Evaluation of Wide Edgelines

J. W. HALL

In many states, single-vehicle run-off-the-road (ROR) accidents constitute one of the most significant traffic accident problems. Described in this paper is a study of the effectiveness of one potentially useful countermeasure—the application of 8-in. wide edgelines. The critical rate technique was used to identify approximately 530 mi of rural two-lane highway with unusually high ROR accident rates. In 1984, 100 of these miles were treated with wide edgelines, and the following year, an additional 76 mi were marked. The remaining mileage was used for comparison purposes. The accident experience on the treatment and comparison sections was monitored after the application of this countermeasure. From the research it is concluded that wide edgelines do not have a significant effect on the incidence of ROR accidents. In addition, this treatment does not have a significant effect on the rate of ROR accidents at night or on curves, or on accidents involving the opposing flow of traffic. It is recommended that this treatment be discontinued on rural highways in New Mexico.

On a nationwide basis, single-vehicle run-off-the-road (ROR) accidents account for approximately 38 percent of all highway fatalities *(1)*. The two predominant collision types within this set of accidents are overturning and impacts with fixed objects. Total statistics for New Mexico are similar, with single-vehicle ROR accidents responsible for 41 percent of the highway fatalities *(2)*; however, because of the relatively clear roadsides in the state, a greater proportion of the ROR accidents involve overturning *(3)*. Clearly, the consequences of a vehicle departing from the traveled way are a function of roadside characteristics, specifically the presence of obstacles and the nature of roadside slopes.

For the past two decades, the technical literature and federal standards have promoted the use of forgiving roadside designs *(4, 5)*. These designs, characterized by flat side slopes, removal of unnecessary fixed objects, and the use of attenuators and breakaway supports, have been used extensively on freeways and some rural highways. In response to the increased emphasis on highway safety in the 1960s, annual highway fatalities have decreased by nearly 20 percent, and the fatality rate per 100 MVM has dropped by 50 percent *(6)*. These dramatic improvements can be attributed to numerous programs affecting the highway, the vehicle, and the road user. During this same time period, fatal ROR accidents have also decreased. However, the improvement in this area has not been as great as that cited for all fatal accidents noted above; and, in fact, there is evidence that after all the effort devoted to clear roadsides, fatal ROR accidents now constitute a larger share of all fatal accidents than they did 20 years ago *(1)*.

During the past decade, a number of studies have suggested some reasons for this unexpected result. There is, for example, a growing body of knowledge indicating that certain fixed objects formerly believed to be "safe" are actually hazardous under some impact conditions *(7, 8)*. Occupants of small vehicles are vulnerable in impacts with certain barriers and with breakaway objects thát post little problem for occupants of larger size passenger cars *(9)*. In addition, there is evidence that the 3:1 front slope criteria often cited as the warrant for longitudinal barrier installation may be too steep *(10)*. Collectively, the results of these studies indicate there is still a lot to be learned about roadside safety.

A second set of studies has established that roadway geometrics contribute to ROR accidents *(11, 12)*. Specifically, locations with adverse alignment, including sharp curves to the left, downgrades, and inadequate superelevation, all have unusually high accident experience. Although this result is not particularly surprising, the concept of using adverse roadway design characteristics as criteria for selecting sites for roadside safety improvements has not become widely accepted. As a result, agencies may sometimes devote resources to providing clear, flat roadsides at locations where vehicle departure from the road is comparatively unlikely.

There are basically two approaches to reducing the problem of run-off-the-road accidents. One approach is to provide a safe, traversable roadside that permits an errant motorist to regain control of the vehicle. This approach has the effect of reducing the severity of these incidents. Logic would suggest that, if all other factors are equal, the nature of the roadside should not affect the frequency of roadside encroachments, although one recent study suggests this may not be true *(13)*. An alternative approach is to improve the roadway to reduce the incidence of vehicle encroachment. Roadway realignment, shoulder widening, and the removal of edge dropoffs are some potential improvements in this regard. This approach may potentially reduce the frequency of these incidents. The relative cost-effectiveness of these two approaches obviously depends on the physical characteristics of the particular site.

The engineering community is committed to providing safe and forgiving highway designs. However, the cost of implementing roadway or roadside improvements on the extensive system of existing highways is an expensive proposition. In response to this situation, most states have developed schemes for assigning a priority to locations for improvement *(6)*. These techniques, which typically rely on previous accident experience, can help optimize the expenditure of limited funds available for remedial action. In many but not all cases the construction of new facilities can incorporate the appropriate safety features with little additional cost. As a practical matter, however, comparatively few miles of new highway are being constructed.

A number of states have experimented with other methods to

The University of New Mexico, Albuquerque, N.Mex. 87131.

reduce ROR accident frequency. A 1982 survey of state highway departments revealed a strong preference for the use of relatively inexpensive treatments such as chevron signs, delineators, and other traffic control devices *(14)*. These countermeasures can have a positive effect on a reasonably attentive driver, although they cannot eliminate all the factors that contribute to crash occurrence. Furthermore, this same survey revealed that few agencies had actually evaluated the effectiveness of these economical treatments.

Pavement markings constitute one class of countermeasures that has been evaluated in a number of studies *(15)*. The effectiveness of pavement markings appears to derive from several factors, including their ability to delineate a travel path, their placement on the roadway where the driver's attention is focused, and their relatively simple message. They also have several drawbacks, including deterioration as a result of traffic and environmental conditions, lower visibility on wet pavements, and blockage by snow and dirt. The commonly used treatments with relevance to ROR accidents are centerlines and edgelines. Although the results of studies of the effectiveness of pavement markings are not entirely consistent, the available data suggest that they have a small but positive effect on driver behavior.

The basic provisions of the ***Manual on Uniform Traffic Control Devices*** (MUTCD) with regard to markings on main rural highways *(16)* are fairly straightforward. Centerlines are yellow, edgelines are white, and both must be reflectorized. Normal line widths are 4 to 6 in. Rural two-lane highways with adequate width and speeds greater than 35 mph should have centerlines, whereas the application of edgelines under these conditions is at the discretion of the engineer. The desirability of edgelines is indicated by the requirement for their installation on rural, multilane divided highways, including Interstate highways.

In recent years, several sources have reported that wider edgelines, typically 8 in. can have an even greater benefit. The installation of these edgelines is certainly consistent with the provisions of the MUTCD. One study *(17)* found that wide edgelines, as opposed to 4-in. edgelines or no edgelines, caused drivers to assume a more central position in their lane and reduced the incidence of both centerline and edgeline encroachments. The researchers observed this improvement for normal drivers as well as for a set of drivers impaired with blood alcohol levels of 0.05 to 0.08 percent. Although these results are certainly encouraging, their relationship to accident experience has not been established. The data suggest that the use of wide edgelines reduces the potential for both ROR and sideswipe accidents, but the actual verification of this hypothesis requires an alternative study design.

In a previous study *(18)*, a procedure for the identification of roadway sections with unusually high ROR accidents was developed and applied to New Mexico's rural, non-Interstate highways. This procedure, described in more detail in the next section, led to the selection of sites warranting further study for possible remedial action. In light of the previous discussion, the application of wide edgelines was a good candidate treatment. The New Mexico State Highway Department painted 19 sections of road, a total length of 100 mi, in June 1984. The following year, New Mexico's informal program was expanded and modified to make it part of an FHWA study.

STUDY PROCEDURE

As discussed earlier, there is some evidence that the use of 8-in. edgelines, as opposed to 4-in. edgelines or no edgelines, can have a positive effect on vehicle tracking patterns. Previous research *(17)* revealed that these changes were near the borderline of statistical significance. The question of greater importance to traffic engineers is whether these minor alterations in driver behavior will produce a significant change in the associated accident experience. The study plan developed in this research to resolve this issue consisted of the following steps:

1. Identify sections of road with high ROR accident experience.
2. Paint 8-in. edgelines on some of the sections identified in Step 1 while the remainder were painted normally and used as comparison sites.
3. Monitor the *after* accident experience of the treatment and comparison sites.
4. Conduct appropriate statistical analyses to determine if any significant reduction in accidents occurred because of the treatment.

Site Identification

It must be noted from the outset that this project was attempting to determine if wide edgelines reduce accident frequency by a significant (in the statistical sense) and meaningful amount. Clearly this treatment would not have an effect on the severity of the accidents that do occur. It is, of course, quite possible that the treatment has no effect, and it is even conceivable that the net effect is detrimental. For example, the wide edgelines could cause motorists to drive closer to the centerline, thus increasing the incidence of opposite-direction sideswipe accidents. In any case, the best opportunity to examine their effectiveness is on sections of road that are experiencing unusually high rates of ROR accidents.

Other researchers *(19)* have described the use of the rate-quality control technique for identifying abnormal roadway sections. This technique compares the accident rates on individual sections of roadway to the systemwide average, and detects sections with rates that are significantly above statistically expected values. The approach also considers various levels of exposure on the different sections. The formula for calculating a road section's critical ROR accident rate (RC) at the 5 percent level of significance is given by

$$RC = RA + 1.645\sqrt{RA/m} + 0.5/m$$

where RA is the systemwide accident rate and m is the vehicle miles of travel on the particular section.

The critical rate is obviously greater than the systemwide accident rate. It decreases with increasing travel on the individual study sections. If the travel and the ROR accident experience on a section are known, the actual section rate can be calculated and compared with its critical rate. Within the limitations imposed by the quality of the traffic accident and travel data, sections on which the actual rate exceeds the calculated critical rate are said to be hazardous at the 5 percent level of significance.

This identification process can be implemented in a fairly straightforward manner once a few details are clarified. The selection of roadway sections for analysis is obviously a basic need. In cooperation with the New Mexico State Highway Department (NMSHD), it was decided to limit the study to rural non-Interstate portions of the federal-aid primary (FAP) and secondary (FAS) systems. The highway department maintains a roadway inventory, which subdivides these roadways into sections of variable length based on the original construction contracts, certain jurisdiction boundaries, major intersections, and other selected physical features. These sections vary in length from several hundred feet to 20 mi, but are reasonably homogeneous and have a constant design speed through each section. The inventory includes information on the length and average daily traffic (ADT) of the sections in a format suitable for computer processing.

The initial step in the analysis was to calculate the average ROR accident rate for the rural FAP and FAS road systems. The average accident rates, given by the sum of all rural ROR accidents for the 3-year period 1981 to 1983 divided by the travel on these systems, were 0.58/MVM and 0.96/MVM for the primary and secondary systems, respectively. Other characteristics of these roadway systems are given in the following table:

	FAP	*FAS*
System length (mi)	3,280	3,776
ADT range vehicles per day (vpd)	120–19,800	7–12,200
Average ADT (vpd)	2,890	1,110
Daily travel (mvm)	6.65	2.58
ROR accidents per mile per year	0.43	0.24

It was previously mentioned that New Mexico has a high incidence of single-vehicle ROR accidents. However, when 1-mi-long rural segments of these systems are examined for a 1-year period, 75 percent do not experience an accident of this type. Even during the 3-year study period 1981 to 1983, one-half of the 1-mi-long segments did not experience a single-vehicle ROR accident. In other words, on a statewide basis these events are relatively common, but their occurrence on individual short sections is infrequent.

The second step in the analysis involved the selection of roadway sections for use in the study. A computer program was developed to process the roadway inventory data and to combine adjacent sections with similar design characteristics and traffic volumes. When the traffic volume on one section was within 100 vpd of the volume on the following section, the two were combined and the vehicle miles of travel on the new, longer section was calculated. This process yielded 933 separate roadway sections (494 on the FAP and 439 on the FAS). The individual sections created by this technique ranged in length from less than 1 mi to more than 30 mi.

The next step in the analysis was the development of a computer program for the calculation of the critical rate on each of these sections. The program searched the 1981 to 1983 files for single-vehicle ROR accidents that occurred on the 933 rural sections and kept a running account of the number of these accidents for each section. The data were then merged with the inventory information to calculate the actual and critical rates for each section. In the case of the FAP system, the critical rate is given by

$$RC = 0.58 + 1.645\sqrt{0.58/m} + 0.5/m$$

This calculation was performed for each of the 494 FAP sections by using the appropriate vehicle miles of travel (m) for the 3-year period. The calculated critical rate was compared with the actual rate on each section, and the program identified 61 sections where the observed ROR accident rate for the study period exceeded the critical rate. Similar calculations for the FAS, using $RA = 0.96$, identified 89 sections on this system that were critical at the 5 percent level of significance. The finding that 150 sections (16 percent of all sections) were critical was unexpected. There are, however, two explanations for this situation:

1. These accidents are not uniformly distributed on the roadway system. As a result, during the 3-year study period many sections had no ROR accidents whereas others had substantially above average accident experience.
2. A number of the critical sections identified by this technique are quite short (<0.5 mi) where the occurrence of one or two accidents was sufficient to classify the section as critical. If problems exist on these sections, they could probably be more effectively treated with spot improvements rather than edgelines.

Critical Site Characteristics

The 150 sections identified in this process account for 15 percent of the vehicle miles of travel on rural FAP and FAS roadways and nearly 22 percent of the mileage on these systems. However, for this 3-year period, they experienced 37 percent of all the single-vehicle ROR accidents on these roadway systems. In other words, they are substantially more hazardous than typical sections of rural highway. As such, they may constitute good candidates for treatment with wide edgelines. This set of sites was reviewed with the NMSHD, and some additional criteria were established for the selection of the actual treatment sites. First, the sections selected for treatment were restricted to lengths of approximately 3 to 8 mi; this restriction was intended to facilitate the actual painting of 8-in. edgelines. Second, treatment sections were required to have at least 10 accidents during the preceding 3 years; this constraint eliminated a couple of apparently critical sections for which the miscoding of a single accident location would have changed the section from critical to noncritical. In addition, sections on multilane highways and sections where reconstruction activity was planned were dropped from the list of potential treatment sites.

The output from the application of the techniques outlined in the preceding paragraph was a set of 19 treatment sites (10 on the FAP and 9 on the FAS). The characteristics of these sites for 1981 to 1983 are summarized in the following table:

	FAP	FAS
Section length (mi)	54.71	46.41
Total ROR accidents	230	118
Daily travel (vm)	134,700	45,800
Accident rate	1.56	2.35
ROR accidents per mile per year	1.40	0.85

These approximately 101 mi of rural FAP and FAS clearly have single-vehicle ROR accident experience that is substantially above their systemwide averages. These 19 sections were painted with 8-in.-wide edgelines in June 1984. The other sections that were identified by the application of the critical technique constituted the comparison sites.

The original study plan called for monitoring the accident experience at the treatment and comparison sites for a period of 18 months, and then conducting an analysis to determine if a significant change had occurred at the treatment locations. The justification for using comparison sites is discussed in the original report *(20)* describing this study. The purpose of the comparison sites is twofold: to account for other changes in the highway transportation system that may contribute to crash reduction, and to account for regression-to-the-mean. In the more traditional but less reliable before-and-after study without comparison sites, any change in the accident experience after the site is treated is attributed to the engineering treatment. This simple approach overlooks the contribution of changes in other relevant factors in the highway transportation system, such as increased enforcement, new vehicle designs, changes in driver behavior, and so forth. In addition, several studies *(21)* describe the problem of regression-to-the-mean and its effect on accident studies. It can be demonstrated that, on the average, a group of sites with unusually high accident experience during one time period will tend to have lower accident experience in a subsequent period. Because locations are often chosen for treatment because of their high accident experience, it becomes difficult to separate the true effect of the treatment from the effect of regression-to-the-mean. However, with the use of comparison sites, which were also chosen because of their high accident experience, the analyst has a better opportunity to identify the true effect of the treatment. Specifically, the comparison sites would be expected to improve in the after period; thus the effectiveness of the wide edgeline should be a function of the difference between the changes at the treatment and comparison sites.

In the fall of 1984, the federal government expressed an interest in the effectiveness of this countermeasure. The NMSHD agreed to participate in the FHWA project by including data from its original study sites and by identifying and treating an additional 100 mi of roadway. The additional set of treatment sites were identified by using accident data from 1982 to 1984 and the critical rate technique. Some of these sections were in the set of comparison sites based on the 1981 to 1983 data, whereas others were not critical during the previous time period. This new set of treatment sites consisted of 14 sections (5 on the FAP and 9 on the FAS) with the mileage evenly divided between the two systems. The NMSHD field crews subsequently determined that two of these sections, with a total length of 24 mi, were not suitable for treatment with 8-in. edgelines; the remaining 76 mi were painted in July 1985.

By the end of 1985, there were three single-vehicle ROR accident data sets relevant to the study of wide edgelines:

1. Data for 19 sections of road with a total length of 101 mi marked in June 1984. This data set consisted of before data for a 41-month period before the treatment and a 17-month period after the treatment.
2. Data for 12 sections of road with a length of 76 mi. Eleven of these sections were painted in July 1985, and the remaining section was marked in October. Accident data were available for a 52-month before period, and with the one exception, for a 5-month after period.
3. Accident data for a set of comparison sites for the 5-year period 1981 to 1985. To facilitate the analysis, all accidents in June 1984 and July 1985, the two months that treatment sections were painted with wide edgelines, were dropped from the analysis. It was subsequently shown that the accident experience during these two months was virtually the same as the monthly average for the 5-year period.

In actuality, the traffic accident data for the preceding year do not become available on January 1 of the following year. It takes time for the accident reports to be assembled, checked and coded, and entered into the computer system. For a number of reasons, this process took a little longer than usual for the 1985 accident data, and a reasonably complete file was not available until April 1986. At this time, new computer programs were developed to compare the before and after accident data. The statistical testing mentioned in succeeding sections was conducted using contingency tables at the 5 percent significance level.

Analysis of All ROR Accidents

The first analysis evaluated the June 1984 treatment sites and the comparison sites, data sets 1 and 3 as previously identified. The results are given in the following table:

	FAP	FAS
Treatment Sites	10	9
Before ROR accidents	246	136
Before accident rate	1.37	2.25
After ROR accidents	74	69
After accident rate	0.99	2.74
Comparison Sites	16	22
Before ROR accidents	467	461
Before accident rate	1.22	2.26
After ROR accidents	150	175
After accident rate	0.95	2.07

The overall accident rate for both FAP and FAS treatment sites decreased from 1.59/MVM to 1.43/MVM, a decrease of 10 percent. During the same time, the accident rate at the FAP and FAS comparison sites dropped from 1.59/MVM to 1.34/MVM, a decrease of 16 percent. The latter decrease was expected due to the aforementioned principle of regression-to-the-mean. If the treatment were truly effective, it would be expected that the decrease at the treatment sites would be even larger. However, this is not the case for this set of study sites.

Only 5 months of after data are available for the sites painted in July 1985. The four FAP sites experienced an increase in the accident rate from 1.03/MVM to 1.26/MVM, a change that appears to be insignificant based on the small after sample size. The ROR accident rate at the eight FAS sites dropped from 1.51/MVM to 0.98/MVM. The overall ROR accident rate at these 12 sites decreased from 1.32/MVM in the before period to 1.09/MVM in the after period. During these same analysis periods, the comparison site rate dropped from 1.16/MVM to 0.96/MVM on the FAP, from 2.27/MVM to 1.56/MVM on the FAS, and from 1.54/MVM to 1.17/MVM for both systems combined. In other words, the overall accident rate at the treatment sites decreased by 17 percent while the rate at the comparison sites decreased by 24 percent. These numbers should be viewed with caution, however, because the treatment accident rates for the after period are based on very small samples (11 accidents on the FAP and 13 accidents on the FAS).

Nighttime and Curve Accidents

The tentative conclusion at this point in the analysis is that the sites treated with the wide edgelines did experience a reduction in single-vehicle ROR accident rates, but the reduction was less than that experienced at a similar set of hazardous comparison sites. It has also been hypothesized that the placement of wide edgelines may have an effect on certain types of accidents, specifically those occurring at night or on curves. To test this theory, data sets 1 and 3, as previously described, were subdivided into the following groups:

- Daytime versus nighttime accidents, and
- Accidents on straight roads versus curves.

Obviously, breaking the data sets into these categories further decreases the sample size available for the analysis. In addition, reliable exposure data do not exist for the amount of travel at night or on curves. Such values would clearly depend on the design characteristics of the road and the nature of the surrounding environment. These characteristics probably vary among the individual study sections, although there is no evidence to suggest that they differ systematically between the treatment and comparison sites. Because the intent of this analysis is to determine the relative effect of this treatment at night and on curves, it is not essential that precise travel figures be used in the rate calculations. Previous research *(10)* on single-vehicle overturning accidents in New Mexico suggests that for the rural highways examined in this study, about 20 percent of the travel may occur during the hours of darkness, whereas 15 percent occurs on curves. These factors were used in calculating the following single-vehicle ROR accident rates, but it is emphasized that the resultant values must be considered rough estimates.

The results of the nighttime and curve analyses are summarized in Table 1. At the treatment sites, 57 percent of the ROR accidents in the before period occurred at night, whereas in the after period, the value dropped to 48 percent. The corresponding figures for the comparison sites are 49 and 46 percent. The average nighttime accident rate decreased by 31 percent at the FAP treatment sites and by 41 percent at the FAP

TABLE 1 SINGLE VEHICLE ROR ACCIDENTS

	FAP	FAS	Both
Day versus Night			
Treatment, daytime	10	9	19
Before ROR accidents	110	54	164
Before accident rate	0.76	1.11	0.85
After ROR accidents	35	39	74
After accident rate	0.59	1.94	0.93
Comparison, daytime	16	22	38
Before ROR accidents	235	234	469
Before accident rate	0.77	1.44	1.00
After ROR accidents	93	84	177
After accident rate	0.73	1.24	0.91
Treatment, nighttime			
Before ROR accidents	136	82	218
Before accident rate	3.78	6.77	4.53
After ROR accidents	39	30	69
After accident rate	2.61	5.96	3.45
Comparison, nighttime			
Before ROR accidents	232	227	459
Before accident rate	3.04	5.57	3.92
After ROR accidents	57	91	148
After accident rate	1.80	5.38	3.04
Curve versus Straight			
Treatment, straight			
Before ROR accidents	101	39	140
Before accident rate	0.66	0.76	0.68
After ROR accidents	37	14	51
After accident rate	0.58	0.65	0.60
Comparison, straight			
Before ROR accidents	256	169	425
Before accident rate	0.79	0.98	0.85
After ROR accidents	91	56	146
After accident rate	0.68	0.78	0.71
Treatment, curve			
Before ROR accidents	145	97	242
Before accident rate	5.37	10.68	6.71
After ROR accidents	37	55	92
After accident rate	3.30	14.57	6.14
Comparison, curve			
Before ROR accidents	211	292	503
Before accident rate	3.69	9.56	5.73
After ROR accidents	59	119	178
After accident rate	2.48	9.37	4.88

comparison sites. The reductions for both types of sites were considerably smaller on the FAS system. Except for the FAS comparison sites, the reduction in nighttime accident rates is greater than the reduction in daytime accident rates. However, the data do not support the contention that wide edgelines produce a significant reduction in nighttime ROR accident rates.

The most striking characteristic of the analysis based on roadway curvature is the large percentage of single-vehicle ROR accidents that occur on curves. (With respect to this variable, it should be noted that the decision of whether a roadway is straight or curved is a judgment made by the investigating officer; it is quite possible that different officers might classify the same site differently.) During the before period, 63 percent of these accidents at the treatment sites and 54 percent at the comparison sites occurred on curves. At both types of sites, the percentages were about 8 percent higher on the FAS system. These percentages are higher than those found in previous studies *(3, 10)* in New Mexico. In the after period, the ROR accident rates decreased on curves on the FAP system (by 39 percent at the treatment sites and 33 percent at the comparison sites), while increasing by 36 percent at the FAS treatment sites. Overall, there was an 8 percent reduction in curve accident rates at the treatment sites, and a 15 percent reduction at the comparison sites.

Opposite-Direction Collisions

It has also been suggested that the application of wide edgelines may have an effect on the frequency of two-vehicle opposite-direction (OD) accidents. On the positive side, it could be argued that the treatment provides the driver with good guidance information that is especially valuable when he is partially blinded by the headlights of an oncoming vehicle. It is possible that drivers may shy away from a wide edgeline, thus moving them closer to vehicles traveling in the opposite direction. As a practical matter, both of these situations may occur, with the result that the net effect on accidents is small. In an attempt to evaluate this situation, a data file consisting of all the opposite-direction, head-on, and sideswipe collisions at the treatment and comparison sites was created and analyzed. It must be emphasized that the study sites were not initially chosen because of their incidence of opposite-direction crashes; in fact, if this criterion had been used in the site selection, a somewhat different set of critical sites would have been chosen. In addition, opposite-direction accidents are relatively uncommon, with the result that their frequency at the study sites is only about 20 percent that of single-vehicle ROR crashes. The before and after comparison of opposite-direction crashes for the locations painted in June 1984 is given in Table 2.

TABLE 2 OPPOSITE-DIRECTION ACCIDENTS

	FAP	FAS	Both
Treatment sites	10	9	19
Before OD accidents	43	30	73
Before accident rate	0.24	0.50	0.30
After OD accidents	16	19	35
After accident rate	0.21	0.76	0.35
Comparison sites	16	22	38
Before OD accidents	69	65	134
Before accident rate	0.18	0.32	0.23
After OD accidents	34	36	70
After accident rate	0.21	0.43	0.29

With the exception of the FAP treatment sites, the opposite-direction accident rate increased in the after period. The average increase for the treatment sites was 17 percent, whereas for the comparison sites, it was 26 percent. Using contingency table techniques, it was shown that there is no significant difference in the change of frequency of opposite-direction collisions at the treatment and comparison sites. The opposite-direction accident rate also decreased at the sites marked in July 1985, but the sample size was too small for meaningful analysis.

Achievement of "Safety" at No Cost

In general, ROR accident rates decreased at the treatment sites, but decreases of similar or greater magnitude were observed at the comparison sites. If comparison sites, which are needed to ensure reliable analyses *(22)*, had not been used, an unwary analyst might have concluded that the observed reduction in accident experience at the treatment sites was significant. The question should then be asked, What caused the reduction in accident rates at those sites that were not improved?

From 1981 to 1985, New Mexico's accident reporting threshold remained constant. The site selection process carefully eliminated sections of road that had or would experience construction activity during the study period. In response to vehicle safety standards, the overall safety of the vehicle fleet probably improved by a minor amount. There is no indication that enforcement activity or driver behavior changed between the before and after periods. During the 5-year study period, the accident experience on New Mexico's rural highways decreased slightly. Other than the painting of wide edgelines, conditions at the treatment and comparison sites were essentially unchanged, or were subject to minor changes that occur over time.

Although portions of the highway safety community are reluctant to accept the fact, it can be shown *(21)* that a set of locations selected for their high accident experience during one time period will, on the average, improve during a subsequent time period. This principle of regression-to-the-mean is not intuitive, but it can be easily demonstrated. In the initial planning for this study *(20)*, New Mexico's rural road system was divided into 7,920 1-mi segments, with termini established by milelog. The ROR accidents on these roads from 1980 to 1982 were assigned to the appropriate 1-mi segments, and the number of segments with 0, 0.33, and 0.67 accidents per year was determined. The 1983 accident experience on these sections, few of which were improved, was also determined. For example, the 94 segments that averaged 2.0 accidents per year in 1980 and 1982 had the following accident experience in 1983:

ROR accidents, 1983	0	1	2	3	4	5
Number of segments	31	36	17	3	6	1

The data show that 67 of the segments improved while 10 got worse. The average ROR accident experience on the 94 segments changed from 2.0 to 1.15, a 42 percent decrease. A similar trend was observed for all groups of roadway sections that had ROR accidents in the before period. On the other hand, the rather large group of segments with zero accidents in 1980–1982 experienced an increase; the result is expected because they could not have gotten any "safer." This same phenomenon is affecting the treatment and comparison sites selected for the wide edgeline study because of their unusually high accident experience.

CONCLUSIONS AND RECOMMENDATIONS

This study has monitored the accident experience of approximately 530 mi of rural two-lane FAP and FAS highways in New Mexico. These roadway sections were selected for study because of their unusually high rates of single-vehicle run-off-the-road accidents. In June 1984, 100 of these miles were marked with 8-in.-wide edgelines, and in July 1985, an additional 76 mi were marked. The remaining 353 mi were maintained in their normal manner and were used in this study as comparison sites. During the 5-year study period, more than 2,100 ROR accidents occurred on these sections.

The data indicate that the accident rate decreased by 28 percent at the FAP treatment sites and increased by 22 percent at the FAS treatment sites; the overall change was a –10 percent. During this same period, the comparison site rate decreased by 24 percent on the FAP and increased by 8 percent on the FAS, for an overall change of –16 percent. Clearly, the treatment sites did not perform any better than the comparison sites. At the sites marked in July 1985, the after accident rate increased at the FAP sites and decreased at the FAS sites, resulting in an overall decrease of 17 percent. The overall change in accident rate for the same time periods at the comparison sites was –24 percent. Even though the sample sizes are smaller in this latter case, the results are the same.

The single-vehicle ROR accident data were subdivided into day and night and curve and straight categories, and reanalyzed. The overall reduction in accident rates at night and on curves was similar for the treatment and comparison sites. There is no basis for concluding that the application of wide edgelines provides a benefit under conditions of darkness or curvature. The extended roadway sections treated in this project included both curves and tangents. It could be argued that the application of wide edgelines only in the vicinity of curves, while retaining standard edgelines on tangents, would be an effective spot improvement. A previous survey *(14)* found, however, that engineers believe that other treatments, including chevrons, delineators, and other warning signs, are more effective than markings for spot improvements at curves.

Finally, the incidence of opposite-direction collisions was examined. The treatment and comparison sites were not chosen initially because of the high rates of these accidents; in fact the rate of these collisions was only about 20 percent of the ROR rate. The overall opposite-direction crash rate increased at both the treatment and comparison sites. However, statistical testing showed that there was not a significant difference between the two types of sites.

The evaluation of the sites treated in July 1985 was hampered by the small sample sizes in the after period. When the 1986 accident data become available, they will be used to complete the analysis.

A previous study *(17)* suggests that wide edgelines improve the tracking behavior of motorists. However, there is no evidence from the current study that this improvement translates into a reduction in any of the accident types that this countermeasure would logically be expected to affect. Pending an evaluation of New Mexico's 1986 accident data for the second set of treatment sites, and an evaluation of the data from other states participating in the FHWA study, New Mexico will discontinue the use of wide edgelines.

ACKNOWLEDGMENT

This project was funded by the New Mexico State Highway Department; the conclusions are not necessarily those of the sponsor. Access to the accident record and roadway inventory data files used in this research was provided by the University of New Mexico Division of Government Research.

REFERENCES

1. *Fatal Accident Reporting System 1983*, NHTSA, U.S. Department of Transportation.
2. *New Mexico Traffic Accident Data 1984*. New Mexico Traffic Safety Bureau, Santa Fe.
3. J. W. Hall. Guardrail Installation and Improvement Priorities. In *Transportation Research Record 904*, TRB, National Research Council, Washington, D.C., 1983.
4. *Handbook of Highway Safety Design and Operating Practices*. FHWA, U.S. Department of Transportation, 1978.
5. *Highway Design and Operational Practices Related to Highway Safety*. American Association of State Highway and Transportation Officials, Washington, D.C., 1967.
6. *The 1984 Annual Report on Highway Safety Improvement Programs*. FHWA, U.S. Department of Transportation.
7. H. E. Ross, et al. *Crash Tests of Small Highway Sign Supports*. Report FHWA-RD-80-502. U.S. Department of Transportation, 1980.
8. H. E. Ross, et al. *Crash Tests of Rural Mailbox Installations*. Report FHWA-RD-80-504. U.S. Department of Transportation, 1980.
9. Roadside Safety Design for Small Vehicles. Proposal from the Texas A&M Research Foundation for NCHRP Project 22-6, College Station, Tex., 1984.
10. J. W. Hall. Survey of Single Vehicle Fatal Rollover Crash Sites in New Mexico. In *Transportation Research Record 819*, TRB, National Research Council, Washington, D.C., 1981, pp. 1–8.
11. P. H. Wright. Priorities for Roadside Hazard Modification. *Traffic Engineering*, Vol. 46, No. 8, Aug. 1976.
12. P. L. Zador, et al. Superelevation and Roadway Geometry: Deficiencies at Crash Sites. In *Transportation Research Record 1026*, TRB, National Research Council, Washington, D.C., 1985, pp. 43–52.
13. J. L. Graham. Effectiveness of Clear Recovery Zones. In *Transportation Research Record 923*, TRB, National Research Council, Washington, D.C., 1983, pp. 72–86.
14. P. H. Wright, et al. Low-Cost Countermeasures for Ameliorating Run-off-the-Road Crashes. In *Transportation Research Record 926*, TRB, National Research Council, Washington, D.C., 1983.
15. S. Bali, et al. *Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments for Rural Two-Lane Highways*. Report FHWA-RD-78-51. U.S. Department of Transportation, 1978.
16. *Manual on Uniform Traffic Control Devices*. FHWA, U.S. Department of Transportation, 1984.
17. Engineering the Way Through the Alcohol Haze. *ITE Journal*, Vol. 50, No. 11, Nov. 1980.
18. J. D. Brogan and J. W. Hall. Using Accident Records to Prioritize Roadside Obstacle Improvements in New Mexico. In *Transportation Research Record 1047*, TRB, National Research Council, Washington, D.C., 1985.
19. *Evaluation of Criteria for Safety Improvements on the Highway*. Roy Jorgensen & Associates, Gaithersburg, Md., 1966.
20. J. W. Hall and R. G. Ringer. Safety Effectiveness of Wide Edgelines. New Mexico State Highway and Transportation Department, Santa Fe, May 1984.
21. E. Hauer. A Common Bias in Before-and-After Accident Comparisons and Its Elimination. In *Transportation Research Record 905*, TRB, National Research Council, Washington, D.C., 1983.
22. F. M. Council, et al. *Accident Research Manual*. Report FHWA-RD-80-16. U.S. Department of Transportation, 1980.

DISCUSSION

ANITA W. WARD
Potters Industries Inc., 377 Route 17 South, Hasbrouck Heights, N.J. 07604.

Congratulations are extended to the officials at the New Mexico State Highway Department for their willing participation in an innovative approach to reduce accidents as well as the accident severity level through the use of wider-than-standard 8-in. edgelines. However, the preliminary recommendation by the author to discontinue 8-in. edgeline treatment on rural highways in New Mexico until the results of other studies are evaluated appears premature in light of the following observations.

PAVEMENT MARKINGS MUST BE VISIBLE TO BE EFFECTIVE

As Hall correctly indicates, some drawbacks of pavement markings include "deterioration due to traffic and environmental conditions, lower visibility on wet pavements, and blockage by snow and dirt" *(1)*. Hall's evaluation, however, considered neither weather nor surface conditions. Analysis of accident experience on clear road surfaces and on dry nights may prove insightful.

Pavement marking visibility at night is dependent on the retroreflective properties of glass beads embedded in the traffic paint. Although it may not have been typical of the lines applied, the 8-in. edgeline slide Hall projected to accompany his presentation indicated bead coverage only in a central 4-in. segment of the line, thus effectively providing drivers with the visual image of only a 4-in. line at night.

The State of New Mexico is making a conscious effort to upgrade the quality of its pavement markings. When the test lines were installed, however, some quality variances were noted. In 1984 one observer reported an application of 13 gal of paint per 8-in. line-mile where 32 gal should have been applied.

Another investigation noted a bead application rate of only 3½ lb/gal of paint versus a specified 6 lb/gal. Moreover, 101 mi of 8-in. edgelines were painted in June of 1984 and 76 mi were painted in July and October of 1985. Even with the highest quality of application, pavement markings have a defined service life. Because they were not restriped, it is unlikely that the pavement markings at the treatment sites remained fully effective over the life of the evaluation.

TREATMENT VERSUS CONTROL SITES

The State of New Mexico's efforts to upgrade the quality of pavement markings should have resulted in control sites that provide a stronger signal to the driver, as these controls have been repainted in the after period. Although delineation in the control sites was improving in the after period, selection criteria in the before period was more stringent for treatment sites than for control sites. As the data in Table 3 indicate, the selection process resulted in treatment sites with higher accident percentages on curves and at night.

WIDE EDGELINE SUCCESSES TO DATE

Hall's recognition that other studies of this treatment are being evaluated is a welcome indication of maintaining an open mind. A growing body of evidence indicates the potential effectiveness of wide edgelines, and it has been suggested that once factors such as environmental conditions and ADT have been taken into consideration, New Mexico may also identify candidate sites for effective treatment with wide edgelines.

In 1984, wider-than-standard edgelines were installed on more than 650 km of highway in Western Australia. The edgeline width of 150 cm was chosen as "a positive measure to reduce single vehicle accidents involving alcohol-affected or tired drivers" *(2)*. Although this is not a controlled before and after study, the author believes the results to be conservative because traffic volumes on all roads are increasing. Single-vehicle accidents were reduced by 34 percent on the treated sites, alcohol-related accidents declined by 24 percent, and the Australian Highway Department reported a benefit-to-cost ratio of 4 to 1. Other reported benefits include significant savings from a dramatic reduction in shoulder maintenance requirements and enhanced safety for cyclists *(2)*.

Ohio let contracts to paint 321.97 mi of two-lane rural state highway with wide edgelines in 1983. The lines were painted in 1983 and 1984, and Ohio has undertaken two preliminary evaluations of the after data. It is important to note that "this is a rough evaluation and is not to be quoted as a preliminary or final statement on the value of the wider edgeline" *(3)*. Based on 2 years of after data for the 8-in. edgelines installed in 1983 and 16 months of after data for the 8-in. edgelines installed in 1984, however, accident experience in the 8-in. edgeline sections either decreased further or increased less than accidents in the control sections. It is particularly significant that the greatest improvement in accident experience has been with respect to injury and fatal accidents *(3)*. Although Hall states that

TABLE 3 SINGLE VEHICLE ROR ACCIDENTS BEFORE *(1)*

	Curves			Night		
	Accidents on Curves	Total Accidents	Percentage of Total	Accidents at Night	Total Accidents	Percentage of Total
Control	503	928	54	459	928	49
Treatment	242	382	63	218	382	57

"clearly this treatment would not have an effect on the severity of the accidents that do occur" *(1)*, his contention is disputed by the actual field results to date. The effectiveness of standard width, 4-in. edgelines in reducing fatal and injury accidents to a greater degree than overall accidents has been repeatedly demonstrated in state, local, and international field tests, as well as in the Federal Highway Administration's Pavement Marking Demonstration Program evaluations *(4)*. Strengthening edgeline width from 4 to 8 in. apparently strengthens the injury mitigating potential as well.

Similar indications of the effectiveness of wide edgelines have been reported in three U.S. counties. In Los Angeles County, California, accidents were reduced by 85.7 percent when wide edgelines were installed. Because of a short test period and small sample size, the accident reduction is not considered statistically significant. However, Los Angeles County concluded that the use of 8-in. edgelines may be beneficial and recommended that additional highway sections be selected for further study of 8-in.-wide edgelines *(5)*. In Spokane County, Washington, while total accidents and injury accidents increased 12.1 and 19.3 percent, respectively, roadway sections with 8-in.-wide edgelines showed decreases of 9.2 and 32.6 percent for these accident categories. These reductions occurred even with traffic volume increases of 9.4 percent on the county road system. Accidents involving drivers who had been drinking showed even more beneficial results. County-wide, alcohol-involved total accidents and injury accidents showed increases of 7.9 and 4.8 percent, respectively. In the wide edgeline sections, alcohol-involved total accidents and injury accidents showed decreases of 28.7 and 39.4 percent, respectively *(6)*. In Morris County, New Jersey, the county engineer has adopted the practice of striping 8-in. edgelines on all county roads. Two years of annualized before and after accident data indicate that on the 115 mi of county roads where these lines were applied, dry-weather fatal and injury accidents declined by 16.1 percent, compared to a decline of only one-half that amount (8.2 percent) on other county roads in New Jersey during a comparable period. As expected, the largest percentage reduction occurred in dry weather at night, when edgelines should be most effective. After the installation of 8-in. edgelines, Morris County experienced a 21.8 percent decrease in injury accidents under dry-weather night conditions *(7)*.

In addition to the positive results indicated by these test demonstrations, at least seven U.S. jurisdictions have already adopted wide edgelines as a standard marking practice. Stronger marking patterns have been in use in Europe for years. Sound engineering judgment and accident reductions experienced to date support New Mexico's initial innovation in exploring the accident reduction potential of 8-in. edgelines, as well as Hall's recommendation to continue to further evaluate the potential benefits through other ongoing studies.

REFERENCES

1. J. W. Hall. *Evaluation of Wide Edgelines*. Report FHWA-NMSHD-86-1. Bureau of Engineering Research, The University of New Mexico, Albuquerque, N.Mex., June, 1986, pp. 3, 4, 12.
2. P. Moses. Edgelines and Single Vehicles Accidents. *Western Roads*, (Australia), April 1986, pp. 6–8.
3. Status Report on Ohio's 8-in. Edgeline Evaluation. *1986 Annual HSIP Report*, Appendix G, Ohio Department of Transportation, Columbus, pp. 4, 7, 8.
4. *1981 and 1982 Highway Safety Stewardship Reports*. FHWA, U.S. Department of Transportation, 1981, pp. 41–58; 1982, pp. 39–64.
5. J. C. Beke. Letter to California Traffic Control Devices Committee, Los Angeles, 1985.
6. R. Kelly. Preliminary Analysis of Spokane County Wide Edgelines. Washington, 1985.
7. N. D. Nedas. Letter to California Traffic Control Devices Committee, Potters Industries, Hasbrouck Heights, N.J., 1985.

AUTHOR'S CLOSURE

I would like to thank Anita Ward and Potters Industries Inc., for commenting on this paper. The discussion, however, raises a few points that must be clarified.

Because the discussion gently chides the New Mexico State Highway Department marking crews for the insufficient use of beads and paint, the reader may assume that using more paint and beads would have altered the results. I have been advised by the highway department that the 8-in. markings were applied in the same manner as 4-in.-wide lines, except that two paint guns were used. To be precise then, the study essentially compares the typical 4-in. line installed by the New Mexico State Highway Department with a line that is twice as wide, using paint and beads at twice their standard application rate.

In my paper I have outlined in great detail the procedure used to select candidate sites. In summary, 150 sections of rural highway with unusually high ROR accident experience, as determined by the critical rate technique, were identified. This set of candidate sites was subsequently pared by eliminating short sections as well as those on multilane highways and those scheduled for improvement. In order to avoid the detrimental effect of small sample sizes, treatment sites were not chosen because of their accident experience on curves or at night, or for the amount of travel under these conditions. It is not surprising, therefore, that the treatment and control sites exhibit differences in their distributions of accidents on curves and during the hours of darkness. It should also be noted that the comparison sites averaged greater lengths and lower volumes than the treatment sites. Although having identical values for these characteristics at the two types of sites may be reassuring, it is certainly not essential.

Proponents of edgelines in general and wide edgelines in particular contend that these devices have a greater effect at night and on curves. The analysis reported in this paper was unable to support this contention. It appears contradictory, however, for Ward to protest that the treatment sites had a higher percentage of accidents under these conditions, which hypothetically provide a greater opportunity for improvement.

The discussion also faults the research for failing to evaluate the effect of wide edgelines on dry pavement during the hours of darkness. As previously noted, because neither darkness nor weather were considered in the site selection process, it is quite possible that a different set of treatment and control sites would have been chosen if these criteria had been used. Although the comparison sites should provide an adequate control for darkness, there is no guarantee they properly control for variations in weather. For these reasons, these characteristics were not discussed in the paper. In the interest of completeness, I will report that in the before period, 42 percent of the treatment site accidents and 38 percent of the comparison site accidents occurred on dry pavement at night. The comparable figures in the after period were 34 and 33 percent, respectively. It is not possible to assign any practical or statistical significance to these values.

Numerous studies reported in the technical literature document the ability of selected countermeasures to reduce crash severity. For example, it is generally agreed that medians, impact attenuators, and obstacle removal can reduce the severity of ROR accidents. The mechanisms that contribute to ROR accident severity reduction are easily identified; however, it would be difficult to argue that they reduce the incidence of roadside encroachment. Conversely, if wide edgelines provide the guidance suggested by their proponents, they could reduce the incidence of roadside encroachments, but there is no logical basis for concluding that they disproportionately affect injury accidents. The severity of ROR accidents is principally determined by speed, the nature of the roadside, vehicle type, restraint usage, and similar factors. It is not influenced by the width of the edgeline, and I seriously question any study that concludes otherwise.

Although Ward references a number of studies that have concluded that there may be a benefit associated with the application of wide edgelines, several of these studies are, in fact, fatally flawed by their failure to use control sites. Regression-to-the-mean is discussed; to reiterate, sites chosen for their perceived hazard in one time period may subsequently "improve" even in the absence of any treatment. Failure to monitor the changes over time on a set of hazardous control sites will result in an overestimation of treatment benefits. The use of large sample sizes, the adjustment for changes in traffic volume, or the use of systemwide accident experience as a control, are clearly not sufficient to alleviate this problem. The reader may want to compare the 16 percent reduction in control site accident experience found in this study with the results cited by Ward.

Although I recognize that the findings of this limited study differ from those of earlier research and, to some extent, may contradict "conventional wisdom," I did not intend to attack either the previous studies or the researchers who have conducted them. In contrast, my purpose was purely a cautionary one urging traffic engineers who may be considering this treatment to proceed circumspectly. If wide edgelines have positive effects, they can only be detected through a carefully controlled study with a large number of sites that are maintained and monitored over an extended time period.

Publication of this paper sponsored by Committee on Traffic Control Devices.