

## HIGHWAY SAFETY REQUIREMENTS FOR LOW-VOLUME RURAL ROADS

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This paper summarizes research that was undertaken to reevaluate the safety needs on low-volume rural roads. Based on a series of functional analyses relating safety performance to specific design and operational elements, a set of revised guidelines was developed. The revised guidelines apply to total roadway width, horizontal curvature, roadside design, speed signs, curve warning signs, centerline markings, and no-passing stripes. These guidelines are proposed to supplement the existing national policies, with each revised guideline either replacing or clarifying the existing national guideline. The widespread application of the revised guidelines should provide for more consistent design and traffic control of low-volume rural roads consonant with a rational balance between highway investment, highway safety, and traffic service.

Low-volume rural roads, those carrying 400 vehicles per day or less, are the backbone of the U. S. rural economy. State "farm-to-market" roads, county roads and township roads provide the accessibility required by agricultural commerce. Also, forest roads and park roads are necessary for the operation, maintenance, and accessibility of national forests and parks.

Although low-volume rural (LVR) roads only carry about 8 percent of the total U. S. highway travel, their economic importance in the national highway program is recognized because they constitute 2 out of every 3 kilometers of public highway. ~~Because they are the largest single class of~~ highway, objective guidelines for their design and operation are imperative to achieve a reasonable balance between cost and safety effectiveness. The bulk of the present LVR road system has been built using design and operational practices that have evolved from subjective experience and judgment rather than from an objective evaluation of quantifiable performance.

National guidelines for the design of LVR roads are contained in the 1971 AASHTO publication "Geometric Design Guide for Local Roads and Streets." For traffic control devices, the basic guidelines are presented in the "Manual of Uniform Traffic Control Devices." But, because these national guidelines reflect more the safety needs of primary

highways, their application to the reconstruction of existing LVR roads is continually being questioned in a time when local highway agencies must spend a majority of their limited funds for highway maintenance.

In designing and operating highways for safety, LVR roads have one intrinsic edge over higher-volume highways because of a considerably lower probability of vehicle-to-vehicle collisions. The basic requirements for the minimization of single-vehicle consequences, however, are similar for all roads. In this area, maximum safety requires wide roadways and shoulders, clear and flat roadsides, gentle alignment, and high quality traffic controls and informational signing.

When considering safety on LVR roads, local highway agencies have been faced with a dilemma. On one hand, the agency would like to provide the same high-type design and operational features as on the primary highway system. On the other hand, the cost of providing this degree of safety often conflicts with the agency's philosophy of economic expediency. Because of this dilemma, LVR roads have historically been designed and operated at minimal cost with minimal overt attention to safety.

Now, the basic scenario of the highway program is changing from the massive road building campaign of the 1950s and 60s toward a concerted effort to rehabilitate existing highways. As this new emphasis mounts, the tendency is for federal matching funds to require that highways, regardless of their functional classification, be redesigned to meet all current standards. And, current standards tend more to reflect the needs of primary highways and, therefore, could require extensive and costly reconstruction of existing LVR roads. Highway agencies express increasing concern on this trend because it would force them to spend unreasonably large amounts of money for the rehabilitation of LVR roads. The alternative, which is more likely, however, is for the highway agencies to avoid these apparently unjustified costs by not implementing any LVR road improvements at all.

What this discussion points to is the need for objective design and traffic control guidelines that will strike a rational balance between maximum safety and minimum cost for LVR roads. With these guidelines, highway agencies could determine where and when to improve LVR roads within the framework of highway rehabilitation for the entire highway system.

Table 1. General Accident Statistics.

	Local Rural Roads	Total Roads	Percent Local of Total
Kilometers <sup>a</sup>	3,555,857	6,141,343	58.0
Million vehicle kilometers/year	136,248	2,140,268	6.4
Average ADT	105	955	9.1
Fatal accidents/year	4,299	39,993	11.0
Injury accidents/year	156,528	1,861,131	8.4
Fatal accidents/million vehicle kilometers	3.16	1.87	169.0
Fatal and injury accidents/million vehicle kilometers	1.18	0.89	132.0
Fatal and injury accidents/kilometer year	0.0452	0.311	14.6

<sup>a</sup>One kilometer = 0.62 miles

The objectives of this research were to:

1. Evaluate existing geometric design and traffic control guidelines, requirements and criteria with regard to their applicability and relevancy to the safety of roads carrying low traffic volumes (under 400 vehicles per day) at normal and reduced speeds.
2. Identify design and traffic control elements for which modifications of guidelines should be considered and recommend interim safety guidelines for low-volume rural roads.
3. Develop a systematic approach for collecting additional information related to safety requirements for low-volume rural roads.

#### Current Safety Performance of Low-Volume Rural Roads

In analyzing the safety requirements for LVR roads, it is first important to dimension their current safety performance.

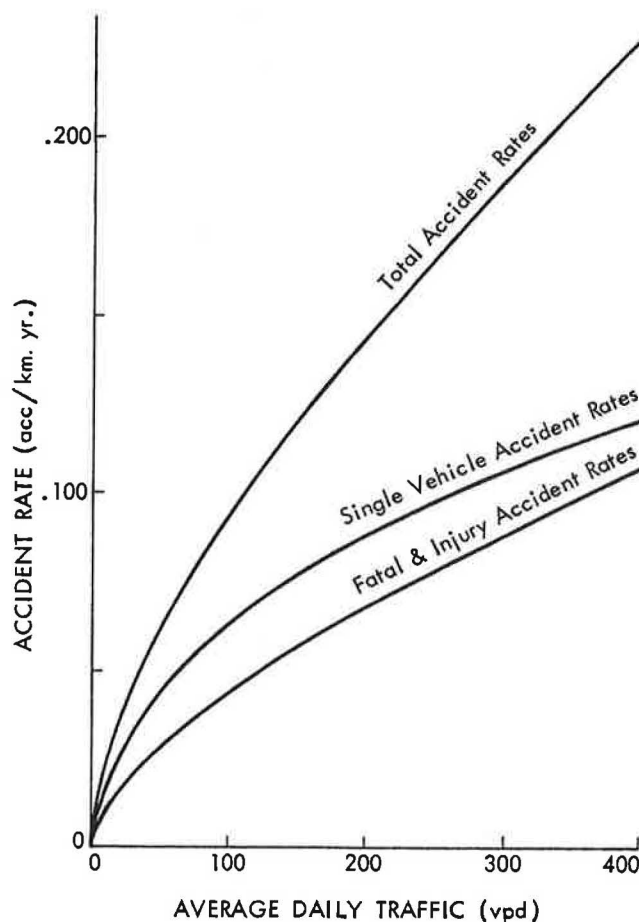
Table 1 shows national statistics for "Local-Rural" roads, which are basically county and township roads with an average ADT of 105 vpd. Although these roads constitute 58 percent of the total U.S. public road system, they experience only 11 percent of the fatal accidents and 8.4 percent of the injury accidents. These statistics indicate that the average frequency of fatal plus injury accidents is one every 22.1 kilometers (13.7 miles) per year on these LVR roads.

These national statistics, together with some other empirical data found in the literature were used to generate the best-fit curves of total accidents, injury plus fatal accidents, and single-vehicle accidents shown in Figure 1. The total accident rates range from 0.061 accidents/km/year (0.098 accidents/mile/year) at 500 vpd to 0.228 accidents/km/year (0.367 accidents/mile/year) at 400 vpd. In other words, the average road carrying 50 vpd will have one accident per year for every 16.4 kilometers (10.2 miles), and the average road carrying 400 vpd will have one accident per year for every 4.3 kilometers (2.7 miles).

The generated rates for injury plus fatal accidents are 47 percent of the total accident rates. The generated rates for single-vehicle accident

as a percentage of total accidents range from 52.9 percent at 400 vpd to 71.4 percent at 50 vpd.

Figure 1. Estimated safety performance of existing LVR roads.



Another dimension of safety performance is the proportion of total hazard contributed by various accident types. Defining hazard as the annual num-

ber of fatal and injury accidents per kilometer, and weighting the different kinds of accidents by their average severity (percent of fatal plus injury accidents), single-vehicle accidents were found to have the majority contribution to LVR road hazard. The percent of the total fatal and injury accidents contributed by single-vehicle accidents ranges from 61.1 percent for roadways with 400 vpd to 77.8 percent for roadways with 50 vpd.

Another way of looking at the current safety performance of LVR roads is to evaluate the impact of accident costs. Using National Highway Traffic Safety Administration costs by accident severity class and applying the percent of accidents by severity class determined for Figure 1, the average cost of an accident on LVR roads was estimated at \$9,500. Applying this average cost to the generated accident rates yields an average cost of accidents per kilometer of LVR road ranging from \$413 (\$665/mile) for a road carrying 50 vpd to \$2,217 (\$3,570/mile) for a road carrying 400 vpd.

These accident rates and costs begin to draw a picture of LVR roads that indicates the difficulty of making safety improvements that have any recognizable impact on the overall safety performance of LVR roads. Given a goal of a 25 percent reduction in accidents, an average of only \$190 per year could be justified per kilometer of LVR road if a cost-benefit balance is to be achieved. What this suggests is that, even with the safety-conservative (high) unit values used for the cost of accidents, only relatively low-cost kinds of improvements can be justified on most LVR roads.

#### Interrogation of National Policies

The interrogation of national policies on geometric design and traffic control elements was conducted early in the project period to identify the standards, criteria, and guidelines currently applicable to LVR roads and to evaluate their functional suitability to the safety performance of LVR roads.

The 1971 Manual on Uniform Traffic Control Devices (MUTCD) is the national policy on traffic control devices. If the MUTCD is interpreted literally, the only traffic control devices that are mandatory on LVR roads are crossbucks at railroad grade crossings. All other devices have generalized warrants or otherwise discretionary application. In evaluating the application of the MUTCD to LVR roads, five traffic control devices appeared to require further clarification regarding their safety requirements on LVR roads. These devices, which are discussed further in the next section of this chapter are: speed signs, stop signs, curve warning signs, centerline markings, and no-passing stripes. Although most of the other regulatory and warning devices might apply under certain circumstances on LVR roads, this application must remain discretionary because of their unclear relationship to safety performance.

The national policies on the geometric design of LVR roads are contained in two AASHTO publications, "A Policy on the Geometric Design of Rural Highways, 1965" (AASHTO Bluebook) and "Geometric Design Guide for Local Roads and Streets, 1970." The AASHTO Local Road Guide mainly summarizes the parts of the 1965 AASHTO Bluebook pertaining to LVR roads.

The major differences in the Local Road Guide relate to the specification of design speeds. In

this change, minimum design speeds ranging from 32.2 kph (20 mph) to 80.5 kph (50 mph) are specified depending on the ADT and type of terrain on the LVR road. Lower ADT's and more severe terrain justify lower minimum design speeds, and higher ADT's and more level terrain justify higher minimum design speeds. These design speed specifications allow a balance between the objectives of safety, service, and economy consistent with roadway function and expected operating speeds.

The design elements identified as pertinent to LVR roads and the general evaluation of suitability of their AASHTO guidelines to the safety performance of LVR roads are as follows:

1. Suitable Safety Requirements for LVR Roads/ Requirements Based On General Analysis of Trade-offs Between Safety, Service, and Economy.
  - . Highway Grade
  - . Cross Slope
  - . Shoulder Cross Slope
  - . Structure Width
2. Suitable Safety Requirements for LVR Roads/ Requirements Based On Objective Functional Analysis of Safety Performance Using Design Speed as Basic Criterion.
  - . Stopping Sight Distance
  - . Passing Sight Distance
  - . Corner Sight Distance
  - . Horizontal Curvature
  - . Vertical Curvature
3. Questionable Requirements for LVR Roads/ Requirements Not Based On Analysis of Trade-offs Between Safety, Service and Economy.
  - . Total Road Width (traveled way plus shoulders)
  - . Shoulder Width
  - . Roadside Design (guardrail, curbs, side slopes, clear zone, etc.)

The elements in the third category are discussed further in the next section of this paper. For the most part, these design requirements call for dimensions that are much greater than those needed for acceptable safety at a reasonable cost.

#### Development of Revised Requirements

The development of revised safety requirements was undertaken for the eight traffic control and geometric design elements that were identified as having questionable national standards or guidelines as they apply to LVR roads. The elements evaluated were speed signs, curve warning signs, stop signs, centerline markings, no-passing stripes, roadway width, shoulder width, and roadside safety design.

Revised safety requirements were developed for most of these elements based on functional analyses, probability of conflict analyses, and cost-effectiveness analyses. The analyses were conducted using available data where possible and safety-conservative assumptions where data were not available. The term "safety-conservative" refers to assumptions that overtly favor safety in the analysis. By so doing, if errors are made in deciding appropriate requirements for design and operational elements, the errors will favor safety at the expense of highway investment, rather than the opposite.

The following discussion summarizes these developments.

## Speed Signs

For most highways, drivers tend to judge their appropriate safe speed according to the geometric design, traffic characteristics, and roadside development of the highway. This would suggest for LVR roads, that because of minimum roadside friction and relatively infrequent encounters with other vehicles, that geometric design elements are the primary determinants of vehicle speeds. Without the other controls, however, drivers might tend to overdrive LVR roads except where directly influenced by physical constraints such as horizontal curvature. For this reason, speed limit signs keyed to the design speed of the highway appear to be an important adjunct to the safe operation of LVR roads.

In keeping with the proposed premise of a direct correspondence between design speeds and operating speeds, all LVR roads should have regulatory speed limit signs displaying their design speed. Signs should be placed at frequent enough intervals so that drivers will see them for almost all expected trips. Also, the speed limit should have zoned values that change as often as needed to maintain correspondence with localized general design speeds.

This practice will provide a consistent display and guide to drivers indicating the maximum operating speed for LVR roads. For drivers who are good judges of geometric design conditions for setting their maximum operating speed, the speed limit signs will reinforce their judgement. For drivers who normally overdrive the geometrics, the speed limit signs will provide a persistent reminder of why they continually experience discomfort.

## Shoulder Need

An evaluation of several studies in the literature indicates conflicting results regarding the general safety effectiveness of highway shoulders. Then too, further analyses of some of the studies, which show that accident rates decrease with increasing shoulder width, indicates that the studies lacked statistical control for traffic volume. Therefore, what was really found was the relationship that shows decreasing accident rates with increasing traffic volumes.

The primary function of shoulders are to provide additional width for tracking corrections, head-on clearances, emergency stops, and leisure stops. The analysis of the tracking and head-on clearance requirements, treated separately in the next section of this report, indicates that shoulders are needed to satisfy reasonable tracking error recovery at design speeds above 72.5 kph (45 mph).

A Poisson probability analysis was used to evaluate the need for shoulders to accommodate emergency and leisure stops. The relative hazard of a highway with no shoulders can be estimated by evaluating the additional conflicts created by vehicles stopped on the traveled way rather than on a shoulder. Vehicles stopped on the traveled way present a hazard, first, to following vehicles and, second, to opposing vehicles when following vehicles pull into the left-lane to pass the stopped vehicle. The hazard to following vehicles, per se, is judged as insignificant if adequate stopping sight distance has been provided. With adequate stopping sight distance, the following vehicle driver should have more than enough time and distance to either stop or pull into the left-lane. The critical situation, therefore, involves the head-on conflicts created by a stopped

vehicle.

The expected conflict rates were calculated using values for the frequency of emergency and leisure stops reported in the literature and by assuming Poisson arrivals for both following and on-coming vehicles. The expected conflict rates range from one every 27 years per kilometer of 50 vpd roadway to 19 per year per kilometer of 400 vpd roadway. An order of magnitude comparison shows that a road carrying 3,000 vpd is expected to have about 2,200 of these conflicts per kilometer per year. This would suggest that the hazard associated with stopped vehicles on LVR roads is relatively insignificant.

The conflict rate for the higher volume LVR roads might be considered as justifying shoulders to accommodate stopped vehicles. But, as discussed earlier, the next section of this report already shows justification for shoulders for the higher (more critical) design speeds, which generally correspond with the higher ADT categories. Therefore, no separate justification for shoulders based on shadowing stopped vehicles is recommended for LVR roads.

## Total Road Width

Total road width is defined here as the width of traveled way plus shoulders, if present. Table 7 of the AASHTO "Geometric Design Guide for Local Roads and Streets," indicates a previous lack of functional analysis regarding road width. To say that the road width requirement for 50 vpd at 32.2 kph (20 mph) is the same as for 400 vpd at 80.5 kph (50 mph) seem inconsistent both with relative safety and with economic efficiency. What is apparently needed is a safety analysis that would relate road width to design speed. Also, if road width was related to design speed like the current requirements for horizontal and vertical alignment, the driver would be able to more readily relate his maximum safe speed to what he sees.

Two traffic conditions are readily apparent in analyzing safety requirements for total roadway width. These are (1) the clearances needed when two opposing vehicles pass, and (2) the lateral width needed to make a tracking correction without encroaching on the roadside.

The clearance requirement is the summation of two vehicle widths, two outside clearances, and one inside clearance. At very low speeds, the total roadway width need only be slightly more than the width of two vehicles. As speeds increase, the lateral margin for error is sensitive to the speed, requiring greater road widths to accommodate the safe passing of opposing vehicles.

The tracking requirement is a function of the initial lateral position of the vehicle, the speed of the vehicle, the perception-reaction time of the driver, the skid resistance of the pavement, and the angle of the tracking correction needed. As speeds increase, the ability to avoid a roadside encroachment is very sensitive to speed, requiring greater road widths to accommodate safe vehicle tracking.

Roadway width requirements for safe tracking were computed for various design speeds such that the tracking correction recovery at all encroachment angles was equivalent to that provided by a 11-meter (36-foot) roadway width (two 3.66-meter lanes and 1.83-meter shoulders) at 96.6 kph (60 mph). Lateral clearances to opposing vehicles were related to design speed and traffic volume such that the total roadway width accommodated reasonable frequencies of

Table 2. Minimum Road Width Requirements

Total Road Width Requirements (Meters) <sup>a b</sup>				
	Lower % Busses & Trucks (as specified below)		Higher % Busses & Trucks (as specified below)	
Design	< 28% for	0- 50 ADT	> 28% for	0- 50 ADT
Speed	< 12% for	51-100 ADT	> 12% for	51-100 ADT
(kph) <sup>c</sup>	< 7% for	101-200 ADT	> 7% for	101-200 ADT
	NA for	201-400 ADT	All% for	201-400 ADT
	Infrequent Trips by Farm Machinery <sup>d</sup>	Frequent Trips by Farm Machinery <sup>d</sup>	Infrequent Trips by Farm Machinery	Frequent Trips by Farm Machinery
32.2 kph	5.5m	6.7m	6.1m	7.3m
40.2	6.1	7.3	6.7	7.9
48.3	6.1	7.3	6.7	7.9
56.3	6.7	7.3	7.3	7.9
64.4	6.7	7.9	7.3	8.5
72.4	7.9	7.9	7.9	8.5
80.5	9.2	9.2	9.2	9.2

<sup>a</sup> 1m = 3.28 ft.

<sup>b</sup> Widths above 7.3 meters (24 ft.) include appropriate shoulder widths.

<sup>c</sup> 1 kph = 0.621 mph.

<sup>d</sup> The determination of "frequent" and "infrequent" are at the discretion of the designer.

head-on meetings of busses and/or large trucks.

Table 2 presents the proposed revisions for total roadway width on LVR roads. Where values exceed 7.3-meters (24-feet), shoulders should be provided as part of the total width. When comparing with the sum of pavement width plus shoulder width proposed in the AASHTO Local Road Guide, the revised values are smaller for the lower design speeds and larger for the higher design speeds.

Four values of total roadway width are given for each design speed in Table 2. These four values derive from four different combinations of design vehicle widths used in the head-on clearance determination. With the design speed established, selecting the appropriate road width value depends, first, on the percent that busses and large trucks are of the highway ADT, and, second, whether the movement of large farm machinery is frequent enough to justify a wider roadway. The deciding values for the percentage of busses and large trucks are different for each ADT range as shown at the top of the table. In considering whether to design for the movement of large farm machinery, the definitions of "frequent" and "infrequent" are left to the discretion of the designer.

#### Curve Design and Warning Signs

A vehicle tracking model similar to that used to evaluate total road width on tangent was used for horizontal curves. The initial idea was to evaluate the adequacy of these previously developed widths for vehicle tracking on horizontal curves. What was found was that, rather than width,

vehicle tracking was most sensitive to degree of curve.

The modification to the general design of highway curves on LVR roads relates to curves with design speeds that are lower than the general highway design speed. Although this practice is not generally recommended, it may be the only practical alternative in mountainous terrain, for example. Then too, many older existing highways have a highway curve with a design speed lower than the general highway design speed. These are the curves that are usually marked with curve warning signs and advisory speed plates.

The same kind of tracking analysis described above demonstrates, for the total roadway widths proposed in Table 2, that certain highway curves with design speeds below the general highway design speed can satisfactorily accommodate recovery from tracking errors by vehicles traveling at the highway design speed. Table 3 presents this correspondence as an allowable but not generally recommended practice. A highway curve with this allowable tolerance should always be marked with curve warning signs and with advisory speed plates displaying the design speed of the highway curve.

#### Stop Signs

The accident reduction effectiveness of installing two-way stop signs was predicted using (1) a Poisson probability of conflict analysis to estimate the annual number of right-angle accidents for various combinations of intersecting traffic volumes on LVR roads; and (2) an estimate of the per-



Table 3. Minimum Design Speeds for Horizontal curves that deviate from the general design speed of the highway but display curve warning signs and advisory speed plates.

Highway Design Speed (kph) <sup>a</sup>	Minimum Design Speed of Deviant Curve (kph)
32.2	32.2
48.3	40.2
64.4	48.3
80.5	56.3

<sup>a</sup> 1 kph = 0.621 mph

centage of accidents reduced for two-way stop control taken from NCHRP Report 162. Table 4 shows the predicted accident reduction for two-way stop control for various traffic volume combinations.

Table 4. Expected annual accident reduction of two-way stop control at LVR road intersections.

Road A ADT	Road B ADT			
	50	100	200	400
50	.0029	.0058	.0117	.0234
100	.0058	.0117	.0234	.0468
200	.0117	.0234	.0468	.0936
400	.0234	.0468	.0936	.1872

Using these effectiveness measures, the average accident cost of \$9,500, an estimate of the annualized cost of stop sign installation, and the increased operating cost of \$0.021 per vehicle stop reported by Anderson et. al., the benefit-cost of two-way stop sign installation was evaluated on LVR roads. The benefit-cost analysis indicates that the increased costs are greater than the safety benefit even for a 100% reduction in right-angle accidents. Therefore, stop signs are not generally justified at the intersection of two LVR roads.

Because this analysis was based on average expected values, it should be recognized that the present discretionary warrants for stop control in the MUTCD are appropriate for LVR roads. Special problems with sight restrictions or with the assignment of right-of-way, particularly when a LVR road intersects a higher-volume through highway, should warrant consideration of stop control on LVR roads.

#### Centerline Markings

No empirical data are available to show the safety effectiveness of centerline stripes on two-lane highways. The primary function of the centerline stripe is to guide drivers in judging the proper clearance interval to opposing vehicles.

To visualize the nature of the problem, a Poisson probability analysis was used to predict the expected number of head-on meetings for various LVR road traffic volumes. This yields the following expected rates.

ADT	Expected Number of Head-on Meetings Per Kilometer Per Day
50	0.9
100	3.9
200	15.6
300	34.8
400	62.1

With these rates, many trips are taken on LVR roads without meeting an opposing vehicle.

The need for centerline markings was also evaluated on a benefit-cost basis using the accident rates and costs generated previously and assuming a 5% reduction in total accidents as reported in NCHRP Report 162. Using a centerline cost of \$124/km (\$200/mile), a 1.5-year life marking, and the \$9,500 average cost of accidents, the benefit-cost balance was found at an ADT of 300 vpd. Therefore, centerline markings are warranted on paved LVR roads when the ADT equals or exceeds 300 vpd.

#### No Passing Stripes

No empirical data are available on the safety effectiveness of no-passing stripes. The primary function of no-passing stripes is to prevent passing maneuvers where limited sight distance would make passing unduly hazardous.

To visualize the nature of the problem, a Poisson probability analysis was used to predict the expected number of head-on conflicts created by passing maneuvers. This yields the following expected rates for various LVR road traffic volumes:

ADT	Expected Annual Number of Passing Conflicts Per Kilometer
50	0.01
100	0.11
200	0.89
300	2.99
400	6.87

If we compute similar conflict rates for higher traffic volumes, the expected number for 2000 vpd for example is 900 per kilometer per year, or well over 100 times that for 400 vpd.

Based on the safety-conservative conflict rates calculated and the order of magnitude comparison with higher volume roadways, no-passing stripes do not appear to be justified on LVR roads. This is particularly true because as demonstrated in a study by Jones, drivers tend to decide to pass more on the availability of adequate passing sight distance than on the presence or absence of no-passing stripes.

A benefit-cost analysis similar to that used for centerline markings was also conducted for no-passing stripes. This analysis indicates that the balance between striping cost and accident benefits is at traffic volumes much higher than 400 vpd.

#### Roadside Design

The AASHTO Local Road Guide presents general

guidelines for roadside design for safety. It's suggestions of 3.1-6.1 meter (10-15 foot) roadside clear zones and 4:1 or flatter side slopes are related to desirable safety performance and should be retained. These suggested values, however, are recognized as idealistic objectives in a "more is better" continuum as applied to existing LVR roads with limited rights-of-way.

A more realistic approach to roadside safety design on LVR roads depends on achieving a balance between the cost and safety effectiveness of the design treatment. For this purpose, these guidelines recommend: (1) the use of the roadside hazard model presented in a report by Glennon to compare the relative hazard reduction of various roadside safety treatments; (2) the use of a multiplier of 4 to modify the referenced model for highway curves; (3) the use of the accident cost values by severity type presented in NCHRP Rept 162 to compute the benefits of the various hazard reductions; and (4) the application of local values for the cost of roadside safety treatments to compute the benefit-cost balance for the various roadside treatments.

Although the application of this procedure to LVR roads (using typical cost ranges for various treatments) indicates that individual roadside safety treatments yield very small safety contributions, some low-cost improvements do appear to be cost-effective especially on highway curves. For example, on highway curves, tree removal and break-away signposts, utility poles, and mailboxes appear to be cost-effective for all LVR road traffic volumes and all reasonable unit costs of treatment. On highway tangents, these same improvements do not appear as cost-effective except for the higher (say, greater than 200 vpd) LVR road traffic volumes.

Guardrail placement on steep slopes, the removal of unnecessary guardrail on flat slopes, and the flattening of steep but low embankments also appear to be cost-effective on highway curves for the higher LVR road traffic volumes. All other kinds of roadside safety treatments including placing guardrail at fixed objects and moving fixed objects laterally do not appear to be cost-effective.

#### Recommended Research

The intent of Task 3 of this research was to recommend follow-on data collection activities leading to multi-variate analysis relating highway design and traffic control elements to highway accidents on LVR roads. Review of several researches, however, demonstrates the futility of these kinds of studies, even for primary highways. And, of course, several of the probability analyses of this report clearly demonstrate that the frequencies of various critical events on LVR roads are very much smaller than on primary highways. Because of these factors, dependency on discrete empirical studies to isolate any functional relationships would not only be cost-prohibitive but potentially fruitless.

Although the multi-variate analyses described above do not appear feasible, some other kinds of studies might be helpful to either verify or modify the revised safety requirements developed in this project. For example, several of the developments used the safety-conservative assumption (either expressed or implied) that LVR roads have a 50-50 directional traffic split during all periods of the day. A study of continuous traffic counts on LVR roads with different ADT's would not only show just how conservative the 50-50 assumption is, but would

also measure hourly volumes to verify the efficacy of the average hourly volumes and 18-hour traffic-flow periods assumed.

Two basic kinds of studies are recommended to verify, modify, or add further depth to the developments of this research. One study would collect accident data on LVR roads to draw a clearer picture of the current safety performance of LVR roads. The other study would collect on-site data of traffic characteristics on LVR roads for the purpose of verifying the revised safety requirements. A brief discussion of these studies is given below.

#### Accident Studies

Accident studies could be conducted at one of three levels of detail. The first level would compile accident data on LVR roads in general. The second level would attempt to further classify these data by several traffic volume categories for LVR roads. And, the third level would add to the second level by relating the accident data to some general quality measure (e.g., high, medium, or low-type design) of individual roads. In proceeding from each level to the next higher level, the difficulty and effort involved in collecting data becomes more demanding and the feasibility of study becomes more uncertain because of limitations on existing data sources.

For the first level of study, accident data could be obtained from those states such as Missouri and North Carolina that have both many kilometers of LVR roads on the state highway system and accident records for those roads. Although the states may not be able to completely isolate LVR roads (400 vpd or less), some other classification may provide a sample that is mostly LVR roads.

The kinds of data desired for the first level of study include accident type, severity, and location. These kinds of data would provide general statistics on the proportions of the various accident types and would allow relative comparisons such as: (1) single versus multiple-vehicle accidents; (2) intersection versus mainline accidents; and (3) accidents on curves versus accidents on tangents. Adequate statistical reliability for this level of study would require a sample of about 16,000 kilometer-years of accident data.

Although the second level of study would add considerable depth to the first level, its feasibility is not clear. Collecting traffic volume data for LVR roads is not a routine task in most jurisdictions. Therefore, some method such as using personal estimates by local highway agency personnel might have to be developed. If feasible, this level would allow classifying the comparative data of the first level into discrete traffic volume categories for LVR roads.

The third level of study, of course, is both the most desirable and the most difficult to accomplish. The goal here is to further classify the data of the second level to generally relate safety performance to some measure of design quality. Although most state highway agencies usually develop sufficiency ratings for their highway system, these ratings do not usually extend to LVR roads. Therefore, some form of either personal estimates by local highway agency personnel or on-site inspection by the project staff might be necessary.

One aspect of data collection that might ease the burden and make the second and possibly the third level of study more feasible, especially if

secondary data sources are not available, is if several years of accident data are available. This would limit the number of kilometers of roadway for which some form of primary data would be necessary.

Another potential form of accident study would involve, say, 10 to 20 LVR road sections in a complete case-study analysis. Although this form of study would not be as statistically tractable as the three-level study described above, it could provide some valuable insights on the safety performance of LVR roads.

#### Traffic Characteristics Studies

This study could be designed to measure several traffic characteristics to verify the adequacy of several assumptions used in the development of the revised safety requirements in this report. Highway sites could be instrumented with sensors and a multi-channel recorder to simultaneously measure speed, speed profile, lateral placement, hourly volume, directional split, vehicle type, etc.

For complete statistical tractability, about 320 days of data collection would be necessary. This would include, for example, an average of 4 days of data at 4 sites each of four different design classifications within five categories of LVR traffic volumes. Although this is a very expensive kind of research, the fact that several kinds of data can be collected simultaneously makes the data collection very cost-effective, especially since these kinds of data are not presently available. Then too, one possible modification to the general experimental plan described above is to eliminate one or more of the lowest volume categories. Based on the orders of magnitude of various probabilities calculated in this report, the data from the higher volume categories could probably be extrapolated to make reasonable estimates for these lower volume categories. Another expediency in the total study of LVR roads would be to conduct the accident studies and traffic characteristics studies together such that both the selection of study sites and the collection of primary and secondary data could be done simultaneously.

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