

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

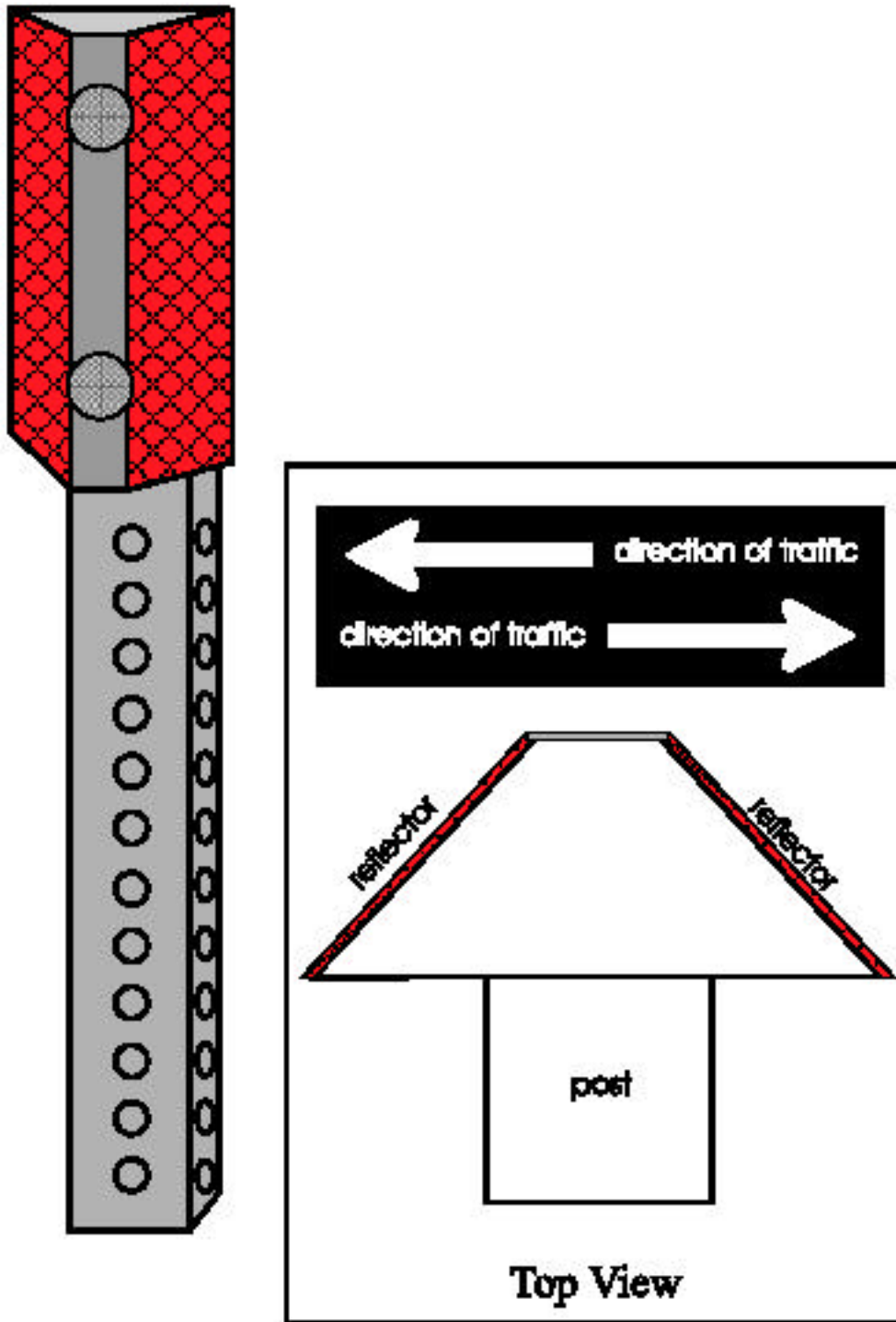


FIGURE 1 Deer reflector example (side and top view) (11).

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.

References

1. Ford, S.G. and S.L. Villa. *Reflector Use and the Effect They Have on the Number of Mule Deer Killed on California Highways*. California Department of Transportation, Sacramento, CA and United States Department of Transportation, Washington, D.C., August 1993, pp.17.
2. Schafer, J.A. and S.T. Penland. Effectiveness of Swareflex Reflectors in Reducing Deer-Vehicle Accidents. *Journal of Wildlife Management*, Volume 49 Number 3, 1985, pp. 774 to 776.

3. Reeve, A.F. and S.H. Anderson. Ineffectiveness of Swareflex reflectors at reducing deer-vehicle collisions. *Wildlife Society Bulletin*, Volume 21, 1993, pp. 127 to 132.
4. Armstrong, J.J. *An Evaluation of the Effectiveness of Swareflex Deer Reflectors*. Research and Development Branch, Ministry of Transportation. Ontario, Canada, 1992.
5. Jared, D. *Evaluation of Wild Animal Highway Warning Reflectors*. Office of Materials and Research, Georgia Department of Transportation. Special Assignment 98003, Atlanta, GA, November 1999
6. Ingebrigtsen, D.K. and J.R. Ludwig. Effectiveness of Swareflex Wildlife Warning Reflectors in Reducing Deer-Vehicle Collisions in Minnesota. *Minnesota Wildlife Report*, Number 3, 1986.
7. Pafko, F. and B. Kovach. Minnesota Experience with Deer Reflectors. In compendium for *Transportation and Wildlife: Reducing Wildlife Mortality and Improving Wildlife Passageways Across Transportation Corridors*. Conference held in Orlando, FL from April 30 to May 2, 1996. Florida Department of Transportation, Tallahassee, FL and United States Department of Transportation Federal Highway Administration, Washington, D.C., August 1996, pp. 116 to 124.
8. Waring, G.H, J.L. Griffis, and M.E. Vaughn. White-Tailed Deer Roadside Behavior, Wildlife Warning Reflectors, and Highway Morality. *Applied Animal Behavior Science*, Volume 29, 1991, pp. 215 to 223.
9. Gordon, D.F., M.C. Coghill, and F.W. Dunham. *Evaluation of Deer Highway Crossing Safety Measures*. Colorado Department of Transportation. Project Number W-38-R-23, Final Report-9206020. Denver, CO, 1969.
10. Gladfelter, L. *Effect of Wildlife Highway Reflectors on Deer-Vehicle Accidents*. Iowa Highway Research Board Project HR-210. Iowa Department of Transportation, Ames, Iowa, 1984.
11. Andrie, S.J., K.K. Knapp, T. McDonald, and D.E. Smith. *Iowa Traffic Control Devices and Pavement Markings: A Manual for Cities and Counties*. Iowa Highway Research Board Project TR-441. Iowa State University, Center for Transportation Research and Education, Ames, IA, April 2001.
12. Zacks, J. L. *An Investigation of Swareflex Wildlife Warning Reflectors*. Report No. HRP 0010 (7). United States Department of Transportation Federal Highway Administration. Washington, D.C., July 1985.

13. Zacks, J.L. Do White Tailed Deer Avoid Red? An Evaluation of the Premise Underlying the Design of Swareflex Wildlife Reflectors. *Transportation research Record 1075*, Transportation Research Board, National Research Council, Washington, D.C., 1986, pp. 35 to 43.
14. Ujvari, M., H.J. Baagoe, and A.B. Madsen. Effectiveness of Wildlife Warning Reflectors in Reducing Deer-Vehicle Collisions: A Behavioral Study. *Journal of Wildlife Management*, Volume 62, Number 3, 1998, pp. 1094 to 1099.