

Guidelines for Installation of Guardrail

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Kentucky, along with most other states, has in the past relied on the American Association of State Highway and Transportation Officials' (AASHTO) *Guide for Selecting, Locating, and Designing Traffic Barriers* for guidance in the installation of guardrail. Additional information related to barrier selection and installation was recently published in AASHTO's *Roadside Design Guide*. However, considerable judgment is required for application of this information, and it was determined that significant benefit could be derived from development of guidelines representative of conditions in Kentucky. Listed as follows are significant results from this study: (a) results from a previous survey of guardrail standards and guidelines were summarized and it was found that only a few states suggested use of reduced guardrail standards that did not conform to AASHTO's barrier guide; (b) warranting guidelines for clear zones and embankments based on Kentucky accident severities and costs were developed from a computer program included as part of the *Roadside Design Guide*; and (c) a procedure was developed to identify and rank in priority order highway sections in need of guardrail [details to support the identification and ranking of the procedure were included in the full research report prepared for the Kentucky Transportation Cabinet in cooperation with the Federal Highway Administration (FHWA)]. This procedure was based on determination of locations with critical numbers and rates of run-off-road accidents, conduction of a field survey to tabulate hazard-index points, determination of improvement costs and benefits, and performance of a cost-effectiveness analysis.

Kentucky, along with most other states, has in the past relied on the American Association of State Highway and Transportation Officials' (AASHTO) publication, *Guide for Selecting, Locating, and Designing Traffic Barriers* (1), for guidance in the installation of guardrail. However, there are geometric constraints on existing roads that do not permit use of the AASHTO guidelines in many cases. In addition, there are other issues to be addressed when outdated guardrail sections or end treatments are damaged and in need of repair. Frequently it is impractical to install guardrail to meet current standards without major reconstruction. Benefits associated with removal of roadside hazards have been well documented and most highway agencies have made significant accomplishments in that area. However, some roadside hazards cannot be eliminated or the cost of removal is prohibitive. An alternative to removal of hazards is to shield those hazards so that the probability of a vehicle striking them is reduced. Longitudinal barriers such as guardrail, median barriers, and bridge rails are used to shield vehicles from hazards. Installation of barriers is usually based on the relative hazard of the barrier versus the unshielded hazard. The AASHTO barrier guide (1) has been used by many states to assist in the determination

of guardrail need and type. Generally, roadside barriers such as guardrail are used to shield vehicles from embankments or roadside obstacles. Warrants presented in the AASHTO publication are useful; however, considerable judgment is required to apply the generalized cases to specific problems in Kentucky. It appears that benefits could be derived from the development of standards and guidelines for the installation of guardrail, with special consideration given to traffic volumes, geometrics, and terrain representative of Kentucky. Priority ranking of safety features for roadways has been accomplished when sufficient information was available to document costs and benefits. The cost-effective selection procedure for guardrail presented in the AASHTO barrier guide is a method to be considered; however, input data necessary for the procedure may limit its application. With the goal to set up an inventory and rank locations in need of guardrail or other barriers on all state-maintained roads, there is a need for a simplified procedure.

STANDARDS FOR INSTALLATION AND REPAIR OF GUARDRAIL

AASHTO *Roadside Design Guide*

The AASHTO *Roadside Design Guide* (2) was developed as an update of the 1977 AASHTO barrier guide (1). The *Roadside Design Guide* was intended to be an updated, consolidated, and expanded source of information containing existing publications and policy statements that pertain to safer roadside design. The publication contains information and guidance on many aspects of safer roadside design for public streets and highways. Information has been extracted from several other AASHTO publications in order to compile in one source the most up-to-date guidelines relating to roadside safety. As with most other AASHTO publications, the *Roadside Design Guide* is not intended to be a standard or policy document, but instead a guide to practices that may be adopted by highway agencies responsible for roadside design, construction, and maintenance. Information contained in the *Roadside Design Guide* that was of particular use to this study was contained in the sections dealing with clear zones, embankments, and the cost-effectiveness analysis. The cost-effectiveness procedure in the 1977 barrier guide (1) allowed a designer to examine alternate safety treatments at specific locations to determine which one was more appropriate. In addition, the procedure was used by several highway agencies to analyze site-specific alternatives and to develop warrants in chart and tabular form using local data. Revisions to the cost-effectiveness procedure and adaption to a microcomputer format has made the new procedure included in the *Roadside*

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Design Guide more attractive to the user because of increase in speed and flexibility. In general, the cost-effectiveness procedure permits a designer to predict total costs of various alternatives under consideration. Total costs include initial construction, anticipated repair and maintenance, salvage value of the improvement, and user costs. User costs were based on the expected number and severity of accidents associated with each alternative. The number of accidents is directly related to the number of predicted encroachments and the probability of the encroachments resulting in an impact with a roadside hazard. Modifications to the procedure that are incorporated into the microcomputer program include the following:

1. An encroachment rate model,
2. A model relating lateral extent of encroachment and accident severity to design speed, and
3. A traffic growth-rate model.

The clear roadside concept was promoted in the second edition of the AASHTO "Yellow Book" (3). It was recommended that an unencumbered roadside recovery area as wide as practical would be desirable. As a result, most highway agencies began to attempt to provide a traversable and unobstructed roadside area of 30 ft or more from the edge of the driving lane. It was noted in the "Yellow Book" that previous studies had shown that 80 percent of the vehicles leaving the roadway out of control were able to recover within a width of 30 ft. The 1977 AASHTO barrier guide (1) in its Figure III-A-3 modified the 30-ft clear zone concept by including variable clear zone distances based on speeds and roadside geometry. This same set of curves for clear zone distances was modified further in the *Roadside Design Guide* in its Figure 3.1 to include traffic volume along with speed and roadside geometry. It was noted that the curves shown in the *Roadside Design Guide* were based on empirical data that were extrapolated to provide information on a wide range of conditions. It was also cautioned that site-specific conditions must be kept in mind when attempting to use the curves. Adjustment factors were developed for horizontal curvature with increasing clear zone requirements for increasing curvature. Embankments on fill slopes are generally categorized as recoverable, nonrecoverable, traversable, or critical. Recoverable slopes are embankment slopes 4:1 or flatter. Vehicles on recoverable slopes can usually be stopped or steered back to the roadway. A nonrecoverable slope is defined as one that is traversable, but such that a vehicle cannot be stopped or returned to the roadway easily. Embankments between 3:1 and 4:1 generally fall into this category. Slopes steeper than 3:1 are critical and are usually defined as a slope on which a vehicle is likely to overturn.

Kentucky Guardrail Policy

Kentucky's Department of Highways' *Maintenance Guidance Manual* (4) provides guidance for new guardrail installations and upgrading existing ones. It is noted that all projects for guardrail installation and upgrading should meet the warrants of Part I-III-A of the 1977 AASHTO barrier guide (1). Each highway district is required to maintain a current inventory

of all substandard and obsolete guardrail and all unshielded locations that are known to meet the warrants of Part I-III-A of the barrier guide. In addition, it is required that a cost-effectiveness ranking be defined for each location based on a statewide inventory. An additional requirement is that the Kentucky Department of Highways' Division of Maintenance prepares and administers an annual Guardrail Improvement Program. Funds budgeted for this program are to be allocated to those locations having the highest ranking factor and those that can be constructed without major reconstruction of the roadway. Alternatives to guardrail, such as hazard removal or relocation, flattening slopes, and pipe extensions are to be considered and may be included in the program. The issue of when to upgrade guardrail and when to repair or maintain with equivalent materials is a continuing problem. It is desirable that guidelines exist for details to be included in standards for repair and maintenance of guardrail on existing roadways that have not been designed and built to current standards. The general policy at the present time is that obsolete or substandard guardrail may be repaired or maintained with equivalent materials in stock or with available guardrail elements.

GUIDELINES FOR RECOMMENDED GUARDRAIL NEEDS

The *Roadside Design Guide* (2) contains figures and tables giving warrants for guardrail based on embankments and roadside obstacles. When considering the need for guardrail relative to embankments, the embankment height and side slope are the factors used to make the decision. The relative severity of encroachments on the embankment must be compared to impact with the guardrail. A figure using fill section height and slope was included in both the AASHTO barrier guide (Figure III-A-1) (1) and the *Roadside Design Guide* (2). Modified warrant charts were included in the *Roadside Design Guide* that consider the decreased probability of encroachments on lower-volume roads. The need for guardrail relative to roadside obstacles considers the necessary clear zone for the given roadway and the relative severity of hitting the obstacle versus hitting the guardrail. The necessary clear zone as a function of design speed, traffic volume, and fill or cut slope were given in Table 3.1 and Figure 3.1 in the *Roadside Design Guide* (2). Although warrants were presented for the need for guardrail based on embankment and roadside obstacle criteria in the *Roadside Design Guide*, the recommendation was made that highway agencies develop specific guidelines for their agency based on their cost-effectiveness evaluations. A cost-effectiveness selection procedure was given in Appendix A of the publication. This procedure was used to develop guidelines for the need of guardrail based on Kentucky data. A computer program (ROADSIDE) was obtained to conduct the cost-effectiveness analysis. Certain parameters, given as part of the program, had to be used, and values are specified unless changed. The accident cost figures and encroachment model were changed from those given as part of the computer program. The accident cost figures were based on the recommendations given in the FHWA's Technical Advisory T7570.1 (5). The encroachment model, which was obtained from TRB *Special Report 214* (6), is the exponential

encroachment model documented in Appendix F. The decision to use this model was made after analyzing the output from the program using alternate encroachment models. The model presented in TRB *Special Report 214* considered curvature and grade, whereas the model presented in ROAD-SIDE (2) required the curvature and grade to be input each time. For the type of analysis performed in this study, it was believed that the model in TRB *Special Report 214* would result in a more useful methodology. In general, it was believed that the use of the encroachment model from TRB *Special Report 214* produced results that were more logical for the objectives being addressed in this study.

Two separate types of analyses were conducted that were related to clear zone and embankment criteria. The computer program required various types of input, and the output was the total cost (including accident, installation, repair and maintenance costs, and salvage value). The total cost was then compared with and without a guardrail using the appropriate set of assumptions. These were the only two alternatives considered. When the total cost with a guardrail present became less than that with no guardrail, it was assumed that a guardrail was warranted. The variables analyzed varied, and included the traffic volume, design speed, lateral placement, longitudinal length, width of obstacle, severity index, and cost of installation. In the clear zone analysis, the total costs of striking a guardrail or fixed object at an isolated point with a longitudinal length of 1 ft and a width of 1 ft were compared. If guardrail was warranted for a single object, then it was assumed that a barrier to shield multiple objects would also be warranted. The lateral offset of the fixed object was varied with a 2-ft offset of the fixed object behind the guardrail and a maximum lateral offset of 10 ft for the guardrail. Severity indices were calculated using Kentucky accident data. Severity index is calculated by dividing the number of equivalent property-damage-only accidents by the total number of accidents. Equivalent property-damage-only accidents are equal to 9.5 times the number of fatal or incapacitating accidents, plus 3.5 times the number of nonincapacitating or possible injury accidents, plus the number of no-injury accidents. The severity of accidents involving a collision with a guardrail or a tree as the first event were compared as a function of speed limit. The severity indices used for guardrail were 2.2 for 40 mph, 2.5 for 50 mph, and 2.8 for 60 mph. These indices were developed from a wide range of accidents involving guardrail impacts. Similarly, for impacts at the end of a guardrail, there were several types of end treatments involved. The severity indices used for fixed objects were 3.1 for 40 mph, 3.4 for 50 mph, and 3.7 for 60 mph. The program limited the speeds to 40, 50, or 60 mph. A minimum length of 200 ft and an installation cost of \$2,000 was used for the guardrail.

Numerous series of computer runs were conducted with the traffic volume and speed held constant and the lateral offset varied. For a specific volume and speed, two sets of computer runs were made. One used the data assuming no guardrail and the second assumed the appropriate data for guardrail. When the total cost at the lateral offset of the guardrail became less than that for a corresponding offset for the fixed object, the guardrail was determined to be warranted. The results of these analyses are given in Table 1. The traffic volume categories varied from 250 to "over 5,000" with speed categories of 40, 50, and 60 mph. For the 50-mph speed cat-

TABLE 1 CLEAR ZONE DISTANCES*

TRAFFIC VOLUME (ADT)	CLEAR ZONE DISTANCE TRAFFIC SPEED		
	40 MPH	50 MPH	60 MPH
250	**	3	12
500	**	9	16
1,000	5	13	19
2,000	9	16	21
3,000	11	18	22
4,000	13	18	22
5,000	14	19	23
Over 5,000	15	20	23

* The minimum clear zone distance needed without the installation of guardrail.

** An ADT of 700 was needed before the minimum two-foot clear zone would be required.

egory, the minimum clear zone distance needed without the installation of guardrail varied from 3 ft for average daily traffic (ADT) of 250 to 20 ft for ADT of more than 5,000. A similar type of procedure was used in the embankment analysis. A limiting factor in this analysis was the lack of data related to the severity of accidents as a function of embankment height and slope. The only accident data noted that yielded accident severity versus embankment height and slope were single vehicle embankment accidents in California in 1963 (7). It should be noted that the data base representing California embankment accidents in 1963 consisted of a greater proportion of larger cars than are currently in the vehicle fleet. Larger cars are less likely to overturn than smaller cars because their wider track width makes them more stable. Severity indices compatible with indices for accidents involving guardrail in Kentucky were calculated using these data and a severity index formula used in Kentucky (8) (Table 2). It was not possible to calculate the severity index as a function of speed. The overall severity index of all accidents involving guardrail in Kentucky was calculated as 2.67. This severity index was compared with those calculated using the California data. It can be seen that the severity of hitting a guardrail (severity index of 2.67) was greater than that for driving over an embankment when the slope was 3:1 or flatter. There was a range of severity indices from 2.47 for embankment height of 3 ft to 2.63 for an embankment height of 25 ft. Therefore, no guardrail could be warranted for a slope of 3:1 or flatter.

TABLE 2 SEVERITY INDEX VERSUS EMBANKMENT HEIGHT AND SLOPE*

EMBANKMENT HEIGHT	SLOPE			
	3:1	2:1	1:1	1:1
3	2.47	2.71	2.96	3.44
8	2.51	2.75	2.99	3.47
15	2.56	2.80	3.04	3.52
25	2.63	2.87	3.11	3.59
35	**	2.94	3.18	3.66
45	**	3.01	3.25	3.74
60	**	3.12	3.36	3.84

* Severity Index (SI) is: $SI = (9.5(K+A) + 3.5(B+C) + PDO)/T$
 where K = fatal accident,
 A = incapacitating injury accident,
 B = nonincapacitating injury accident,
 C = "possible" injury accident, and
 T = total accidents.

** No data.

It should be noted that the severity of an accident involving an embankment relates to the vehicle overturning or striking fixed object hazards either on the slope or at its base. Therefore, these severity indices must be used with caution for slopes that are nontraversable or include fixed objects. A speed of 50 mph was used in the embankment analysis. The severity indices were not classified by speed so one representative speed had to be selected. It was believed that the 50 mph speed would be most representative of the roads for which this analysis would be used. For the guardrail installation, a lateral placement of 5 ft was assumed with a longitudinal length of 200 ft and a width of 1 ft. When the embankment was considered, a lateral placement of 7 ft was assumed, with a longitudinal length of 200 ft and a width of the embankment height times the slope (for example, the width would be 20 ft for an embankment height of 10 ft and a slope of 2:1). For a given traffic volume, the total cost of the guardrail was compared with various embankment heights. When the cost associated with the embankment exceeded that for the guardrail, a guardrail was warranted. The results of this analysis are presented in Table 3. For a slope of 2:1, the embankment height at which guardrail was warranted varied from 40 ft for ADT of 250 to 15 ft for ADT of more than 5,000. When the slope became steeper than 2:1, a guardrail was warranted in all cases in which the embankment height was above a minimum level. Using *Roadside Design Guide* Figure 5.1 (2) as a reference, this minimum embankment height would be about 5 ft.

PROCEDURE TO IDENTIFY AND RANK LOCATIONS IN NEED OF GUARDRAIL

Develop Critical Numbers and Rates of Run-off-Road Accidents

A procedure has been in place for several years to develop average and critical accident rates for use by the Kentucky Department of Highways in the identification of high-accident locations (9). In general, the critical rate for a type of highway is calculated using statistical tests to determine whether the

accident rate for a specific class of highway is abnormally high compared with a predetermined average for highways with similar characteristics. The statistical tests are based on the commonly accepted assumption that accidents approximate the Poisson distribution. Using this procedure, locations have routinely been inspected and accident data have been analyzed to offer recommendations for improvements, when appropriate. Another study resulted in the development of accident reduction-factors for use in the cost-optimization procedure to rank proposed safety improvements (10). The general procedure to develop critical accident numbers and rates relies on the historical accident file and a volume file. Accident data are available from the Kentucky Accident Records System. Volume data used for the calculation of accident rates were obtained from the Statewide Mileage File. As previously noted, the general procedure to develop accident rates, including critical accident rates and numbers, has been documented (9,11). An annual report is now produced to calculate average and critical rates as a means of analyzing statewide accident statistics (12). It was necessary to determine numbers of accidents and to develop average rates and critical rates as input for the high-accident identification program. To permit the use of this procedure to develop average and critical numbers and rates of accidents for use with the guardrail location selection program, the procedure to identify only those accidents associated with vehicles running off the road had to be modified. It was assumed that guardrail installation would be of benefit only in accidents where vehicles ran off the road. Analysis revealed that three types of accidents made up a very high percentage (99 percent) of the total. Those three types of accidents were

1. Single-vehicle collision with a fixed-object at an intersection;
2. Single-vehicle collision with a fixed-object not at an intersection; and
3. Single-vehicle, run-off-road accident, not at an intersection.

It was found that approximately two-thirds of all run-off-road accidents involve collisions with fixed objects. Other run-off-road accidents included noncollisions, possibly involving roll-overs. A summary of fixed-object accidents and their overall severity based on a calculated severity index was prepared (8). It can be seen by the magnitude of the severity index that the most severe fixed-object accidents are those involving trees (3.52), culverts and headwalls (3.38), earth embankments, rock cut, and ditches (3.14), and bridges (2.95). The most frequently occurring fixed-object accidents are collisions with earth embankment, rock cut, and ditches; and trees, utility poles, and fences. The least severe accidents are those involving buildings and walls (1.56) and fire hydrants (1.70). The severity index for guardrail impacts was 2.67, which was in the mid-range of severity indices.

After identification of those accidents that could be affected by the installation of guardrail, average and critical numbers and rates of run-off-road accidents were summarized for 1-mi sections. The average and critical numbers for 1983-1987 are shown in Table 4 for various highway types. Accident rates by highway types for rural and urban areas are presented in Tables 5 and 6, respectively. Also shown in these tables

TABLE 3 EMBANKMENT GUIDELINES

TRAFFIC VOLUME (ADT)	EMBANKMENT HEIGHT (FT)*
	SLOPE**
	2:1
250	40
500	31
1,000	24
2,000	20
3,000	18
4,000	17
5,000	16
OVER 5,000	15

* The maximum embankment height permitted without guardrail.

** Guardrail not warranted for slope of 3:1 or flatter. Guardrail would be warranted for a slope steeper than 2:1 when the embankment height was above a minimum level of about 5 feet.

Note: Refer to text section titled "Guardrail Need Guidelines" for methodology used in development of table.

TABLE 4 STATEWIDE AVERAGE AND CRITICAL NUMBERS OF RUN-OFF-ROAD ACCIDENTS FOR 0.3- AND 1-MILE SECTIONS BY HIGHWAY TYPE CLASSIFICATION (1983–1987)*

Rural or Urban	Highway Type	Accidents Per 0.3-Mile Section		Accidents Per 1-Mile Section	
		Average	Critical Number	Average	Critical Number
Rural	One-Lane	0.20	2	0.67	3
	Two-Lane	0.63	3	2.10	6
	Three-Lane	1.64	5	5.46	12
	Four-Lane Divided (Non-Interstate or Parkway)	1.36	5	4.54	11
	Four-Lane Undivided	2.30	7	7.67	15
	Interstate	2.21	7	7.37	15
	Parkway	0.74	3	2.46	7
	All Rural	0.68	3	2.26	7
Urban	Two-Lane	2.75	8	9.18	17
	Three-Lane	3.00	8	10.00	19
	Four-Lane Divided (Non-Interstate or Parkway)	3.48	9	11.59	21
	Four-Lane Undivided	4.27	10	14.24	24
	Interstate	8.56	17	28.53	43
	Parkway	1.28	5	4.26	10
	All Urban**	3.48	9	11.60	21

* Includes small number of miles of one-, five-, and six-lane highways.

TABLE 5 STATEWIDE RURAL RUN-OFF-ROAD ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (1983–1987)

Highway Type	Total Mileage*	AADT	Run-off-the-Road Accident Rate (Acc/100 MVM)
One-Lane	328	200	183
Two-Lane	21,288	1,200	94
Three-Lane	15	2,280	132
Four-Lane Divided (Non-Interstate or Parkway)	293	7,460	33
Four-Lane Undivided	60	8,460	50
Interstate	576	18,380	22
Parkway	545	4,080	33
All	23,106	1,800	69

* Average for the five years.

are the total mileage and annual average daily traffic (AADT) for each highway type. Using the previously referenced equation, critical accident rates were calculated for each type of rural and urban highway, and cross-tabulated by volume category and section length. Also calculated were critical run-off-road accident rates for spots (defined as highway sections 0.3 mi in length) on rural and urban highways.

List Locations with Critical Rates of Run-off-Road Accidents

An existing computer program to identify high-accident locations was modified to identify run-off-road accident locations. Output from this computer program was a listing of accident locations by decreasing critical rate factor in order of county, route, and mileposts. For this analysis, the critical

TABLE 6 STATEWIDE URBAN RUN-OFF-ROAD ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (1983–1987)

Highway Type	Total Mileage*	AADT	Run-off-the-Road Accident Rate (Acc/100 MVM)
Two-Lane	1,161	6,240	81
Three-Lane	11	9,350	59
Four-Lane Divided (Non-Interstate or Parkway)	258	18,940	34
Four-Lane Undivided	168	18,270	43
Interstate	159	44,530	35
Parkway	40	6,780	34
All	1,807**	12,650	50

* Average for the five years.

** Includes small number of miles of one-, five-, and six-lane highways.

rate factor was defined as the average accident rate for a section divided by the critical rate for that same section. Other information presented in the printout included number of accidents, number of lanes, highway class, rural-urban designation, and AADT. The listing represented all highway sections of 1-mi length with five or more accidents in a 5-year period. It was assumed from the beginning that sections 1 mi in length were the most appropriate for analysis to determine the need for guardrail; however, 0.3-mi sections with three or more accidents in a 5-year period were also analyzed and determined to have advantages as alternate means of identifying locations in need of guardrail. A similar computer summary was prepared for 0.3-mi sections listing accident locations by decreasing critical rate factor in order of county, route, and mileposts. Another form of output from the run-off-road accident identification procedure was a listing of all locations with critical rate factors greater than 1.0. A critical rate factor greater than 1.0 means that the accident rate for a section of highway exceeds the critical rate for that class or type of highway statewide. Included for each accident are milepost location, date of accident, directional analysis, description of accident type, light and road surface conditions, collision type, and number injured or killed.

These listings represent the first step of a method for identification of locations in need of guardrail. With the use of previously discussed computer printouts of locations with critical rates of run-off-road accidents, a listing by county can be prepared for selecting highway sections that should be subjected to the field survey. This procedure would eliminate the need to survey all highway sections, thereby concentrating efforts on sections previously identified as having accident rates exceeding the critical level. Locations with critical rates greater than 1.0 have high accident rates; however, these locations do not necessarily need guardrail because guardrail may already exist or there may be other improvement alternatives. A total of 1,069 1-mi and 2,845 0.3-mi sections were identified throughout the state.

Develop a Hazard-Index Point System

Before conducting a field survey, it was found that there was a need to develop a system for relating the operational and geometric characteristics of highway sections with their accident history to determine which sections exhibited the great-

est need for guardrail. In addition to accident statistics, there are several characteristics that can be associated with the potential for accidents. The following characteristics were selected to represent a hazard-index rating of highway sections.

<i>Characteristics</i>	<i>Rating Points Possible</i>
1. Number of run-off-road accidents	15
2. Run-off-road accident rate	15
3. Traffic volume	10
4. Speed limit or prevailing speed	10
5. Lane and shoulder width	10
6. Roadside recovery distance	10
7. Embankment slope	10
8. Embankment height	10
9. Culvert presence	5
10. Subjective roadside hazard rating	5

An attempt was made to include characteristics representative of accidents and accident potential, operations, and cross section. Point-system weightings of each characteristic were determined by subjective evaluation. The result was combining number of accidents and accident rate to make up 30 of a possible 100 points. Traffic volume and speed limit, considered to be operational characteristics, totaled 20 of the possible 100 points. Cross-section characteristics made up an additional 40 points. Because of their frequency of occurrence and the hazard associated with culvert headwalls or openings near the roadway, a special category was created to represent this condition. For a culvert present within 5 ft of the road, 5 points were assigned. Also included was a general category representing a subjective roadside hazard rating with 5 points possible. This rating was based on a visual observation that was compared with photographic documentation of roadway sections depicting various degrees of roadside hazard.

Conduct Field Survey

Another step in the overall process of identifying locations in need of guardrail is a field survey of locations having critical rate factors of 1.00 or greater. General guidance in the selection of variables to consider in the field survey was taken from the earlier work by Zegeer (13). Specific cross-section information that will require a field survey includes the following: (a) lane and shoulder width, (b) roadside recovery distance, (c) embankment slope, (d) embankment height, (e) presence of a culvert, and (f) subjective roadside hazard rating. Additional field data collection may be required to obtain prevailing speed if it is less than the speed limit.

In order to implement the field survey process, a form was developed for use by Kentucky Department of Highways' personnel to document roadway cross-section and other conditions determined to be useful. This form includes space for all variables that will require rating points to be assigned, in addition to general location information and accident statistics.

It is recommended that additional information be documented for each highway section to be surveyed. Included will be the following general information: date, county, district, route number, range of mile points, type of area, terrain, AADT, and number of lanes. The result will be a combination of field and other data collection, primarily from files maintained by the Department of Highways. Only 10 variables or characteristics will be assigned hazard-index rating points.

Other characteristics for which data are not to be collected will not be assigned rating points but will be available to provide general information to the decision maker. Tests of the survey form were conducted to determine if it was reasonable and understandable for use by field personnel to document operational and cross-section information. It was determined that a listing of accident locations by county having critical rate factors shown would provide sufficient information to select those locations to be surveyed. Listings of accident locations are arranged by increasing route number within a county, and mile points are given to permit location of a specific section on a route. In addition, critical rate factors are tabulated for use in selecting factors greater than 1.0 or some other desirable minimum level. The remaining information necessary to prepare for and complete the field survey process consisted of detailed listings of individual accidents at 0.3-mi and 1-mi sections. The resulting package of information determined to be necessary to efficiently conduct the field survey contained the following:

1. A listing of accident locations by county with critical rate factors tabulated,
2. A county map,
3. A route mile point log by county, and
4. A detailed listing of individual accidents for 0.3-mi and 1-mi sections.

Tabulate Hazard-Index Points

After assignment of hazard-index points to each of the variables or characteristics (from the accident history and the field survey), the next step is to summarize and tabulate hazard-index points for each highway section. It is recommended that lists of locations be prepared with total hazard-index points in decreasing order for all locations statewide and then for several subcategories such as district, county, and highway class (federal-aid or functional class). The purpose for this listing will be to identify a manageable number of locations for which cost-effectiveness analysis can be performed. The result will be a listing of locations with a combination of accident history and cross-section characteristics that could serve as the basis for collection of cost and benefit data.

Determine Improvement Costs

As part of the field survey process, it will be necessary to evaluate each location having a critical rate factor of 1.00 or greater to determine whether improvements should be recommended. Because the run-off-road accident analysis will identify locations based on number and rate of accidents only, it is likely that some locations having existing barriers or other roadside improvements will appear on the list. This will require that each location be assessed to determine whether any improvement should be made. However, it is anticipated that improvement alternatives will be available at the majority of locations and that the type and cost of these improvements will need to be documented.

At the beginning of this study, it was generally assumed that the primary type of improvement would be installation of guardrail. The focus on guardrail was the result of an initial

request to identify locations in need of guardrail so that a listing of priority order could be prepared and made available to the Department of Highways. This listing was to be used to assist in the selection of projects to be funded for installation and enhancement of guardrail. It is obvious that several alternatives usually exist when encountering roadside hazards. Among the most frequently mentioned are removal or relocation of fixed objects and flattening side slopes. Frequently encountered roadside hazards and the cost to remove or reduce the hazard potential were tabulated by Zegeer et al. (13). Additional information on improvement costs is available from the Kentucky Department of Highways' unit bid prices, which are tabulated for all projects awarded during each calendar year (14). As an example, unit bid prices for W-beam guardrail installation was \$8.06/linear ft during a recent year.

Determine Improvement Benefits

The benefits of improvements associated with roadside hazards are primarily the result of reduced accidents. To determine the expected benefits from various types of improvements, it will be necessary to relate accident reduction factors to specific types of improvement alternatives. Previous work by Creasey and Agent (15) provides a wide range of accident reduction factors that may be directly applied to improvements recommended as part of this program. Selected accident reduction factors from Creasey and Agent's work that may be related to run-off-road accidents were tabulated. Included are reduction factors for the following major areas of safety improvements:

- Pavement marking,
- Construction-reconstruction,
- Safety barriers,
- Safety poles and posts, and
- Removal or relocation of roadside obstacles.

Detailed accident data for each location will be available from the run-off-road accident summaries prepared as part of the analysis to determine critical rates. The type of information presented, previously noted, included the number of fatalities and injuries and the total number of accidents. These data can be converted to total accident benefits by associating accident severity (types of injuries and property damage) with costs for each type. Costs for each level of accident severity have been developed and recommended by FHWA (4). Those accident costs recommended by FHWA and recommended for use in determining improvement benefits areas are as follows:

- Fatality: \$1,500,000;
- Injury: \$11,000; and
- Property damage only: \$2,000.

Therefore, the combination of accident reduction factors, accident severity from the historical data at a specific location, and costs for each accident severity level will result in an accident reduction benefit (cost savings) associated with each improvement alternative.

Analyze Cost-Effectiveness

The final step in the process of evaluating roadside safety needs is to combine cost and benefit data to determine the cost-effectiveness of alternative improvements. A simple listing of improvement alternatives in order of decreasing benefit-cost would provide information to allow selection of locations with the greatest benefit-cost ratio. However, with restricted budget amounts available, it would be appropriate to use a budget optimization procedure to select those alternatives so that maximum benefits could be derived. Documentation of a procedure for budget optimization was prepared by Crabtree and Mayes and adapted for the Highway Safety Improvement Program in Kentucky (16). Output from the budget optimization procedure will be a listing of information for each location, consisting of the location name and number, accident history, input for each improvement alternative, and benefit-cost ratio for each alternative. For each budget specified, a listing will be provided showing the selected alternative at each location, alternative costs and benefits, and the benefit-cost ratio. In general, budget optimization will provide a listing of selected projects and selected alternatives for a given budget. If a certain amount of money is designated for roadside safety improvements, this procedure will allow maximum benefits to be achieved.

SUMMARY OF RESULTS

The following is a summary of significant results related to this investigation of standards and guidelines for guardrail installations:

1. From a previous survey of guardrail standards and guidelines, it was determined that only a few states suggested the use of reduced guardrail standards. Georgia, Pennsylvania, and Indiana were exceptions, with lower standards considered only for low-volume, low-speed roads.
2. The AASHTO *Roadside Design Guide* (2) offered general guidance related to roadside safety and suggested that states develop their own warranting criteria for clear zones and embankments based on localized cost-effectiveness.
3. Kentucky's guardrail policy requires administration of an annual Guardrail Improvement Program, including a cost-effectiveness ranking for each location based on a statewide inventory.
4. A computer program (ROADSIDE) from the *Roadside Design Guide* was modified and used to develop warranting guidelines for clear zones and embankments based on accident severities and costs representative of Kentucky conditions.
5. A procedure was developed to identify and rank in order of priority locations in need of guardrail based on the following steps:
 - a. Development of critical numbers and rates of run-off-road accidents,
 - b. Preparation of a list of locations with critical rates of run-off-road accidents,
 - c. Development of a hazard-index point system,
 - d. Conduction of a field survey,
 - e. Tabulation of hazard-index points,
 - f. Determination of improvement costs,

- g. Determination of improvement benefits, and
- h. Analysis of cost-effectiveness.

IMPLEMENTATION

A procedure was developed to identify and rank in order of priority highway sections in need of guardrail. This procedure permits adoption of a systematic process of identifying locations with the greatest need for guardrail. Based on an initial selection of locations with critical numbers and rates of run-off-road accidents, a field survey will be required to catalog operational and cross-section characteristics for input into a hazard-index point system. It is recommended that locations be categorized in decreasing order of hazard-index points statewide and for subcategories such as district, county, or highway class. When only guardrail is considered as an improvement alternative, the need for guardrail can be determined based on a comparison of cross-section characteristics with criteria presented in Table 1 for clear zones and Table 3 for embankments. These criteria or warranting guidelines were developed using the computer program ROADSIDE from the *Roadside Design Guide* (2) based on accident severities and costs representative of Kentucky conditions. Whether only guardrail or other alternatives are considered, sufficient information will be available to determine improvement priorities based on cost-effectiveness and budget optimization.

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