

REFERENCE

Huijser, M.P., P. McGowen, J. Fuller, A. Hardy, A. Kociolek, A.P. Clevenger, D. Smith and R. Ament. *Wildlife Vehicle Collision Reduction Study: Making America's Highways Safer for Drivers and Wildlife: Report to Congress*. Federal Highway Administration, U.S. Department of Transportation, 2007.

INTRODUCTION

In 2007 the Federal Highway Administration published a *Report to Congress* that focused on the reduction of wildlife-vehicle collisions (WVC). This report generally included the following:

- A description of the size of the WVC problem and its characteristics. This information is summarized below.
- An annotated bibliographic description of the research related to the effectiveness of 47 WVC mitigation measures. The DVCIR Center Toolbox (www.deercrash.com) and its conclusions were used as a reference. The reader is referred to the reference above and the DVCIR Toolbox (plus recent summaries) for more details on this subject.
- A discussion of the WVC impact on wildlife populations (e.g., endangered species) is of interest. This subject is not discussed here because the issue is not generally relevant to deer species. The reader is referred to the above reference for more details.
- Two expert panel categorizations based on the research available regarding the effectiveness of the majority of the mitigation measures. These categorizations and the current literature were then apparently used by the authors of the report to provide recommendations about the implementation and research needs of the mitigation measures. The results of these activities are noted below.
- A cost-benefit analysis of the mitigation measures using their apparent crash reduction effectiveness. The results of this activity are briefly discussed in this document but a more extensive cost-benefit analysis was also recently published in *Ecology and Society* and is summarized separately on the <http://www.deercrash.com> website.
- Planning and design considerations and suggestions. This information focuses on some activities that could be completed during the planning/design stages of roadway development. It includes identifying the WVC problem areas, data collection/monitoring, discussions about roadway alignments/removal, and WVC-related design features. The reader is referred to the reference above for more detail. A more detailed discussion of planning and design considerations was published in a related Best Practices Manual, which was also summarized separately on the <http://www.deercrash.com> website.

WVC PROBLEM CHARACTERISTICS

The authors first summarized the data that could be used to help describe the WVC problem. Three common sources for WVC data were noted. These sources include police reports, carcass counts, and the insurance industry. This report specifically used the Fatality Analysis Reporting System (FARS), the Highway Safety Information System (HSIS), and the General Estimates System (GES) crash databases along WVC literature to define and discuss the WVC problem.

The GES database (a national sample of vehicle crashes) was used to show that an average of 292,000 WVCs occurred annually in the United States between 2001 and 2004. This number of WVCs represented about 4.6 percent of the total annual number of vehicle crashes that occurred in the United States during that time period. However, the authors of the *Report to Congress* suggested that the actual annual number of WVCs for large animals was really between one and two million due to the generally acknowledged under-reporting of wildlife-related crashes. An analysis of additional GES data also showed that WVCs have increased by an average of about 6,769 per year since 1990 while the overall number of all vehicle crashes in the United States remained relatively steady.

Several WVC characteristics were also summarized. First, the seasonal trends for WVCs indicated that collisions with large animals generally peaked in the fall and spring. It was also found that WVCs occurred most often in the early morning and evening. WVCs were also typically single vehicle events and were generally less severe (e.g., resulted in fewer human injuries or fatalities) than other types of vehicle crashes. Most WVCs clearly involve a direct collision with wildlife, but it was also determined that other crashes could be connected to the appearance and avoidance of wildlife. A review of the databases available indicated that a driver swerving to avoid an animal could result in collisions with other vehicles, overturning, and run-off-the-road object collisions. An analysis of the crash databases also proved that WVCs occurred at similar rates for drivers of all ages (rather than increasing for younger and older drivers like many crashes). The majority of WVCs also occurred along straight portions of two-lane rural roadways during dry weather. Not surprisingly, WVCs were, therefore, more likely to occur along roadways with low average daily traffic. One study that was cited, however, also showed that WVC levels might decrease when average daily traffic is high enough that the roadway becomes a crossing barrier. Finally, other references that were described showed that 77 percent of all WVCs in nine states were with deer, and that WVCs typically occurred around mixed natural landscapes.

The economic impacts of WVCs were also estimated using two approaches. First, the average costs of property damage, injuries (possible, evident, and severe), and fatalities in a WVC were calculated, along with the percentage likelihood that a WVC would result in the associated severity (See Table 1). These figures are 1994 USDOT crash cost estimates that have been adjusted to 2006 US dollars. The second approach estimated the costs for an average deer-vehicle crash (DVC) from the literature and is shown in Table 2. This second cost estimate does not represent realistic cost estimates for an individual DVC, but rather estimates the average cost of all DVCs combined. The total economic impact of an estimated 1,000,000 DVCs per year in the United States was estimated to be \$8,388,000,000, and thus, the cost of an average DVC was estimated to be \$8,388 (See Table 2). This figure was also used later in this report to conduct the cost-benefit analysis (discussed below).

WVC MITIGATION METHODS REVIEW

The authors of the *Report to Congress* used the results of a literature review to provide a general description of the 47 mitigation measures they considered along with their advantages and disadvantages (i.e., direct and indirect benefits, and undesirable effects), costs, design guidelines, case studies, and contacts for more information. This information can be valuable to

Table 1. Average Costs and Frequency of Property Damage, Injury, and Fatalities in Wildlife-Vehicle Collisions

Severity	Average Cost per Severity (2006 Dollars)	Severity Frequency of Wildlife- Vehicle Collisions (Percentage)
Property damage only	2,570	95.37
Possible human injury	24,418	2.34
Evident human injury	46,266	1.75
Severe human injury	231,332	0.47
Human fatality	3,341,468	0.04

Table 2. Estimated Costs of an Average Deer-Vehicle Collision

Cost Component	Average Cost per Deer-Vehicle Collision (Dollars)
Vehicle repair costs per collision	1,840
Human injuries per collision	2,702
Human fatalities per collision	1,671
Towing, accident attendance, and investigation	125
Lost monetary value of deer involved	2,000
Carcass removal and disposal per collision	50
Total	8,388

those considering mitigation implementation. The DVCIR Center toolbox was used as a reference for some of this summary. A number of the mitigation measures summarized in the *Report to Congress* were considered sub-topics of similar measures in the DVCIR Center toolbox. For example, wildlife overpasses and underpasses were not treated as separate measures in the toolbox.

WVC MITIGATION METHOD CATEGORIZATIONS

The *Report to Congress* also includes several categorizations of some of the mitigation measures it summarized. First, a technical working group (TWG) of seven national WVC experts was convened and asked to evaluate, based on the literature provided, the crash reduction effectiveness of 34 mitigation measures. Each individual in the TWG was asked to group each measure into one of the following categories (definitions are directly from the *Report to Congress*):

- **Successful:** Mitigation measures that have been used in one or more locations for which properly designed evaluations have been conducted that show them to be effective.

- Demonstrated: mitigation measures that have been implemented in multiple locations and that may even be accepted as standards or standard approaches but for which there have not been found valid evaluations.
- Attempted: Mitigation measures that have been suggested and that at least one agency has considered sufficiently promising to implement on a small scale in at least one location. However, data on effectiveness have not been documented or have not yet been published.
- Unknown: Mitigation measure that have not been tried, or have been tried, but not for WVC reduction, where not implemented correctly, or are only recently being tried.
- Failed: Mitigation measures that have been used in one or more locations and for which properly designed evaluations have been conducted and show them NOT to be effective.

The category that received the most votes for each mitigation measure considered by the TWG is shown in Appendix A. The number and proportion of votes in that category are also indicated. Overall, 4 measures were categorized as successful, 13 measures as demonstrated, 9 as attempted, 6 as unknown, and 2 as failed. Of particular importance are those that were voted as successful or failed. The successful measures included wildlife crossing guards (although it was noted that this mitigation hasn't been proven and is just "intuitive that it definitely works"), wildlife fencing, and long tunnels/bridges, and underpasses/overpasses with fencing. The failed measures were standard wildlife warning signs and audio signals in the right-of-way or deer whistles. Overall, most of the mitigation measures are contained in categories that imply uncertain effectiveness. This conclusion generally agrees with the categories of the crash data research-based DVCIR Center toolbox.

The TWG members were then asked, through e-mail communication, to categorize these same 34 mitigation measures into the following groups:

- Recommended for implementation
- Recommended for further research
- Not recommended for implementation or further research

The same group did these categorizations with the same variability in background and knowledge of the research available as indicated in the activity described above. Therefore a review that was completely research-based would only result in a recommendation for implementation or a recommendation against implementation or further research if a measure had been declared successful ($n = 6$) or failed ($n = 2$), respectively. This outcome did not occur and apparently the TWG members considered more than just research. The category given the most votes (and the number of votes) is indicated in Appendix A. It should be noted that in some cases none of the TWG members provided categorizations. Overall, the majority (for those with a minimum of six votes) of the TWG members categorized 3 measures as recommended for implementation, 13 for further research, and 11 were not recommended for further research or implementation. One measure also had three votes for further research and three votes for a negative recommendation.

The mitigation measures that were recommended for implementation included wildlife crossing guards, wildlife fencing, and underpasses/overpasses with fencing. Those measures not

recommended for implementation or research included: standard wildlife warning signs, roadside animal detection systems, in-vehicle warning on-board animal detectors, deer reflectors/mirrors, audio signals in right-of-way or deer whistles, olfactory repellents, deer flagging models, hazing, intercept feeding, wildlife relocation, anti-fertility treatments. Recall that in the last categorization only four measures were considered successful. Three of these four were recommended for implementation (long tunnels/bridges were recommended for further research). Only two measures were considered failures in the last categorization, but only one was not recommended for implementation or research in this activity. The other seven measures not recommended for implementation or research must have been categorized in this manner by the majority of the TWG based on factors other than the research. It is assumed that these other factors include, among others, expert opinion and research completed that didn't focus on crash data or crash reduction. Unfortunately, this categorization and the following lists do not differentiate or define the reasons, but do make declarative statements about whether the mitigation measures should be researched or implemented in any manner. It is also important to note that mitigation measures that are implemented may also need research to be completed that isn't directly focused on but relates to their effectiveness (e.g., height of fencing). This differentiation is also not made in this categorization or the one below (although it may be implied).

Finally, the authors of the *Report to Congress* appear to have taken the above results and grouped the mitigation measures into three additional categories. The results of this categorization can be found in the column titled "Conclusions Suggested by Report Authors" in Appendix A. These categories are only somewhat altered from the second TWG listing and there is an implication that the lists below are based on the majority voting. However, additional characteristics have been added to the categories and the link between these and the second TWG categorization is not always clear. The consideration of undefined factors other than research (in the past categorizations) to make conclusions about the need for *any* research or implementation of the mitigation measures also needs to be kept in mind. The mitigation measures included in the three categories defined by the authors of the *Report to Congress* are listed and described below.

- Where feasible and appropriate, the following mitigation measures should be implemented:
 - Public information and education
 - Wildlife fencing
 - Underpasses/overpasses with fencing

The last two mitigation measures in the list above were considered successful and recommended for implementation in the first two categorizations. The first mitigation measure listed was categorized as demonstrated and recommended for further research during these two activities. This mitigation measure could have been categorized as needing more research. However, it is expected that the recommendation for implementation for public information/education above is based on a common acceptance that education is one part of what is needed for a successful crash reduction program. The conclusion is not research-based and it is assumed that the inclusion of measures in the list above does not exclude them for further research into the many questions that remain about the specifics of implementation and design.

- Research or construction resources should not be used for the following mitigation measures:
 - Standard warning signs
 - Deer reflectors and mirrors
 - Audio signals in the right-of-way or deer whistles
 - Olfactory repellents
 - Deer flagging models
 - Hazing
 - Intercept feeding
 - Wildlife relocation
 - Anti-fertility treatments
 - Seasonal road closures (not voted on in second categorization)
 - Reflective collars placed on wildlife

There are 11 mitigation measures recommended for no further research or implementation. The two at the bottom of the list were summarized in the literature review but only one was included in both of the two previous TWG categorizations. The categorization of seasonal road closures is apparently based on the opinions of the research by the *Report to Congress* authors. Two of the mitigation measures above (i.e., standard wildlife warning signs and audio signals in right-of-way or deer whistles) were categorized as failed and not recommended in the previous two activities. The remaining eight mitigation measures were believed to be demonstrated, attempted or unknown (i.e. not proven successful or failed) in the first categorization, but generally not recommended (as above) in the second. As noted previously, the recommendation for no more research to be done on these measures is clearly based on something other than what is contained in the crash reduction research (e.g., expert opinion or non-crash evaluations).

- Mitigation measures that may be promising, but require further investigation:
 - Reduce traffic volume on road network (not voted on in second categorization)
 - Reduce speed by reducing the posted speed limit
 - Reduce speed by traffic calming or reducing the design speed
 - Wildlife crossing guards
 - Large non-standard wildlife warning signs
 - Seasonal wildlife warning signs
 - Animal detection systems
 - In-vehicle warnings – roadside animal detection system to on-board (not voted on in second categorization)
 - In-vehicle warnings – on-board animal detectors
 - Increase visibility through roadway lighting
 - Increase visibility through vegetation removal
 - Investigate deicing alternatives
 - Influence plant species/nutritional value in right-of-way
 - Wildlife culling
 - Habitat alteration
 - Boulders forming a barrier/fence

- Long tunnels/bridges
- Overpasses/underpasses
- Increase visibility – wider road striping (not voted on in second categorization)
- Expanded median

There were 20 mitigation measures categorized by the authors of the *Report to Congress* as generally needing more research. It is assumed that this categorization is not intended to limit their potential implementation and subsequent evaluation. As in the past, the largest number of mitigation measures is listed in this category. All but two of the measures were grouped as demonstrated, attempted, or unknown in the first TWG categorization. This relationship makes sense if the first categorization was based on research results as indicated. The wildlife crossing guards and long tunnels/bridge mitigation measures, however, were categorized as successful (i.e., they had not been proven through evaluation but it was stated that “...it is intuitive that [they] definitely work.”). This conclusion would seem to imply that these two measures, at least, should be in the implementation category (but still require more research). Recall that the public information/education mitigation measure was categorized as demonstrated (and in need of further research) and was included in the implementation category above (although it clearly needs to be researched). There is a slight inconsistency here. Finally, the second TWG categorization (discussed previously) considered only 17 mitigation measures. Only three of the measures listed above were *not* identified as requiring further research. Wildlife crossings guards were recommended for implementation (and successful in the first categorization). In addition, the roadside animal detection system and on-board animal detector mitigation measures were recommended for no further research or implementation in the second TWG categorization (and attempted in the first categorization). It would appear that there were factors other than the status of the research (or the TWG results) used by the authors of the report to reach their conclusions for these two or three mitigation measures (or a misprint may have occurred).

The two categorizations and authors conclusions described above are also listed in Appendix A (along with the TWG votes placed). From a research point of view, it is important to compare the first categorization (theoretically based on research), the second categorization (apparently based on more than research), and the third categorization or authors conclusions described above. Of particular interest are those measures that are successful or failed in the first categorization and those that are recommended for no research in the second and third categories. Overall, the groups of mitigation measures in each of the categorizations generally appear to be linked. This does not appear to be true in a few instances. It does appear that a requirement for repeated and robust crash reduction (or animal behavior) analysis or research was, in theory, only applied in the first categorization. The final two categorizations take other subjective factors into account. Recommendations related to research should be based on previous well-designed and repeated mitigation measure evaluation projects.

COST-BENEFIT ANALYSIS

A cost-benefit analysis of DVC-related mitigation measures was also documented in the *Report for Congress*. This exercise was completed only for those mitigation measures that were determined to have adequate data (from the literature reviewed) to do this type of evaluation. The analysis was left incomplete for those mitigation measures missing the necessary data. Overall,

the mitigation measures selected were analyzed with respect to their implementation costs and benefits (e.g., percent reduction in DVCs). The report authors emphasized, however, that their cost-benefit analyses was not all inclusive and relied on a series of assumptions. Their objective was to produce additional decision-making information that could be used for a simple economic-based comparison of a select group of mitigation measures. A more detailed cost-benefit analysis of DVC-related mitigation measures is documented in recent *Ecology and Society* article (which is also summarized in the toolbox update, see www.deercrash.com).

In the *Report to Congress* cost-benefit analysis the mitigation measure implementation annual costs were defined for one kilometer (approximately 0.62 miles) of roadway based on information estimated from existing literature. The benefits for each mitigation measure were also estimated by calculating the annual value of the DVCs avoided (See Table 2) for the same roadway segment. The difference between the benefits and costs for a consistently defined roadway segment (e.g., one kilometer (approximately 0.62 miles) and five DVCs per year) was then calculated. The results of this annual difference (i.e., benefits minus costs) or balance were summarized in the following manner. The following mitigation measures produced a “strongly negative balance” and were not recommended for implementation:

- Long tunnels
- Long bridges
- Anti-fertility treatment

These mitigation measures, the authors suggested, were those that produced a promising result from a cost-benefit perspective:

- Wildlife fencing (with dig barrier)
- Wildlife fencing with gap and animal detection systems
- Wildlife fencing with underpasses
- Wildlife fencing with under- and overpasses

Finally, the following mitigation appeared to be effective and promising, but the calculations indicated they were slightly less cost-effective:

- Animal detection systems
- Wildlife fencing with overpasses

Overall, it was determined that the other mitigation measures analyzed in the cost-benefit analysis (not listed above) generally received slightly positive or slightly negative balances. In addition, it was emphasized that this analysis based a number of assumptions and the current state-of-the-knowledge. All these inputs would need to be reconsidered for a similar analysis of mitigation measures at a particular location. It is generally thought that this may have been one of the first attempts at a benefit-cost analysis of DVC mitigation measures.

DVCIR CENTER FINDINGS

The *Report to Congress* contains some very useful information. It is a good reference to use for a better understanding of what we know about estimating WVC and/or DVC problem in the United States. It also includes very brief summaries of 47 WVC and/or DVC mitigation measures that include information about their effectiveness and implementation. The cost-benefit calculations are also of interest. In general, however, many of the mitigation measures that are considered in the report are sub-categories of those discussed in detail within the DVCIR Center toolbox and the update summaries being added to www.deercrash.com. The mitigation measure categorizations in the DVCIR Center toolbox, however, are based on the amount, pattern, results, and adequacy of the safety data analysis completed in the published research.

Thirty-four mitigation measures were categorized in the *Report to Congress*. The results of the first categorization (See Appendix A) generally agree with those in the DVCIR Center toolbox. The results of the second categorization and the author's conclusions (See Appendix A) about mitigation measure research needs, however, appear to incorporate factors other than the adequacy or repeatability of the WVC and/or DVC safety- or animal-behavior-based research that has been completed. Overall, the authors of the *Report to Congress* concluded that 3 WVC/DVC mitigation measures should be implemented (where feasible), that 11 of the mitigation measures should *not* be implemented or researched any further, and that 17 of the measures held promise and should be further investigated. These results are summarized in Appendix A.

There is some concern that the research-oriented conclusions noted above, which appear to be based on more than the adequacy and repeatability of the existing research (e.g., expert opinion), may result in a reduced amount of exploration, evaluation, and monitoring of those mitigation measures recommended for implementation (e.g., public information and education) and potentially the complete disregard of those measures recommended for *no* implementation or research. The research studies related to many of the measures that meet this latter criterion are described in detail within the DVCIR Center toolbox and its update summaries (see www.deercrash.com). It is proposed that WVC/DVC mitigation measures that have only been studied once or twice (and sometimes very poorly and/or after decades of conflicting research results) should not be included in the "no further implementation or research needed" category until at least a pattern of positive or negative results is produced (e.g., two well-designed and significantly sized studies using currently accepted data analysis methods produce similar and comparable outcomes). The results of the cost-benefit analysis should also be considered within the context of the current state-of-the-knowledge related to the crash reduction effectiveness of WVC/DVC mitigation measures. It is recommended that the content and conclusions of the *Report to Congress* be considered by practitioners and researchers (for decision-making purposes) in conjunction with the DVCIR Center toolbox and its update summaries (see www.deercrash.com).

Appendix A
Mitigation Measure Categorizations by the Technical Working Group (TWG)
and Report Author Conclusions

Table A-1. Mitigation Measure Categorizations by Technical Working Group (TWG)¹

Mitigation Measure	TWG Categorization One (Number of Votes)	TWG Categorization Two (Number of Votes)	Conclusions Suggested by Report Authors
Public information and education	Demonstrated (7/7)	Further Research (7/7)	Implement
Standard Wildlife Warning Signs	Failed (5/7)	Not Recommended (4/7)	Do Not Implement or Research
Large, Nonstandard Wildlife Warning Signs	Demonstrated (5/7)	Further Research (5/7)	Further Research
Seasonal Wildlife Warning Signs	Demonstrated (7/7)	Further Research (7/7)	Further Research
Animal Detection Systems	Attempted (5/7)	Not Recommended (5/7)	Further Research
In-Vehicle Warnings: Roadside Animal Detection System Linked to On-Board Computer Warning System	Unknown (7/7)	No Vote	Further Research
In-Vehicle Warnings: On-Board Animal Detectors	Attempted (7/7)	Not Recommended (7/7)	Further Research
Increase Visibility of Animals to Drivers: Roadway Lighting	Demonstrated (7/7)	Further Research (7/7)	Further Research
Increase Visibility of Animals to Drivers: Vegetation Removal	Demonstrated (7/7)	Further Research (7/7)	Further Research
Increase Visibility of Animals to Drivers: Wider Striping	Unknown (7/7)	No Vote	Further Research
Increase Visibility of Animals to Drivers: Reflective Collars for Animals	Unknown (7/7)	No Vote	Do Not Implement or Research
Reduce Traffic Volume on Road Network	Unknown (7/7)	No Vote	Further Research
Temporary Road Closures	Unknown (7/7)	No Vote	Do Not Implement or Research
Reduce Vehicle Speed by Reducing the Posted Speed Limit	Demonstrated (6/7)	Further Research (6/7)	Further Research
Reduce Vehicle Speed by Traffic Calming/Reducing Design Speed	Demonstrated (5/7)	Further Research (5/7)	Further Research
Wildlife Crossing Guards	Successful (4/7)	Recommended (4/7)	Further Research
Deer Reflectors and Mirrors	Demonstrated (6/7)	Not Recommended (5/7)	Do Not Implement or Research

Table A-1. Continued

Deer Whistles	Failed (6/7)	Not Recommended (6/7)	Do Not Implement or Research
Olfactory Repellents	Attempted (4/7)	Not Recommended (4/7)	Do Not Implement or Research
Deer Flagging Models	Attempted (6/7)	Not Recommended (6/7)	Do Not Implement or Research
Hazing	Attempted (4/7)	Not Recommended (5/7)	Do Not Implement or Research
Deicing Alternatives	Attempted (7/7)	Further Research (4/7)	Further Research
Intercept Feeding	Attempted (7/7)	Not Recommended (5/7)	Do Not Implement or Research
Influence Species Composition or Minimize Nutritional Value of Vegetation in Right of Way	Demonstrated (7/7)	Further Research (5/7)	Further Research
Increase Median Width	Unknown (7/7)	Further Research (4/7)	Further Research
Wildlife Culling	Demonstrated (7/7)	Further Research (4/7)	Further Research
Wildlife Relocation	Demonstrated (6/7)	Not Recommended (6/7)	Do Not Implement or Research
Anti-Fertility Treatment	Demonstrated (7/7)	Not Recommended (4/7)	Do Not Implement or Research
Habitat Alternation Away from the Road	Attempted (4/7)	Further Research (3/7) & Not Recommended (3/7)	Further Research
Wildlife Fencing	Successful (4/7)	Recommended (6/7)	Implement
Boulders Fence	Attempted (7/7)	Further Research (5/7)	Further Research
Long Tunnels and Long Bridges over Landscape	Successful (7/7)	Further Research (4/7)	Further Research
Wildlife Underpasses and Overpasses	Demonstrated (7/7)	Further Research (4/7)	Further Research
Underpasses/overpasses and fencing	Successful (7/7)	Recommended (4/7)	Implement

¹Only those categories with the most votes (out of 7) are indicated. Definitions for the terms indicated are in the text of the attached summary. Mitigation measure descriptions can be found in the *Report to Congress*.