. Large databases of reported crashes by location are generally available and are normally used in roadway safety evaluations, but roadside carcass frequency, by location, could be a more accurate measure of DVC problem locations. Some jurisdictions in the United States quantify the number of carcasses collected, but it is expected that few specify the roadway location where they are collected. It is recommended that a pilot study be completed that investigates the collection of roadside carcass locations and its potential value to defining the DVC problem. The ability to collect this information efficiently should be evaluated, and the carcass data compared to reported DVC frequencies and locations to determine if any patterns emerge. The collection of this data could produce a more accurate measure of the DVC problem and possibly help identify problem locations that would have been missed if only reported DVCs are used. Activities similar to those described in the recommendation above should be completed if enough roadside deer carcass data becomes available. A relationship between reported DVC frequencies and locations and those that result from the use of roadside deer carcass data could also be defined and applied as appropriate. The weaknesses and strengths of the reported DVC and roadside carcass data collected should also be investigated.

- There are many factors, some more quantifiable than others, which can lead to a DVC. There is a need to more adequately quantify the relationships between these factors, and to more properly define their individual or combined impacts on the occurrence of a DVC. The ability to proactively define roadway segment locations (and possibly roadway designs) that could result in a higher than acceptable DVC concern requires this information. The development of a valid DVC frequency and/or rate prediction model is recommended. But, these models would need to properly take into account and recognize the inherent characteristics of DVC data, and the strength and interrelationships of the factors that may impact the occurrence of DVC. The most useable DVC prediction model would include the fewest number of easily collected or estimated independent input variables that appear to produce adequately calculated answers. It should be recalled that many factors believed to impact the occurrence of a DVC might not be independent (e.g., posted speed limit and adjacent land cover).

- The DVC problem has both ecological and transportation safety impacts. It is expected that an effective DVC countermeasure program will include a combination of engineering, education, enforcement, and ecological measures and activities. The valid installation and evaluation of DVC countermeasures requires the coordination and cooperation of transportation and natural resource professionals. An effective and acceptable DVC countermeasure should reduce vehicle-animal interactions while still allowing necessary animal behavior and movements (given an existing roadway). In many cases, the implementation of a countermeasure will require some type of tradeoff between these two simultaneous objectives.

  It is recommended that the installation and evaluation of DVC countermeasures be completed with teams of transportation safety and ecology professionals. This type of active coordination, cooperation, and communication is recommended throughout the roadway development process (e.g., planning, design, and maintenance/operation) and for all types of countermeasures (from deer crossing signs to wildlife crossings). The complexity and interdisciplinary characteristics of the DVC problem, its potential solutions, and the specialized nature of analyzing their ecological and transportation safety impacts requires this type of partnership for proper countermeasure evaluations. It is expected that this approach will result in a more all-encompassing approach to DVC countermeasure research that consistently applies the most current and generally accepted ecological and safety data collection and analysis procedures.

- From a transportation safety analysis point of view, there is a general need for more well-defined and documented research related to the impacts of DVC countermeasures. The interdisciplinary team approach suggested above should address this need by involving transportation safety analysts/engineers and ecologists in the data collection, experimental design, results evaluation, and report development stages of DVC countermeasure projects. The analysis methodologies used (given the study time period and funding), and any weaknesses or confounding impacts they might produce in the project results, will also be adequately addressed by this type of research team.

- Five categories of countermeasures were identified in the Conclusions section of this chapter. The types of evaluations that need to be completed for each of the categories are somewhat different and described below.

    - Used with Conflicting Study Results: It is recommended that a properly funded, designed, and documented evaluation of these countermeasures (i.e., deer whistles and roadside reflectors/mirrors) within the roadway environment be completed to definitively determine their DVC reduction effectiveness. These measures have been implemented for decades, but the research studies that have focused on their DVC reduction effectiveness have produced conflicting results. Many of them are lacking in their approach and/or documentation.

    - Used with Generally Positive Results: It is recommended that the DVC and ecological impacts of exclusionary fencing/wildlife crossing installations continue to be evaluated, and that these studies use the most generally accepted analysis procedures. More specific safety analysis should more accurately represent the DVC reduction capabilities of these installations, and possibly reduce the variability in the DVC reductions produced by past studies.

- The DVC and ecological impacts of combining exclusionary fencing with one-way gates, earthen escape ramps, and/or wildlife crossings should also continue to be investigated. In addition, because past research into exclusionary fencing/wildlife crossing installation has consistently shown DVC reductions there are questions about the details of their application and design that need to be investigated. For example, the DVC reduction effectiveness, ecological impacts, and cost effectiveness of minimum and preferable exclusionary fencing heights and wildlife crossing designs are needed. More information about how to properly locate exclusionary fencing and wildlife crossing is also necessary, along with how to solve the problem of the required gaps in exclusionary fencing. The National Cooperative Highway Research Program recently funded a project that focuses on the use and effectiveness of wildlife crossings. Additional analysis related to the use of one-way gates, earthen escape ramps, and at-grade crossing designs may also be appropriate.

- Used but Rarely Studied: This list of countermeasures includes speed limit reductions, deer crossing signs and technologies, hunting or herd reduction, and roadside vegetation management. These measures have all been suggested as DVC countermeasures, and in some cases been used somewhat extensively. The past evaluations of the DVC reduction capabilities of these countermeasures, however, have been limited to very few studies. The DVC impact of typical deer crossing signs, for example, has not been studied, but improvements to their design have been and are also currently being considered. In other cases, the primary focus of the studies related to these countermeasures has not been DVC reduction and some of the safety analysis is lacking in rigor. Additional evaluations are recommended (using the interdisciplinary approach previously recommended) to determine the actual impact of these measures on DVCs. Replicating and improving upon the studies previously completed to refute or support their results is necessary.

- Used but Not Studied: A number of the countermeasures discussed in this toolbox are being used (sometimes sporadically), but their DVC impacts have never actually been studied. It is recommended that the efficient and effective application of these potential countermeasures (i.e., in-vehicle technologies; public information/education campaigns; and roadway maintenance, design, and planning policies) be investigated, and their DVC impacts properly quantified.

- Not Generally Used, but Rarely Studied: Four countermeasures (e.g., roadway lighting, deer-flagging models, intercept feeding, and repellents (along roadways)) summarized in this toolbox have rarely been studied for application in the roadway environment. It is recommended that it may be appropriate to further evaluate these measures and support or refute the results of the studies that have been completed. It is rare that non-definitive and unreplicated studies are used to determine the overall usefulness of a roadway safety improvement. New studies that follow currently accepted ecological and safety data analysis approaches are recommended along with an evaluation of the advantages and disadvantages of applying these measures.

- In addition to interdisciplinary teams, the complexity and variability of the DVC problem, the factors that impact it, and its potential solutions require long-term (i.e., multi-year) and large-scale (i.e., multi-jurisdictional) evaluation projects. Two organizational activities are recommended to address this issue.

  First, it is recommended that a properly funded regional or national roadway deer-vehicle (or large ungulate-vehicle) crash reduction research center be created. It is believed that the initiation and operation of this type of center would begin to address the more consistent and long-term approach needed to properly evaluate the effectiveness of existing and proposed DVC countermeasures. In addition, the center can serve as a focal point for those interested in the reduction of large ungulate-vehicle crashes, promote standardized and generally accepted research in the area, and encourage interdisciplinary DVC evaluation teams through the request for proposal process. It should also lead to an increase in the current state-of-the-knowledge, more appropriate countermeasure installations, and a reduction in the costly DVC safety problem.

Second, it is also recommended that an annual DVC or large ungulate-vehicle crash symposia be established for those interested in the area of study. It is suggested that these meetings should also include interdisciplinary workshops about the most current and generally accepted procedures for ecological and transportation safety data collection and analysis procedures. Information sharing sessions would focus on gaps in the current state-of-the-knowledge, current DVC countermeasure research, and application issues. The organization of this meeting could be one of the first activities for the research center previously suggested.

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