Comparison of Safety Effects of Roadside Versus Road Improvements on Two-Lane Rural Highways

RAHIM F. BENEKOHAL AND MICHAEL H. LEE

The cost-effectiveness of roadside improvements was compared with road improvements on two-lane rural highways in Illinois. Accident reductions due to the improvements on 17 resurfacing, restoration, and rehabilitation projects were determined, and the benefits from the accident reductions were compared with the improvement costs. Accident data for 2 years before and 2 years after the improvements were extracted for two categories: (a) fixed-object, off-roadway, single-vehicle (FOS) accidents and (b) related accidents, which include overturned, other noncollision, head-on, and sideswipe accidents in addition to the FOS accidents. The roadside improvement costs were used in a benefit/cost analysis of the FOS accidents, and the road improvement costs were used in a benefit/cost analysis of the related accidents. Benefits, in terms of number of accidents reduced, were computed using the before-and-after study with control site approach. Roadside improvements reduced accidents by 7.02 per year, road improvements by 33.35 accidents per year. On the average, for every $28,471 spent on the roadside improvement, or for every $26,487 spent on the road improvement projects, one accident was reduced. The benefit/cost ratios for roadside improvements were very similar to those for road improvements. The cost-effectiveness approach and benefit/cost analysis indicated that the roadside improvements provided similar benefits to the road improvements. A more comprehensive study with a larger number of sites is suggested to evaluate the cost-effectiveness of highway improvements over a longer period of time.

This study compares the cost-effectiveness of roadside improvements with that of road improvements on two-lane rural highways in Illinois. The distinction between roadside and roadway improvements is made using the AASHTO definition of the terms. According to the AASHTO *Transportation Glossary* (*1*), *roadside* is a general term denoting the area adjoining the outer edge of the roadway; *roadway* is the portion of a highway, including shoulder, for vehicular use. In this study, *road improvement* denotes roadside improvement and roadway improvement.

The types of roadside improvements frequently made in these projects included removal of culvert headwalls and replacement with end sections and grates; removal or relocation of trees, utility poles, posts, and fences; and installation or end treatments of guardrails. Road improvements included these roadside improvements as well as widening the traveled lane and widening or upgrading the shoulder.

A roadside improvement project on a two-lane rural highway in most cases would cost considerably less than a road improvement project. On the other hand, the roadside improvement would yield less accident reduction than the road improvement. Given a limited highway safety improvement budget, are a few roadside improvements more cost-effective than a single road improvement? This study attempted to determine benefit/cost ratios and the cost-effectiveness of roadside and road improvements.

The study identified a sample of highway sites whose roadsides were improved, but whose sideslopes remained practically unchanged. The actual costs of the roadside and road improvements were determined for each project. The cost of each type of improvement was compared with the benefits from the reductions in number of accidents. The approach used for the comparison is a before-and-after study with control site approach. For the improved and control sites, accident data for 7 years were obtained from Illinois Department of Transportation (IDOT): accident data for 2 years before the improvements were compared with accident data for 2 years after the improvements. Benefit/cost analyses were conducted to evaluate the effectiveness of each type of improvement.

BACKGROUND

A review of the literature on roadside safety indicated that the most frequently hit objects or features include utility poles, trees, ditch embankments, signposts, guardrails and fences, drainage facilities, and bridge structures (*2–4*). The highest percentage of fatalities is associated with fixed-object collisions with trees, utility poles, embankments, and culverts (*2,3*). A study of run-off-the-road accidents on two-lane rural roads (*5*) showed that 75 percent of these accidents involved fixed objects and 25 percent were turnover accidents. One-third of the fixed-object accidents and three-fifths of the turnover accidents involved injuries or fatalities. In Illinois from 1980 to 1985, 23,958 accidents per year occurred on two-lane rural highways (*6*). Single-vehicle run-off-the-road (SVROR) accidents constituted about 25 percent of these accidents. About 46 percent of the SVROR accidents were fatal and injury accidents.

A study of the effects of shoulder type on accident frequency (*3*) indicated that shoulder stabilization on two-lane roads was effective in reducing accidents on narrow roadways (20 ft or less), but was virtually ineffective on roads with widths of 24 ft or more. The study found that nearly 47 percent

R. F. Benekohal, University of Illinois at Urbana-Champaign, 205 N. Mathews Ave., Urbana, Ill. 61801-2397. M. H. Lee, CH2M Hill/Leisch Associates, 1890 Maple Ave., Suite 200, Evanston, Ill. 60201.

of the single-vehicle accidents were collisions with fixed objects or roadside features and that nearly 51 percent of these collisions resulted in death or injury. A different study (*7*) showed that increasing pavement width by 1 ft would have the same effect on accident frequency as increasing shoulder width by 1 ft. Another study (*8*) found that the addition of paved shoulder width decreased the frequency and severity of accidents.

Perchonok et al. (*4*) found that accident frequency was higher on curves than on straight roads and higher on downgrade tangents than on upgrade tangents. The frequency was also higher immediately after the curve than farther downstream. The injury rate for accidents on vertical curves was higher than that for level roads. Cleveland et al. (*9*) concluded that average daily traffic (ADT) was the most significant parameter in the frequency of accidents for two-lane rural roads with ADT values ranging from 2,000 to 13,000, followed by driveway and intersection density and geometric parameters. They found that effects of longitudinal alignment parameters were significant in accident prediction for rural two-lane roads with ADT values of 4,000 or less, whereas effects of roadside elements were more significant at higher ADT values.

Vehicle-tree and vehicle-utility pole accidents are common types of fixed-object accidents on rural roads. It was reported (*10*) that of total accidents in Michigan from 1981 to 1985, 2.8 percent were with trees; 11 percent of these accidents were fatal. Another study (*11*) found that accident severity was higher for wooden poles than for the metal ones, mainly because of the frangible bases of the metal types. Zegeer and Cynecki (*12*) conducted a study to determine the different cost-effective treatments for utility pole accidents.

A study by Kohutek and Ross (*13*) concluded that for steep and flat sideslopes, leaving the culvert unprotected in its original position was the most cost-effective alternative for ADT values less than 750 and culvert offset greater than 12 ft. Guardrails were found to be cost-effective for double box culverts with moderate traffic volumes (>2,000 ADT) and for single box culverts with high traffic volumes (>20,000 ADT).

Accident characteristics on the rural Interstate system were studied by Nemeth and Migletz (*14*). After safety upgrading, the accident rates on improved sites were lower than those on control sites. The fatal accident rates were nearly the same, but injury accident rates were higher on the improved sites. They concluded that minor safety upgrading on projects was effective in reducing the injury and total accident rates.

Zegeer et al. (*15,16*) developed relationships between accident and cross-section elements for two-lane roads (mostly rural). They used accident data from a 5-year period (in most cases), collected for 1,362 rural sections in seven states, to develop different prediction models.

The possibility of combining accident data from different states for analysis was studied by Ng and Hauer (*17*). They used the data from seven states (used by Zegeer et al.) and concluded that for similar geometric and traffic conditions, different states had different numbers of accidents per mile-year. Therefore, they recommended that accident data for analysis not be pooled from different states, but that each state develop its own safety standards based on accident experience in that region.

DATA COLLECTION

Site Selection

Resurfacing, restoration, and rehabilitation (3R) projects on two-lane rural highways in Illinois during 1983–1985 were identified. These projects were either resurfacing or widening and resurfacing with some roadside improvements. They had some roadside and roadway improvements, but the sideslopes practically remained unchanged–the sideslope change was either for a very short length compared with the project length or for less than 1 percent. Construction plans for each project were reviewed to identify the type of improvements and to assess suitability of the project for this study.

From a total of 167 such 3R projects, 87 projects with some roadside improvements were selected for further analysis. The remaining projects either did not have roadside improvement or did not have a substantial amount. Projects with more than two lanes and those located mostly in urban areas were deleted because of the scope of this study. An urban area includes locations in or adjacent to a municipality or other urban areas with a population greater than 5,000. Because of these constraints, the number of selected projects was reduced from 87 to 68.

Additional roadway information for the 68 selected projects was obtained from IDOT roadway description records. The information included ADT, lane width, unpaved shoulder width, paved shoulder width, and number of days for which accident data were available for before-and-after improvement conditions. The project length, type of roadway and roadside improvements, amount of improvements, cost for each item of work, and percentage of the project located in rural or urban areas were also recorded. The amount of roadside and roadway improvements for each project was taken from the construction plans—this process was very time-consuming because each page of the construction plan had to be carefully reviewed to determine the type and amount of improvements.

Sixty-eight projects could be used for this study. However, for only 51 were the accident data for 2 years before (1981–1983) and 2 years after (1985–1987) the improvement conditions available. This further limited the number of improved sites to 51.

Traffic Data

The ADT values for improved and control sites were obtained from IDOT roadway description records. Every attempt was made to select projects with uniform ADT values over the entire length or to select portions of a project that had less ADT fluctuation between segments. When ADT values were not the same for different segments of a project, a weighted ADT was computed by dividing vehicle-miles traveled by the project length. The weighted ADT was then compared with ADT values from IDOT maps. Generally, there was very close agreement between the two ADT values.

Traffic growth rate on rural highways in Illinois was determined from IDOT data for 1982–1989. The data showed annual vehicle-miles traveled on rural federal-aid primary routes and number of miles of rural highways on the system. ADT values and growth rate for the 7-year period were determined from this information. The average annual increase over the 7-year period was about 1.9 percent. This rate is very close to a traffic growth rate of 1.5 percent used by IDOT for long-term traffic projection on two-lane rural highways. ADT for 1987 was adjusted using 1.5 percent growth rate to reflect traffic volumes in the base year and analysis year. The base year is 1984 because most of the construction projects were undertaken from 1983 to 1985. The future year for economic analysis is 1994. The future year used for the analysis is not necessarily the same as the design year for a facility. Because major improvements have a service life of about 20 years, half of the service life was added to the base year to come up with 1994.

Roadway Improvement Data

Roadway improvement included widening the traveled lane and/or widening or upgrading the shoulder. Roadway width before the improvement, roadway width after the improvement, average ADT of the improved site, and average ADT of the control site are summarized in Table 1. The traveled lane was widened by 0 to 3 ft, and accordingly the shoulder was narrowed by 0 to 3 ft for 16 of the 17 projects—the width of the traveled lane in project 99 decreased by 0.5 ft because of restriping of the pavement edge. In resurfacing-only projects (18, 97, and 162), the total width of the traveled lane, and accordingly the total width of the shoulder, remained unchanged.

Accident Data

Accident data for improved and control sites were obtained for a period of 7 years (1981–1987). The accident data were separated into two groups: improved sites and control sites. The improved sites had some roadside or roadway improvement. For each improved site, one or two control sites were located immediately before or after the improved site. Most of the control sites had the same length as the corresponding improved sites.

For the improved and control sites, the accident data were further separated into two categories of accident:

1. Fixed-object, off-roadway, single-vehicle (FOS) accidents and
2. Related accidents.

The accidents included in the FOS category were SVROR accidents involving certain fixed objects for which the first involvement was running off the road and the second involvement was striking one of the following fixed objects: guardrail (excluding bridge guardrail), highway sign, culvert headwall, bridge abutment, guardrail on bridge approach, light standard, advertising sign, fence (excluding median fence), underpass structure, barricade, building, mailbox, water hydrant, impact attentuator, tree, utility pole, ditch or embankment, or delineator post. The non-FOS accidents were not used in this study.

Multivehicle accidents on or off the roadway, overturn accidents, and other noncollision types were excluded from the FOS category. Accidents with the following fixed objects were also excluded: curb or channelizing island curb, concrete median barrier, traffic signal, bridge or bridge guardrail, median fence, machinery, thrown or falling objects, falling load, railroad gate or signal, snow bank, animals, pedestrians, train, parked motor vehicle, and pedalcyclists.

The related accidents included the FOS accidents plus overturn accidents, other noncollision accidents, head-on accidents, and sideswipe accidents in the same or opposite directions.

STUDY APPROACH

A before-and-after study with control site approach was used to evaluate cost and effectiveness of the roadside and road

TABLE 1 LANE AND SHOULDER WIDTH BEFORE AND AFTER IMPROVEMENTS AND AVERAGE DAILY TRAFFIC FOR IMPROVED AND CONTROL SITES

PROJ	LANE WIDTH		SHOULDER WIDTH UNPAVED		SHOULDER WIDTH PAVED		ADT	
ID	BEF	AFT	BEF	AFT	BEF	AFT	IMPRVD	CONTROL
18	12	12	8	8	0	0	600	1350
27	9	12	11	7	0	1	1450	2200
32	9	11	8	6	0	0	1150	1550
50	9	12	11	8	0	1	1950	2100
59	9	11	4	3	2	1	1950	2700
85	9	11	11	8	0	1	800	1400
91	9	12	11	8	0	0	2400	1700
96	9	11	8	5	0	1	1050	750
97	11	11	10	7	0	3	2950	3000
99	12	11.5	10	10	0	0.5	3050	2600
106	9	12	9.5	7	1.5	1	2600	2350
107	9	11	11	8	0	1	900	600
109	9	11	8	5	0	1	800	850
128	10	12	10	4	0	4	1900	1750
130	8	11	5.5	4	1.5	0	700	600
131	11	13	5	3	0	0	3850	3900
162	11	11	1	1	0	0	3400	4200

improvements. This approach yields more accurate results than a simple before-and-after study when the control sites have characteristics similar to those of the improved sites. Selection of suitable control sites is very important in a before-and-after accident study with control sites (*18*). To increase the accuracy of this experimental design, it was confirmed that the control sites did not have roadside or roadway improvements during the study period. If a control site had roadside or roadway improvements during 1981–1987, the control site was deleted from the list. Although these exercises limited the number of available control sites to one-third the number of improved sites (*17*), they increased the reliability of the results from this analysis.

Selection of Control Sites

Control sites were located immediately in advance of an improved site (Site A) or past the improved site (Site B). These control sites usually had the same length as the corresponding improved sites, but were not improved. For each control site, information about ADT, length, location (urban or rural), number of lanes, lane width, shoulder width, type of traffic control devices used on different segments of a site, location of intersections and bridges, and roadway alignment (curve or tangent) was obtained from IDOT's roadway description records. After the review and comparison of the information from each control site with that of the corresponding improved site, either Site A or Site B was selected when two suitable control sites were available.

Suitability was determined by comparing the control site's roadway and traffic information with that of the corresponding improved site. If control sites had significantly different ADT values than the corresponding improved sites, the control sites were not used. If a control site was located in both urban and rural areas, the urban part was deleted. Some parts of control sites were also deleted if roadway geometry changed from two to four lanes, or if the roadway did not continue. This deletion of parts is not critical when accident frequency on a control site is compared with accident frequency on the adjacent improved site. When comparing accident frequencies (number of accidents divided by the site length) between improved and control sites, equal length requirement is not as critical as it is in comparing the number of accidents. This is because the effect of site length on number of accidents is linear (*6,15,16*). On the other hand, when number of accidents on control sites is used to adjust number of accidents on improved sites, comparable site lengths should be used.

For the 51 improved projects, only 39 corresponding control sites were identified. The remaining 12 projects did not have suitable control sites. Of these 39 control sites, 18 had some roadside or roadway improvements during the study period and were deleted. The remaining 21 control sites did not have roadside or roadway improvements or resurfacing during 1981–1987. Because resurfacing and roadway improvements could affect accident frequency, only those 21 control sites were considered in selecting the final control sites.

Characteristics of Control Sites

ADT values of the 21 remaining control sites were compared with ADT values of the corresponding improved sites. The difference between the ADT of each improved site and the ADT of its corresponding control site was computed. On the basis of the ADT differences, the sites were assigned to four groups—see Tables 2 and 3. The first three groups were those sites with differences less than or equal to 100, 400, or 800. The last group included all 21 sites regardless of ADT differences.

Accident data and number of control sites for different ADT groups are summarized in Tables 2 and 3 for the FOS and related accidents. The tables indicate that for the selected groups of control sites, the total number of accidents [sum of property-damage-only (PDO), injury, and fatal accidents] increased for the after period. Only Group 1 of the FOS accidents showed no increase in total number of accidents for the after condition.

The difference in ADT between a control site and its corresponding improved site was less than 800 vpd for 17 locations; for the last four sites, however, the difference was quite high (a range of 1,350–2,650 vpd). These four sites were considered unsuitable; thus, only 17 control sites were used for the final analysis.

Ideally one would try to find control sites with roadway and traffic conditions identical to those of the corresponding

TABLE 2 NUMBER OF FIXED-OBJECT ACCIDENTS IN BEFORE AND AFTER PERIODS FOR CONTROL SITES

Group	Difference In 1987 ADT	Number of Control Sites	BEFORE				AFTER			
			PDO	INJ	F	Total	PDO	INJ	F	Total
1	$\lvert ADT_{imp} - ADT_{con} \rvert \leq 100$	4	6	1	0	7	5	1	0	6
2	$\lvert ADT_{imp} - ADT_{con} \rvert \leq 400$	10	10	7	0	17	15	6	0	21
3	$\lvert ADT_{imp} - ADT_{con} \rvert \leq 800$	17	14	9	1	24	19	12	0	31
4	Regardless of difference in ADT	21	5	12	1	28	20	13	0	33

ADT_{imp} = is average daily traffic for improved sites

ADT_{con} = is average daily traffic for control sites

PDO = property damage accidents, INJ = injury accidents, F = fatal accidents

TABLE 3 NUMBER OF RELATED ACCIDENTS IN BEFORE AND AFTER PERIODS FOR CONTROL SITES

Group	Difference In 1987 ADT	Number of Control Sites	BEFORE PDO	BEFORE INJ	BEFORE F	BEFORE Total	AFTER PDO	AFTER INJ	AFTER F	AFTER Total
1	$\lvert ADT_{imp} - ADT_{con} \rvert \leq 100$	4	11	6	0	17	14	11	1	26
2	$\lvert ADT_{imp} - ADT_{con} \rvert \leq 400$	10	20	14	0	34	35	19	2	56
3	$\lvert ADT_{imp} - ADT_{con} \rvert \leq 800$	17	29	21	1	51	45	29	2	76
4	Regardless of difference in ADT	21	33	27	2	62	51	33	2	86

improved sites. However, it is almost impossible to satisfy the ideal experimental design requirements in actual roadway and traffic conditions. Often accident analysis is conducted a few years after the improvements have been completed, as in this study. Furthermore, the improvements are not proposed according to a careful experimental design for statistical analysis, but are proposed by state officials because there is a need for highway improvement. In this project, it was attempted to use a before-and-after study with control site approach to work completed in the past. This situation imposed conditions that were not ideal—using control sites with different ADT values than the corresponding improved sites. Such imperfection in design might introduce minor errors that it was not possible to quantify.

It should be mentioned that using a control site with an ADT identical to that of an adjacent improved site does not mean that the accident frequency for the two sites is considered to be the same. Rather it means that the difference in number of accidents for before-and-after periods for a control site is assumed to be equal to the expected value of the change in number of accidents for an adjacent site (the site planned for future improvement) with a similar ADT, if the adjacent site did not have the roadway or roadside improvements. In other words, the change in the number of accidents for a site with future improvement plan is assumed to be equal to the change in the number of accidents on the corresponding control site with a similar ADT if the improvement was not to occur.

After a review of the ADT difference between control sites and improved sites, it was concluded that for this study the contribution of the errors would be negligible (see Table 1). Of the 17 control sites, three had an ADT difference of 50 vpd. For practical purposes, one may assume that these three control sites had the same ADT as their corresponding improved sites. For half the remaining 14 control sites, ADT values were higher than those of improved sites; for the other half of the control sites, ADT values were lower than those of improved sites. Therefore, it is reasonable to assume that the errors due to volume difference would cancel one another.

Statistical Analyses

The statistical analyses were performed with the data from 17 improved and 17 control sites. Data analyses for 51 sites and different adjustment options are reported elsewhere (*19*). The analyses were performed to determine whether the changes in accident frequencies were statistically significant. Accident frequencies (accidents per mile) for the FOS and related accidents under before-and-after conditions were computed on the control and improved sites (eight sets)—for example, frequency of the FOS accidents for the improved sites before the improvement, frequency of the FOS accidents for the control sites before the improvement of the adjacent sites, and frequency of the related accidents for the improved sites after the improvement. The accident frequencies are given in Tables 4 and 5.

Four paired *t*-tests were performed to evaluate the change in accident frequency on the control and improved sites. The difference in accident frequencies before and after improvement conditions was computed for the FOS and related accidents on the control and improved sites (four sets)—for example, the difference between frequency of the FOS accidents for the improved sites after the improvement and frequency of the FOS accidents for the improved sites before the improvement and the difference between frequency of the related accidents for the improved sites after the improvement and frequency of the related accidents for the improved sites before the improvement.

A paired *t*-test is normally used for experiments with paired design. Pairing observations (paired design) is a special case of randomized block design, where block size is 2. Blocking should be used to reduce sources of discrepancy, whenever appropriate (*20*). In this study, there are 17 blocks (sites) and each block has two treatments (before and after). By using sites as blocks and finding the difference in accident frequencies for each site, it was possible to obtain a more meaningful comparison of conditions before and after treatment. The *t*-value for the paired *t*-test was computed as

$$t = \frac{X_D - X_O}{S_D/(N_D)^{1/2}}$$

where

X_D = sample mean of the differences,
X_O = sample standard deviation of the differences,
S_D = expected value of treatments difference, and
N_D = number of pairs.

For each set, the mean and variance of the differences were computed and used in running a paired *t*-test (*21*). The summary of computations for these tests is given in Table 6.

TABLE 4 FREQUENCY AND NET REDUCTION IN FOS ACCIDENTS

PROJ ID	IMPROVED SITES LENGTH	IMPROVED SITES ACCIDENT/MILE BEF	IMPROVED SITES ACCIDENT/MILE AFT	CONTROL SITES LENGTH	CONTROL SITES ACCIDENT/MILE BEF	CONTROL SITES ACCIDENT/MILE AFT	NET RED. PER YEAR
18	9.24	0	0	9.23	0.108	0	-0.054*
27	7.1	0.563	0.282	7.09	0.423	0.846	-0.352
32	8.87	0.451	0.564	8.86	0.226	0.677	0.169
50	7.89	0.253	0.507	7.88	0.381	0	-0.317
59	3.51	0.285	1.140	3.5	0.286	0.286	-0.427
85	6.56	0	0	6.55	0	0	0
91	4.06	0.739	0	4.05	0.247	0.493	0.493
96	8.82	0.113	0.113	3.41	0	0.880	0.440
97	11.95	0.335	0.251	15	0.267	0.2	0.009
99	4.6	0	0	1.98	0	0	0
106	14.19	0.141	0.070	6.37	0.314	0.628	0.192
107	9.8	0.204	0.306	6.99	0	0	-0.051
109	6.42	0.312	0.312	6.41	0.312	0.156	-0.078
128	3.74	0.267	0.535	3.73	0.804	0.536	-0.268
130	3.69	0	0	3.58	0	0	0
131	4.1	1.463	0.732	4.09	0.244	0.489	0.488
162	6.33	0.948	0.474	5.59	0.179	0.179	0.237
TOTAL	120.87			104.3			

* This site is treated as no change in accident frequency

TABLE 5 FREQUENCY AND NET REDUCTION IN RELATED ACCIDENTS

PROJ ID	IMPROVED SITES LENGTH	IMPROVED SITES ACCIDENT/MILE BEF	IMPROVED SITES ACCIDENT/MILE AFT	CONTROL SITES LENGTH	CONTROL SITES ACCIDENT/MILE BEF	CONTROL SITES ACCIDENT/MILE AFT	NET RED. PER YEAR
18	9.24	0.216	0.108	9.23	0.217	0.000	-0.054
27	7.1	1.972	0.704	7.09	0.846	1.834	1.127
32	8.87	0.789	1.015	8.86	0.451	1.580	0.452
50	7.89	0.887	1.014	7.88	0.888	0.127	-0.444
59	3.51	0.855	1.425	3.50	1.429	0.857	-0.571
85	6.56	0.152	0.152	6.55	0.000	0.000	0.000
91	4.06	2.217	1.232	4.05	0.494	0.494	0.493
96	8.82	0.340	0.567	3.41	0.000	0.880	0.327
97	11.9	1.590	0.753	15	0.733	0.933	0.518
99	4.6	0.000	0.435	1.98	0.505	0.505	-0.217
106	14.1	1.128	1.128	6.37	0.314	1.256	0.471
107	9.8	0.714	0.714	6.99	0.000	0.000	0.000
109	6.42	0.467	0.623	6.41	0.312	0.312	-0.078
128	3.74	2.674	0.535	3.73	1.072	1.072	1.070
130	3.69	0.271	1.084	3.58	0.000	0.838	0.012
131	4.1	2.927	1.951	4.09	0.978	1.711	0.855
162	6.33	3.318	1.896	5.59	0.179	0.179	0.711
TOTAL	120.87 Miles			104.3 Miles			

TABLE 6 SUMMARY OF COMPUTED VALUES FOR PAIRED *t*-TESTS

Condition	N_D	$X_B - X_A = X_D$	S_D
1) Control Sites FOS Accidents	17	-0.09	0.314
2) Control Sites Related Accidents	17	-0.244	0.579
3) Improved Sites FOS Accidents	17	0.046	0.384
4) Improved Sites Related Accidents	17	0.304	0.832

Where:

X_B is sample mean for before improvement condition
X_A is sample mean for after improvement condition
X_D is sample mean differences
S_D is sample standard deviation of differences
N_D is number of differences (number of pairs)

Analyses of Test Results

The first paired *t*-test checked whether the difference in accident frequencies between before and after conditions was significant for the FOS accidents on the control sites. The paired *t*-test indicated that the difference was significant with an 87 percent confidence level (the computed t was -1.195). The 87 percent significance level was relatively low; however, considering the sample size and the type of accidents used (FOS accidents on the control sites), the level of significance was accepted for this test. Thus, with an 87 percent confidence level, there was an increase in the frequency of the FOS accidents for the control sites during the after-improvement period.

The second paired t-test checked whether the difference in the frequencies of the related accidents between conditions on the control sites before and after the treatments on the other sites was significant. Using the values in Table 6, the paired t-test indicated with a 94 percent confidence level (computed value of t was -1.745) that the difference was significant. This means the number of the related accidents on the control sites increased during the after-improvement period.

The first and second paired t-tests indicated an increase in the number of accidents on the control sites because of some factors other than geometric improvements (perhaps increase in traffic volume, change in driver population or behavior, or other unknown variables). It is reasonable to expect that the same factors will also increase the number of accidents on the improved sites because the improved and control sites are adjacent. Therefore, a before-and-after study with control site approach is used to account for the effects of factors other than geometric improvements. It should be noted that the total length of the control sites is about 17 mi shorter than the total length of the improved site. Thus, the change in the number of accidents on the control sites will be a conservative estimate of the change in the number of accidents on the improved sites.

The values in Table 6 indicate that the number of accidents on the improved sites may have decreased where an increase was expected without the improvements. If the indication is true, it means not only that the number of accidents did not increase but also that the number decreased. The purpose of the third and fourth paired t-test is to examine the net change in the number of accidents on the improved sites.

The third paired t-test checked whether there was a net reduction in the frequency of the FOS accidents on the improved sites after the roadside improvements. For this test, the hypothesis was that the change in the frequency of the FOS accidents on improved sites was equal to the change in the FOS accidents on the control sites. The test indicated with a 92 perent confidence level that the net difference in the number of accidents for before-and-after conditions was significant. Thus, with a 92 percent confidence level, it can be concluded that the FOS accidents were reduced on the site with some roadside improvements.

The purpose of the fourth paired t-test was very similar to that of the third paired t-test, except that it dealt with related accidents. The hypothesis was that the number of related accidents on the improved sites decreased after the roadway improvements, considering the increasing trend on the control sites. The test indicated with a 92 percent confidence level that the number of related accidents on the improved sites decreased for the after-improvement period. This reduction is due to the road improvements.

Therefore, the results of the third and fourth paired t-tests from the 17 improved sites indicated, with a confidence level of 92 percent, that the number of accidents on the improved sites decreased during the 2-year period after the roadside and roadway improvements; the decrease was for both FOS and related accidents. The number of accident reductions resulting from each type of improvement was computed, and economic analyses for roadside and road improvements were performed.

ECONOMIC ANALYSIS

The actual costs of improving the road and roadside were determined for each project. The benefits from the improvements were determined in terms of the number of accidents reduced because of the improvements. Two types of economic analyses were made: benefit-cost ratio and cost-effectiveness analysis.

Improvement Costs

Improvement costs of various roadside and road improvement works were determined for each project. These costs, along with total annualized cost of improvement for a project, are shown in Table 7. The improvement costs consisted of roadside improvement, widening, shoulder improvement, traffic control and protection, and mobilization. The improvement cost did not include incidental items of work, which could affect the total cost of improvement. For example, trench backfill was incidental to pipe culvert extension and was already included in the latter cost.

Three types of improvement costs were calculated:

1. Roadside improvement cost,
2. Widening and/or shoulder improvement cost, and
3. Road improvement cost.

The roadside improvement cost included the cost of all items of work involving removal, relocation, installation, extension, and reinstallation of fixed objects and features to improve roadside—tree removal, headwall removal, culvert removal, guardrail removal, fire hydrant removal, wall removal, delineator removal, fence relocation, culvert extension with end section and grate, impact attenuators, guardrail installation, sign installation, and delineator installation. The widening and/or shoulder improvement cost included the widening of the traveled lane and the widening or upgrading of the shoulder. The road improvement cost was the total of improvement costs 1 and 2, plus traffic control and protection and mobilization costs.

The roadside improvement cost was used in the benefit-cost analysis of the FOS accidents, and the road improvement cost was used in the benefit-cost analysis of the related accidents. Sometimes it was difficult to split the cost of a certain improvement by the two accident types even though the improvement affects both types of accidents. For instance, culvert extension would affect the FOS accidents and, to some degree, the related accidents. In such improvement items, rather than allocating the cost of items to one of two categories (which would be subjective), all such items were included in the roadside improvement cost category. Thus, culvert extension cost was included in the benefit-cost analysis of the FOS accidents. This study did not perform a sensitivity analysis on including the shared costs in the roadside improvement category. The items included in the roadside improvement cost category and their service life are given in Table 8.

Annual Cost

The improvement cost for each item of a project was determined separately. The quantity of each item of work was

TABLE 7 TOTAL COST FOR EACH IMPROVEMENT ITEM AND TOTAL ANNUALIZED COST FOR EACH PROJECT

PROJ ID	TREE	CULVERT	GUARD RAIL	WALL HYDRANT	SIGN	W&RS	TRAFF/ MOBIL	TOT ANN. ROAD	TOT ANN. RDSIDE
18	3620	39660	42828	0	1444	91643	83447	32803	17054
27	5430	127533	58574	0	2137	563527	46232	82765	27923
32	1193	34535	73739	0	3982	402068	46232	62222	21902
50	2904	142105	0	1119	1698	472241	46956	64101	17404
59	0	27272	15307	0	472	211320	45326	29790	6706
85	1140	1376	10434	0	0	425489	57803	45758	2290
91	488	12051	0	0	0	324351	46956	34917	1522
96	0	40159	8177	0	0	604665	46956	65341	6734
97	7510	117483	20104	5067	849	630105	57803	81476	19605
99	0	76555	0	0	0	68094	43269	18277	8260
106	8542	141221	27999	0	0	1055535	65185	125211	24413
107	7113	37648	7614	0	0	656303	54836	70620	6659
109	0	13993	9952	0	0	334168	51927	38271	3546
128	0	39752	17633	0	0	456434	46956	52335	7060
130	1550	153705	3970	0	0	220007	41618	40419	16888
131	0	13854	13707	0	0	131977	46956	21054	4961
162	646	8105	24613	0	1205	75927	46956	17994	6942

TOTAL ANNUAL COST OF 17 PROJECTS $883354 $199867

Where:

"TREE"	is total cost column for tree removal
"CULVERT"	is total cost column for headwall removal, culvert removal, and culvert extension
"GUARDRAIL"	is total cost column for guardrail removal, impact attenuator, and guardrail installation
"WALL/HYDRNT"	is total cost column for fire hydrant removal, wall removal, and fence relocation
"SIGN"	is total cost column for sign installation and delineator removal/installation
"W&RS"	is total cost column for widening and resurfacing improvement cost
"TRAFF/MOBIL"	is total cost column for traffic control and mobilization
"TOT ANN. ROAD"	is total annualized road improvement cost for that project
"TOT ANN. RDSIDE"	is total annualized roadside improvement cost for that project

TABLE 8 ITEMS INCLUDED IN ROADSIDE IMPROVEMENT COST CATEGORY AND THEIR SERVICE LIFE

Item	Service Life
1) Tree removal	20
2) Headwall removal	20
3) Culvert removal	20
4) Guardrail removal	20
5) Fence relocation	10
6) Culvert extension including end sections and grates	10
7) Impact attenuator installation	3
8) Guardrail installation and reinstallation	10
9) Highway sign installation	5
10) Delineator installation	4
11) Embankment	15
12) Others, such as, removal of walls, buildings, fire hydrant, delineator	20

obtained from construction plans and/or summaries of quantities for bid items. The quantity was then multiplied by the unit cost to get the total cost of that item. The statewide average cost (average of 1983, 1984, and 1985) for a given item of work was used as the unit cost for that item. When there was a lump sum cost in a project (e.g., mobilization cost), the statewide average cost for that item of work was used.

The maintenance cost was not included in the roadside or road improvement work because it is difficult to quantify and the type of work varies with administrative policies and normal maintenance practices. The salvage value of an improved item was also assumed to be zero because it is generally negligible.

The annual cost of each item of work was computed by multiplying the total cost of the item by a capital recovery factor for that item. The capital recovery factor was calculated on the basis of the service life of that item and an interest rate of 4 percent, which was suggested by IDOT. The annualized costs of all items of work were then added to get the total annualized cost of improvement for a project (see Table 7). For 17 projects, the total annual cost was $199,867 for the roadside improvements and $883,354 for the road improvements in the analysis year.

Estimated Benefits

A highway improvement would have many benefits to the motorists and the communities surrounding the highway. Some of the benefits to road users would be a decrease in travel time, delay, fuel consumption, pollution, and vehicle maintenance cost, and an increase in comfort level and safety (reduced frequency or severity of accidents). This study used only the benefits from a reduction in the number of accidents in the economic analysis. Number of accidents reduced because of the improvements was computed using the before-and-after study with control site approach. The number of accidents reduced was converted to a dollar figure by using either the statewide average cost of an accident in Illinois or the cost suggested by FHWA. The average cost of an accident for the base year (1984) was calculated as the mean of accident costs for 1983, 1984, and 1985. This cost was increased annually by 4 percent to reflect the average cost of an accident in the analysis year (1994). The accident cost was based on National Safety Council costs and Illinois statewide average distribution of different types of accidents: PDO, injury, and fatal. The average cost of an accident in Illinois in 1984 was about $9,400. With the 4 percent interest rate, the computed cost for 1994 was about $15,000. This estimate is very low compared with the $53,700 suggested by FHWA (*21*). These accident costs are used only for illustrative purposes and do not mean an endorsement of one agency over the other.

Accident Reduction

The methodology for computing the number of accidents reduced was discussed with the study approach. The following equation is used to compute the number of accidents reduced. In this equation, the number of accidents (FOS and related) occurred on the improved and control sites before and after the improvements.

$$N = [(n_{Ib} - n_{Ia}) - (n_{cb} - n_{ca})]/2$$

where

N = total number of accidents reduced on 17 improved sites per year,
n_{cb} = total number of accidents occurring on 17 control sites during 2 years before the improvement of corresponding adjacent sites,
n_{ca} = total number of accidents occurring on 17 control sites during 2 years after the improvement of corresponding adjacent sites,
n_{Ib} = total number of accidents occurring on 17 improved sites during 2 years before the improvement, and
n_{Ia} = the total number of accidents occurring on 17 improved sites 2 years after the improvement.

This equation has two main components. The first part ($n_{Ib} - n_{Ia}$) represents the accident change on the improved sites, and the second part ($n_{cb} - n_{ca}$) shows the change in the number of accidents on the control sites. To illustrate, this equation is applied to one of the 17 sites. Project 32 had 0.451, 0.564, 0.226, and 0.667 FOS accidents per mile in the before-and-after-improvement conditions on improved and control sites, respectively. Applying these numbers to the equation, net reduction of FOS accident frequency per year is 0.169 as shown in the Table 4.

Tables 4 and 5 show accident frequencies for 17 improved and control sites. For the FOS accidents, changes in the total accident frequency after the improvement were as follows:

- Seven improved sites had net decrease,
- Six improved sites had net increase, and
- Four improved sites had no change.

It should be noted that in Project 18, the FOS accident frequency decreased on control site but exhibited no change on the corresponding improved site. This case was treated as no change in the total accident frequency after the improvement. For the related accidents, the following changes in the total accident frequency were observed:

- Ten improved sites had net decrease,
- Five improved sites had net increase, and
- Two improved sites had no change.

The changes in traffic volume after an improvement affect the number of accidents during service life of improved sites. To account for this increase, N should be adjusted. This adjustment was determined using the infomation provided by Zegeer et al. (*2*) to adjust the historical accident data for future ADT. Since N already included the effect of ADT increase on the number of accidents for first 5 years (1981–1982 to 1986–1987), the adjustment was required only for the remaining period of the service life. The adjustment factor for the remaining period, K, was 1.17 for the FOS and related accidents (*19*). The adjusted number of accidents reduced in the analysis year was computed by multiplying K by N. The computations are summarized in Table 9. The adjusted number of the FOS accidents reduced was 7.02 per year, and the adjusted number of the related accidents reduced was 33.35 per year.

Benefit/Cost Comparisons

The benefits were calculated by multiplying average number of accidents reduced in the analysis year by the average cost of the accident in that same year. The benefit/cost ratios are given for accident costs of $15,000 and $60,000. The $60,000 value is an accident cost in 1994 comparable with the FHWA figure ($53,700 increased with a rate of 2 percent only because of recency of data). Sensitivity of the benefit/cost ratios to the average cost per accident is illustrated in Table 9. The results clearly show that the benefit/cost ratio is very sensitive to the accident cost, and the accident cost can significantly influence the economic analysis of the improvements.

TABLE 9 BENEFIT/COST ANALYSIS FOR FOS AND RELATED ACCIDENTS

n_{ca}	n_{cb}	n_{la}	n_{lb}	N	N * K	Interest Rate	Annual Cost	B/C(1) Ratio	B/C(2) Ratio
A. FOS ACCIDENTS/ROADSIDE IMPROVEMENTS									
31	24	33	38	6	7.02	4%	$199,867	0.53	2.11
B. RELATED ACCIDENTS/ ROAD IMPROVEMENTS									
76	51	103	135	28.5	33.35	4%	$883,354	0.57	2.27

(1) The B/C ratio is based on average accident cost of $15,000, in 1994.
(2) The B/C ratio is based on average accident cost of $60,000, in 1994.

The benefit/cost ratios changed from 0.53 to 2.11 for the FOS accidents and from 0.57 to 2.27 for the related accidents, depending on the accident cost. This is because FHWA recommends a much higher cost per accident than that given by the National Safety Council. The recommended cost per accident by FHWA includes combined fatal-plus-injury cost (also PDO if available), which reflects the amount individuals are willing to pay to reduce the number and severity of accidents. FHWA encourages the states to use these cost figures in the economic analysis of highway safety projects.

The results from the study indicated that the benefit/cost ratios for the roadside and road improvements were very close (0.53 compared to 0.57, for 2.11 compared to 2.27). Thus, based on these data, the roadside improvements were as cost-effective as the road improvements. It is important to note that this study is based on 17 projects and data for 2 years before and 2 years after the improvements. A more comprehensive study with a larger number of sites is suggested to evaluate the long-term effectiveness of each type of improvement.

Cost-Effectiveness Analysis

An alternative economic analysis is to compare the cost-effectiveness of the roadside improvements with that of the road improvements. To do this, the average cost of an accident reduction is computed. Spending $199,867 on the roadside improvements resulted in 7.02 accident reductions per year. That is, an average of one accident was reduced for every $28,471 spent on the roadside improvement projects. Similarly, spending $883,354 on the road improvement projects reduced the number of related accidents by 33.35 per year. On the average, one accident was reduced for every $26,487 spent on road improvement projects.

The cost-effectiveness approach avoids the argument about the average accident cost that exists in the benefit/cost ratio approach. The cost-effectiveness approach also indicated that the road improvements provided benefits similar to the roadside improvements.

Relationship of Costs, Number of Accidents, and ADT

The relationship of improvement costs, number of accidents, and ADT was also investigated. Roadside costs were plotted against number of the FOS accidents and ADT: roadside costs versus net reduction in the FOS accidents; roadside costs versus frequency of the FOS accidents before the improvement for the improved and control sites; roadside costs versus frequency of the FOS accidents after the improvement for the improved and control sites; roadside costs versus average ADT for the improved and control sites; roadside costs versus ADT before the improvement for the improved and control sites; and roadside costs versus ADT after the improvement for the improved and control sites. Road costs were also plotted against number of the related accidents and ADT.

In addition, values for ADT before and after the improvement were plotted against corresponding number of accidents: ADT versus frequency of the FOS accidents before the improvement for the improved and control sites; ADT versus frequency of the FOS accidents after the improvement for the improved and control sites; ADT versus frequency of the related accidents before the improvement for the improved and control sites; and ADT versus frequency of the related accidents after the improvements for the improved and control sites. A total of 30 plots was drawn, but are not shown here because of limited space.

The linear regression analyses were done on these 30 plots, and the square of the correlation coefficient, R^2, was computed for each plot. The R^2 ranged from 0.00014 to 0.437. Four plots had R^2-values ranging from 0.253 to 0.437; these were plots of ADT versus frequency of accidents. The relationship between ADT and accident frequency is discussed by Benekohal and Hashmi (*19*). The rest of the plots had R^2-values less than 0.2. It was concluded that there is no distinct relationship between the road cost and the related accident frequency/reduction or between the roadside cost and the FOS accident frequency/reduction within the scope of this study. Further investigation did not present any distinct relationship between the improvement costs and ADT.

CONCLUSIONS AND RECOMMENDATIONS

The data indicated that the roadside and road improvements reduced the total number of accidents on the study sites. Roadside and road improvements reduced the number of accidents by 7.02 and 33.35 per year, respectively. The total annual cost of the roadside and road improvements was $199,867 and $883,354, respectively. The benefit/cost ratios for the roadside and road improvements were very similar (0.53 compared with 0.57, or 2.11 compared with 2.27), indicating that the roadside improvements were as economical as the road improvements.

The cost-effectiveness approach was used to compare the roadside improvements with the road improvements. On average, for every $28,471 spent on the roadside improvements, or for every $26,487 spent on the road improvement projects, one accident was reduced. The cost-effectiveness approach also indicated that the road improvements provided similar benefits to the roadside improvements. Because the benefit/cost ratio is very sensitive to the unit cost of the accident, it is recommended that the cost-effectiveness approach be used for economic analysis.

It is important to note that this study was based on 17 projects and data only for 2 years before and 2 years after improvements. A more comprehensive study is suggested to evaluate the long-term effectiveness of a roadside and road improvement program using a larger number of sites. It is recommended that the computerized accident data be kept for more than seven years for a more comprehensive study on the cost-effectiveness of highway improvements.

ACKNOWLEDGMENT

The authors would like to thank the Illinois Department of Transportation and FHWA for supporting this study, particularly John Sanford and John Blair of IDOT for their help in retrieving accident and cost data. The authors also wish to thank Asma M. Hashmi for data collection and analysis.

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Publication of this paper sponsored by Committee on Operational Effects of Geometrics.