

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

Final Report

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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.			
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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 than 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-foot (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 the studies that have been completed before the 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.