complete separation of the splice plates. The intermediate post remained tethered until both it and the sign panel hit the ground. The tether then snapped and the post bounced about 5 ft away to the right.

As in the previous tests, the upper posts remained fully attached to the Z-bars. The nonimpacted post was twisted 90° clockwise and bent about 18 in above the base plate. The sign panel's lower left corner was bent when it hit the ground and the lower right edge bent as it was folded against its support by the extreme rotation. The impacted support sustained a dent on the upstream flange where it was struck by the bumper and sustained bent flanges where it separated from the downstream splice plate.

Vehicle damage was again limited to a large dent in the front of the car, 12 in deep and 24 in wide in the bumper, grill, and hood. As in the previous high-speed test, it precluded driving the car from the scene after impact.

FINDINGS

All four impacts with the posts resulted in changes in vehicle momentum below the preferred 750 lb•s. Decelerations were tolerable in the two tests measured, and no violent vehicle reactions or abrupt changes of vehicle direction occurred. Impact was deliberately off center in the two high-speed impacts, but even then the vehicles exited on the same trajectories along which they entered. In all cases, the slip bases released as designed, but the lack of downstream flange continuity across the hinge (as in the one-direction design) prevented the sign panel from remaining upright on the nonimpacted support.

Based on these four tests, the following findings can be stated:

1. The omnidirectional sign support tested meets American Association of State Highway and Transportation Officials (AASHTO) criteria for momentum transfer, and all of the resulting momentum changes were below 750 lb•s;
2. Vehicle damage was light in all cases, and the lower-speed tests resulted in slightly lighter damage than the high-speed tests;
3. Off-center impact in the high-speed tests did not adversely affect vehicle trajectory or appurtenance performance;
4. The impacted posts were dented by the vehicle bumper, and the flange ends were bent at the hinge;
5. The nonimpacted posts sustained greater damage than the impacted ones because they were bent and twisted when the sign panels fell;
6. The sign panel sustained a bent lower left corner in each test when it hit the ground; during the first test, one of the riveted vertical seams separated due to twisting of the panel; and
7. The slotted splice plates on the nonimpacted post did not develop enough resistance to maintain the sign in an upright position.

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REFERENCES

1. K.C. Hahn and J.E. Bryden. Crash Tests of Omnidirectional Slip-Base Sign Supports. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, Res. Rept. 94, Oct. 1981.
2. Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances. TRB, Transportation Research Circular 191, Feb. 1978.

Guardrail Installation and Improvement Priorities

J. W. HALL

The methodology and findings of a detailed study of New Mexico traffic crashes involving impacts with guardrails, selected fixed objects, or overturning are described. Analysis of computerized accident records for 1978 and 1979 found that guardrail accidents were more often characterized by rural conditions, unfamiliar drivers, and snow-covered roads. Guardrail accidents tend to be less severe than other single-vehicle crashes. Field studies were conducted at the sites of 113 pairs of guardrail and nearby run-off-the-road crashes. Roadway geometrics were similar at both types of sites; both had significant downgrades and curvature to the left. Roadside slopes behind the guardrail did not differ significantly from front slopes at the run-off-the-road sites. Highly significant correlations were found among certain crash-site parameters. Average values of roadway and roadside characteristics at both types of crash sites were more adverse than for the roadway system in general. The research has developed a severity-reduction model that can be used to prioritize sites that warrant guardrail installation or upgrading.

The intent of guardrail is to reduce the severity of impact for motorists who have left the roadway. Guardrails should be designed to lessen the injury to occupants of vehicles that strike it and to safely redirect vehicles back to the roadway.

It is possible to learn something of guardrail use from accident records. Data from 1978 Fatal Accident Reporting System (FARS) records (1) indicate that more than half of the fatal accidents in the United States involve a single vehicle. Approximately 27 percent of all fatal accidents involve fixed objects, and of these approximately one-ninth involved vehicles that have struck guardrail. Another substantial component of the fatal-accident experience in this country involves noncollision accidents (primarily overturning), which account for approximately 11 percent of the fatal accidents nationwide.

In an attempt to determine the nature of the guardrail accident problem in New Mexico, an analysis was conducted of 1978 and 1979 New Mexico accident data. Of the 100 000 reported accidents during this two-year period, 22 percent of all accidents involved either fixed objects or overturning, and these accidents accounted for 42 percent of all fatal accidents. Guardrail was involved in 1.8 percent of the fatal accidents. The fixed-object and

overturning accidents were grouped into three classes:

1. Guardrail--574,
2. Overturning--8037, and
3. Other fixed object--13 894.

The severity index for these accidents was highest for overturning accidents (0.53), an intermediate value for guardrail (0.37), and lowest for other fixed objects (0.28). The severity index for the other-fixed-objects class is misleadingly low because the category includes objects that are known to cause little or no injury, such as fences, fire hydrants, etc. On the other hand, those fixed objects that are more likely to be shielded by guardrail, including abutments, bridges, and culverts, all have severity indices higher than that reported for the guardrail accidents in New Mexico.

Contingency-table techniques were used to make comparisons among the 22 000 accidents that involved overturning and fixed objects in New Mexico. An analysis was conducted of various characteristics of these accidents as reported in the New Mexico accident record system. On the basis of the accident statistics, it was possible to draw a few conclusions about guardrail use and effectiveness in New Mexico. Guardrail accidents occur to a lesser extent in New Mexico than is reported nationwide. The guardrail accidents that do occur in New Mexico have moderate severity, which is consistent with that reported in other states. The accidents tend to be less severe than both overturning accidents and impacts with those fixed objects that are often shielded by guardrail. The guardrail accidents in New Mexico tend to be rural in nature, as suggested by the higher speeds and the dark, unlighted conditions under which many of them occur. With respect to the other single-vehicle, nonpedestrian accidents in New Mexico, the guardrail accidents show more involvement in snow and with unfamiliar drivers and less with use of alcohol. Horizontal curves were overrepresented at the overturning sites, whereas guardrail and other fixed objects showed no specific difference in this regard.

The findings from this analysis of the computerized accident record system are not conducive to engineering action. There is a suggestion that more guardrail needs to be used in New Mexico. It is also possible that the guardrail that is used could be improved to reduce the severity of accidents that occur. With these thoughts in mind, this study was designed to evaluate the potential for guardrail improvement in New Mexico. The primary objective of this study was to determine the relative priority of upgrading existing guardrail that does not meet current standards versus the installation of new guardrail at locations where it is not currently used. Clearly, both items are important because New Mexico has older guardrail as well as a number of locations where guardrail is warranted but not installed.

STUDY METHODOLOGY

In accord with the objectives of this research, a study procedure was developed that would evaluate the effect of current guardrail installations and that would also evaluate the merits of installing guardrail at additional locations. The study was restricted to the state highway system.

The study plan for this research called for a paired comparison of guardrail accidents with those accidents susceptible to severity reduction through guardrail use. To ensure the comparability of traffic volume as well as climatic and topographic conditions, a pair of nearby accident sites were selected on state-administered routes. Each pair consisted of a guardrail accident site and a nonguardrail accident site. The latter were the sites of overturning accidents or accidents with those fixed objects that might be susceptible to corrective action through proper guardrail use.

The 1978 and 1979 New Mexico accident record system was used together with a detailed sampling scheme to select pairs of nearby guardrail and certain types of run-off-the-road accidents. The 125 pairs of sites identified through this process were subsequently reduced to 113 when supposedly valid sites could not be located on the photologs or in field site investigations. Sites were located in 22 of New Mexico's counties on 34 different highway routes. With the exception of severity, which was used as a partial criterion for choosing sites, this set of accidents exhibits characteristics similar to those for all guardrail, overturning, and fixed-object accidents. The similarity of the characteristics of the sample and the population suggests (but does not prove) the absence of bias in the site-selection process. Among the accident sites with guardrail, 28 percent involved guardrail at bridges. Accidents involving culverts and embankments each accounted for 17 percent of the nonguardrail sites, while the remaining sites involved overturning or accidents with abutments, bridges, and ditches.

The objectives of this study suggest that several types of data should be collected and analyzed. With respect to guardrail crashes, it is necessary to know the characteristics of the guardrail--specifically, its height, type, terminal treatment, and the effectiveness with which it performed in the crash. Other data requirements for both guardrail and nonguardrail sites include roadway geometries and the nature of the roadside. A description of the specific measurement procedures is contained in the project report (2).

The extensive data sets collected in the field were supplemented with data from the investigating officer's report and from New Mexico State Highway Department files. The data were processed by using standard computer programs.

ANALYSIS OF DATA

The mean values of the geometric characteristics in the vicinities of both the guardrail and nonguardrail crash sites are summarized in Table 1. The maximum degree of curvature at the guardrail sites exceeds the corresponding value at the nonguardrail sites. On the other hand, the minimum degree of curvature is slightly less at the guardrail sites. The mean degree of curvature, which is the average value at each site of the curvature at the 10 measurement positions, is essentially the same at both the guardrail and nonguardrail sites. A similar condition exists for the approach degree of curvature, which is the mean value of the degree of curvature in the area immediately upstream of the crash site.

A further analysis of the data made use of a signed degree of curvature. For the purpose of this analysis, curves to the left were assigned a positive sign, while those to the right were assigned a negative sign. Although the signing convention is arbitrary, it does serve to distinguish between the direction of curvature. As shown in Table 1, the nonguardrail sites have a more pronounced curvature to the left. This is true for both the average of all 10 curvature readings and for the curvature in the area immediately upstream of the crash sites. Although it may be obvious, it is worth noting that

Table 1. Summary of mean values of geometric characteristics: guardrail and nonguardrail crash sites.

Item	Mean Values	
	Guardrail	Nonguardrail
Degree of curvature		
Maximum	3.61	2.75
Minimum	0.15	0.22
Mean[a]	1.41	1.44
Approach[b]	1.58	1.51
Mean signed[a,c]	0.18	0.42
Approach signed[b,c]	0.27	0.42
Superelevation (%)		
Maximum	3.70	3.87
Minimum	0.91	0.84
Mean[d]	2.31	2.42
Approach[b]	2.27	2.43
Gradient (%)		
Maximum	0.71	0.66
Minimum	−1.82	−1.42
Mean[e]	−0.58	−0.40
Approach[b]	−0.74	−0.47

[a]Mean of 10 curvature values.
[b]Mean value in the area immediately upstream of the site.
[c]Sign convention: + for left curves, - for right curves.
[d]Mean of 10 superelevation values.
[e]Mean of 11 gradient values.

Table 2. Site characteristics.

Item	Mean Values	
	Guardrail	Nonguardrail
Pavement width (ft)	24.6	24.6
No. of lanes	3.0	3.0
Shoulder width (ft)	5.8	6.8
Continuous downhill distance (ft)	1100	1400
Speed limit (mph)	52.0	52.4
Traffic volume[a]	5400	5400
Pavement friction	0.75	0.75
No. of driveways	0.57	0.57
No. of intersections	0.10	0.03
No. of spot-fixed objects	2.5	2.2
Length of continuous-fixed objects (ft)	400	330
Shoulder slope (%)	1.59	2.04
Front slope (%)	4.2	18.3[b]
Back slope (%)	21.0	0.8[b]
Embankment depth (ft)	35.8	23.5[b]

[a]Volume of average daily traffic (ADT).
[b]Statistically significant difference at $\alpha = 0.05$.

a driver has less recovery room on a curve to the left than one to the right.

Analysis of the superelevation data showed no differences between the guardrail and nonguardrail sites. Superelevation was assigned an algebraic sign of + if it was proper for the particular location, i.e., a normal crown section on a tangent and proper superelevation on the curve. The gradient data given in Table 1 indicate that the guardrail sites tend to be on steeper downgrades than the nonguardrail sites. The minimum, mean, and approach gradients are all less in the case of the guardrail crash sites.

As might be expected, all of the parameters shown in Table 1 have rather high standard deviations, i.e., the curvature values had an extreme range and included sharp curvature as well as many tangent sections. Because of the high standard deviation of the data, none of the differences suggested in the summary characteristics are statistically significant. Additional characteristics at the study sites are indicated in Table 2. These characteristics relate to the width of the roadways, roadside slope information, and the presence of driveways and intersections. The roadway width factors are of obvious importance, while the last two would logically be limited by the installation of guardrail. The pavement width, which was the total pavement width for undivided highways and the one-directional roadway width for divided highways, was virtually the same at both sites. Shoulder widths were somewhat higher at the nonguardrail sites. The length of the continuous downhill distance in advance of the crash site was higher at the nonguardrail sites.

Most of the crashes occurred on high-speed rural highways that have a median speed limit of 55 mph. Because of the proximity of the paired guardrail and run-off-the-road crash sites, it was not possible to distinguish the traffic volumes at the two types of sites, and therefore the average volumes at both were the same. Pavement friction, which was measured with a 70-lb drag tester, had identical values at guardrail and nonguardrail sites.

As shown in Table 2, there is no difference in the number of driveways between the guardrail and nonguardrail sites. There are approximately three times as many intersections at the guardrail sites as at the nonguardrail sites, but the number of intersections in total is quite small, and the apparent difference is not statistically significant. The number of spot-fixed objects, which included trees, poles, and large rocks, is virtually the same at both the guardrail and nonguardrail sites. The length of continuous-fixed objects was approximately 400 ft at the guardrail sites and 330 ft at the nonguardrail sites. The continuous-fixed objects within this grouping included the length of guardrail that, on average, was five times longer at the guardrail sites.

The slope of the shoulder at the nonguardrail sites averaged 2 percent, while at the guardrail sites the slope was approximately 1.5 percent. The difference is not statistically significant. A principal factor in distinguishing between the guardrail and nonguardrail sites was the roadside slope characteristics. The front slope, which was measured immediately beyond the shoulder, is significantly higher at the nonguardrail sites than at the guardrail sites. The positive sign associated with the slopes indicates a fill or embankment type of slope. The back slope was measured in the area behind the guardrail in the case of guardrail sites and at the point where the slope changed to a cut slope or leveled out in the case of the nonguardrail site. Not surprisingly, the back slope was significantly higher at the guardrail sites, although it does not differ from the front slope at the nonguardrail sites. The depth of embankment was 35 ft at the guardrail sites versus only 23 ft at the nonguardrail sites.

The general characteristics of the guardrail at the crash sites are summarized in Table 3. The principal type of guardrail, which accounted for nearly two-thirds of all the guardrail crash sites, was the blocked-out W-beam, while a quarter of the guardrail was of the non-blocked-out W-beam type. The principal terminal type at the guardrail crash sites was the buried-end type of terminal, which is normally accompanied by a guardrail flare. The breakaway cable terminal type and the old style nonburied terminal type each accounted for approximately a quarter of the sample.

The field crew attempted to identify the reason for the installation of the guardrail at the crash sites. In some cases there were multiple reasons for guardrail installation. Bridge approaches and embankments each accounted for 31 percent of the guardrail installations. Rivers, culverts, and other purposes each accounted for approximately 10 percent. The average height of guardrail was 2.23 ft above ground level. However, a significant range

in heights was found; some rails were as low as 1.2 ft and others as high as 3.2 ft. In general, older installations tended to have lower heights.

An analysis was made of the severity of accidents involving different types of guardrail. The results, presented in Table 4, are shown for the type of guardrail, the terminal type, and the purpose for which the guardrail was installed. Twelve of the accidents that involved guardrail resulted in fatalities, 75 resulted in injuries, and 26 resulted in property-damage-only (PDO) accidents. Contingency-table analysis showed that crash severity was independent of both guardrail type and purpose, although crash severity for guardrail at bridge approaches was slightly higher than expected. Severity was also found to be independent of terminal type, a finding that needs to be interpreted carefully, since most crashes did not involve a direct hit on the terminal.

The independence of guardrail type and crash severity is surprising, especially since laboratory tests have shown that certain types of guardrail perform better than others. It must be noted, however, that guardrail tests are typically performed under extreme conditions with respect to speed and impact angle and these conditions are often not met in real-world guardrail crashes. Although there is good reason to believe that the blocked-out W-beam design provides a safer environment for impacting vehicles, the independence of crash severity and guardrail type indicates that there may be other factors that are of equal or greater importance than guardrail type alone in projecting guardrail crash severity.

Correlation analyses were conducted among the parameters at both the guardrail and nonguardrail sites. Several interesting findings from these analyses include the following:

1. At the guardrail sites, locations with sharper curvature to the left tend to have flatter side slopes, while the opposite was true at the nonguardrail sites;
2. At both types of sites, embankment heights were greater on steeper downgrades;
3. As might be expected, both types of sites showed traffic volume to be positively correlated with pavement width, shoulder width, and speed limit;
4. Higher guardrail heights were negatively correlated with crash severity; and
5. At both types of sites, front slopes were positively correlated with severity.

Because other research (3) has suggested a relation between vertical and horizontal alignment and crash occurrence, an analysis was conducted to examine what relation, if any, existed between the roadway curvature and gradient at the crash sites. The curvature used in this analysis was the approach curvature from 250 through 50 ft before the site. The gradient was the average value of the gradient from 200 ft before the site to the site itself. Average values of curvature in excess of 2 degrees were categorized as sharp, while those between 0.1 and 2 degrees were categorized as gentle.

The results of the contingency-table analysis of the combined horizontal and vertical curvature for guardrail and nonguardrail crash sites are presented in Table 5. Statistical testing indicated that, at both guardrail and nonguardrail sites, curvature and gradient are not independent. The small number of observations in certain cells of the table detract from the statistical significance of this finding. However, the table clearly indicates the excess number of crashes at both the guardrail and nonguardrail sites that occur on curves to the left. Testing did indicate that, at both types of sites, crashes occurred on downgrades at curves at approximately twice the statistically expected level.

An attempt was made to relate observed crash severity to roadway and roadside parameters by using multiple regression techniques. The equations that were developed explained only a small portion of the observed variation. The discrete nature of the severity scale (fatal, injury, and PDO), coupled with the fact that many parameters not measured in this study can contribute to crash severity, led to the abandonment of this approach.

Discriminant analysis was used to determine if a

Table 3. Guardrail characteristics at study sites.

Item	Value
Type of guardrail (%)	
Blocked-out W-beam	64.9
Regular W-beam	23.4
Thrie beam	6.3
Cable	2.7
U-channel	2.7
Terminal type (%)	
Buried	39.0
Breakaway	26.5
Old style	24.8
Not applicable	9.7
Purpose for installing guardrail (%)	
Bridge approach	31.0
Embankment	31.0
River	10.6
Culvert	9.7
Other	8.8
Overpass or underpass	7.1
Ditch	1.8
Avg guardrail height (ft)	2.23
Range of heights (ft)	1.2-3.2

Table 4. Crash severity versus guardrail characteristics.

	No. of Accidents		
Item	Fatal	Injury	PDO
Type of guardrail			
Blocked-out W-beam	7	52	13
Regular W-beam	4	14	8
Thrie beam	1	4	2
Other	0	5	3
Terminal type			
Buried	4	29	11
Breakaway	2	22	6
Old style	3	17	8
Not applicable	3	7	1
Purpose			
Bridge approach	5	26	4
Embankment	3	19	13
River	1	7	4
Culvert	0	10	3
Other	3	13	2

Table 5. Combined effect of approach curvature and approach gradient.

	Curvature[a]				
Gradient (%)	Sharp Right	Gentle Right	Nearly Tangent	Gentle Left	Sharp Left
Guardrail sites					
>-2	3	6	71	6	8
<-2	2	3	6	4	4
Run-off-the-road sites					
>-2	2	7	61	9	8
<-2	3	0	11	6	6

[a]Tangents have a curvature of less than 0.1 degree, gentle curves between 0.1 and 2.0 degrees, and sharp curves greater than 2.0 degrees.

set of independent variables could be used to establish the classification of the dependent variable--crash severity. The independent variables used in the discriminant analysis to predict the severity of guardrail crashes were approach degree of curvature and gradient, roadside slope, guardrail height, traffic volume, pavement width and friction, shoulder width, and posted speed limit. All of these parameters except guardrail height and posted speed limit were also used in the discriminant analysis at the nonguardrail crash sites.

The results, summarized in the table below, show the actual severity of the accidents versus the severity based on the discriminant analysis:

	Classified Severity		
Actual Severity	Fatal	Injury	PDO
Guardrail crash sites			
Fatal	10	2	0
Injury	3	66	2
PDO	0	10	12
Nonguardrail crash sites			
Fatal	12	6	1
Injury	7	53	15
PDO	0	0	13

It is not possible to use the entire set of study sites because one or more data items might be missing at a particular site. In the case of the guardrail sites, the discriminant analysis properly classified 84 percent of the accidents according to their actual severity. The analysis for the nonguardrail sites properly classified 73 percent of the crash severities. Recognizing that the discriminant analysis does not give direct consideration to many nonhighway factors (such as vehicle type and actual speed at time of collision), the discriminant analysis does a good job of distinguishing crash severity on the basis of the selected roadway and roadside parameters. A subsequent analysis found that two factors that can influence crash severity--vehicle occupancy and safety belt use--reportedly were not significantly different for the guardrail and run-off-the-road crashes.

The discriminant analysis was also applied to the entire data set to determine the feasibility of distinguishing the type of site on the basis of selected crash-site characteristics. The characteristics used for this purpose were the approach degree of curvature and gradient, the roadside slope, and the shoulder width. These variables were employed to create a model that would classify a site on the basis of these characteristics as either a guardrail or a run-off-the-road crash. Good success was obtained with the data from the guardrail sites, where 90 percent of the sites were properly classified on the basis of these four variables. On the other hand, only 62 of the nonguardrail sites were properly classified, while the remainder were erroneously classified as having characteristics more similar to those of the guardrail sites. This finding is important because it indicates that, despite the differences among guardrail sites, the sites are generally similar enough to be properly classified. On the other hand, nearly half of the nonguardrail sites exhibit roadway and roadside characteristics that are more similar to those at the guardrail sites. On a statistical basis, as opposed to an engineering design basis, nearly half of the nonguardrail sites should have had guardrail installed. The results of the discriminant analysis of sites are summarized in the table below:

	Classified Site	
Actual Site	Guardrail	Run-off-the-Road
Guardrail	102	11
Run-off-the-road	51	62

Several differences between the characteristics at guardrail and nonguardrail sites have been cited. It is also important to note that both sites have different characteristics than the roadway system in general. Although an extensive sampling procedure would be necessary to thoroughly describe the system characteristics, it is possible to reach some general conclusions through logic and limited sampling. Intuition suggests that there are as many curves to the right as to the left, and if the directions of curvature are assigned opposite algebraic signs, then the average curvature on the road is zero. Also, for every upgrade there is a corresponding downgrade, and the result is that the average gradient is zero. A recent study (4) supports both of these conclusions, as well as finding that the average roadside slope is approximately 14 percent.

Data from this study show, however, that the sites of both types of crashes have significant curvature to the left. It was also found that the average gradient at the guardrail sites was significantly less than zero. The roadside slopes, which had average values of 18 percent at the nonguardrail sites and 21 percent behind the guardrail, are also steeper than for the roadway system in general. In other words, the roadways and roadsides at these sites are significantly different than the typical roadway. The relevance of this to the engineer is that the crashes are considerably more frequent at locations with adverse geometrics and that the engineer has a basis for selecting sites for corrective action.

PRIORITIZING GUARDRAIL IMPROVEMENTS

The numerous findings reported in this paper, which for the sake of brevity will not be recounted, form a partial basis for developing a guardrail improvement program that would assign the proper weights to the upgrading of existing guardrail versus the installation of new guardrail. Recognition must be given, however, to the following facts:

1. When normalized for vehicle travel or highway mileage, New Mexico currently uses less guardrail than most other states, and
2. For the most part, existing guardrail in New Mexico appears to be performing satisfactorily.

As those familiar with guardrail use are aware, the installation of guardrail is warranted by the engineer's inability, due to economic or physical constraints, to provide a clear, traversible roadside. Guardrail is a fixed object and will not prevent accidents. Its only proven benefit is that, when properly installed, it can reduce severity. Priorities must therefore be based on the severity-reduction potential of upgrading versus new installation.

From a practical viewpoint, severity reduction actually embodies two concepts. In one instance it refers to the decrease in crash severity from fatal or injury to PDO. Recognizing that the difference between fatal and injury accidents is primarily one of degree and luck rather than substance, and that a PDO accident is the best result that guardrail can produce, the proper perspective for judging this component of severity reduction is the potential to change accidents from injury to PDO crashes. The second aspect of severity reduction deals with the potential for an improvement at a specific location to reduce the statewide number of injury accidents involving guardrail. Superficially, this second component would appear to be directly related to traffic volume, since higher volume moving past a

particular site would seem to increase the likelihood of impact with a guardrail. However, data from this and other studies clearly show that the probability of a vehicle departing from the traveled roadway is related to roadway characteristics--specifically, curvature and gradient. This is also supported by accident rate data, which are not the same for all road systems. The fact is that geometrics are more likely to be worse on non-Interstate facilities, thus increasing the probability of a vehicle running off the road. This is indicated by the data base of more than 3000 guardrail, fatal, injury overturning, and selected fixed-object accidents from which the study sites for this project were selected, which shows that the rates for these types of accidents are 27 percent higher on the federal-aid primary system and 40 percent higher on the federal-aid secondary system than on the Interstate system. The data also show that the severity indices for these crashes are identical on the three types of roadway systems. Although it is therefore appropriate to consider traffic volume in setting priorities, it is necessary to make an adjustment on the basis of the roadway system.

Numerous studies support the concept that speed at impact is related to crash severity. At the same time, the engineer has negligible control over speed at impact and, for the rural state highways examined in this study, there is little evidence that the vehicular speed at impact is related to the posted speed limit. The complete absence of a significant correlation between posted speed limit and crash severity at both the guardrail and nonguardrail sites, which can be attributed partly to the 55-mph speed limit at most of the study sites, supports this concept. Thus, while corrective action involving the upgrading or installation of guardrail may be concentrated on higher-speed facilities, the justification for such action is not that these facilities have higher speed limits.

A literal interpretation of the data from this study suggests that the top priority for improvement should be given to the highest rate-adjusted volume location on the steepest downgrade that has the sharpest curve to the left and the steepest side slope. At this location, wherever it may be, the existing guardrail should meet or exceed American Association of State Highway and Transportation Officials (AASHTO) guardrail standards (5) or new guardrail should be installed. The chances are that if this location exists, it is already adequately shielded. The more likely situation is that this condition does not exist, but rather that there are separate locations with highest volume, steepest downgrade, etc. The problem is further complicated by the fact that certain parameters that the engineer is not likely to measure, such as the extent of roadway use by nonfamiliar drivers, affect the probability of a vehicle leaving the roadway and thus influence the potential merits of an improvement.

A factor that increases the difficulty of establishing priorities is that 62 percent of the guardrail crashes and 54 percent of the nonguardrail crash sites are at tangent locations that are characterized by upgrades or minor downgrades. However, this set of design characteristics exists on more than 75 percent of the rural New Mexico state highway system. Thus, while these good design characteristics are found at a substantial number of crash sites, they are actually underrepresented with respect to their share of the roadway system. It is difficult to conceive of a priority scheme that would emphasize these locations for either upgrading or the installation of new guardrail.

The New Mexico State Highway Department, through its inventory, can identify all of its existing guardrail installations, classified by design adequacy. The Highway Department can identify locations that meet current AASHTO standards for the installation of new guardrail. There is good reason to assume that the existing warrants, as they relate to embankment depth and slope, are conservative, in that they do not require the use of guardrail at locations with obviously hazardous conditions. A more realistic set of warrants would clearly increase the number of potential sites to be prioritized.

The priority for selecting sites for improvement will be established by using a severity-reduction index calculated on the basis of three parameters: adjusted volume, potential for severity reduction, and likelihood of vehicle departure. The product of these three factors is a measure of the increased safety provided at a location through the installation or upgrading of guardrail to current standards.

The importance of traffic volume, adjusted for the rate of run-off-the-road types of accidents on the various types of facilities, has been previously noted. The roadway system factor (R) in the index is established from the average daily traffic (V) at the site, as follows:

R = V for Interstate highways,
R = 1.27V for federal-aid primary highways, and
R = 1.40V for federal-aid secondary highways.

The severity reduction potential of a guardrail installation is established on the basis that a properly designed and installed guardrail might achieve a severity index of 0.30, which is the lower limit of values reported in the technical literature. Analysis of New Mexico's accident data showed that guardrail of the older design currently has a severity index of approximately 0.4, while guardrail at bridges has a severity index of 0.45. Similar analyses determined the severity indices for accidents involving ditches (0.40), culverts (0.50), embankments (0.51), and abutments (0.60). This information was used to establish the severity-reduction factor (S), as follows:

Type of Improvement	S
Upgrade deficient guardrail	0.10
New guardrail at ditch	0.10
Upgrade guardrail at bridge	0.15
New guardrail at culvert	0.20
New guardrail at embankment	0.21
New guardrail at abutment or bridge	0.30

The third factor in the index is based on geometrics and reflects the relative probability of running off the road under various conditions of roadway alignment. The factor was established on the basis of the ratio of curvature and alignment conditions found at the study sites to the estimated extent of similar characteristics on the remainder of the roadway system. The ratios were normalized to a base value of unity. The alignment factor (A) is as follows:

	Curvature			
Gradient (%)	2°R-0.1°L	0.1°L-2°L	>2°R	>2°L
>-2	1.0	1.3	2.2	7.1
<-2	1.0	1.8	7.5	15.0

These three factors are used to calculate a severity-reduction index. The index is given by SRI = RSA/250, where SRI is the severity-reduction index (the other parameters are described above), and 250 normalizes the index to a range of 0 to approximately 100.

The index would be used in the following manner.

Initially, a set of locations would be identified where a guardrail is warranted or where existing guardrail is not in accord with current design standards. The limited data requirements for the index calculation can be met with existing records systems. The index could be calculated for each site, and highest priority would be given to sites with the highest values.

The procedure was applied to data collected in this study. This approach is not completely valid, since conditions at some of the nonguardrail crash sites do not meet AASHTO guardrail warrants. The resulting hazard indices ranged from 0 to 89. Although the median index value is 3.2, 25 percent of the sites have index values in excess of 7, and these are the locations needing the most immediate attention. Although the actual severity of individual crashes is not used directly in the model, the correlation between the calculated index and actual severity is positive, which suggests that the locations of more serious accidents tend to have higher indices. As a group, the nonguardrail sites had a significantly higher mean index (9.0) than the guardrail sites (3.3). This implies that more attention would initially be given to the nonguardrail sites. Among the sites with indices in excess of 7, only 27 percent were the locations that currently have guardrail. Bias in the sample used for this application of the model, which was due to the inclusion of some run-off-the-road sites that do not warrant guardrail, may be responsible for this result. The common characteristic of most of the guardrail sites with high indices is poor terminal treatment. W-beams without blockouts also tend to have higher indices. Cable guardrail sites tended to have low index values, principally because these locations had low traffic volumes. Sites with the highest indices are distributed proportionately among Interstate, primary, and secondary roadway systems, which indicates that concentration of improvements on one type of system would not be appropriate.

CONCLUSION

The research discussed in this paper has developed a rational and justifiable methodology for distributing funds for improvement between guardrail installation and upgrading. The merit of this approach is that it has the potential to achieve a high severity reduction for guardrail and selected run-off-the-road crashes under the constraint of a moderate funding level. It is recognized, however, that the optimal solution to the specific issue of new versus upgraded guardrail is not necessarily a component of a plan for the most cost-effective expenditure of limited highway monies. A well-conceived priority scheme for all highway improvements clearly needs to address issues and project types that were outside the scope of this project.

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REFERENCES

1. Fatal Accident Reporting System, Annual Report. National Highway Traffic Safety Administration, U.S. Department of Transportation, 1978.
2. J.W. Hall. Priorities for Guardrail Installation and Improvement. FHWA, Final Rept. FHWA-NMDOT-80-1, Nov. 1980.
3. Roy Jorgenson Associates, Inc. Cost and Safety Effectiveness of Highway Design Elements. NCHRP, Rept. 197, 1978.
4. J.W. Hall and P. Zador. A Survey of Single-Vehicle Fatal Rollover Crash Sites in New Mexico. New Mexico State Highway Department, Santa Fe, Nov. 1980.
5. Guide for Selecting, Locating, and Designing Traffic Barriers. AASHTO, Washington, DC, 1977.