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Highway Fences as Deterrents to Vehicle-Deer Collisions

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A survey of highway fencing along I-80 in Centre County, Pennsylvania, showed that 2.26-m (7.41-ft) type 3 modified fence has little value as a deterrent to vehicle-deer collisions; many deer crawl under the fence to the planted right-of-way, and the many gaps underneath provide easy penetration. From December 1974 through March 1976, numbers and position of deer were observed from a vehicle driven along 9.65 km (6 miles) of I-80 at night. Bimodal patterns of abundance were found. Deer were most numerous in spring and fall. Of 2577 deer sightings, 74.5 percent were on the highway side and 25.5 percent on the far side of the fence. Comparisons between a control area on the north side of the highway, where the fence was unmodified, and test areas on the south side, where gaps underneath were plugged or the top five wires were removed or repaired or both, showed that large numbers of deer crossed a fully repaired fence. Only six deer were reported killed during the 16 months of the study, and no live deer were seen on the highway. These results, relative to previous findings beginning in 1967, strongly suggest that high traffic volumes prevent deer from venturing onto the highway, thus reducing collisions.

More than 26 000 white-tailed deer carcasses are annually reported as highway kills by Pennsylvania game protectors; many more are undoubtedly injured or die undetected and unreported. We have been engaged in research on vehicle-deer collisions for more than a decade, and the purpose of this report is to share some of our findings.

Four-lane, divided highways that traverse habitats where deer are plentiful—such as Pennsylvania's I-80—are of particular concern. Divided highways have approximately twice as many deer collisions per kilometer as other highway types (1). When planted rights-of-way provide abundant food for deer and the surrounding habitat provides less abundant or less desirable food, the rights-of-way may be visualized as long, narrow pastures with high-speed vehicle traffic. Bellis and Graves (2) noted that 286 deer were reported killed on a 12.87-km (8-mile) section of I-80 in north-central Pennsylvania in the 14-month period after the opening of the highway in 1968.

A study of deer abundance, behavior, and mortality along I-80 in both agricultural and forested areas of Pennsylvania (3) disclosed that deer come to the highway borders primarily to feed, are most abundant between dusk and dawn, and show strong bimodal activity patterns across seasons, being very abundant in the fall—especially in November—and in the spring (summer and winter are times of low deer abundance along the highways). Deer mortality is highly correlated with this abundance on a monthly basis (2).

Early studies on abundance and mortality of deer on rights-of-way were done in 1968 and 1969 along an unfenced section of I-80 when traffic volume was relatively low. In 1970, a fence 2.26 m (7.41 ft) high was installed at or near the outer margins of the right-of-way where it joins the forest. This resulted in a progressive decline in deer mortality in ensuing years. It is not clear whether the decline was due to a fence that prevented access of deer to the right-of-way, to a smaller deer population in these regions, to changing traffic volume on I-80, or to some other unknown factor or factors. We therefore developed a study to determine the effectiveness of fences as deterrents to vehicle-deer collisions in an area known to have a large deer population.

STUDY AREAS

The majority of our work was done along a 9.65-km (6-mile) section of highway that extends from mileage marker 139-36 just east of Moshannon Creek in Centre County to marker 145-36 just west of the Snow Shoe rest area in Centre County. A survey to determine fence quality and deer crossing sites was made on an adjacent section of highway east of the experimental 9.65-km section and overlapping it by 6.81 km (4.23 miles). It ran from marker 141-24 to 149-44 inclusive, a distance of 13.55 km (8.42 miles). This section included all of the area studied by Carbaugh and others (3) and an additional 10 sectors [606 m (2000 ft)] that extend east to the PA-144 overpass. These 13.55 km were chosen because two types of fence (type 1 chain link and type 3 modified) and a wide variety of cover and terrain types were found there.

A deciduous forest with smaller stands of white pine and hemlock paralleled the highway on both sides. There were numerous streams and springs that cause occasional pools and marshes. A few permanent dwellings and several hunting camps were in the area but none within 500 m (1640.5 ft) of the highway. Strip-mining areas, scattered farms, and the village of Snow Shoe were all located within a 6-km (3.73-mile) band that paralleled the north side. A rest area was on each side of the highway in the fence survey area, which also included the Snow Shoe Interchange.

The highway margins alternated between fill areas (downslopes) and cut areas (upslopes), many of which were terraced. Planted areas between the highway and the forest border varied in width from 12 to 107 m (39.37 to 351.07 ft) and contained mixtures of grasses and crown vetch that occupied the steeper slopes and had spread widely since the study was made in 1968 and 1969. Smaller areas had clover, and some aspen and birch had invaded the terraces in cut areas.

Type 3 modified wire mesh fence had been installed at or near the junction of the planted areas and the forest border and type 1 chain link fence in the vicinity of the interchange and rest areas. Type 1 was 1.60 m (5.25 ft) high and extended for 2.28 km (1.42 miles) on the north side in the vicinity of the rest area and the Snow Shoe Interchange. Two sections that totaled 1.80 km (1.12 miles) were on the south side at the rest area and the interchange. The remaining 11.26 km (7 miles) on the north and 11.75 km (7.30 miles) on the south were paralleled by type 3 modified fence designed to be 2.26 m (7.41 ft) high. This fence had a wire mesh that extended 1.32 m (4.33 ft) above the ground and five horizontal wires stretched above it; the top two wires angled 45° away from the highway. In this paper, these wires are designated 1, 2, 3, 4, and 5; wire 1 was at the bottom and wire 5 was at the top of the fence.

QUALITY AND USE OF THE FENCE

Study Methods

The fence was surveyed between November 3 and November 13, 1974. Data were recorded by mileage-marker sectors used for deer observation. The data recorder was guided by two aides, one on the highway signaling the marker identification number and the other between him and the data recorder at the fence.

Results

Gaps below the fence, which were created when the fence was installed over small stream beds or other recessions (especially in rocky areas), were by far the most prevalent type of deficiency. Data on the occurrence of these gaps are given in Table 1. Gap sizes are grouped from 0.23 to 0.30 m (9 to 12 in) from the ground to >0.76 m (>30 in); the larger gaps were usually beds of temporary streams. Gaps less than 0.23 m in size were not recorded, but subsequent study showed that deer often crawled under gaps that small or smaller. Where two or more gaps occurred between posts, only the largest was recorded; hence, the data in Table 1 are conservative estimates of fence condition. A few flaps had been cut into the fence to allow human passage; most had been folded shut. Altogether, there were 297 gaps, including flaps, below the north fence and 196 below the south fence, a total of 493 in the 13.55-km (8.42-mile) study section.

At least 118 of the 493 gaps were used by deer, as shown by tracks under the fence, hairs attached to the fence bottom, or both. Few deer used gaps in the 0.23- to 0.30-m category probably because a larger gap was usually located nearby. Because a deer may get under the higher gaps without leaving hairs or detectable tracks and because we only detected very recent use in our survey, these figures are also very conservative.

Downbends (Table 1) were points where the chain link was bent downward from 8 to 15 cm (3.1 to 5.9 in). These were created by humans and by deer that occasionally cross between the top of the chain link and wire 1.

Damage to the top wires was found 49 times on the north side and 47 on the south side of the fence. The most common type of damage was caused by trees or large branches falling on wire 5 or on 4 and 5 together, but all the wires were damaged or broken in various combinations at one damage site or the other. Excessive fence damage was found 7 times on the north side and 5 times on the south side. This varied from sections of all the fence removed for penetration by a four-wheeled vehicle to the lower chain link removed with wires 1 through 5 intact or large fallen trees that were lying on the fence and had driven it down to a height of 0.3 to 1.0 m (11.8 to 39.4 in).

By and large, type 1 chain link fence had better underside protection against crossing by deer because it was stronger, less easily bent, and in the areas surveyed was constructed on flat ground in unwooded areas. But, as tracks on muddy ground in the rest area showed, deer often jumped it. Deer can also jump the 2.26-m (7.41-ft) type 3 modified fence. Most deer, however, seem to prefer to crawl under the fence.

Of the 60.96-m (200-ft) sectors (227) that were surveyed along the 13.55 km (8.42 miles) of highway, 144 sectors had at least one type of flaw on the north side (63.4 percent), and 124 sectors had at least one on the

Table 1. Data on gaps and other damage to fence along 13.55 km (8.42 miles) of I-80.

Portion of Fence	Gaps: Height (m)	Gaps: Number	Gaps: Number Known to Be Used by Deer	Number of Downbends of Chain Link	Number of Locations of Damage to Top Wires	Number of Locations of Excessive Damage
North	0.23-0.30	132	7	38	49	7
	0.30-0.46	98	19			
	0.46-0.61	33	16			
	0.61-0.76	16	8			
	>0.76	14	8			
	Flaps[a]	4	1			
Total		297	59			
South	0.23-0.30	89	5	45	47	5
	0.30-0.46	70	31			
	0.46-0.61	20	13			
	0.61-0.76	8	5			
	>0.76	6	3			
	Flaps[a]	3	2			
Total		196	59			
All		493	118	83	96	12

Note: 1 m = 40 in.

[a]Cut in fence by humans.

south side (54.6 percent). Most flaws were gaps on the underside of the fence. (Downbends are not included in these totals or percentages because they appear to be of minor importance.) The longest section of the fence where no flaws occurred was 5 sectors on the north side [304.80 m (1000 ft)] and 6 sectors on the south side [365.76 m (1200 ft)]. Thus, deer easily penetrated the fence. No matter where they were along the 13.55 km of highway, they had easy access to the planted areas and could easily return to the forest behind the fence. Further observations along other sections of I-80 disclosed the same types and numbers of flaws in the fence. On the basis of these findings alone, the value of the fences as deterrents to deer was highly questionable.

DEER ABUNDANCE AND SEASONAL PATTERNS

Study Methods

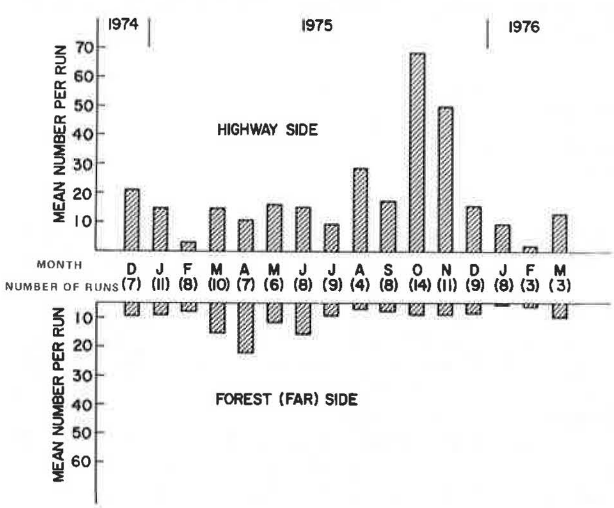
Data on numbers and locations of deer were taken from a vehicle driven at about 27 km/h (16.78 mph) along the emergency lane at night. A 12-V spotlight was used to locate deer. Study sectors were designated by highway mileage markers located at 60.96-m (200-ft) intervals; thus, each sector was 60.96 m long and included any planted areas and the forest behind.

One trip along all sectors on the south side of the highway and the return trip along the sectors on the north side constituted a run of approximately 60 min. Each run began on the hour. The driver of the vehicle counted traffic during the run, and the observer spotted deer and recorded the data on a tape recorder. Data were later coded and transferred to cards for future analysis. Information gathered on runs included date, time of day, sector number, number of deer, and whether deer were on the roadside or on the far side of the fence. Sex, age, and behavioral data, if known, were also recorded. Permission to use the emergency lane was granted by the Pennsylvania State Police, and a red triangular warning reflector was mounted on the rear of the vehicle.

Results

From December 1974 to August 1975 inclusive, 70 runs were made between marker 139-36 and marker 145-36.

Figure 1. Mean number of deer seen per run along 9.65 km (6 miles) of I-80 on highway and far sides of fence (December 1974 through August 1975 includes both sides of highway).



On September 13, 1975, the south fence was experimentally modified. The north fence was unmodified and served as one control against which data for the modified fence could be compared. Consequently, in this portion of the paper, which deals with overall "normal" abundance, data for the north side from the experimental phase of the study are included with preexperiment data in determining numbers of deer per run and overall totals. Fifty-six runs were made during the experimental period.

Exclusive of deer on experimental sections of the highway, 2577 sightings of deer were recorded on 126 runs for a mean of 20.5 sightings/run. Of these, 1919 sightings (74.5 percent) were on the highway side of the fence, and 658 (25.5 percent) were behind the fence.

The mean number of deer seen per run on the highway side and behind the fence are shown on a monthly basis in Figure 1. Data for September 1975 through March 1976 (the experimental period) were corrected by multiplying by 2 to put all data on a 19.31-km-run (12-mile-run), round-trip basis. Data in Figure 1 are consistent with previous findings (3). A typical bimodal pattern of seasonal abundance is evident; the greatest numbers of deer are present in the fall, and there is a lesser peak of activity in the spring. The ratio of deer on the far side of the fence to those on the highway side varied over the 16 months, but only in March 1975 were more deer sighted on the far side.

STUDY OF FENCE MODIFICATION

Study Methods

Regular runs to count deer were made from December 1974 to August 1975 inclusive on both sides of the highway from mileage marker 139-36 to marker 145-36, a distance of 9.65 km (5.4 miles).

On September 13, 1975, the fence on the south side was modified, but that on the north side (control area) was left unchanged. The south fence was divided into three contiguous 3.22-km (2-mile) test areas that were treated in the following manner:

1. Test area 1 (marker 139-36 to marker 141-36)— Logs were placed under the bottom of the fence so that deer could not crawl under it, and the five horizontal wires were removed from the top, which reduced the height to 1.32 m (52 in);
2. Test area 2 (marker 141-36 to marker 143-36)— The underside of the fence was left unchanged, but the five horizontal wires were removed; and
3. Test area 3 (marker 143-36 to marker 145-36)— Logs were placed under the bottom of the fence, and any damage to the top wire strands caused by fallen trees was repaired so that all strands were in place and taut.

Subsequent runs were made as before from September 1975 through March 1976. Only deer sighted on the highway side of the fence were used in comparing control and test areas.

Results

Results of the experiment are given in Table 2. Overall, there was a vast increase in numbers of deer after September 1975 when the south fence was modified. This was apparently caused by the normal seasonal increase. However, test area 1 showed a decrease in numbers from 312 to 200; hence, one might conclude that obstructing holes under the fence reduced use of the right-of-way by deer even though the height of the fence had

Table 2. Comparison of deer sightings in control and test areas before and after fence was modified (numbers of deer on highway side of fence only).

Area	Number of Deer: Before Fence Modification	Number of Deer: After Fence Modification	Percentage and Direction of Change	Result of Comparison
Control	285	948	3.33 × increase	$X^2 = 229.9,\ p < 0.01$
Test area 1	312	200	1.56 × decrease	
Control	285	948	3.33 × increase	$X^2 = 3.19,\ p > 0.05$
Test area 2	178	486	2.73 × increase	
Control	285	948	3.33 × increase	$X^2 = 44.8,\ p < 0.01$
Test area 3	196	307	1.57 × increase	

been reduced to only 1.32 m (4 ft) by removal of the five horizontal top wires. Unfortunately, this conclusion is not supported by data on test area 3 where obstructions were placed in openings under the fence and the top wires were repaired.

In test area 2, no significant difference between test and control areas was found ($X^2 = 3.19$, $p > 0.05$). Both showed a similar seasonal increase. The control area had a 333.6 percent increase in numbers and the test area a 273.0 percent increase. Thus, there were proportionately fewer deer in the test area than in the control area after modification of the fence, but the increase was not very different from the increase in the control area.

The most impressive finding was that large numbers of deer gained access to the rights-of-way even in areas in which the top wires of the 2.26-m (7.41-ft) fence were made secure and gaps under the fence were obstructed (test area 3).

DISCUSSION OF RESULTS

Our November 1974 survey of fence quality and passage under and over it by deer, as indicated by tracks and hairs attached to the underside, revealed that it is highly penetrable by deer and that in its current form it is probably of little value in reducing vehicle-deer collisions. The presence of 493 gaps under the fence in 27.10 km (17 miles) [13.55 km (8.42 miles) on each side], 118 of which are known to have been used by deer at least once, reveals that the fence can easily be penetrated. In addition, damage to top wires and excessive damage such as that caused by fallen trees reduce the effectiveness of the fence even further. Because no flaws were more than six sectors [365.76 m (400 yd)] apart and most were close together, it is evident that deer have easy access to the rights-of-way.

The abundance of gaps on the underside of the fence and their regularity at least reduce the possibility of deer being trapped on the highway side of the fence. There was no evidence in the study that the fences were "funneling" deer along the highway by preventing their return to the forest from the right-of-way, but that could be an important contributing factor in accidents along highways where openings under the fence are widely separated.

Deer not only had access to many gaps under the fence in the study area but also appeared to know the openings quite well. On many occasions when runs were made, the investigator followed the deer with the spotlight when they moved. Many deer seemed to know precisely where they were going in returning to the far side of the fence, quickly moving to a gap on the underside and slipping under. A few deer jumped the fence in test areas where the top wires were removed, but none were seen to jump the intact 2.26-m (7.41-ft) fence.

In our survey, we saw no evidence of deer getting through a gap that measured less than 0.23 m (0.76 ft) high, but Falk (4), who tracked deer in areas where the fence had been repaired, subsequently found two gaps less than 0.23 m high that deer had crawled under. In our study, only 5.4 percent (12 of 221) of the 0.23- to 0.30-m (0.76- to 1-ft) gaps showed evidence of deer passage, but this was probably because higher gaps were usually nearby and deer were not forced to use the small ones.

The overall seasonal pattern of abundance of deer in the planted areas was similar to the bimodal patterns found in earlier studies. This bimodal pattern is likely a reflection of the abundance of food, both in the woods and in the planted areas. When food becomes scarce in the woods in the fall, deer come to the planted areas to feed; in winter, there is little food near the highway, so few deer are seen there even though there is a scarcity of food in the woods. In spring, many deer feed on the planted areas as they begin to green up before the high production of new food in the forest; in summer, abundant food (especially grass and clover) is available in the planted areas but, because food is abundant in the forest, deer do not come in large numbers to the planted areas to feed. This seasonal pattern can be expected to occur whenever planted rights-of-way are available to deer whose numbers approach or exceed the capacity of their forest habitats to sustain them.

Although seasonal patterns remained essentially the same, as reported by other investigators, the number of deer per run seen over extended periods varied widely when our earlier and later studies on I-80 were compared. In 1968 and 1969, Carbaugh and others (3) saw a mean of 17.2 deer/run along the south side of 12.87 km (8 miles) of I-80; Tubbs (5) saw a mean of 7.3 deer/run in the same area (south side) in 1970 and 1971; and Bobak (6) saw a mean of 8.9 deer/run on I-80 in the same area in 1973 and 1974, but this included deer along the north side of the highway as well. On a mean deer per kilometer per run basis, we thus obtain the following (1 km = 0.62 mile):

Time Period	Deer per Kilometer per Run
1968-1969	1.34
1970-1971	0.57
1973-1974	0.35

By using preexperiment data from the current 9.65-km (6-mile) study area as well as data from the control area for the experimental period, we obtained 1.52 deer/km/run (2.45 deer/mile/run), the highest figure of all four studies. However, it is not quite valid to compare the current 9.65-km area with the original 12.87-km (8-mile) area that it overlaps to the east because the original 1968-1969 area contains the rest area and the interchange where deer abundance is known to be low because of human activity. In fact, the 9.65-km area was moved westward in order to get data from an undisturbed region where deer were expected to be more abundant. In any case, it is apparent that the abundance of deer on the right-of-way has varied widely over the years. We are in no position to explain this variability. It has been shown that traffic volume and traffic mix had no significant effect on the number of deer seen (3). Only slight changes in the quality and quantity of vegetation have occurred on the right-of-way; thus, we do not feel that the availability of food has been a significant factor in determining changes in abundance. One possible cause for variation from year to year may be annual variations in the size of the deer herd in the forest habitat in Centre County. A more likely hypothesis is that deer moved freely across the area before and immediately after the opening of the highway but did not continue such movement after the highway had been open to traffic for a while.

We are in a much better position to discuss the effects of fencing, especially where experimental data have demonstrated its relative ineffectiveness. The type 3 modified fence, as it is presently constructed, has not served to keep deer from the right-of-way and thereby reduce vehicle-deer collisions. The critical weakness in the fence seems to be not the height but the underside. The increase in numbers of sightings in the control area, where the fence was unrepaired during the fall and winter, was significantly greater than in test areas 1 and 3, where gaps underneath were plugged (even though the top wires had been removed in test area 1). This is not to say that sealing the holes at the bottom of a short fence will hold back deer. Deer were seen to jump the fence after the top wires were removed and, in test area 1, many deer got across the fence even though the bottom had been made impenetrable. In fact, the 2.26-m (7.41-ft) fence in test area 3, the top of which was fixed and the bottom sealed, also allowed many deer to cross to the right-of-way.

The validity of the experimental design might be questioned on the basis that deer on the north side (control area) were free to cross to the south (experimental) side and vice versa. But only six deer were reported killed on the highway, and no deer were seen on the highway or in the emergency lanes during surveys. Thus, it appears that deer in control and experimental areas were effectively separated in our test. Another criticism might be that experimental areas were contiguous with themselves and with areas to the east and west where the fence was unmodified. There was probably some "leakage" of deer between test areas and at the ends of the 9.65-km (6-mile) strip of right-of-way. However, our experience suggests that deer do not move nearly the length of our 3.22-km (2-mile) experimental areas in their foraging along highways.

Because only six deer were reported killed during the course of our study on the 9.65 km of highway, we made no attempt to analyze mortality in relation to the number of deer seen in test and control areas. However, some comments on mortality are in order here, especially since the fence has been shown to be relatively ineffective but at the same time a significant reduction in vehicle-deer collisions has been found since the highway was opened in 1968.

In the 14 months after the opening of the highway, 286 deer were reported killed on the original 12.87-km (8-mile) study area of I-80 (2). Twenty-two were reported killed in the same area in 10 months of 1970 and 1971 (5); 2 were reported killed in the same area in 12 months of 1973 and 1974 (6); and only 6 were reported killed during this study. The number of deer killed and the number seen on the right-of-way on runs were not correlated, which suggests that something other than deer abundance was the prime cause of mortality. In addition, the number of live deer seen on the highway itself has been progressively declining since studies were begun. Peek and Bellis (7), who surveyed the original 12.87-km section of I-80 before it was opened to traffic, saw 13.7 percent of 1277 deer observed on the highway lanes. Carbaugh and others (3) found 4.2 percent on traffic lanes immediately after the highway was opened. Tubbs (5) found 0.3 percent on traffic lanes in 1970 and 1971, and in our current study we saw none on the traffic lanes during 16 months.

Factors that were correlated with this large reduction in mortality include the volume of highway traffic, which has drastically increased since 1968, and changing behavior patterns of deer as the highway was built and opened to traffic. Collectively, highway vehicles appear to prevent deer from venturing onto the highway, at least in our I-80 study areas, and thereby severely reduce the chances of vehicle-deer collisions in spite of the occasional high abundance of deer. The fence has had little effect in reducing vehicle-deer collisions and, since deer in the planted areas rarely venture onto the highway now, the fence is not needed as a device to prevent deer from gaining access to the planted areas. It may be useful in making I-80 a limited-access highway.

On highways where traffic volume is lighter and studies show that many deer venture onto the highway, construction of a fence might be warranted, but in such cases the cost of constructing and maintaining a truly deer-proof fence could well exceed its benefits in reducing highway accidents.

RECOMMENDATIONS

In light of the greatly reduced mortality of deer on I-80 in an area where the fence has been shown to be ineffective and where traffic volume has been negatively correlated with deer mortality and with the number of live deer seen on the traffic lanes, we recommend that, in areas such as I-80 that have very high traffic volumes, the installation of fences as deer deterrents be discontinued. The traffic itself forms a moving fence that inhibits deer from moving into traffic lanes, and installation of the fence would appear to be difficult to defend in light of the findings of this study.

Along Interstate highways that have lower traffic volumes, deer fencing might be justified if it is carefully maintained and if special emphasis is given to installation and repair of the underside, especially where it crosses depressions, rocky areas, and small streams. Damage to the top of the fence should be monitored frequently, and necessary repairs should be made if the relative effectiveness of the fence is to be maintained. But many deer will cross a fully repaired 2.26-m (7.41-ft) fence, especially when food in their forest habitat behind the fence is in short supply.

In areas where traffic volume itself does not prevent deer from venturing into traffic lanes and where fencing might be warranted, a different approach to fence placement should be tried—at least experimentally. Currently, fences are placed at or near the junction of the forest and the planted areas adjacent to the highway. An alternative for consideration is placing them closer to the highway. Hungry deer will attempt to cross over or crawl under the fence to reach the right-of-way, especially when food is scarce. If they were allowed to feed on the planted areas on one side of the highway, their desire to cross the fence would probably be lessened; in fact, lower, less expensive fences might be enough to keep them off traffic lanes. This suggestion, made earlier by Bellis and Graves (2), should be tested along currently unfenced sections of four-lane highways where fences are about to be installed. In view of the findings in this report, additional advantages are that gaps under the fence would not occur as frequently on the more level ground near the highway, and there would be a far less severe problem with falling trees.

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Economic Impact of Highway Snow and Ice Control

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An overview of a national study of highway snow and ice control that involved the Federal Highway Administration and eleven state highway agencies is presented. A method of establishing level of service for winter maintenance based on an economic analysis is discussed. A winter maintenance questionnaire was distributed to Idaho, Illinois, Minnesota, and Utah to determine the public's attitude toward the maintenance effort being made in each state. The study also examined the user costs that occur during winter maintenance. Accident rates, user delay, traffic volumes, and vehicle speeds during snow and ice storms were evaluated. A telephone survey was made to businesses to determine losses caused by poor traveling conditions. Environmental damage to wells, plants, and lakes was investigated as well as deterioration of roadway, structures, and vehicles that can be associated with winter maintenance. The ESIC economic computer model developed through the study yields costs for maintenance and traffic and safety by storm and level of service, written warning of possible environmental damage, and annual costs for structural deterioration and vehicle corrosion.

The impact of snow and ice storms has long been a concern to the traveling public. Before the development of the automobile, travel during winter weather was somewhat limited. With the advent of the motor vehicle, a demand for better all-weather roadway conditions required the development of better snow and ice removal techniques. Since that time, considerable effort has been expended by various highway and research agencies to quantify the effects of winter maintenance programs on highway facilities, the environment, highway users, and the levels of service provided.

In an effort to combine and consolidate the available information and add to weaker areas, a national pooled fund study was undertaken. Participating in the study were the Federal Highway Administration and the state highway agencies of Idaho, Illinois, Maryland, Michigan, Minnesota, Montana, New Hampshire, South Dakota, Virginia, and Washington with Utah's as the lead agency. The objective of the research project was to develop a rational method for determining the costs and benefits accrued through snow and ice control on highways. This method included the development of an economic computer model (ESIC) and a user's manual or guide on how to implement the model, verification of the model on a small scale, and a report on the state of the art of snow and ice removal.

RESEARCH APPROACH

An illustration of the research approach to the study is shown in Figure 1. The first phase of the study included a literature review of the different aspects that make up an economic analysis of snow and ice removal policies.