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16. Abstract The justification of safety improvements for low volume rural roads has been difficult. Roadblocks of a primarily economic nature have prevented the improvement of many features associated with this type of road, features which have been known to have adverse safety implications for many years. In this report traditional methods of developing a safety index for these roads have been explored and found unsuitable. These methods include the correlation of accident rates with specific roadway features and the location of "black spots" where atypical numbers of accidents occur. Neither of these approaches in general are of value on low volume (ADT $\leq$ 1000) rural roads. The combination of two relatively new concepts for safety improvements is recommended as a result of this study. They are "process based improvements" and "low cost safety improvements." For example, one "process" is to eliminate all hazardous concrete culvert headwalls in a district. The "low cost" aspect relates to either breaking the headwall off at ground level or building up the soil of the roadside to the level of the headwall top surface. A procedure is presented here to identify those combinations of "processes" and "low cost improvements" that should be given priority in a low volume roadway safety improvement program.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

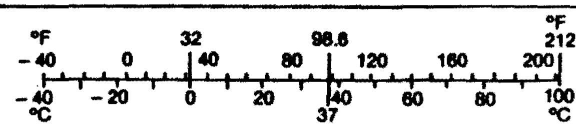
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

SAFETY IMPROVEMENTS FOR LOW VOLUME RURAL ROADS

by

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and

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Research Report 1130-2F
Research Study No. 2-18-89/0-1130
Safety Index for Low Volume Highways

Sponsored by the

Texas Department of Transportation

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February 1992

SUMMARY OF FINDINGS

The safety of low volume rural roads in this country can be enhanced if we are willing to recognize several basic facts, and overcome some of our traditional thinking about highway safety.

Fact No. 1—The funds that society is willing to spend on highway safety are limited.

Fact No. 2—Low volume rural roads in this country constitute a huge physical plant.

Fact No. 3—The number of people killed and injured on low volume rural roads is relatively small, when compared to other highways.

Fact No. 4— Given Facts 1, 2 and 3, safety upgrades (i.e., investments) on low volume rural roads must be low cost investments if they are to be cost effective.

Fact No. 5—Numerous low-cost improvements to deficiencies throughout the low volume rural highway system will save more lives and reduce more injuries than a few, "up-to-standard" improvements.

Fact No. 6—Because it is difficult to identify "high accident sites" on the rural, low volume highway system, improvements to the system will generally be more efficient if carried out on "problem-specific" basis, rather than a "site-specific" basis.

DISCLAIMER

IMPLEMENTATION STATEMENT

The findings justify the use of a combination of "Process Based Problem Identification" and "Low Cost Safety Improvements" to rectify many long term deficiencies on low volume rural roads. A program is suggested for each SDHPT District such as the one illustrated below. Note this "Example" is not proposed for any specific district, but is presented as an example of what might be most appropriate in one hypothetical district.

Explanation

Example District Safety Improvement Program

Ranked Deficiencies	Number in District	Severity Index	Unit Cost of Materials	Man Hours per Unit	Equip. per Unit
1 Guardrail Segments	52	5	$ 0	4	2
2 Culvert Headwalls	28	7	$ 100	8	4
3 Pavement Edges	NA	NA	$ 0	20	20
4 Bridge Parapets	72	7	$1800	28	10
.					
.					
.					
N Other Deficiency	20	4	$1500	24	12

Notes:

(1) The severity index in column 3 is based upon values provided in "Guide for Selecting, Locating, and Designing Traffic Barriers," AASHTO, 1977.

(2) The unit costs associated with pavement edges are costs per mile. The unit costs associated with improvements to guardrail segments, culvert headwalls and bridge parapets are costs per segment, per headwall and per parapet, respectively.

Compiling these figures based on District materials, equipment and labor requirements and comparing them with the availability of each factor should result in some fairly obvious choices about which tasks should be accomplished first. By undertaking one artifact or process at a time, savings in equipment commitment and labor skills should be developed to maximize task efficiency. With experience easier ways of producing the same improvement will result and efficiency should increase as the work on a particular artifact progresses.

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INTRODUCTION

In the last 50 years, the highway and environmental factors that influence and affect traffic safety (e.g., roadside structures, roadway alignment, road surface conditions, etc.) have been discussed in a number of reports published by the American Association of State Highway Officials (AASHO).[1] A 1940 AASHO policy emphasized appropriate lane and shoulder widths and use of guardrail among other items necessary for safe operation of motor vehicles. In a 1938 text, Gubbels emphasized the roll of highway cross-section (see Figure 1). A 1965 report (typically referred to as the blue book) established geometric design policies for rural highways. And, a 1967 report sought "... to identify those aspects of design and operation on facilities in various sections of the country which [sic] could be improved to increase safety ..." (p 1). The 1967 report is divided into two major subject areas: (1) roadside design and appurtenances and (2) traffic operations. Prominent among the factors addressed in the former subject area are the following:

- Narrow Bridge Structures
- Bridge Rails
- Bridge Parapets
- Guardrails
- Guardrail Ends
- Rail Transitions
- Trees
- Skid Resistance
- Animal Crossings
- Roadside Slopes
- Drainage Structures
- Signs
- Utility Poles

If the highway and environmental factors that influence and affect traffic safety are well known, and if the policies to deal with these factors have been well established, why do so many low volume rural roads fail to meet these established policies?

The answer to this question varies according to the training and perspective of the respondent.

Plaintiff Attorney: There is no excuse. It is a simple case of negligence.

Highway Engineer: We have never had the funds available to upgrade the old, low-volume country roads.

Highway Researcher: It is not cost-effective to upgrade low volume roads to meet current policies. It costs lives and injuries to invest limited safety funds where extremely few accidents occur.

The response of the plaintiff lawyer is obviously self serving. Nevertheless, on some occasions -- in the writers' experience rare occasions— this response is not always inappropriate. Some low volume rural roads that are deficient exist. It should also be understood that the failure of a given segment of highway to comply with all applicable design policies or standards does not necessarily mean that the highway department -- or personnel in that

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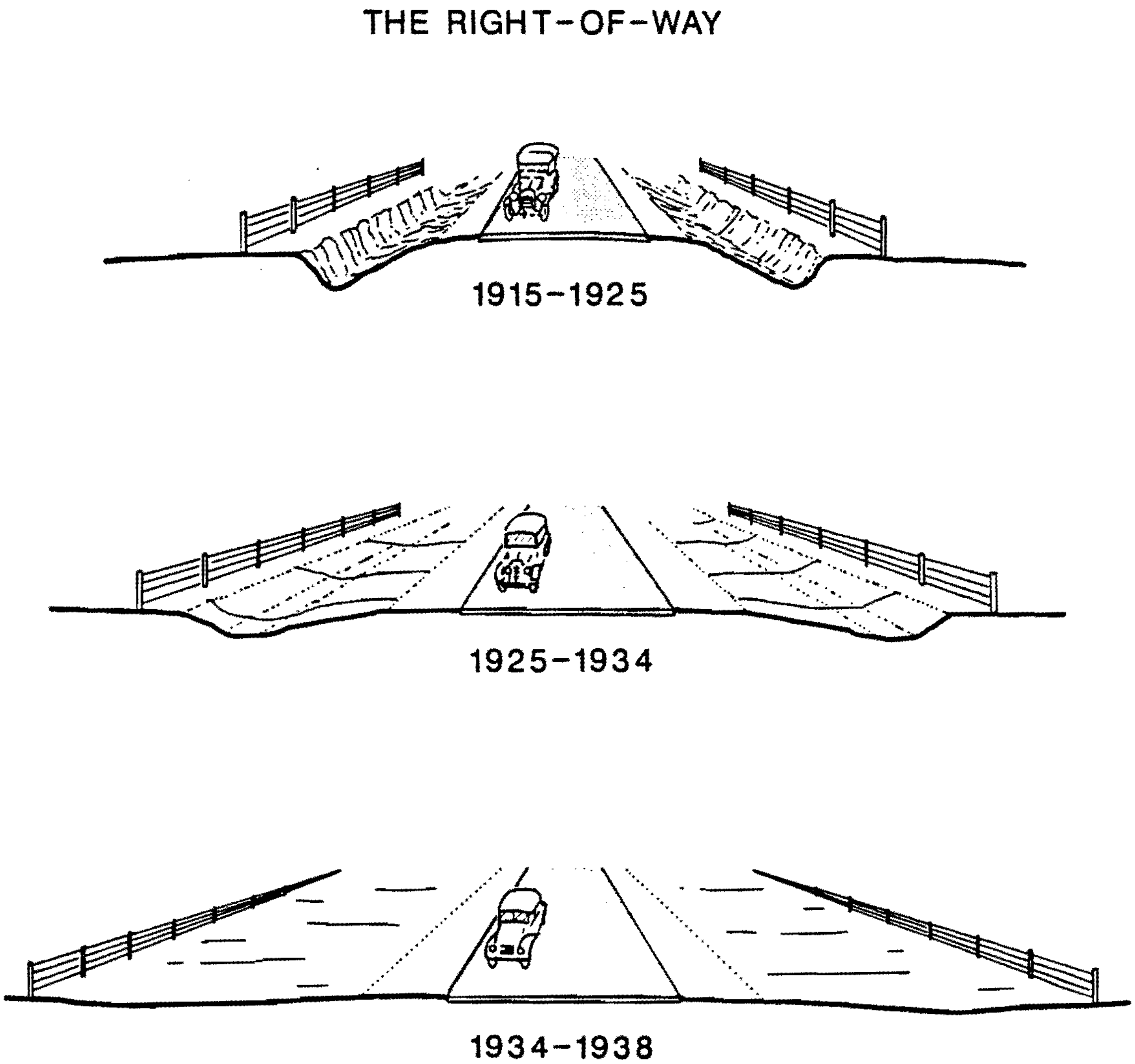
[1]In 1973 AASHO changed its name to AASHTO (the American Association of State Highway and Transportation Officials).



"The cross-section should be, and it may be, such that an automobile traveling at the rate of fifty or sixty miles an hour may leave the pavement at a thirty-degree angle, cross the ditch, and crash through the right-of-way fence without capsizing."

Figure 1: Cross Sections Taken from Gubbels (1938)

department -- are negligent. As the highway engineer's response indicates, we do not now have, nor will we ever have, sufficient funds to bring all low volume rural roads up to current policies and standards. The system is too vast and the costs are too great for this goal to ever be achieved.

Rather than lament the fact that we do not have sufficient funds to address all the needs of low volume rural roads, the highway researcher takes available funding as a "given" and asks how we should invest those dollars that are available to save the most lives and reduce the most injuries. Seen in this light, the positions of the highway engineer and the highway researcher are not antithetical but complimentary. The highway researcher seeks to develop more efficient programs and technologies for reducing accident frequency and severity; the highway engineer seeks to employ these programs and technologies to upgrade deficient roads as quickly as possible, within a prescribed budget.

Granted that the low volume rural road system cannot be brought up to current standards in the foreseeable future, decisions have to be made regarding which roads should be upgraded and to what extent. If a highway department's procedure for investing construction and maintenance funds is rational, if the procedure allows for efficient investments to redress existing safety problems, that department is acting responsibly, even if individual highway locations are allowed to remain at a sub-standard level. On the other hand, if a department does not possess a rational process for allocating safety funds, if deficient highway locations or characteristics are not corrected due to oversight, that department is remiss.

Through taxation, the public has entrusted highway departments with the responsibility for constructing and maintaining its highways, ensuring its mobility and guarding its safety. In fulfilling this responsibility, departments have an obligation to continually look for better ways and means of investing those funds with which they have been entrusted. It is the purpose of this report to consider how safety funds might be more rationally allocated to enhance the safety of low volume rural roads.

PHYSICAL AND ENVIRONMENTAL CONDITIONS INFLUENCING HIGHWAY SAFETY

Many different physical and environmental conditions affect the frequency and severity of traffic accidents on low volume rural roads. Table 1 is a partial listing of some of these conditions (e.g., surface conditions, roadside obstacles, bridge or guardrails, drainage structures, other structures, communication, or geometrics).

At the outset of this study, the literature pertaining to the relationship between highway safety and various physical or environmental factors was reviewed. Over 40 publications, including many from Texas engineers, were examined to define those factors that are most conspicuously related to highway safety. The factors of "primary influence," from the viewpoint of the authors, are shown in Table 2.

TABLE 1: CONDITIONS/OBJECTS THAT IMPACT HIGHWAY SAFETY

SURFACE CONDITIONS

- Friction - low or differential
- Rutting
- Potholes
- Edge - low and high sides of superelevation
- Soft Shoulder
- High Sideslope
- Grade Crossing

ROADSIDE OBSTACLES

- Signs
- Mailboxes
- Monuments
- Utility Poles
- Vegetation - trees
  - visibility obstruction

BRIDGE OR GUARDRAILS

- Short Rails
- Rail Ends
- Bridge Parapets
- Substandard Bridge Rail
- Substandard Guardrail
- Substandard Transition

DRAINAGE STRUCTURES

- Headwalls
- Culvert Ends
- Curbs

OTHER STRUCTURES

- Narrow Bridges
- Underpasses

COMMUNICATION

- Signing
- Driver Expectancy Violation
- Delineation

GEOMETRICS

- Lane Width
- Shoulder - width and composition
- Curvature - vertical and horizontal
- Lane Drops
- Gore Area

Environmental Factors

Annual exposure to rain, snow, ice and fog is certainly a known contributor to accident rate. The interaction between rainfall and tire/pavement friction has been studied at length and is the subject of a newly proposed program within the Texas Department of Transportation (TxDOT) (Ivey, Griffin and Lock, 1990).

When ice is widespread throughout an expanse of highway, it promotes many minor accidents. A potentially greater problem is associated with the icing of bridges. When bridges ice over, major collisions sometimes result when the driver, operating at high speeds, is surprised by a sudden loss of traction. This problem is well understood and is dealt with primarily through signing and applications of sand and salt.

TABLE 2: PHYSICAL FACTORS THAT IMPACT HIGHWAY SAFETY

ENVIRONMENT	GEOMETRY
Annual Exposure	Pavement Width
Rain	Shoulder (Edges)
Ice	Vertical Curves
Fog	Horizontal Curves
Smoke	Intersections
	Bridge Width
SURFACE	**ROADSIDE**
Friction Number (FN)	Side Slope
Differential Friction	Ditches
Drainage	Guardrail
Roughness	Bridge Rail
	Objects

Surface Conditions

Low pavement friction, poor drainage and road roughness all relate to safety. When these conditions are localized rather than widespread, they are particularly threatening. Of the many examples that could be cited to demonstrate this phenomenon, three will suffice:

Friction

1(a) On a 10 mile segment of rural highway there is generally low tire/pavement friction throughout. There is no atypical wet weather accident experience.

(b) On a 10 mile segment of rural highway there is generally high tire/pavement friction. On one 400 yard uphill segment the wheel paths have flushed badly and the friction in those paths is very low. There is a steady occurrence of accidents on that segment.

Drainage

2(a) Ruts in the wheel paths are continuous on a ten mile stretch of rural highway causing water to pond up to depths of 1/2 inch during rainfall. There is no atypical wet weather accident experience.

(b) Severe ponding occurs in an area at the foot of a sag vertical curve due to shoulder buildup on one part of a generally well drained rural highway. There is a steady, predictable occurrence of accidents at that site.

Roughness

3(a) Potholes, pavement ravelling and subgrade subsidence are common throughout a 10 mile section of rural highway. Traffic moves slowly and there is no atypical accident experience.

(b) A series of potholes occurs over about 50 yards in a horizontal curve on a 10 mile section of rural highway where the pavement is generally good and speeds are consistent with rural speed limits. There is a steady, predictable occurrence of accidents at that site.

Geometry

Numerous studies have attempted to draw a relationship between pavement or lane width and safety, and shoulder width and safety. In a recent study based on Texas data (Griffin and Mak, 1987), it was found that as lane width varies from nine to 14 feet, accidents per mile can be reduced by as much as 50 percent in the ADT range from 700 to 1000 vehicles per day. Shoulder widths have a less predictable influence on safety with most studies showing significant reductions of accidents as shoulders approach nine feet and as the shoulder surface material progresses from unimproved sod to pavement (TRB, 1987).

Vertical curves have been studied at some length recently due to AASHTO's change in design eye height and the effect that this change may have on minimum stopping sight distances. Fambro, Urbanik, Hinshaw, Hanks, Ross and Tan (1989) have recently affirmed that crest vertical curve design has little safety significance unless reduced stopping sight distance is combined with some type of traffic conflict, such as an intersection.

Horizontal curves have long been known to contribute to accidents. In general, as the degree of curvature increases the accident rate goes up. At least one study has shown accident rates for single vehicle run-off-road on curves are as much as four times greater than those on tangents (Kipp, 1952). Perchonok, Ranney, Baum and Morris (1978) have shown that accident rates increase as the curvature increases. The primary problem in these accidents appears to be loss of control on the outside of severe curves.

The influence of at-grade intersections on accidents has been studied for many years. In general, if intersections are associated with reasonable geometrics (primarily those yielding good sight distance) and are adequately signed, there is little more that can be done. The recent study by Fambro et al. (1989) has shown the problem when intersections are associated with the limited visibility produced by some crest vertical curves.

Regardless of what we do to improve the safety of intersections, it should be recognized that intersections are inherently more hazardous than tangents, or most curves for that matter. It is perhaps this simple: given an intersection, the greater the traffic volume passing through that intersection, the greater the number of traffic conflicts; the greater the number of traffic conflicts, the greater the number of accidents.

Bridge width can be a problem when bridges are significantly narrower than the approach roadway. A bridge safety index was formulated in the late 1970s that can help in prioritizing the rebuilding of narrow bridges (Ivey, Olson and

Walton, 1979). More recently, Mak (1987) has summarized the literature on narrow bridges and concluded that accident rates on two lane roads will decrease as bridge width is increased up to 28 feet. Beyond 28 feet, further increases in bridge width may, in fact, be counterproductive. Another study often cited in the literature (Cirillo, 1967) suggests that the influence of bridge width on safety applies primarily to bridges less than 100 feet in length.

Roadside

Sideslope and roadside ditch geometry have a significant influence on the ability of drivers to recover from an unanticipated excursion off the paved surface. Recovery is generally unlikely if the side slopes are much greater than four to one. The more acute the ditch angle between foreslope and backslope, the greater the probability of a vehicle rolling when the slope change is encountered. Guidelines for slopes and ditch cross-sections are given in a 1977 AASHTO report that is informally referred to as "The Barrier Guide."

Safety problems associated with guardrails and bridge rails -- and especially with guardrail and bridge rail ends -- have been problems on older roadways for many years. The 1967 AASHO report entitled "Highway Design and Operational Practices Related to Highway Safety," and its later revision (AASHTO,1974), have illustrated the problem. The 1977 AASHTO Barrier Guide gives recommendations in this area that are still fairly good, although end treatments for guardrails have advanced considerably since 1977. Some relatively low cost devices that have excellent performance characteristics are now available. Sentry, CAT and ET-2000 are examples, although some of these devices may still be too costly for use on low volume roadways. Subsequent sections will give possible low cost alternatives.

Roadside objects are the most notorious cause of serious (i.e., injury producing, life-threatening) traffic accidents on low volume rural roads. Culvert headwalls, utility poles, trees, non-yielding signs and even monuments are serious long term safety problems. Such objects have been and continue to be violations of the spirit of the forgiving roadside. They represent a primary area of focus for safety improvements on rural roads. These objects can be dealt with at modest cost, if appropriate policies are developed. Such policies are the subject of the following sections.

IMPROVING THE SAFETY OF LOW VOLUME RURAL ROADS

Major safety improvements to low volume rural roads are relatively uncommon. Yes, pavements are occasionally resurfaced. But, improvements to geometrics and structures are very rare. And, as a rule, shoulders and side slopes receive only minimum maintenance, as do pavement markings and traffic signs.

The main reason for the lack of attention devoted to low volume roads is the "do all syndrome" (DAS). DAS requires that if one element of the roadway is brought up to "standards" all elements must be brought up to "standards." In effect DAS keeps anything from being done. Two examples will serve to illustrate this point.

Example (1): Many highway engineers feel they cannot <u>improve</u> a bridge rail even though a poorly performing rail has been struck and partially destroyed many times through the years. They feel if they upgrade the rail, the entire bridge needs to be re-done to bring the width and approaches up to current policy recommendations. There is certainly not enough money available to replace the bridge, so time after time the 1930 bridge rail is rebuilt to 1930 standards.

Example (2): If there are several culvert headwalls along a segment of old highway that pose a real hazard to anyone who departs the paved surface, they could, with minor maintenance effort, be broken back and leveled off. If that is done, however, it is thought the pavement must be widened, the culverts extended, the ditches regraded, shoulders added, etc. Obviously there is not money for all this rebuilding, therefore, nothing is done.

Two groups at times foster and promote the DAS philosophy. First, the Federal Highway Administration (FHWA), in their legitimate efforts to bring all roads "up to standard," often will not participate in partial fixes. For low volume roads, it is clear that exceptions should be made. Lives are being lost needlessly. Societal costs are being incurred that cannot be justified.

Second, the American legal system rebukes engineers for not adhering to DAS. If an engineer goes to a highway site and directs that items A, B and C be upgraded, but that items D, E and F be left untreated, that same engineer may be reproved in a court room when he or she is examined by a plaintiff attorney whose client has been killed or injured at the site. The plaintiff attorney will argue (1) that his or her client was injured or killed due to the engineer's failure to correct D, E and/or F, (2) that the engineer had, in fact, visited the site and was therefore well aware that D, E and F were substandard, and (3) that the failure to correct D, E and F was "negligence" since maintenance forces were available to address D, E and F, at a cost that, retrospectively, seems paltry.

If federal participation (i.e., federal funding) is sought for a restoration project on a low volume rural road, FHWA's rules must, obviously, be accommodated. But, at times these rules chafe. When engineers for the state truly believe that a given highway location should be restored to a level short of applicable federal standards, and if a variance for the project cannot be obtained, the state should strongly consider funding the desired safety project without the participation of the federal government.[2]

By the same logic, state policy regarding the upgrading and restoration of low volume rural roads should not kowtow to the effrontery of the plaintiff attorneys' creed. To base the state safety policy on the highway department's defense in a court of law is an abdication of the public trust. Appropriately, this has not been the case in Texas.

In any event, DAS should definitely be rejected in all states if reasonable improvements are to be made on rural highways. The next section discusses the relative merits of determining (a) <u>where</u> highway improvements should be made versus (b) <u>which</u> improvements (e.g., resurfacing, clearing the roadside, realignment, etc.) should be made.

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[2]A progressive sign is that FHWA engineers seem to be developing an appreciation of the argument that "net societal good" is better realized by upgrading many deficient highway locations to "acceptable" levels rather than by upgrading a few deficient locations to a high standard.

TWO DIFFERENT APPROACHES TO UPGRADING THE SAFETY OF LOW VOLUME RURAL ROADS

Of the two approaches to upgrading the safety of low volume rural roads presented in this section, the first is the more traditional. Nevertheless, it will be argued that this approach is less likely to result in the cost effective allocation of highway safety funds the second.

The second or alternative approach to upgrading highway safety on low volume rural roads is seen to be more cost effective than the first. But, for this second approach to be set in place, DAS must, necessarily, be set aside.

Location Based Problem Identification

If highway safety funds are to be allocated in a cost effective manner, the first step in the process is usually to determine where accidents are presently occurring and, by inference, where they will be occurring in the future. The identification of high accident locations (referred to as "black spots" by the British) is typically accomplished by reviewing automated accident data files and selecting those locations that sustained an inordinate number of accidents (or displayed an inordinate accident rate) over the previous year or years.

Having identified and prioritized a candidate set of high accident locations, the second step in the process requires that engineering personnel be dispatched to the candidate high accident locations to determine which roadway features or characteristics are contributing to the abnormal number of accidents recorded at each location and to propose treatments to remedy any deficiencies found.

The third step in the process is to deploy maintenance forces (or retain contractors) to make the desired corrections or modifications at the identified locations. Ideally, these forces should be deployed in a manner that would maximize the number of accidents reduced for each dollar spent on remediation.

The three step process for prioritizing and treating highway locations in need of repair is generally reasonable <u>if</u> we are dealing with a wide variety of highways (i.e., a wide variety of traffic volumes). When we restrict our analysis to highways carrying fewer than, say, 1000 vehicles per day, however, the process outlined above is not reasonable, for theoretical and economic reasons. The reason for this is the lack of leverage in dealing with low volume roadways. By having leverage on the problem we mean that by changing, say, three percent of the system, we have the opportunity to address more than three percent of the accidents. Because there are so few accidents on these roadways, however, accident data do not allow for the identification of "black spots" which can be economically changed to reduce a significant number of accidents. A detailed discussion of the "black spot" approach to traffic accident problem identification is given in Appendix A.

Process Based Problem Identification

As an alternative to determining <u>where</u> accidents are occurring on low volume rural roads, the approach presented here asks: "Why and how are people being killed and injured on low volume rural roads?" By what <u>process</u> are they becoming involved in accidents?

- Are vehicles running off bridges?
- Are vehicles overturning on roadsides?
- Are vehicles striking objects?
- What objects are vehicles striking?

If the answers to questions such as these can be found, if the processes by which accidents are produced can be deduced, if treatments can be devised to thwart these processes, then a very cost effective means of improving the safety on low volume roads can be set in place.

In Appendix B, 23 figures are used to describe the conditions and circumstances surrounding accidents on low volume rural roads. These figures were generated from the 6123 police-reported accidents that occurred in Texas in 1988 on two-lane rural roads with average daily traffic (ADT) counts of fewer than 1000. 4490 (73.3%) of these accidents were single vehicle accidents; 1633 (26.7%) were multivehicle accidents. Brief comments on each of these 23 figures are presented in Table 3.

Although the 23 figures in Appendix B characterize the nature of accidents on low volume rural roads, it is clear that many of these characterizations do not suggest countermeasures within the control of highway engineers. For example, Figure 3 (in Appendix B) suggests that limiting or restricting the licensure of 18 and 19 year old drivers might be worthy of consideration by the appropriate state agency, but such an option does not fall within the purview of highway engineers. On the other hand, many of the accident characterizations shown in Appendix B do suggest physical changes to the highway environment -- changes that do fall within the responsibilities of highway engineers. Figure 13 (Appendix B) suggests, for example, that over a third or all single vehicle accidents on low volume rural roads (in Texas) occur on horizontal curves. Countermeasures to address these accidents might include (a) better delineation and/or signing for sharp horizontal curves (e.g., curves of eight degrees or more), or (b) a concerted effort to clear the roadsides and upgrade the shoulders on the outside of <u>all</u> horizontal curves in excess of, say, eight degrees.

As a second example, in 1988 some 250 (of 1941) single vehicle, fixed-object accidents on low volume rural roads in Texas (1988) involved a collision with a culvert headwall (Figure 19, Appendix B). Culvert headwall accidents are potentially very serious accidents, i.e., accidents that are frequently associated with injury and death. Given the magnitude and severity of culvert headwall accidents, the wholesale upgrading of these structures throughout the low volume rural highway system in Texas would seem to be a good investment, if the costs associated with these upgrades can be kept low.

PRIORITIZING SAFETY IMPROVEMENTS

From the accident characterizations presented in Appendix B (and Appendix B is just a "first cut" at this problem), individual engineering countermeasures can be devised and then prioritized. Such prioritizations should be based upon five factors:

(1) What is the magnitude of the problem (e.g., how many vehicles strike culvert headwalls)?

TABLE 3: COMMENTS ON THE 23 FIGURES FOUND IN APPENDIX B

FIG	COMMENTS
1	The frequency of multivehicle accidents rises slowly as a function of increasing traffic volume. The frequency of single vehicle accidents rises rapidly up to about 300 or 400 vehicles per day and then stabilizes or decreases slowly.
2	Three out of four drivers involved in single vehicle accidents are male. In multivehicle accidents, 70 percent of all drivers are male.
3	Eighteen and 19 year old drivers are well over represented in accidents on low volume rural roads. The number of drivers involved in single vehicle accidents falls steadily from 19 to 80 years of age. For multivehicle accidents, the number of accident-involved drivers decreases after age 18 but then becomes relatively stable after age 50 or 60.
4	Of 4507 drivers involved in single vehicle accidents, 2335 (52%) were speeding (above the limit or unsafe for conditions), and 1141 (25%) were driving while intoxicated. Of 3285 drivers involved in multivehicle accidents, 410 (12%) were speeding, and 215 (7%) were driving while intoxicated. [Note: Some drivers may have been speeding and driving while intoxicated.]
5	Forty-six percent of the vehicles involved in single vehicle accidents were single unit trucks, predominantly pickup trucks. For multivehicle accidents the corresponding percentage was 44 percent. [Note: In 1988, on a statewide basis, single unit trucks accounted for 28 percent of all accident involved vehicles.]
6	Of 4490 single vehicle accidents, 846 (19%) produced at least one incapacitating injury (A) or fatality (F). For multivehicle accidents the corresponding frequency and percentage are 219 and 13 percent. [Comment: In Figures 9, 10 and 11 it will be shown that single vehicle accidents are relatively more common than multivehicle accidents late at night, during hours of darkness, and on week ends. Minor, property damage only (PDO) accidents that occur during these hours of the day and days of the week may very well be under reported. Therefore, the fact that 19 percent of all reported single vehicle accidents involve an incapacitating or fatal injury may be spuriously high.]

TABLE 3 (continued)

FIG	COMMENTS
7	Single vehicle accidents are generally more severe than multivehicle accidents as demonstrated by the fact that cumulative multivehicle accident severity rises more rapidly than does cumulative single vehicle accident severity.
8	Both single vehicle accidents and multivehicle accidents are distributed fairly evenly throughout the year.
9	Multivehicle accidents are predominantly a daytime phenomenon, with accidents peaking in the late afternoon. Single vehicle accidents, on the other hand, are a nighttime phenomenon with accidents peaking between about 9 PM and midnight.
10	Fifty-eight percent of single vehicle accidents occur during hours of darkness (including dawn and dusk); 19 percent of multivehicle accidents occur during hours of darkness.
11	Multivehicle accidents are distributed fairly evenly throughout the week, with, perhaps, a slight increase on Fridays and Saturdays. Single vehicle accidents predominate on Fridays, Saturdays and Sundays -- during late night and early morning hours.
12	Wet roadway surfaces are associated with only 12 percent of all single vehicle accidents and 10 percent of all multivehicle accidents.
13	Of 4490 single vehicle accidents, 1619 (36%) occurred on horizontal curves. Of 1633 multivehicle accidents, 193 (12%) occurred on curves.
14	Twenty-six percent of all single vehicle accidents occur on the roadway, 30 percent occur on the shoulder and 44 percent occur beyond the shoulder. Not surprisingly, over 97 percent of all multivehicle accidents occur on the roadway.
15	The first harmful event in single vehicle accidents is striking a fixed object (43%), followed by overturning (33%) and striking an animal (17%).
16-18	Striking fixed objects is relatively more common on higher ADT highways. Overturning and striking animals are relatively more common on lower ADT highways.
19	Of fixed objects struck in single vehicle accidents, the most often cited is fence (16%) followed by tree or shrub (8%) and culvert headwall (6%).

TABLE 3 (continued)

FIG	COMMENTS
20-22	Striking fences is relatively more common on lower ADT highways. The likelihood of striking a tree or shrub is fairly evenly divided across highway traffic categories. Striking culvert headwalls is relatively more common on higher ADT highways.
23	Single vehicle accidents do not typically occur at intersections or driveways. But, 37 percent of all multivehicle accidents occur at intersections, seven percent are intersection related, and another 24 percent occur at driveways.

(2) How severe are such accidents (e.g., do impacts with culvert headwalls typically result in "property damage only" accidents, or might these accidents likely produce and serious or fatal injuries)?

(3) Is a countermeasure available to treat the problem (e.g., are means available to reduce the frequency and/or severity of culvert headwall accidents)?

(4) Is the cost of the countermeasure acceptable, given the effectiveness of the countermeasure and the magnitude and severity of the problem it seeks to address?

(5) Can the countermeasure(s) be easily implemented as part of on-going maintenance, repair and restoration activities?

Some would object that to consider the cost of a countermeasure is inappropriate. If a problem exists, the problem should be fixed. Such thinking is naive. Whether we want to admit it or not, we always consider the costs of safety when we design new highways or repair existing facilities. Sometimes these cost considerations are explicitly stated in the form of economic equations. On other occasions, cost considerations are implicit.

Consider the following hypothetical example. A 25 mile stretch of two-lane, rural road carrying 350 vehicles per day is characterized by narrow lanes, a two-to-one side slope, no shoulders, poor vertical and horizontal alignment, cluttered, non-forgiving roadsides -- and two accidents per year. To correct the design deficiencies associated with this road we might consider reconstructing these 25 miles of highway to new construction standards for federal-aid highways. But, to even consider such a suggestion is obviously absurd. Why? Because the cost of bring these 25 miles of highway up to new construction standards is prohibitive, granted that this road is experiencing only 0.08 accidents per mile per year, while carrying 350 vehicles per day. The very notion of bringing these 25 miles of highway up to new construction standards would not even be entertained. Implicitly, the cost of such an action is unacceptable.

Having argued that cost is always an issue in the repair and restoration of highways, it will now be argued that enhancements to low volume rural roads must be kept to a relatively low level in order to be cost effective.

In Texas, approximately half the mileage on the state maintained highway system carries fewer than 1000 vehicle per day. But, only four or five percent of the accidents recorded are on those same roads. Or, in other words, if we upgraded all of the low volume rural roads in Texas (i.e., those roads carrying fewer than 1000 vehicle per day), we would have to treat or modify half of the state system, but the potential benefits of this policy would address only four or five percent of the accidents recorded statewide.

LOW COST SAFETY IMPROVEMENTS

Recognizing (1) that accidents on low volume rural roads are relatively rare events and (2) that the system itself is immense, highway researchers have begun looking for low cost means of improving the design and operational deficiencies that are often associated with these roads. The philosophic justification for "low cost safety improvements" was first developed by Ivey and Morgan (1986). It was stated as follows:

- The new design results in a significant improvement in safety for the majority of drivers and passenger.
- The new design does not result in a significant deterioration in safety for any group of vehicle occupants.
- There are no other proven designs of equal or better cost-effectiveness that produce a safer condition for a larger spectrum of vehicle occupants.

This phrase -- low cost safety improvements -- represented a reaction of safety engineers to a problem in highway safety that remains extremely frustrating. That problem can be described by a question.

> "What can we do -- and what are we restrained from doing -- about the hundreds of thousands of miles of older, low-volume roadways that need safety improvements that cannot now be justified?"

Safety Standards and The "Take-It-or-Leave-It" Philosophy

In partial answer to this question, let us now turn to the subject of "standards" and examine the effect they have on the safety of low volume rural roads. It will be conceded that standards can serve to enhance highway safety, but it should also be understood that they can be a liability that shunts available safety funding in inappropriate directions. As an example, consider a report that is informally referred to as NCHRP 230 and entitled "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances" (Michie, 1981).[3] Technically, NCHRP 230 is not a standard, but a policy or guideline that has been widely accepted by the states and FHWA. This report was a critically needed contribution to the development of safer roadside structures

[3]NCHRP stands for the National Cooperative Highway Research Program.

when it was published in 1981. Although it continues to be a viable and valuable guide, it is now being revised and should be published in mid 1992.

In response to the evaluation criteria provided in NCHRP 230, manufacturers have developed and marketed a variety of devices and appurtenances (e.g., guardrail end treatments, crash cushions, etc.) that are intended to enhance safety by mitigating the severity of collisions involving roadside structures. The effectiveness of these devices and appurtenances in reducing injury severity, given an accident, is beyond debate. These devices have saved, and are continuing to save, hundreds, if not thousands of lives each year. Nevertheless, the installation of these devices is not without costs. In another paper prepared for TRB, Ivey, Griffin and Bronstad show that the available guardrail end treatments that meet NCHRP 230 cost between $2,000 and $5,000 per installation, compared to the cost of the commonly used end treatments of Turndown and BCT having costs of $400 to $1,000 (Ivey, Griffin and Bronstad, 1991).

Most commercially available guardrail end treatments and crash cushions cost taxpayers between $6000 and $30,000 per installation. Although these prices may seem high, they are, nevertheless, cost effective at certain highway sites characterized by high traffic volumes, i.e., at sites where accidents are not rare events. But, at sites where traffic volume is low, where accidents are rare events, the utility of installing such expensive devices cannot be defended. In order to receive Federal participation, it has often been necessary for these roadside appurtenances to meet NCHRP 230 evaluation criteria (regardless of where they are installed). Because of this the decision is usually made to not use these very effective, but very expensive, devices on low volume rural roads. The highway engineer is often faced with a take-it-or-leave-it choice, and typically he/she, quite logically, chooses to leave it.

Low Cost Safety Improvements (LCSI): Roadside Appurtenances and Retrofits

If FHWA were to alter its current policy and agree to the installation of less expensive, and admittedly less effective, roadside appurtenances on low volume rural roads, many more of these lower-cost, lower-effectiveness devices would be developed by manufacturers. Under existing FHWA policies, however, manufacturers have no incentive to incur such development costs, and highway engineers do not have the option of installing these low cost safety improvements (LCSI) devices in those selected locations where they would be cost effective. If such LCSI devices were commercially available, and acceptable under FHWA policies, they would fill an obvious need -- and serve to increase the <u>net</u> safety of low volume rural roads.[4]

The following four examples demonstrate the basic concept of LCSI roadside appurtenances -- and retrofits to existing appurtenances:

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[4]As a simplified example, if a crash cushion meeting NCHRP 230 criteria and costing $20,000 is 95 percent effective in reducing injuries, how should it be compared to a crash cushion costing $2000 which does not meet NCHRP 230 criteria, but is 80 percent effective in reducing injuries? It should be apparent that, other things being equal, it is much more cost-effective to use the $2000 cushion at 10 sites than to use the $20,000 cushion at one.

Example 1: Concrete Culvert Headwalls

There are still many old style culvert headwalls that could be made much safer simply by breaking them off at ground level. Figure 2 shows one such culvert headwall. Figure 3 shows how a similar headwall looks after it was broken off to ground level. Figure 4 depicts how the same result can be achieved by using fill material to bring the ground level up to the top of the headwall. And, in Figure 5, a combination of breaking off the posts and rail above the ground beam and raising the shoulder up to the level of the ground beam could vastly improve safety at this point on the roadside.

Example 2: Concrete Bridge Rail

Figure 6 shows an old style concrete bridge rail on a low volume ranch road. Many rails of this style were installed in the 1930s. Chipping on the leading surface of the parapet shows this one has passed the test of time and traffic. A significant safety improvement is shown in Figure 7. A short, low speed variety of a light weight concrete crash cushion such as ADIEM (Ivey, 1991) greatly increases safety at sites like this. The cost of a 9 foot ADIEM barrier is projected to be $1,500 per installation.

Example 3: Guardrail -- Bridge Rail Transition

In Figure 8 and the top portion of Figure 9, old style guardrail -- bridge rail transitions are shown. The lower portion of Figure 9 shows guardrails can be modified to significantly improve safety at a modest cost.

Example 4: Guardrail Removal

Many short segments of guardrail have no value and simply constitute a formidable "spearing" hazard. Figure 10 shows how removal of such a rail can constitute an improvement to roadside safety. Figure 11 shows a short segment of rail and typical culvert end. By removing the rail, using the posts for guardposts supporting delineators and converting the culvert end with an E-shaped reinforced concrete shape, as in Figure 12, a relatively safe portion of roadside will result.

Example 5: Side Road Culverts

Circular culverts at property entrances can also be rendered much safer if the same E-shaped, precast shape shown in Figure 11 is applied. Figures 13 and 14 show two sites where such a modification would be appropriate.

Some critics argue that the installation of Low Cost Safety Improvements means doing "less than the best" job on any given improvement area. This is the fallacy of looking at one site instead of the overall safety problem. Low Cost Safety Improvements means doing the best job that can possibly be done with the funds available. It means doing "something" on our low volume roadways, as opposed to doing "nothing." It means progress toward the practical limit of safety cost effectiveness.

Figure 2: Drainage Culvert Headwall

Figure 3: Headwall Broken Off at Ground Level

Figure 4: Headwall with Fill Added to Bring Ground Level up to Top of Headwall

Figure 5: Concrete Rail Style Culvert Headwall

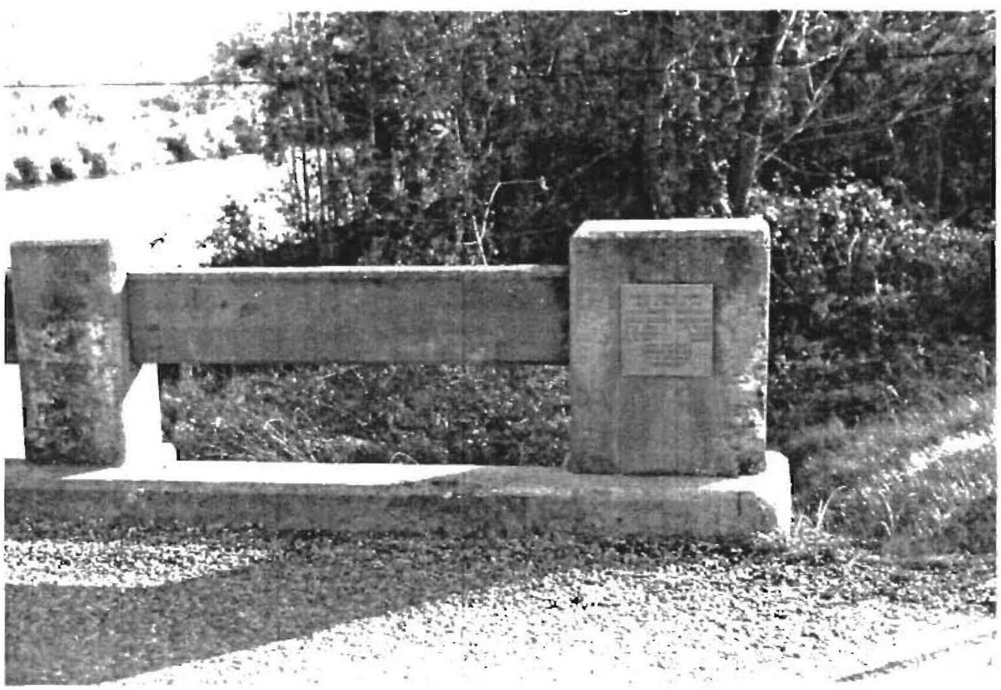


Figure 6: Old Style Bridge Rail and Parapet

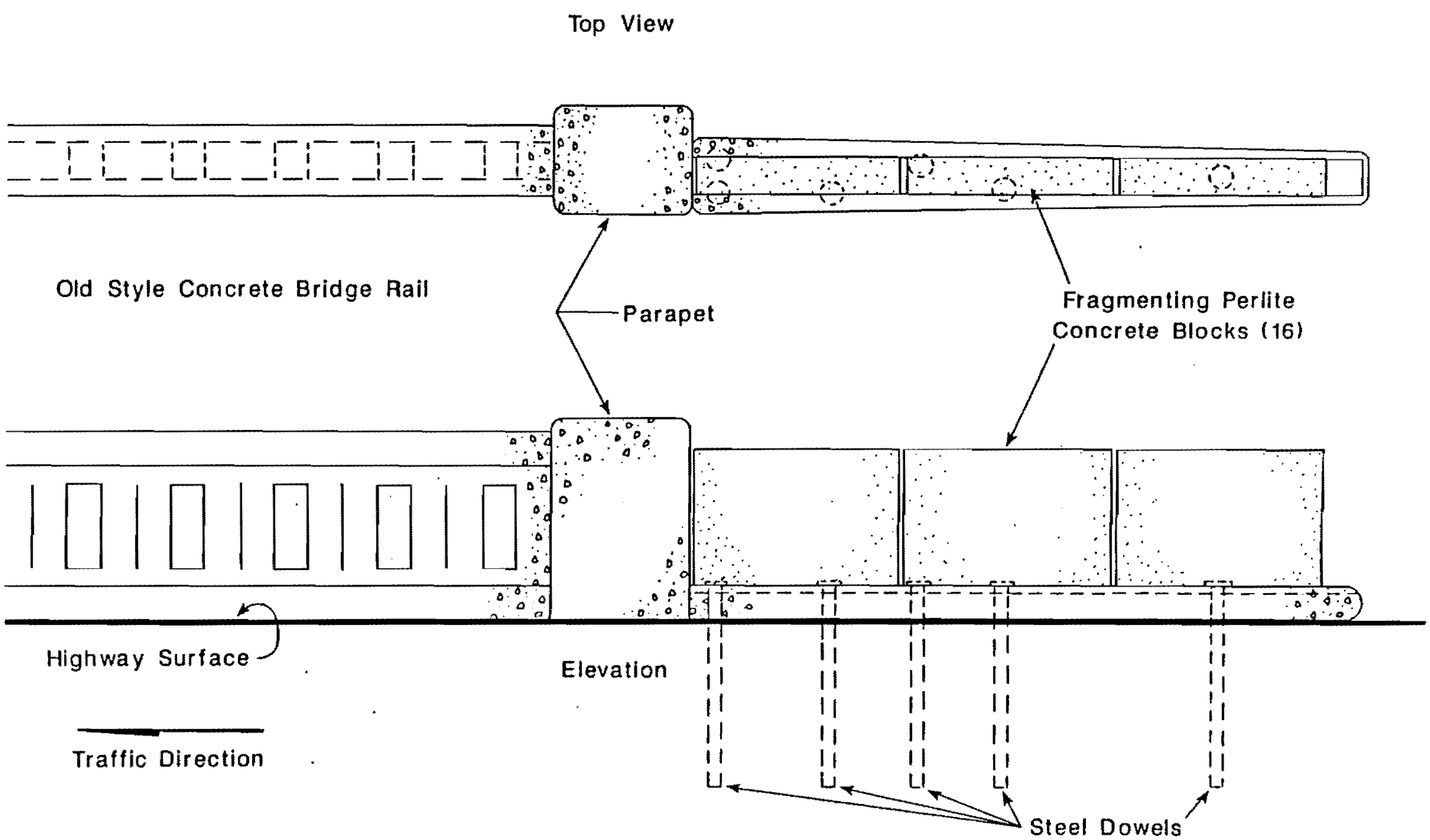


Figure 7: Concrete Bridge Parapet

Figure 8: Guardrail Unattached to Bridge Parapet

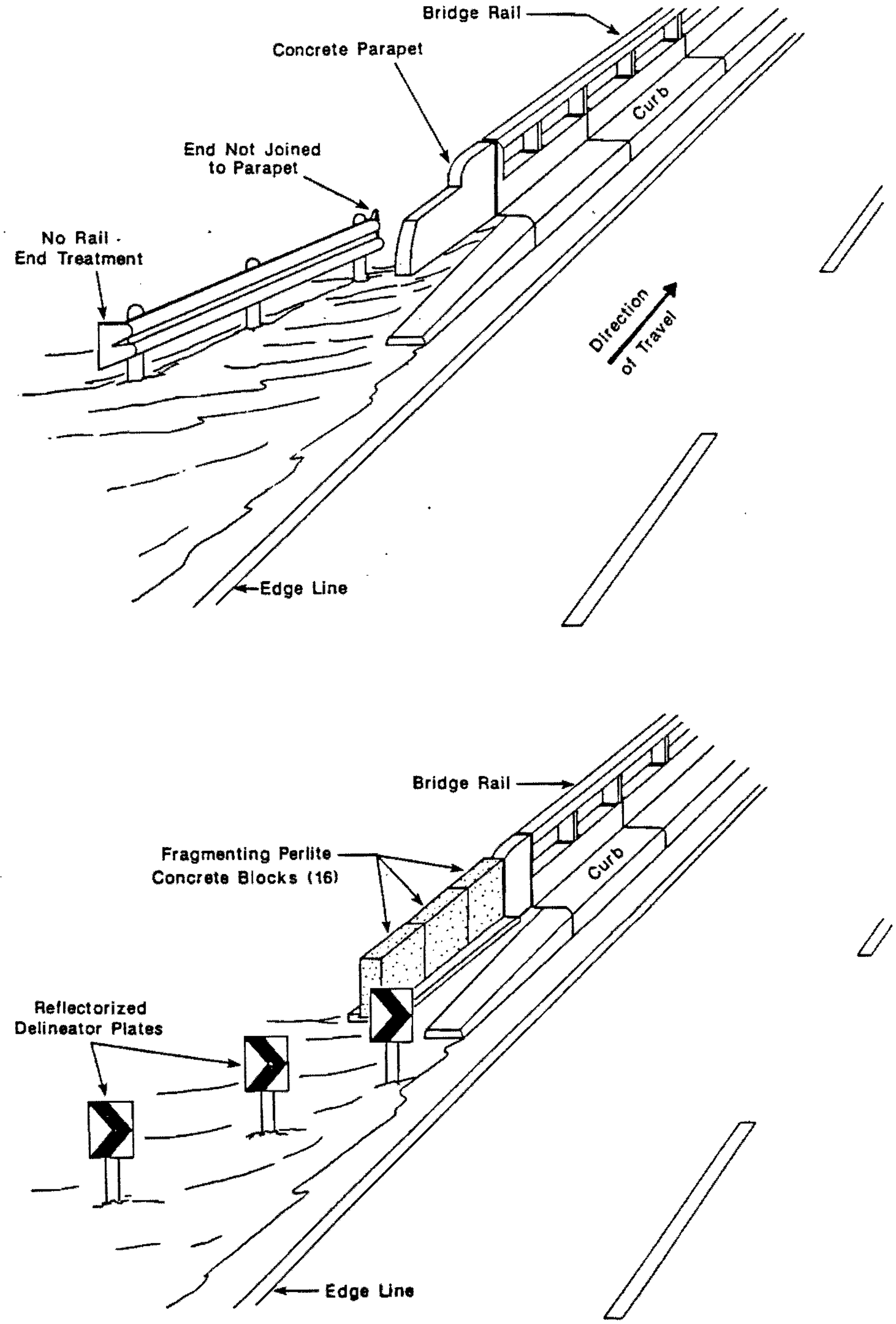
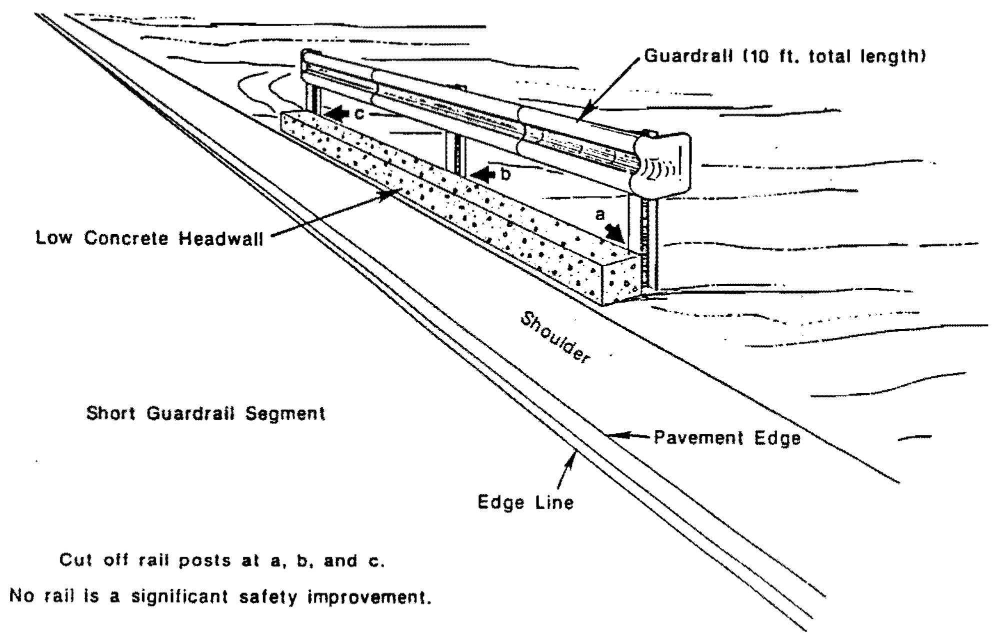


Figure 9: Guardrail — Bridge Rail Transition and Proposed Improvement



A low concrete headwall with a straight segment of guardrail is shown in this figure. A significant Safety Improvement could be realized by removing the guardrail and posts.

Figure 10: Low Concrete Headwall and Guardrail Segment

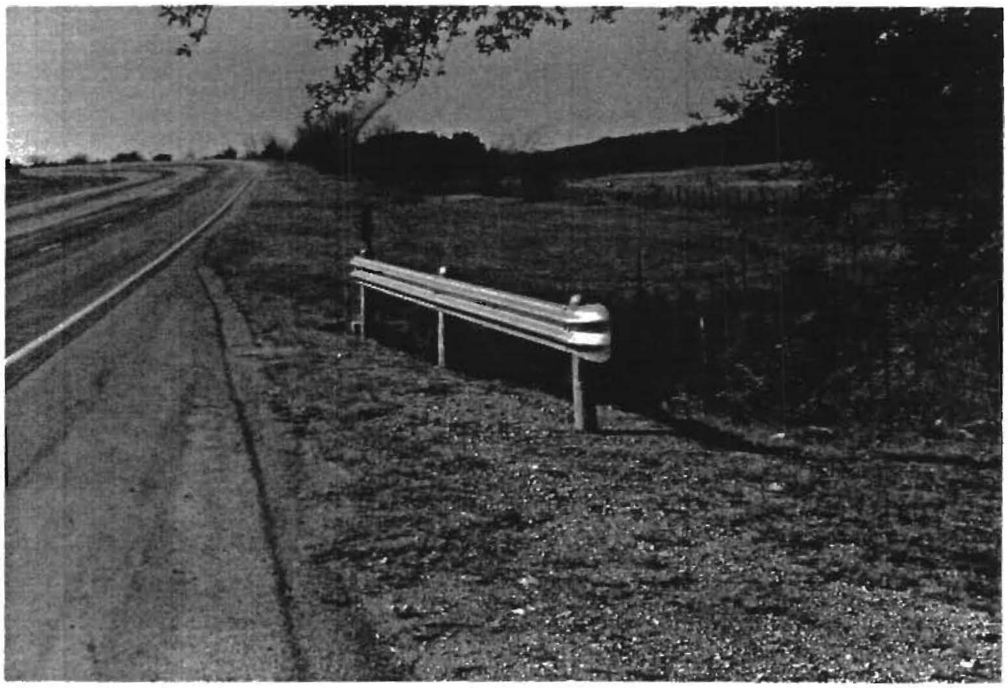


Figure 11: Short Segment of Rail in Advance of Drainage Structure

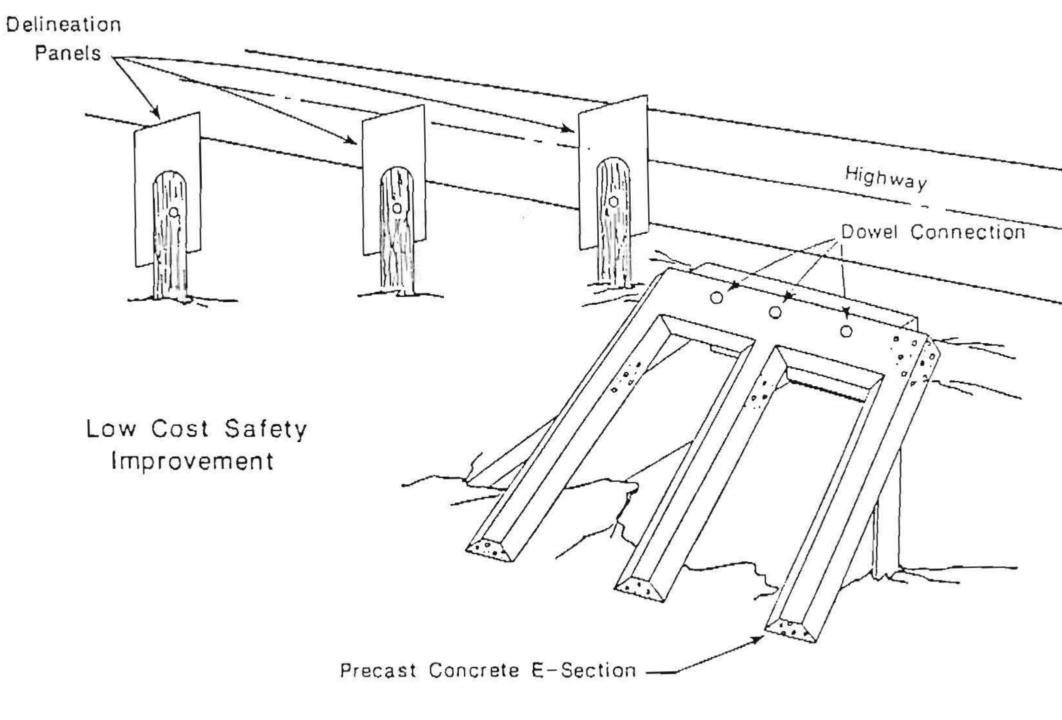


Figure 12: Rail Removal in Combination with Box Culvert Protection

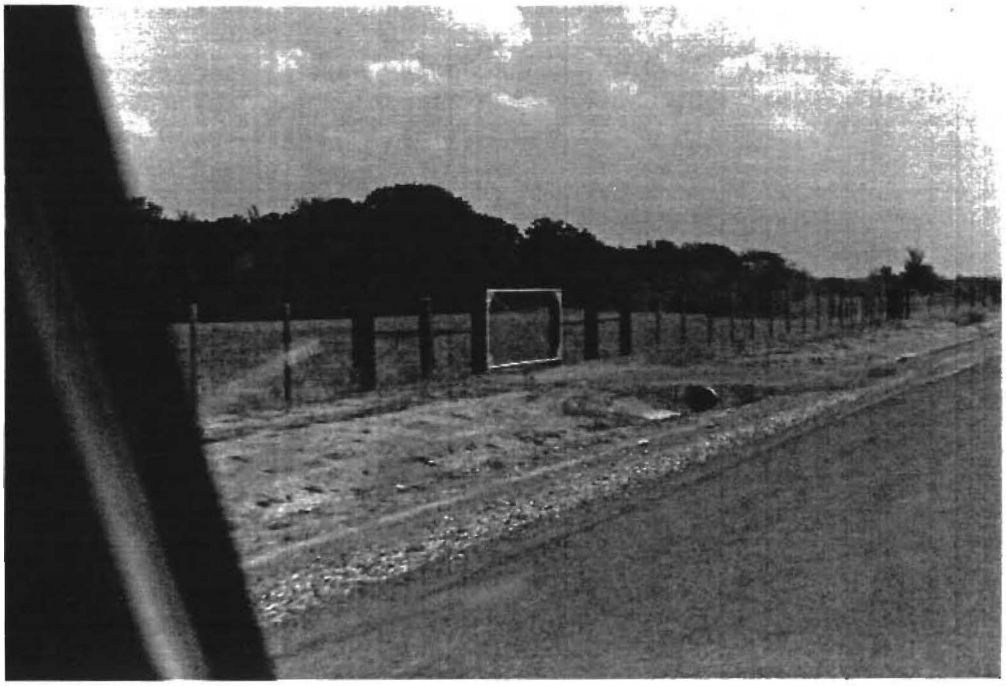


Figure 13: Single Tube Culvert

Figure 14: Double Tube Culvert

General Application of the LCSI Philosophy

Just as the installation of LCSI roadside appurtenances would increase the net safety of low volume rural roads, the general application of this philosophy to other maintenance, repair and restoration activities would serve the cause of safety.

- If we cannot afford to realign (i.e., straighten) all horizontal curves in excess of eight degrees, can we afford to improve the surface friction, superelevation, shoulders, or roadsides (on the outside) of these curves?

- If we cannot afford to realign (i.e., flatten) crest vertical curves with "inadequate" stopping sight distance, are there other measures, such as signing that could be taken to enhance the safety of these locations?

- If we cannot afford to replace hazardous, short-segment guardrail installations with "state-of-the-art" guardrails of adequate length and safe end treatments, can we not at least remove the existing short-segment rails?

- If we cannot afford paved shoulders, can we not at least recognize the need to emphasize pavement edge maintenance?

The Optimum Approach

Preceding sections have developed the concepts of Process Remediation (rather than remediation based upon so-called "high accident locations") and Low-Cost Safety Improvements. Both have definite advantages. Together their advantages are multiplied. In this section a method of combining both concepts in an organized program for safety improvement of low volume rural roadways will be discussed. First it should not be assumed that the Process Remediation plan should be followed from the highest frequency process deficiencies down to the one of lowest frequency. If this were done the first items to be worked on would be horizontal curves since nearly half the accidents occurred on curves. Rebuilding curves, however, involves almost completely rebuilding large elements of the roadway, a situation that is obviously not cost effective.

In order to prioritize process deficiencies it is necessary to determine both what remedial method can be used on a particular element and what resources are available to perform the task. It must be recognized that only extremely low cost methods may be used on low volume rural roads. If the materials for improvements are reasonable or are available from past activities, the improvements must also not be labor intensive. The man hours available for performance of the proposed tasks must not compete with other necessary activities but must be the result of better time organization for the manpower requirements. Consider the following:

Example 1: Short Guardrail Segment

A two man crew with truck including an acetylene torch and gas bottles could remove all short segments of guardrail in a District within a week's time. The first goal of the program would require no materials except acetylene and oxygen and very few man and equipment hours per guardrail segment removed.

Example 2: Culvert Headwalls

A two man crew with truck mounted concrete hammer could be used to break old headwalls off close to grade. The truck could be specifically set up to perform that single task. In a matter of a few weeks or sporadically in a year's time all the dangerous headwalls in a District could be removed. The second goal of the program could be the removal of all such walls. Practically no materials would be needed and only a few man and equipment hours per headwall would be required.

A program is suggested for each TxDOT district such as the one illustrated in Table 4. Note this "Example" is <u>not</u> proposed for any specific district, but is presented as an example of what might be most appropriate in one hypothetical district.

Explanation

TABLE 4. EXAMPLE DISTRICT SAFETY IMPROVEMENT PROGRAM

Ranked Deficiencies	Number in District	Severity Index	Unit Cost of Materials	Man Hours per Unit	Equip. per Unit
1 Guardrail Segments	52	5	$ 0	4	2
2 Culvert Headwalls	28	7	$ 100	8	4
3 Pavement Edges	NA	NA	$ 0	20	20
4 Bridge Parapets	72	7	$1800	28	10
.					
.					
.					
N Other Deficiency	20	4	$1500	24	12

Notes:

(1) The severity index in column 3 is based upon values provided in "Guide for Selecting, Locating, and Designing Traffic Barriers," AASHTO, 1977.

(2) The unit costs associated with pavement edges are costs per mile. The unit costs associated with improvements to guardrail segments, culvert headwalls and bridge parapets are costs per segment, per headwall and per parapet, respectively.

Compiling these figures based on district materials, equipment and labor requirements and comparing them with the availability of each factor should result in some fairly obvious choices about which tasks should be accomplished first. By undertaking one artifact or process at a time, savings in equipment commitment and labor skills should be developed to maximize task efficiency. With experience easier ways of producing the same improvement will result and efficiency should increase as the work on a particular artifact progresses.

CONCLUSION

The safety of low volume rural roads in this country can be enhanced if we are willing to recognize several facts and overcome some of our traditional thinking about highway safety.

Fact No. 1—The funds that society is willing to spend on highway safety are limited.

Fact No. 2—Low volume rural roads in this country constitute a huge physical plant.

Fact No. 3—The number of people killed and injured on low volume rural roads is relatively small, when compared to other highways.

Fact No. 4— Given Facts 1, 2 and 3, safety upgrades (i.e., investments) on low volume rural roads must be low cost investments if they are to be cost effective.

Fact No. 5—Numerous low-cost improvements to deficiencies throughout the low volume rural highway system will save more lives and reduce more injuries than a few, "up-to-standard" improvements.

Fact No. 6—Because it is difficult to identify "high accident sites" on the rural, low volume highway system, improvements to the system will generally be more efficient if carried out on "problem-specific" basis, rather than a "site-specific" basis.

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ABBREVIATIONS

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
TRB	Transportation Research Board

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APPENDIX A

PRIORITIZING HIGH ACCIDENT LOCATIONS ON LOW VOLUME RURAL ROADS

INTRODUCTION

If highway safety funds are to be allocated in a cost effective manner, the first step in the process is usually to determine where accidents are presently occurring and, by inference, where they will be occurring in the future. The identification of high accident locations (referred to as "blackspots" by the British) is typically accomplished by reviewing automated accident data files and selecting those locations that sustained an inordinate number of accidents (or displayed an inordinate accident rate) over the previous year or years.

Having identified and prioritized a candidate set of high accident locations, the second step in the process requires that engineering personnel be dispatched to the candidate high accident locations to determine which roadway features or characteristics are contributing to the abnormal number of accidents recorded at each location and to propose treatments to remedy any deficiencies found.

The third step in the process is to deploy maintenance forces (or retain contractors) to make the desired corrections or modifications at the identified locations. Ideally, these forces should be deployed in a manner that would maximize the number of accidents reduced for each dollar spent on remediation.

The three step process for prioritizing and treating highway locations in need of repair is generally reasonable if we are dealing with a wide variety of highways (i.e., a wide variety of traffic volumes). When we restrict our analysis to highways carrying fewer than, say, 1000 vehicles per day, however, the process outlined above is not reasonable, for theoretical and economic reasons.

THEORETICAL OBJECTIONS TO PRIORITIZING HIGH ACCIDENT LOCATIONS ON LOW VOLUME RURAL ROADS

Imagine that we would like to identify and prioritize the first 30 high accident locations (one-mile segments) from a sample of 1000 potential high accident locations (one-mile segments) throughout a low volume, rural highway system.[1] This imaginary 1000-mile highway system sustains an average of 200 accidents per year. Or, the average (mean) accident rate for the system taken as a whole is 0.2 accidents per mile per year ($\mu_+ = 0.2$).[2]

For the sake of argument, let's imagine that each of the 1000, one-mile segments in the system has exactly the same accident rate, 0.2 accidents per year (each $\mu_i = 0.2$). Under this set of circumstances, there are no "true" high

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[1]Assume for the sake of specificity that the annualized average daily traffic throughout this highway system is less than 1000 vehicles per day.

[2]In 1985 there were 33,454 miles of rural, two-lane, Farm-to-Market roads in Texas carrying 1,000 or fewer vehicles per day. In that same year, 6,108 accidents were recorded along these highways, i.e., 0.1826 accidents per mile per year. Griffin, L.I. and K.K. Mak, "The Benefits to be Achieved from Widening Rural, Two-Lane, Farm-to-Market Roads in Texas," Policy Development Report 0130-2, prepared for the Texas State Department of Highways and Public Transportation, April 1987.

accident locations in this highway system. Each location sustains 0.2 accidents per year, plus or minus chance fluctuation from year to year. If a given location sustains an inordinate number of accidents this year, those accidents are more logically attributable to random error than to some inherent deficiency in the highway environment. This set of circumstances will be referred to as Scenario 1.

By the same logic used in Scenario 1, if the mean accident rates for each of the 1000 one-mile segments are similar (i.e., if the variance of the μ_i's about μ_+ is small), locations that sustain an inordinate number of accidents this year may be "true" high accident locations, but, more likely, they are "fluke" locations - locations that have sustained an inordinate number of accidents due to chance fluctuation (Scenario 2). On the other hand, if the mean accident rates across all 1000 one-mile segments are dissimilar (i.e., if the variance of the μ_i's about μ_+ is large), locations that sustain an inordinate number of accidents this year may be flukes, but, more likely, they are "true" high accident locations - locations that are, in fact, in need of remedial treatment (Scenario 3).

The Concept of "Leverage" in Prioritizing High Accident Locations

To better appreciate the implications of the three scenarios just presented, consider the remedial functions shown in Figure 1. The diagonal function shown in this figure represents the conditions described in Scenario 1. In this scenario there are no high accident locations. Therefore, it follows that it is not possible to rank order accident locations (e.g., a set of, say, 1000 one-mile highway segments) into any arrangement that improves upon chance, i.e., remedial work might just as well begin at the first mile of highway in the system, or the last - or at any one-mile segment in between.

If we are totally unable to rank order highway segments in need of remediation, it also follows that if we repair 3 percent of a highway system, we have opportunity (on average) to address 3 percent of the accidents that are occurring throughout the system. If we repair 10 percent of the highway system, we have opportunity (on average) to address 10 percent of the accidents that are occurring throughout the system. Or, in other words, the cumulative proportion of future accidents in the system equals the cumulative proportion of miles remediated, i.e., the remedial function for Scenario 1 is a diagonal line.

Under the conditions outlined in Scenarios 2 and 3, accidents are not evenly distributed throughout a highway system, but cluster more frequently around some highway locations than others. In Scenario 2, this clustering is relatively inconsequential (i.e., the individual μ_i's are similar); in Scenario 3 the clustering is more pronounced (i.e., the individual μ_i's are dissimilar). As the clustering of accidents at individual locations becomes more pronounced, we are better able to rank order locations in need of remediation and we say that we have "leverage" on the problem. By having leverage on the problem we mean that by remediating, say, 3 percent of the system, we have opportunity to address more than 3 percent of the accidents that will occur in the future. If we remediate 10 percent of the system, we have opportunity to address more than 10 percent of the accidents that will occur in the future. If the cumulative proportion of future accidents addressed exceeds the cumulative proportion of highway miles in

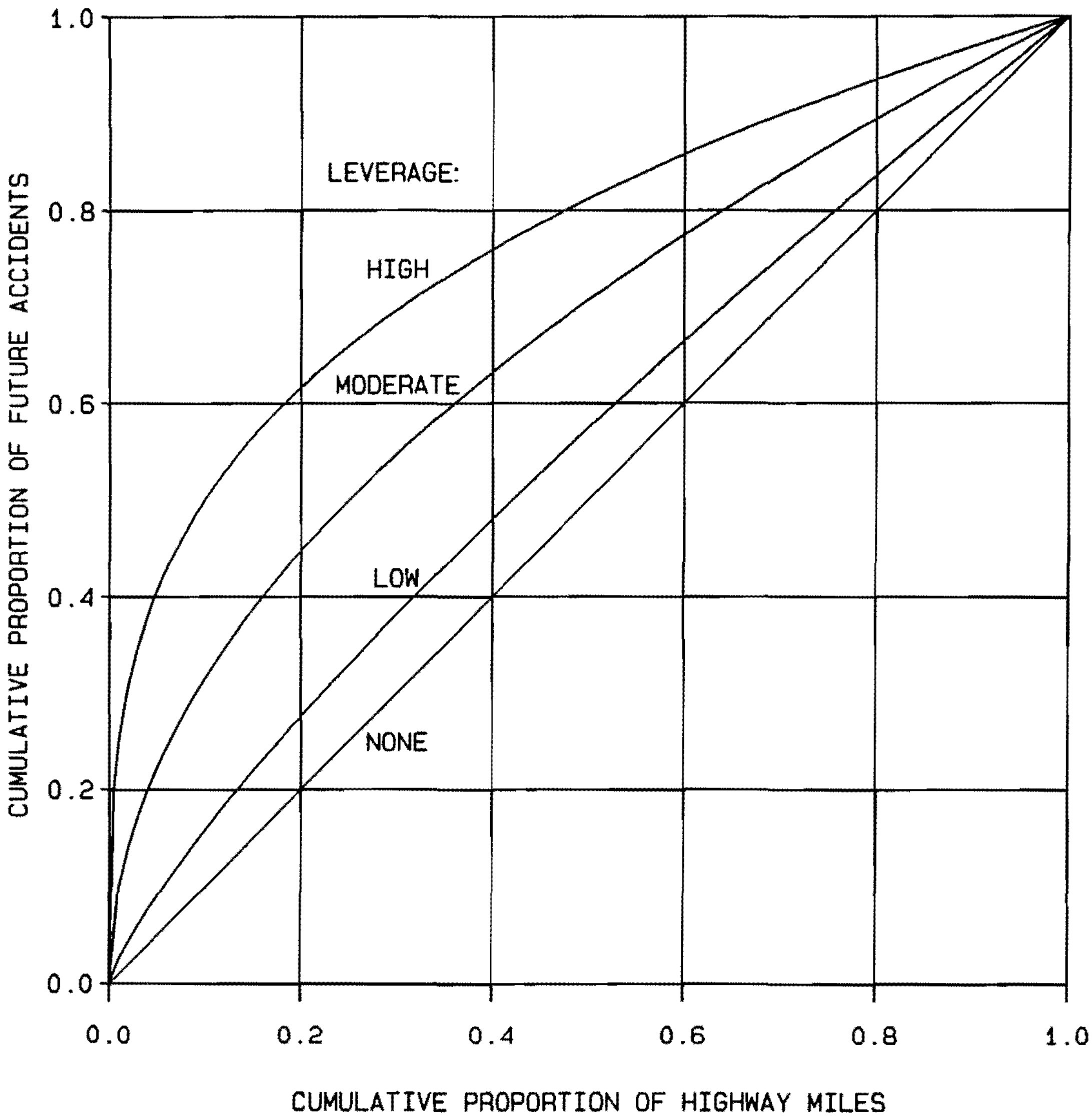

FIGURE 1: THEORETICAL REMEDIAL FUNCTIONS SHOWING THE LEVERAGE AVAILABLE FOR PRIORITIZING ACCIDENT LOCATIONS

the system, we have leverage in assigning remedial treatment, and the functions shown in Figure 1 lie above the diagonal. The higher a function lies above the diagonal, the more leverage we have.[3]

Two points fall out of the previous discussion as corollaries:

(1) If we try to prioritize high accident locations throughout a homogeneous or restricted highway system (e.g., a system carrying fewer than 1000 vehicles per day), our leverage on the problem will, other things being equal, be needlessly small.

(2) If we have no leverage (or very little leverage) in prioritizing high accident locations, the benefits of prioritization will be small to nonexistent.

Simulated Remedial Functions

To better understand and appreciate the remedial functions shown in Figure 1, a simulation study was performed. In this study, it was assumed that we were working with a 1000-mile highway system that on average sustains 200 accidents per year. Therefore, an average one-mile segment of highway in the system sustains 0.2 accidents in a year (μ_+).

Next, it was assumed that the average (mean) accident rates for the individual one-mile segments (μ_i's) are distributed about μ_+ in the form of a gamma distribution as shown in Figure 2. Each of the four distributions shown in this figure has the same mean or center of gravity (0.2), but a different variance.[4]

Model	Gamma Alpha (α)	Beta (β)	Mean	Variance
1	0.20	1.00	0.20	0.20
2	0.50	0.40	0.20	0.08
3	0.80	0.25	0.20	0.05
4	2.00	0.10	0.20	0.02

For individual highway locations, it was further assumed that accidents varied from year to year (about a mean of μ_i) in accordance with a Poisson distribution. For the highway location shown in Figure 3, for example, μ_i equals 0.2. Eight years out of 10, this location sustains no accidents. One or two years in 10 it sustains 1 accident. And, very rarely (fewer than two years in a hundred) it sustains two or more accidents.

In Figure 4 the highway location depicted has a mean accident rate of 0.8

[3]At this point it should be clear that the diagonal line in Figure 1 represents a remedial function with "no leverage" in prioritizing high accident locations.

[4]The mean of a gamma distribution is equal to $\alpha\beta$. The variance of a gamma distribution is equal to $\alpha\beta^2$.

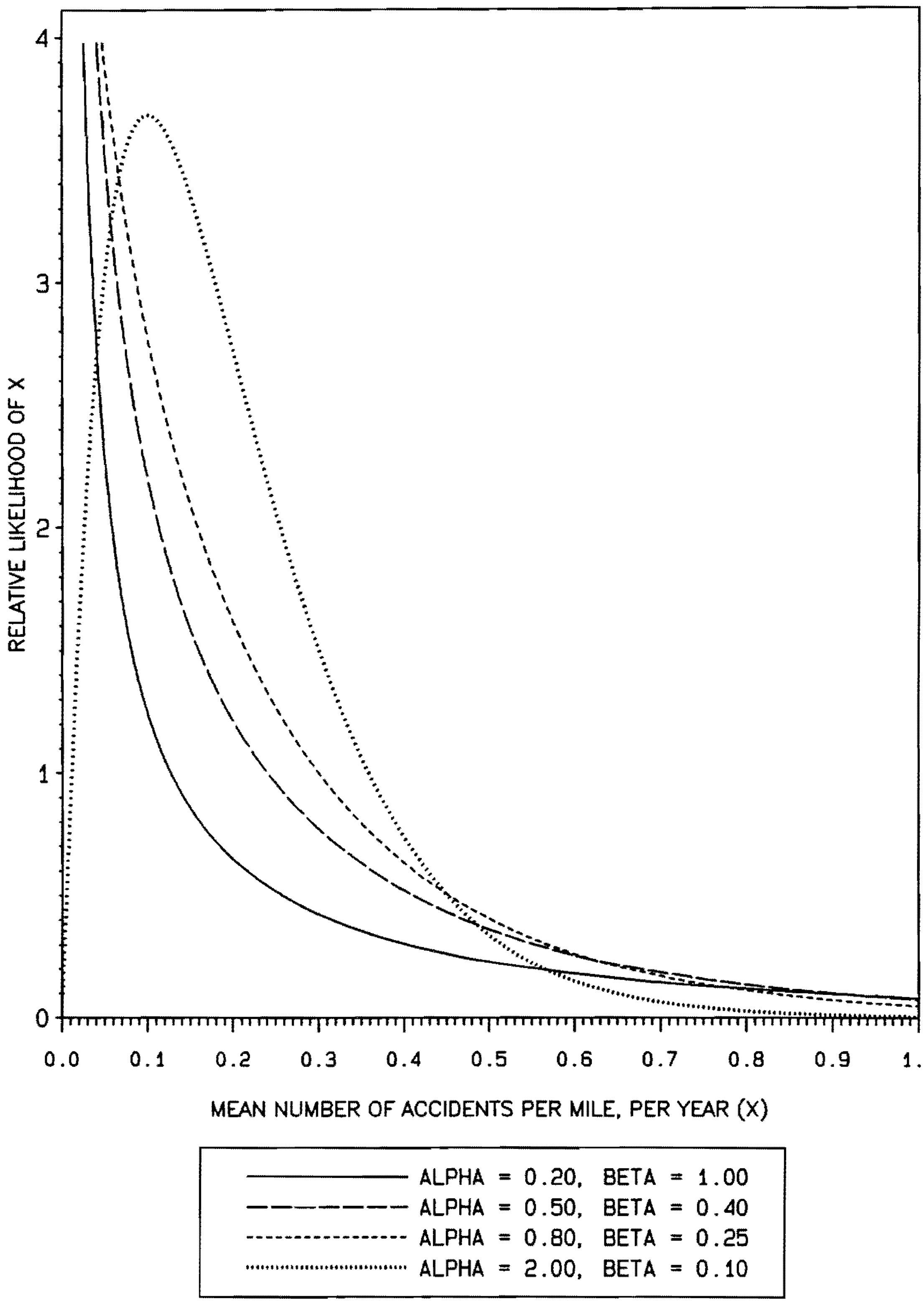

FIGURE 2: GAMMA DISTRIBUTIONS WITH DIFFERENT VALUES FOR ALPHA AND BETA

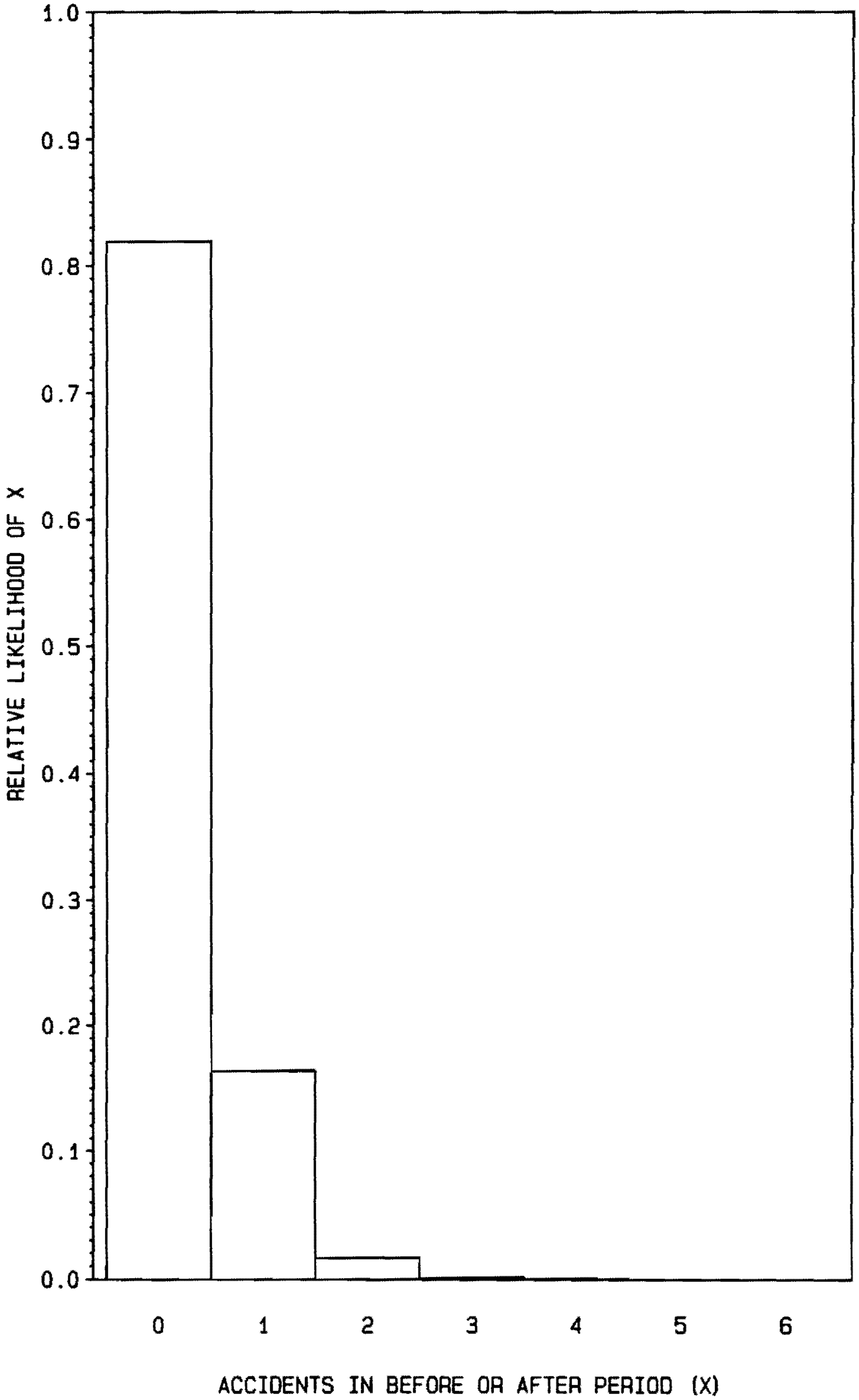

FIGURE 3: POISSON DISTRIBUTION WITH A MEAN OF 0.2

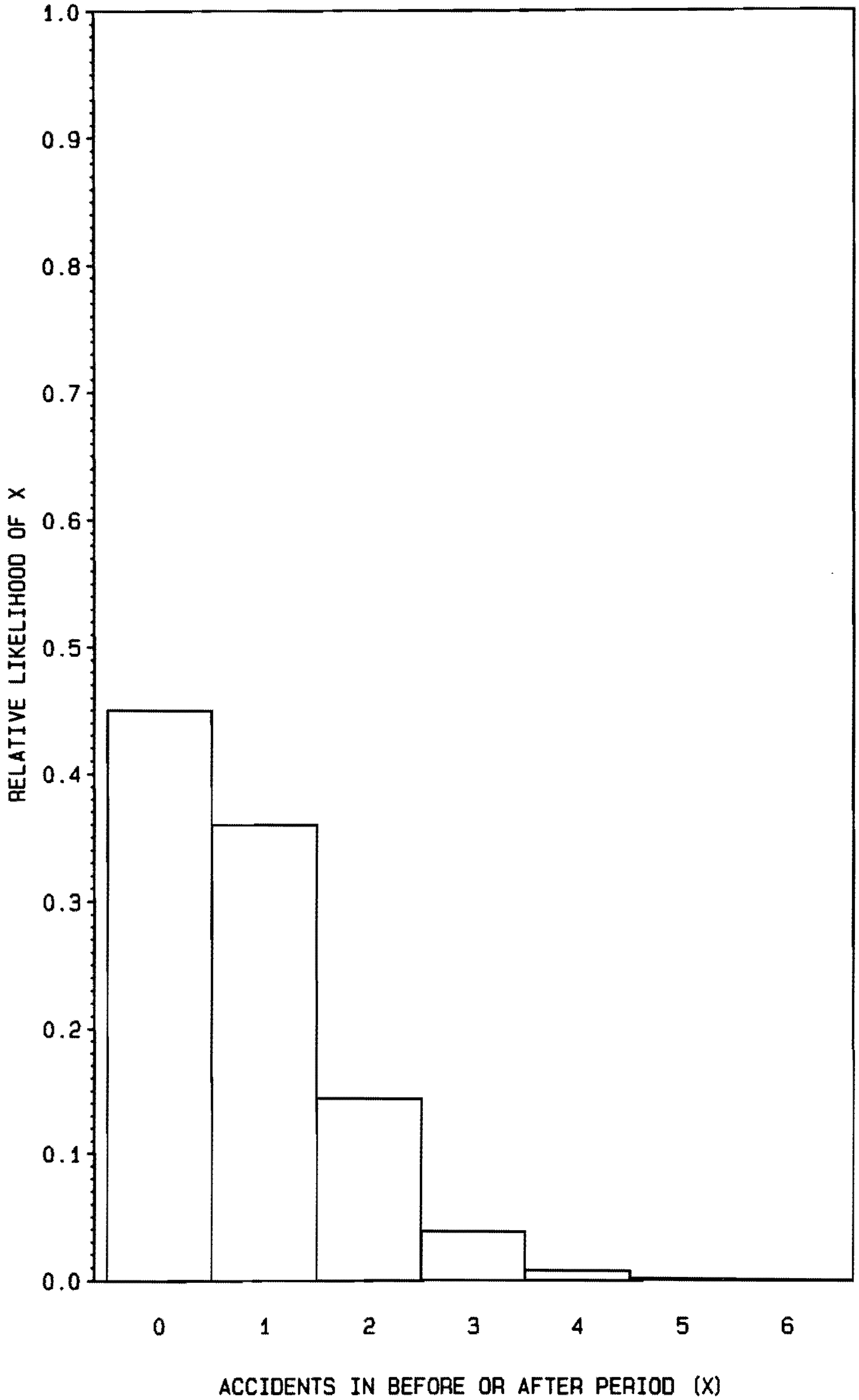

FIGURE 4: POISSON DISTRIBUTION WITH A MEAN OF 0.8

accidents per mile per year. On average, this location sustains no accidents for four or five years each decade, one accident for three or four years each decade, and two or more accidents approximately twice each decade.

Using the gamma random number generator in the Statistical Analysis System (SAS), 1000 μ_i's were chosen for each of the four gamma models shown in the box above, 4000 μ_i's in all. Then, using the Poisson random number generator in SAS, two accident counts were generated for each μ_i.[5] The first accident count represented accidents at a particular location during a "before" period; the second accident count represented accidents at the same location during an "after" period. The 1000 highway locations in each model were then rank ordered on "before" accidents.

Table 1 reports the results of the simulation for Model 1. The gamma distribution used in this simulation had an α of 0.20 and a β of 1.00. The first rank ordered one-mile segment (location) in this table had a mean accident rate of 1.228 accidents per mile per year (from the gamma random number generator) and reported accidents of 5 before and 1 after (based upon the Poisson random number generator used with a mean of 1.228). Tables 2, 3 and 4 can be read in similar fashion.[6,7]

Figure 5 depicts the simulated remedial function for Model 1 based upon the data in Table 1. In this figure the remedial function is well above the diagonal. Available leverage for prioritizing locations in need of remediation is good. In Models 2 through 4 leverage is progressively reduced as the variance of the gamma distribution on which the simulation is conducted increases (Figures 6-8).

ECONOMIC OBJECTIONS TO PRIORITIZING HIGH ACCIDENT LOCATIONS ON LOW VOLUME RURAL ROADS

Look once again at Table 1, the simulated results from Model 1. In this table the first 30 locations (one-mile segments) singled out for remediation are shown. These 30 locations constitute 3 percent of the 1000 mile highway system. The accidents that were recorded during the after period throughout these 30 miles of highway account for 17 percent of all after accidents. Or, by remediating 3 percent of the highway system, we have opportunity to address 17 percent of future accidents throughout the system, i.e., our leverage in Model 1 (through the first 3 percent of highway miles chosen for remediation) is 17/3

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[5]*SAS/STAT™ Guide for Personal Computers, Version 6 Edition.* Cary, NC: SAS Institute, 1985.

[6]The correlations of simulated accidents from before to after for Models 1 through 4 were 0.41, 0.23, 0.13, and 0.06, respectively. There were, obviously, 1000 before-after pairs generated for each model.

[7]It would be of interest to take a sample of three or four years of accident data from, say, 1000 miles of highway carrying fewer than 1000 vehicles per day and fit a gamma distribution to the data. If the data do, in fact, follow gamma, the parameter estimates for α and β would serve to show whether the values assumed in Models 1 through 4 are realistic, i.e., whether the values assumed in Models 1 through 4 bracket the estimated values.

Table 1: Simulated Before and After Accidents Drawn from Poisson Populations with Means Generated from a Gamma Distribution with Paramenters $\alpha = 0.20$ and $\beta = 1.00$

RANK ORDERED SEGMENT	CUMULATIVE PROPORTION OF MILEAGE	MEAN ANNUAL ACCIDENTS	SIMULATED ACC BEFORE	SIMULATED ACC AFTER	CUMULATIVE PROPORTION OF AFTER ACC
1	0.001	1.228	5	1	0.005
2	0.002	2.658	4	3	0.020
3	0.003	1.069	4	1	0.025
4	0.004	1.863	4	1	0.030
5	0.005	0.457	4	1	0.035
6	0.006	2.121	4	0	0.035
7	0.007	1.464	4	1	0.040
8	0.008	1.716	3	1	0.045
9	0.009	1.783	3	3	0.060
10	0.010	1.562	3	1	0.065
11	0.011	1.007	3	0	0.065
12	0.012	0.831	3	0	0.065
13	0.013	1.978	3	4	0.085
14	0.014	1.688	3	1	0.090
15	0.015	2.897	3	1	0.095
16	0.016	1.596	3	2	0.105
17	0.017	1.776	3	1	0.110
18	0.018	1.820	2	3	0.125
19	0.019	0.519	2	0	0.125
20	0.020	2.569	2	3	0.140
21	0.021	0.495	2	0	0.140
22	0.022	0.416	2	1	0.145
23	0.023	0.362	2	0	0.145
24	0.024	0.550	2	0	0.145
25	0.025	2.760	2	2	0.155
26	0.026	0.447	2	0	0.155
27	0.027	1.355	2	2	0.165
28	0.028	0.487	2	1	0.170
29	0.029	1.211	2	0	0.170
30	0.030	0.349	2	0	0.170
⋮	⋮	⋮	⋮	⋮	⋮
996	0.996	0.023	0	0	1.000
997	0.997	0.000	0	0	1.000
998	0.998	0.286	0	0	1.000
999	0.999	0.065	0	0	1.000
1000	1.000	0.014	0	0	1.000
		187.095	191	200	

Table 2: Simulated Before and After Accidents Drawn from Poisson Populations with Means Generated from a Gamma Distribution with Paramenters $\alpha = 0.50$ and $\beta = 0.40$

RANK ORDERED SEGMENT	CUMULATIVE PROPORTION OF MILEAGE	MEAN ANNUAL ACCIDENTS	SIMULATED ACC BEFORE	SIMULATED ACC AFTER	CUMULATIVE PROPORTION OF AFTER ACC
1	0.001	1.653	4	0	0.00000
2	0.002	1.417	4	2	0.00935
3	0.003	1.104	4	0	0.00935
4	0.004	0.546	4	0	0.00935
5	0.005	1.326	3	0	0.00935
6	0.006	0.957	3	0	0.00935
7	0.007	2.513	3	2	0.01869
8	0.008	0.411	2	0	0.01869
9	0.009	0.606	2	1	0.02336
10	0.010	0.441	2	0	0.02336
11	0.011	0.475	2	0	0.02336
12	0.012	1.238	2	2	0.03271
13	0.013	0.712	2	2	0.04206
14	0.014	0.290	2	0	0.04206
15	0.015	0.342	2	0	0.04206
16	0.016	2.355	2	2	0.05140
17	0.017	0.486	2	0	0.05140
18	0.018	0.728	2	0	0.05140
19	0.019	0.428	2	1	0.05607
20	0.020	0.182	2	0	0.05607
21	0.021	0.448	2	1	0.06075
22	0.022	0.272	2	0	0.06075
23	0.023	0.666	2	0	0.06075
24	0.024	0.971	2	0	0.06075
25	0.025	0.507	2	0	0.06075
26	0.026	1.159	2	2	0.07009
27	0.027	0.638	2	0	0.07009
28	0.028	0.744	2	0	0.07009
29	0.029	0.151	2	0	0.07009
30	0.030	0.062	2	0	0.07009
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
996	0.996	0.157	0	1	1.00000
997	0.997	0.254	0	0	1.00000
998	0.998	0.157	0	0	1.00000
999	0.999	0.133	0	0	1.00000
1000	1.000	0.180	0	0	1.00000
		203.483	226	214	

Table 3: Simulated Before and After Accidents Drawn from Poisson Populations with Means Generated from a Gamma Distribution with Paramenters $\alpha = 0.80$ and $\beta = 0.25$

RANK ORDERED SEGMENT	CUMULATIVE PROPORTION OF MILEAGE	MEAN ANNUAL ACCIDENTS	SIMULATED ACC BEFORE	SIMULATED ACC AFTER	CUMULATIVE PROPORTION OF AFTER ACC
1	0.001	0.982	4	0	0.00000
2	0.002	0.568	4	0	0.00000
3	0.003	0.911	4	0	0.00000
4	0.004	0.446	3	0	0.00000
5	0.005	0.562	3	2	0.01042
6	0.006	0.455	3	0	0.01042
7	0.007	1.217	3	1	0.01563
8	0.008	0.122	3	0	0.01563
9	0.009	0.347	3	0	0.01563
10	0.010	0.302	2	0	0.01563
11	0.011	0.314	2	0	0.01563
12	0.012	0.562	2	0	0.01563
13	0.013	0.486	2	0	0.01563
14	0.014	0.164	2	1	0.02083
15	0.015	0.829	2	0	0.02083
16	0.016	1.472	2	5	0.04687
17	0.017	0.536	2	0	0.04687
18	0.018	0.329	2	0	0.04687
19	0.019	0.341	2	1	0.05208
20	0.020	0.676	2	0	0.05208
21	0.021	0.200	2	0	0.05208
22	0.022	0.744	2	1	0.05729
23	0.023	0.263	2	0	0.05729
24	0.024	0.406	2	0	0.05729
25	0.025	0.743	2	0	0.05729
26	0.026	0.544	2	3	0.07292
27	0.027	1.004	2	0	0.07292
28	0.028	0.366	2	1	0.07813
29	0.029	1.571	2	1	0.08333
30	0.030	0.536	2	0	0.08333
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
996	0.996	0.027	0	0	0.99479
997	0.997	0.817	0	1	1.00000
998	0.998	0.070	0	0	1.00000
999	0.999	0.156	0	0	1.00000
1000	1.000	0.022	0	0	1.00000
		202.133	228	192	

Table 4: Simulated Before and After Accidents Drawn from Poisson Populations with Means Generated from a Gamma Distribution with Paramenters α = 2.00 and β = 0.10

RANK ORDERED SEGMENT	CUMULATIVE PROPORTION OF MILEAGE	MEAN ANNUAL ACCIDENTS	SIMULATED ACC BEFORE	SIMULATED ACC AFTER	CUMULATIVE PROPORTION OF AFTER ACC
1	0.001	0.409	3	1	0.00508
2	0.002	0.131	3	0	0.00508
3	0.003	0.417	3	0	0.00508
4	0.004	0.275	2	0	0.00508
5	0.005	0.449	2	0	0.00508
6	0.006	0.358	2	0	0.00508
7	0.007	0.312	2	0	0.00508
8	0.008	0.457	2	1	0.01015
9	0.009	0.134	2	0	0.01015
10	0.010	0.441	2	0	0.01015
11	0.011	0.163	2	1	0.01523
12	0.012	0.280	2	0	0.01523
13	0.013	0.102	2	0	0.01523
14	0.014	1.082	2	0	0.01523
15	0.015	0.164	2	0	0.01523
16	0.016	0.588	2	3	0.03046
17	0.017	0.378	2	0	0.03046
18	0.018	0.394	2	0	0.03046
19	0.019	0.563	2	0	0.03046
20	0.020	0.300	2	0	0.03046
21	0.021	0.575	2	2	0.04061
22	0.022	0.607	2	1	0.04569
23	0.023	0.520	2	0	0.04569
24	0.024	0.497	2	1	0.05076
25	0.025	0.438	2	1	0.05584
26	0.026	0.383	2	0	0.05584
27	0.027	0.159	2	0	0.05584
28	0.028	0.337	2	0	0.05584
29	0.029	0.316	1	0	0.05584
30	0.030	0.229	1	0	0.05584
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
996	0.996	0.024	0	0	0.98985
997	0.997	0.066	0	1	0.99492
998	0.998	0.461	0	1	1.00000
999	0.999	0.793	0	0	1.00000
1000	1.000	0.231	0	0	1.00000
		201.586	221	197	

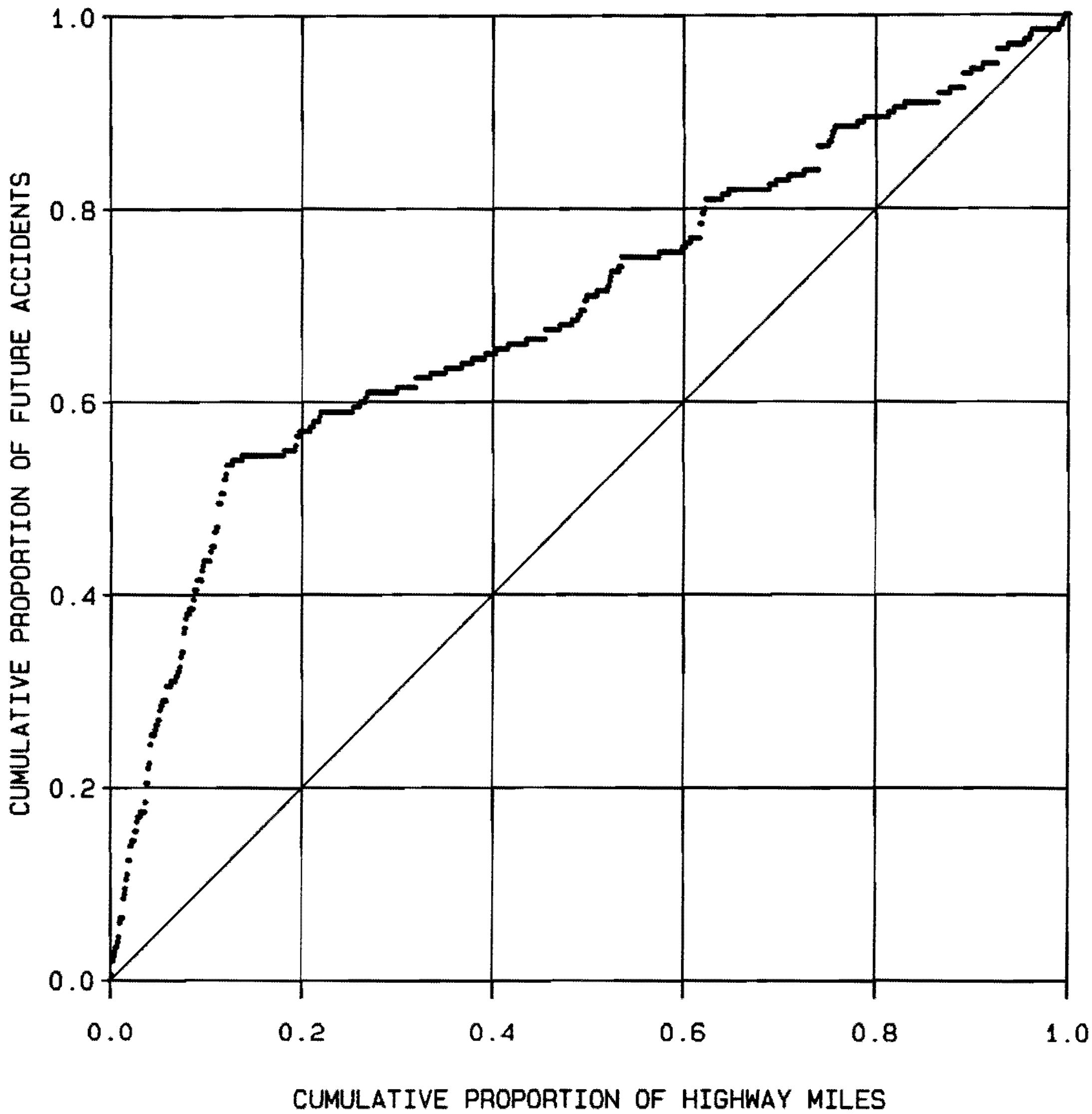

FIGURE 5: SIMULATED CURVE SHOWING THE LEVERAGE AVAILABLE FOR PRIORITIZING ACCIDENT LOCATIONS (SOURCE GAMMA DISTRIBUTION: ALPHA = 0.20, BETA = 1.00)

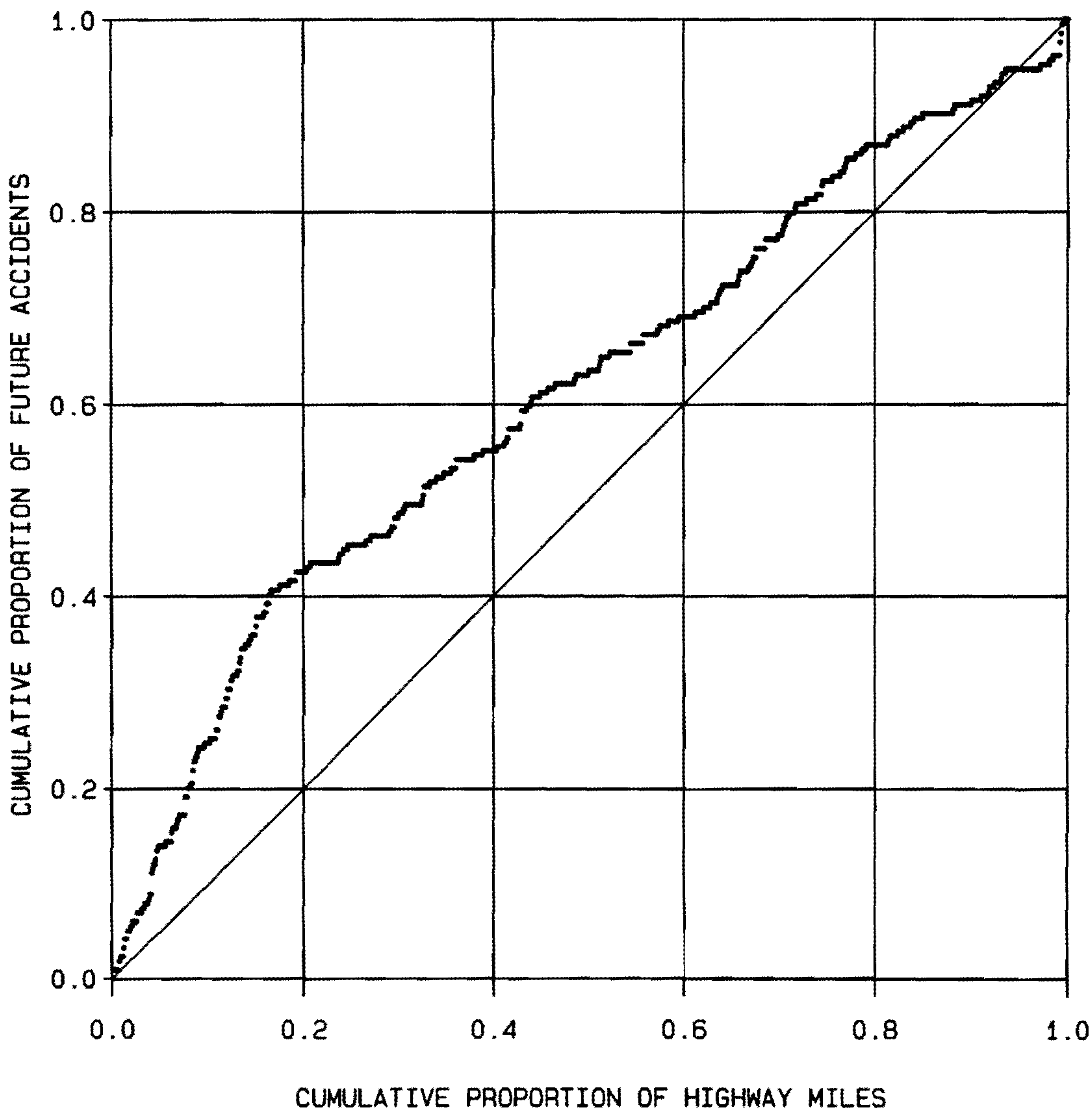

FIGURE 6: SIMULATED CURVE SHOWING THE LEVERAGE AVAILABLE FOR PRIORITIZING ACCIDENT LOCATIONS (SOURCE GAMMA DISTRIBUTION: ALPHA = 0.50, BETA = 0.40)

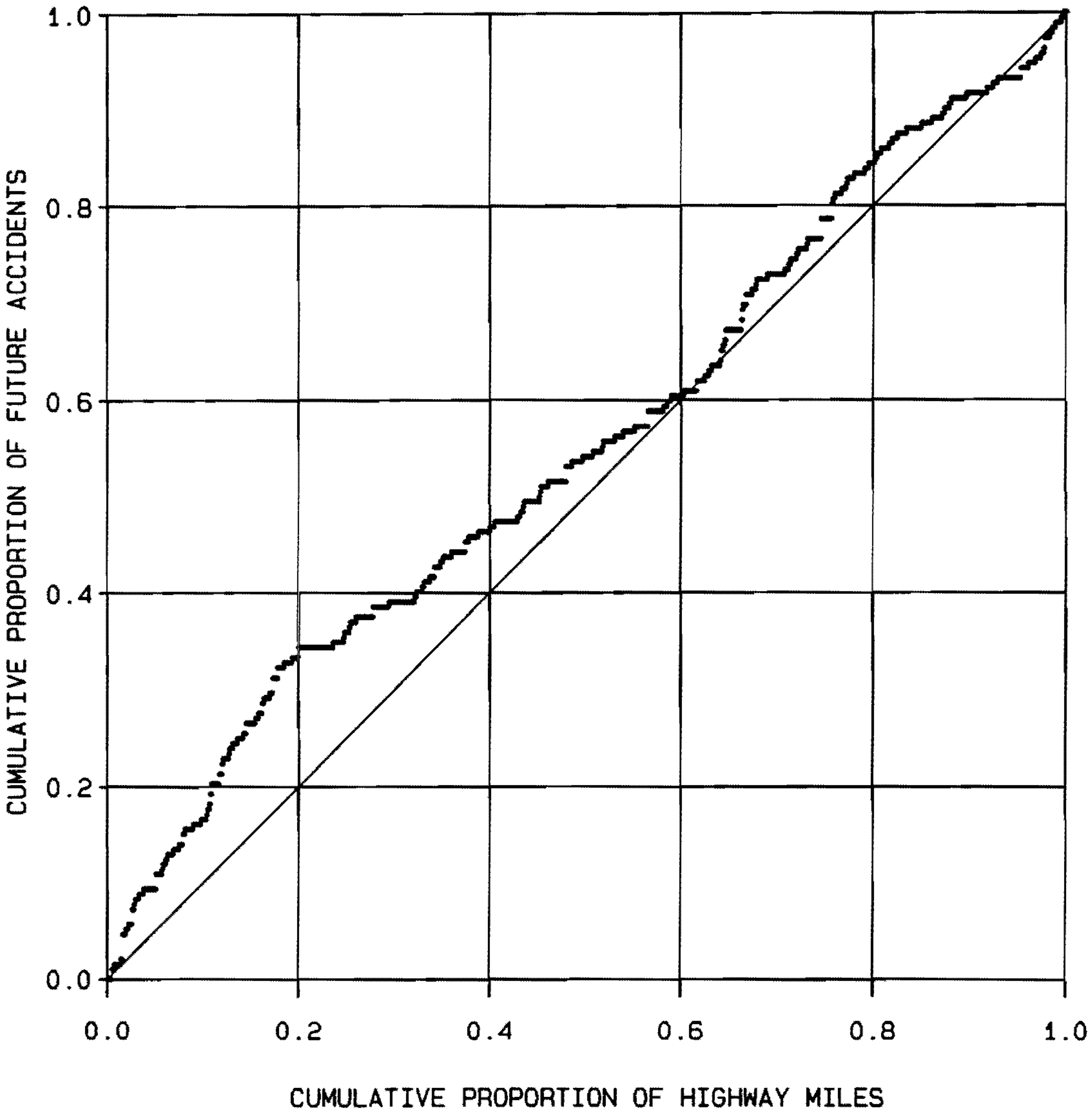

FIGURE 7: SIMULATED CURVE SHOWING THE LEVERAGE AVAILABLE FOR PRIORITIZING ACCIDENT LOCATIONS (SOURCE GAMMA DISTRIBUTION: ALPHA = 0.80, BETA = 0.25)

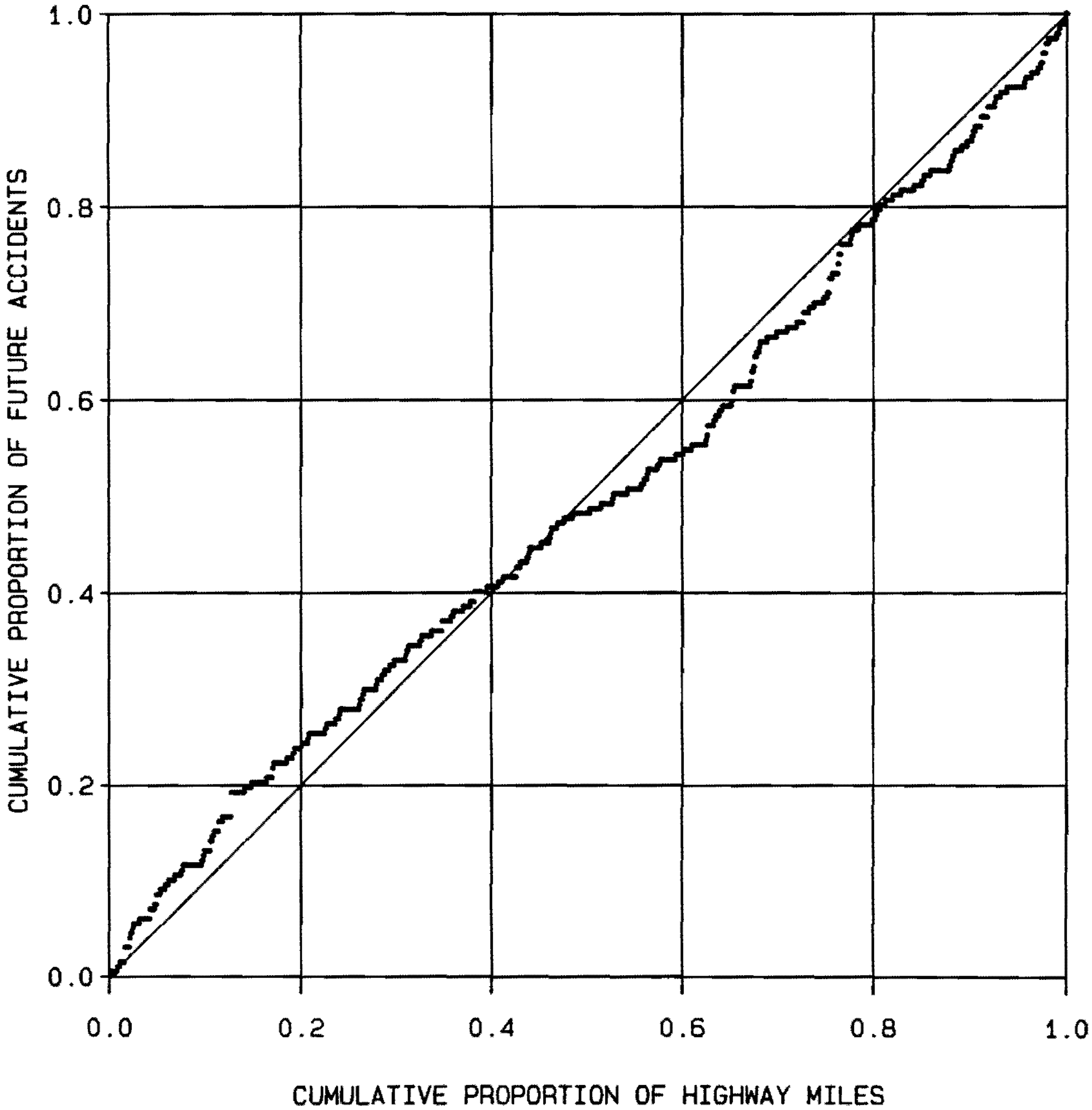

FIGURE 8: SIMULATED CURVE SHOWING THE LEVERAGE AVAILABLE FOR PRIORITIZING ACCIDENT LOCATIONS (SOURCE GAMMA DISTRIBUTION: ALPHA = 2.00, BETA = 0.10)

or 5.67.

Rather than looking at the percents or proportions generated in the Model 1 simulation, however, look for a moment at the "number of miles of highway" and the "number of accidents" that would be affected by treating the first 30 high accident locations. By remediating 30 miles of highway this year, we would have opportunity to address only 34 accidents next year (1.13 accidents per mile). The problem that we run into is that accident rates on low volume rural roads (on a per mile basis) are very low. Thus, even when we have good leverage to prioritize those locations in need of remediation, other things being equal, the costs of remediation on a "per accident" basis will be high.

CONCLUSION

To speak of "high accident locations" on low volume rural roads is misleading. A *bona fide* high accident location on a low volume rural road is an "average accident location" or a "low accident location" on roads carrying higher volumes of traffic.

To allocate safety funds to the treatment of 30 miles of low volume highway in the hope of addressing 34 accidents next year is a poor investment. Those same funds would be much better spent on higher volume highways that are sustaining more than 1.13 accidents per mile.[8]

If highway safety funds are to be cost effectively allocated, that allocation should be made on the basis of two factors: (1) available funds and (2) investment opportunities (i.e., opportunities to reduce traffic accidents, and the deaths and injuries that result from those accidents). If the cost allocation process is artificially constrained, if a portion of available funds is required to be spent on low yield investments (e.g., low volume rural roads), the "best" overall return on our safety investment will not be realized - lives will be lost and needless injuries will be suffered.

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[8]Under Models 2, 3 and 4 those same safety funds would be allocated to address 0.47, 0.56 and 0.37 accidents per mile next year, respectively.

APPENDIX B

A DESCRIPTION OF ACCIDENTS ON LOW VOLUME RURAL ROADS

In this appendix 23 figures are used to describe the conditions and circumstances surrounding accidents on low volume rural roads. These figures were generated from the 6123 police-reported accidents that occurred in Texas in 1988 on two-lane rural roads with average daily traffic (ADT) counts of fewer than 1000. 4490 (73.3%) of these accidents were single vehicle accidents; 1633 (26.7%) were multivehicle accidents.

Brief comments on each of these 23 figures follow:

FIGURE	COMMENTS
1	The frequency of multivehicle accidents rises slowly as a function of increasing traffic volume. The frequency of single vehicle accidents rises rapidly up to about 300 or 400 vehicles per day and then stabilizes or decreases slowly.
2	Three out of four drivers involved in single vehicle accidents are male. In multivehicle accidents, 70 percent of all drivers are male.
3	18 and 19 year old drivers are well over represented in accidents on low volume rural roads. The number of drivers involved in single vehicle accidents falls steadily from 19 to 80 years of age. For multivehicle accidents, the number of accident-involved drivers decreases after age 18, but then becomes relatively stable after age 50 or 60.
4	Of 4507 drivers involved in single vehicle accidents, 2335 (52%) were speeding (above the limit or unsafe for conditions) and 1141 (25%) were driving while intoxicated. Of 3285 drivers involved in multivehicle accidents, 410 (12%) were speeding and 215 (7%) were driving while intoxicated. [Note: Some drivers may have been speeding and driving while intoxicated.]
5	46 percent of the vehicles involved in single vehicle accidents were single unit trucks, predominantly pickup trucks. For multivehicle accidents the corresponding percentage was 44 percent. [Note: In 1988, on a statewide basis, single unit trucks accounted for 28 percent of all accident involved vehicles.]
6	Of 4490 single vehicle accidents, 846 (19%) produced at least one incapacitating injury (A) or fatality (F). For multivehicle accidents the corresponding frequency and percentage are 219 and 13 percent. [Comment: In Figures 9, 10 and 11 it will be shown that single vehicle accidents are relatively more common than multivehicle accidents late at night, during hours of darkness, and on week ends. Minor, property damage only (PDO) accidents that occur during these hours of the day and days of the week may very well be under reported. Therefore, the fact that 19 percent of all reported single vehicle accidents involve an incapacitating or fatal injury may be spuriously high.]
7	Single vehicle accidents are generally more severe than multivehicle accidents as demonstrated by the fact that cumulative multivehicle accident severity rises more rapidly than does cumulative single

vehicle accident severity.

8 Both single vehicle accidents and multivehicle accidents are distributed fairly evenly throughout the year.

9 Multivehicle accidents are predominantly a daytime phenomenon, with accidents peaking in the late afternoon. Single vehicle accidents, on the other hand, are a nighttime phenomenon with accidents peaking between about 9 PM and midnight.

10 58 percent of single vehicle accidents occur during hours of darkness (including dawn and dusk); 19 of multivehicle accidents occur during hours of darkness.

11 Multivehicle accidents are distributed fairly evenly throughout the week, with, perhaps, a slight increase on Fridays and Saturdays. Single vehicle accidents predominate on Fridays, Saturdays and Sundays - during late night and early morning hours.

12 Wet roadway surfaces are associated with only 12 percent of all single vehicle accidents and 10 percent of all multivehicle accidents.

13 Of 4490 single vehicle accidents, 1619 (36%) occurred on horizontal curves. Of 1633 multivehicle accidents, 193 (12%) occurred on curves.

14 26 percent of all single vehicle accidents occur on the roadway, 30 percent occur on the shoulder and 44 percent occur beyond the shoulder. Not surprisingly, over 97 percent of all multivehicle accidents occur on the roadway.

15 The first harmful event in single vehicle accidents is striking a fixed object (43%), followed by overturning (33%) and striking an animal (17%).

16-18 Striking fixed objects is relatively more common on higher ADT highways. Overturning and striking animals are relatively more common on lower ADT highways.

19 Of fixed objects struck in single vehicle accidents, the most often cited is fence (16%) followed by tree or shrub (8%) and culvert headwall (6%).

20-22 Striking fences is relatively more common on lower ADT highways. The likelihood of striking a tree or shrub is fairly evenly divided across highway traffic categories. Striking culvert headwalls is relatively more common on higher ADT highways.

23 Single vehicle accidents do not typically occur at intersections or driveways. But, 37 percent of all multivehicle accidents occur at intersections, 7 percent are intersection related, and another 24 percent occur at driveways.

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

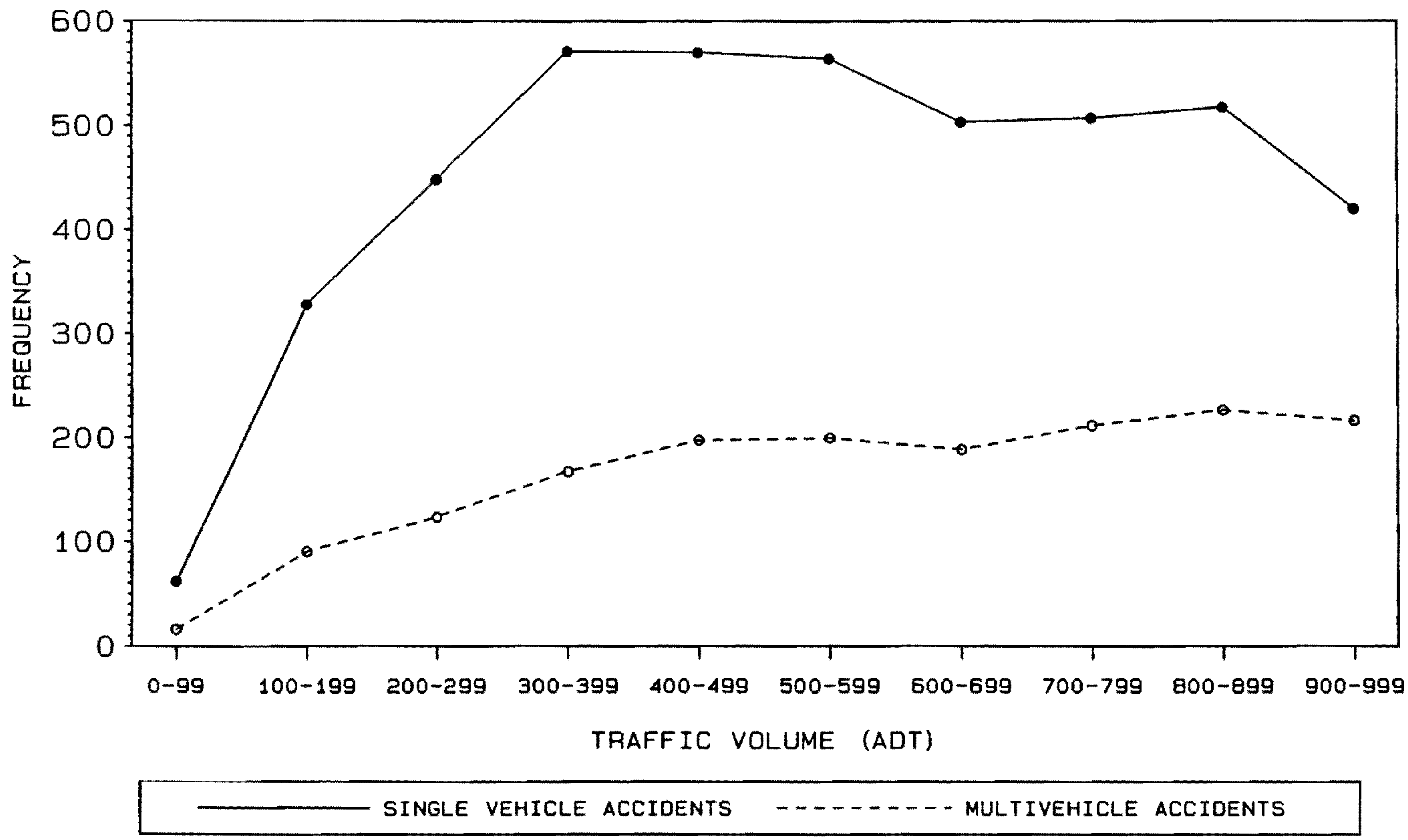

Figure 1: ACCIDENTS (N=6123) BY TRAFFIC VOLUME

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

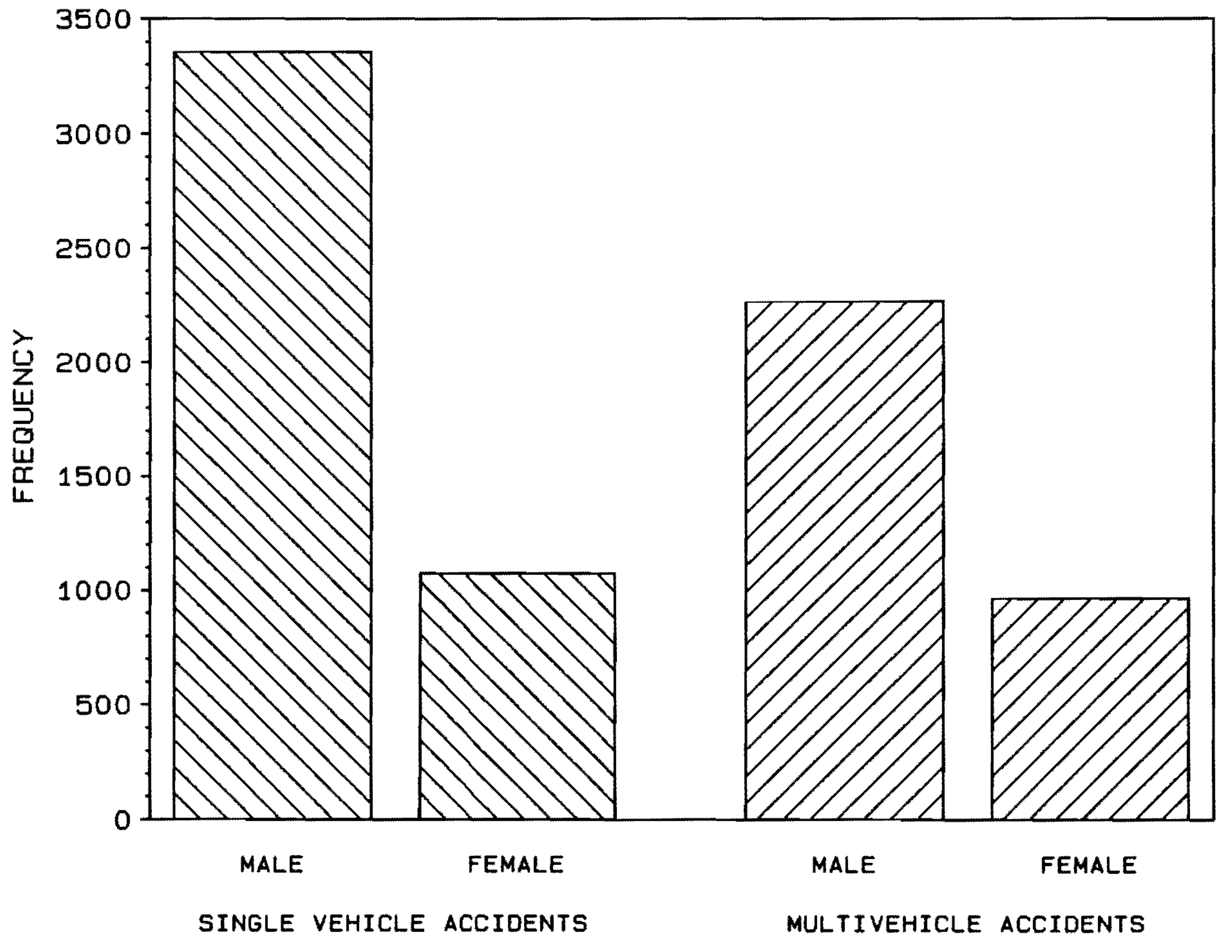

Figure 2: ACCIDENT-INVOLVED DRIVERS (N=7792) BY SEX

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

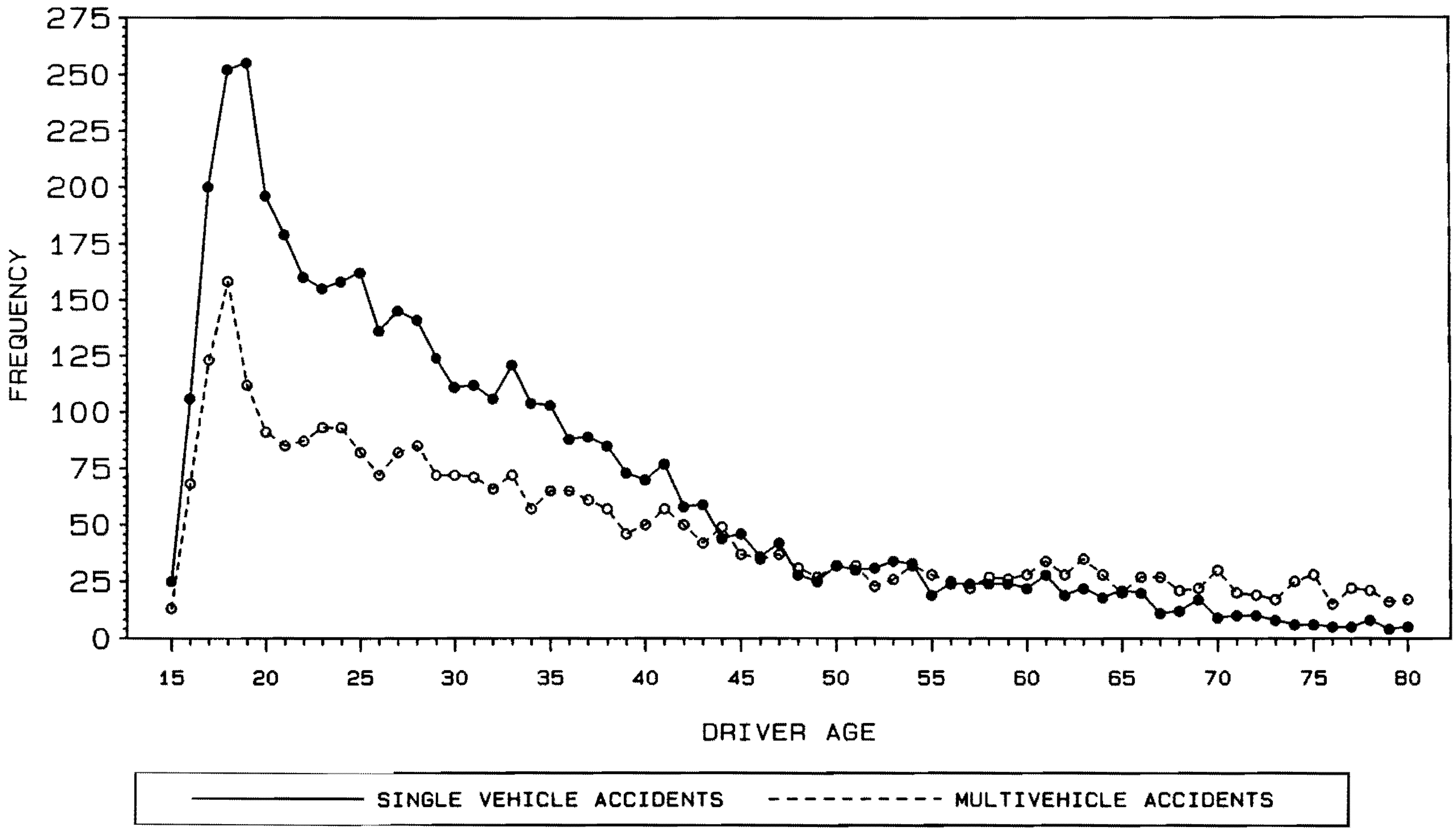

Figure 3: ACCIDENT-INVOLVED DRIVERS (N=7792) BY AGE

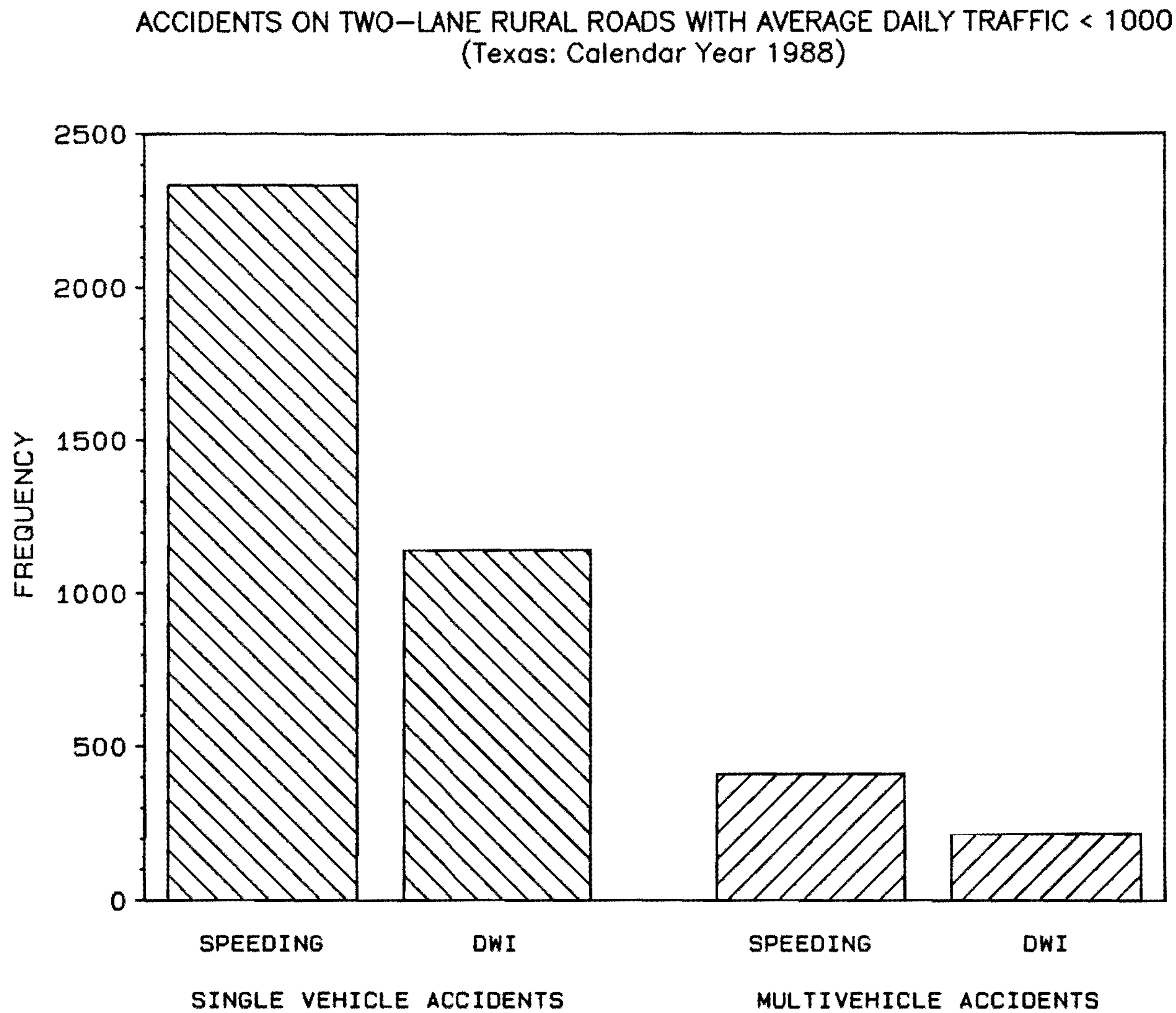

Figure 4: ACCIDENT–INVOLVED DRIVERS (N=7792) BY TWO CONTRIBUTING FACTORS

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

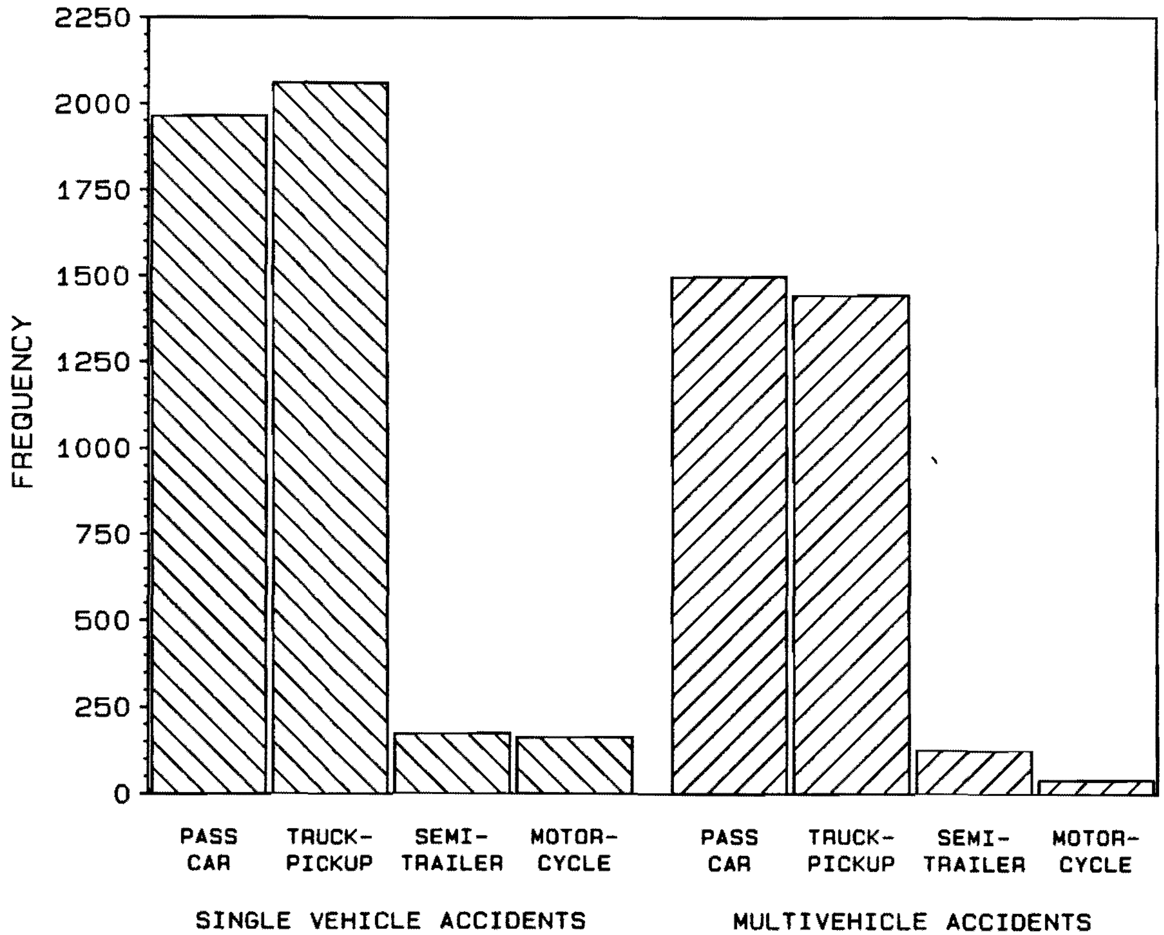

Figure 5: ACCIDENT-INVOLVED VEHICLES (N=7792) BY VEHICLE TYPE

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

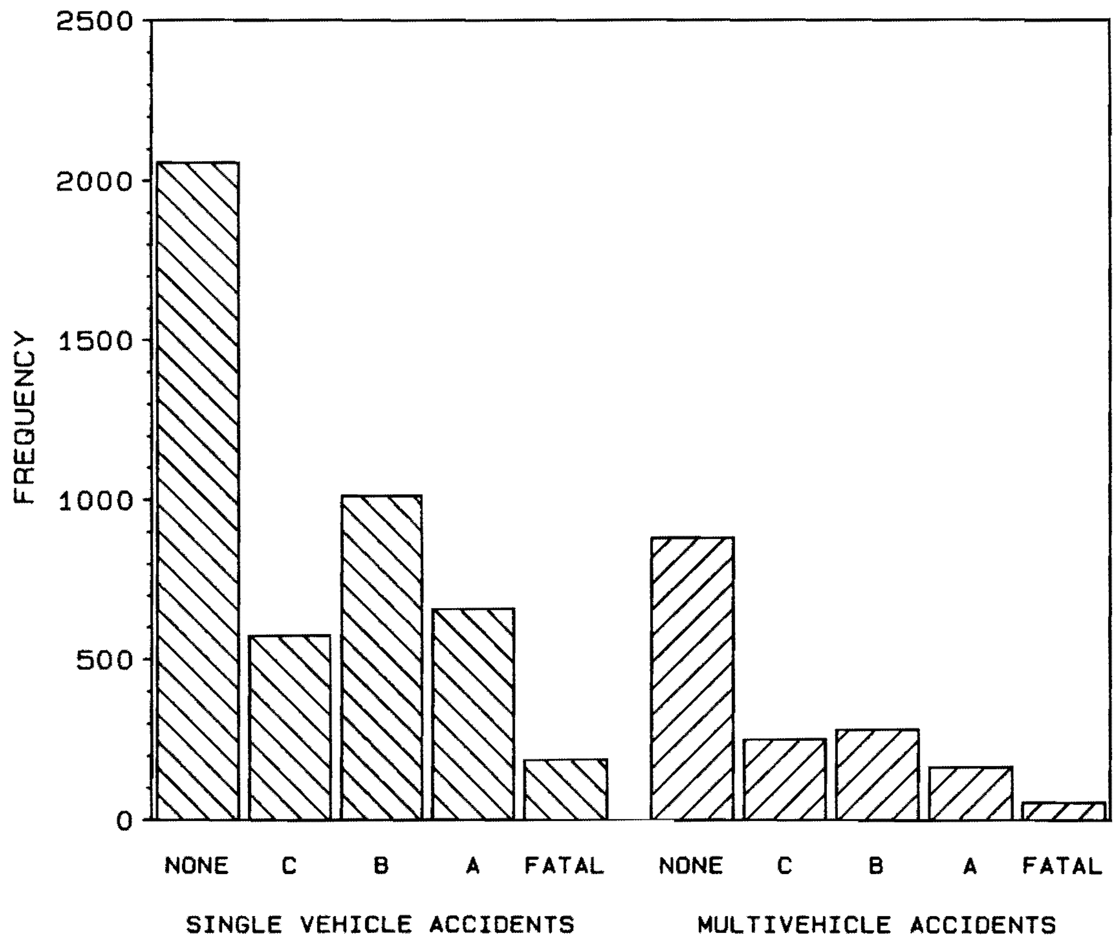

Figure 6: ACCIDENTS (N=6123) BY MOST SEVERE INJURY SUSTAINED

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

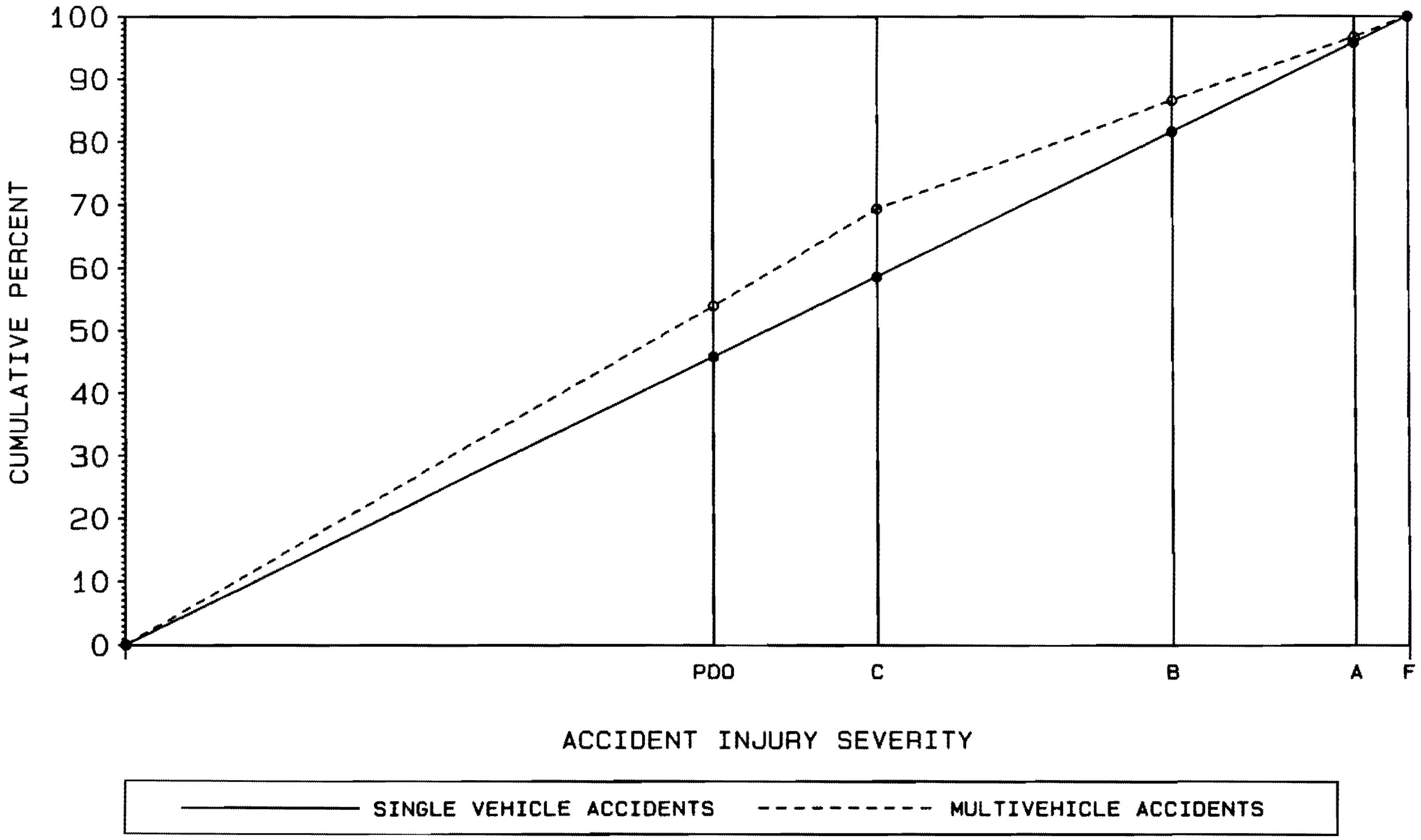

Figure 7: CUMULATIVE PERCENT OF ACCIDENTS (N=6123) BY ACCIDENT SEVERITY

ACCIDENTS ON TWO–LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

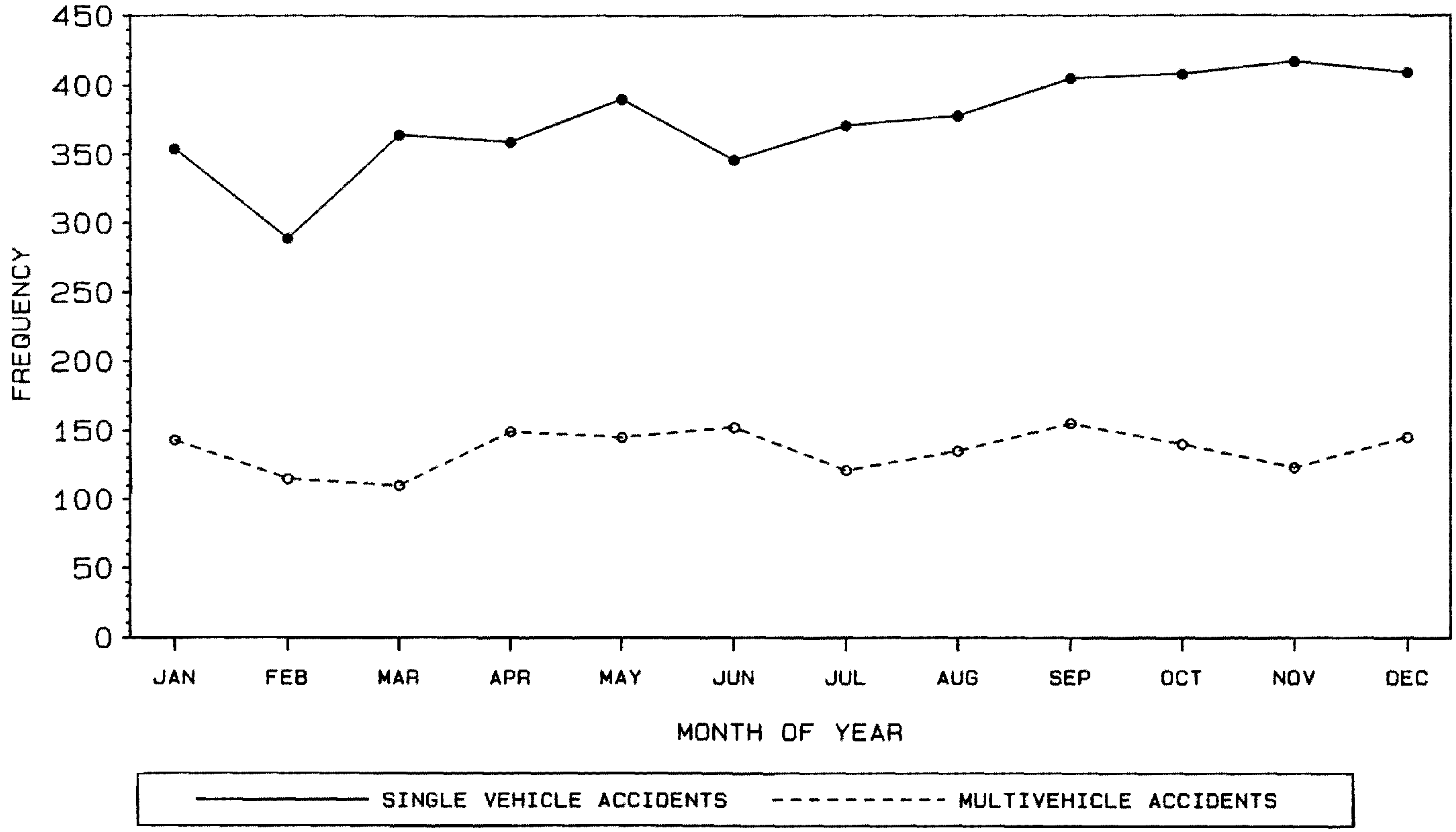

Figure 8: ACCIDENTS (N=6123) BY MONTH OF YEAR

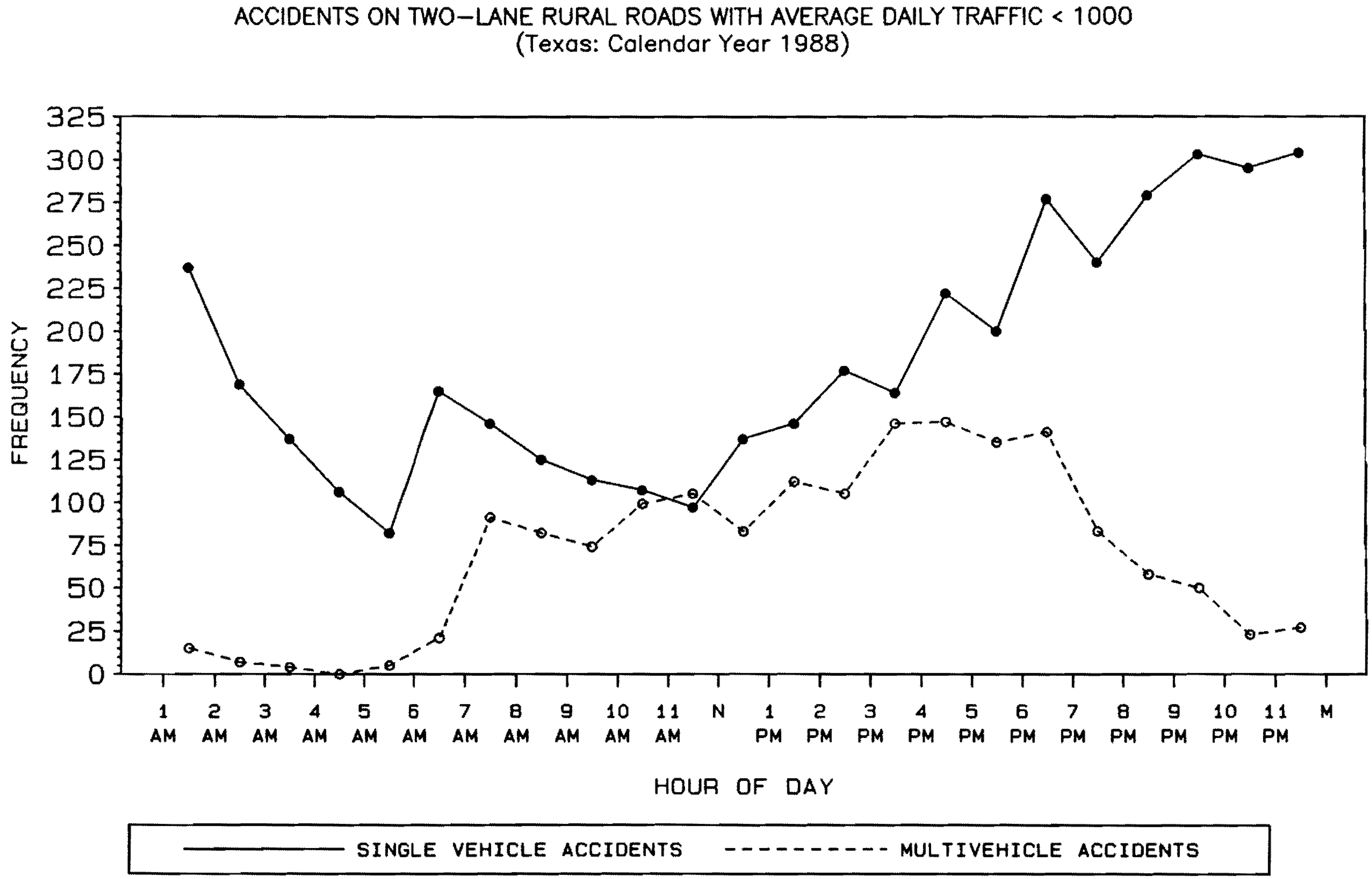

Figure 9: ACCIDENTS (N=6123) BY HOUR OF DAY

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

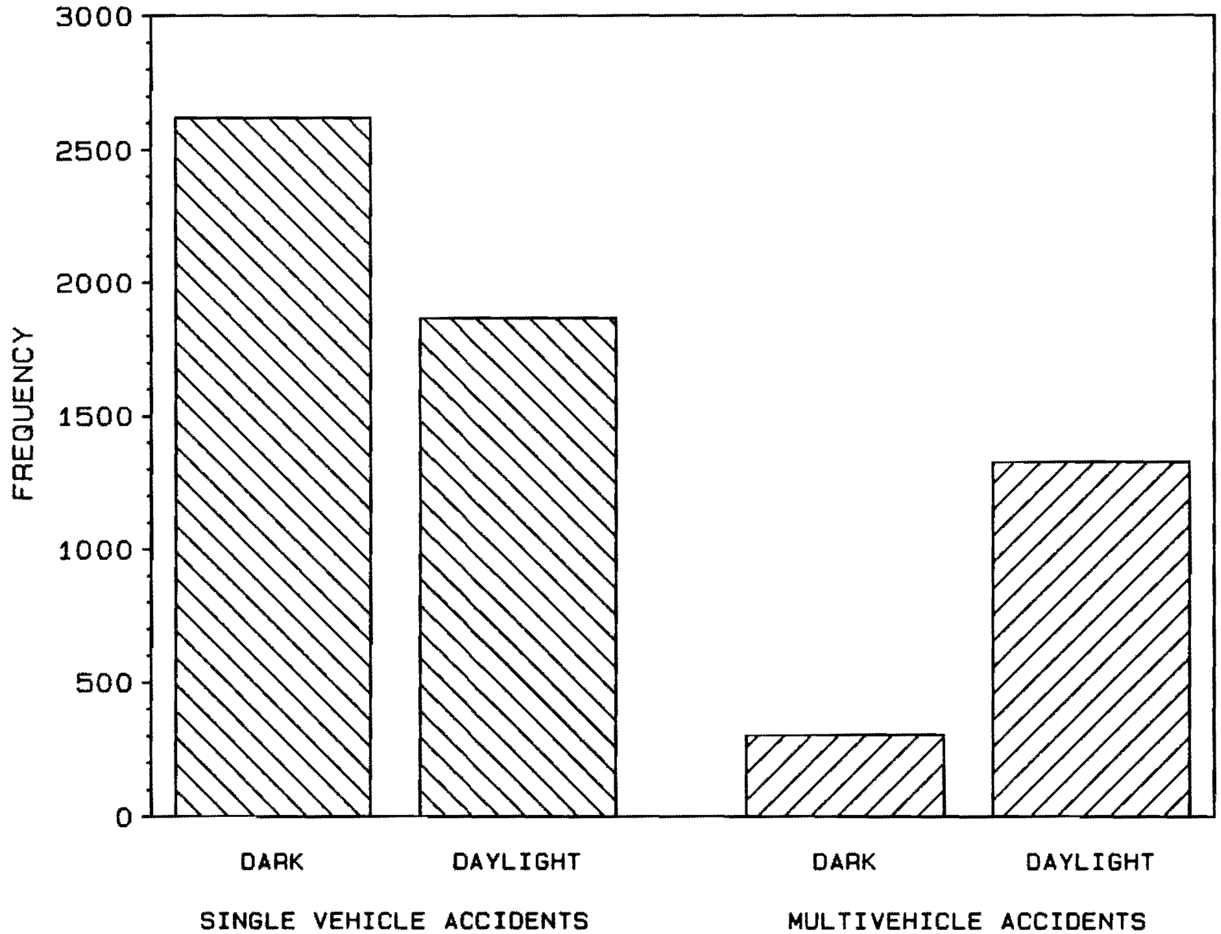

Figure 10: ACCIDENTS (N=6123) BY LIGHT CONDITION

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

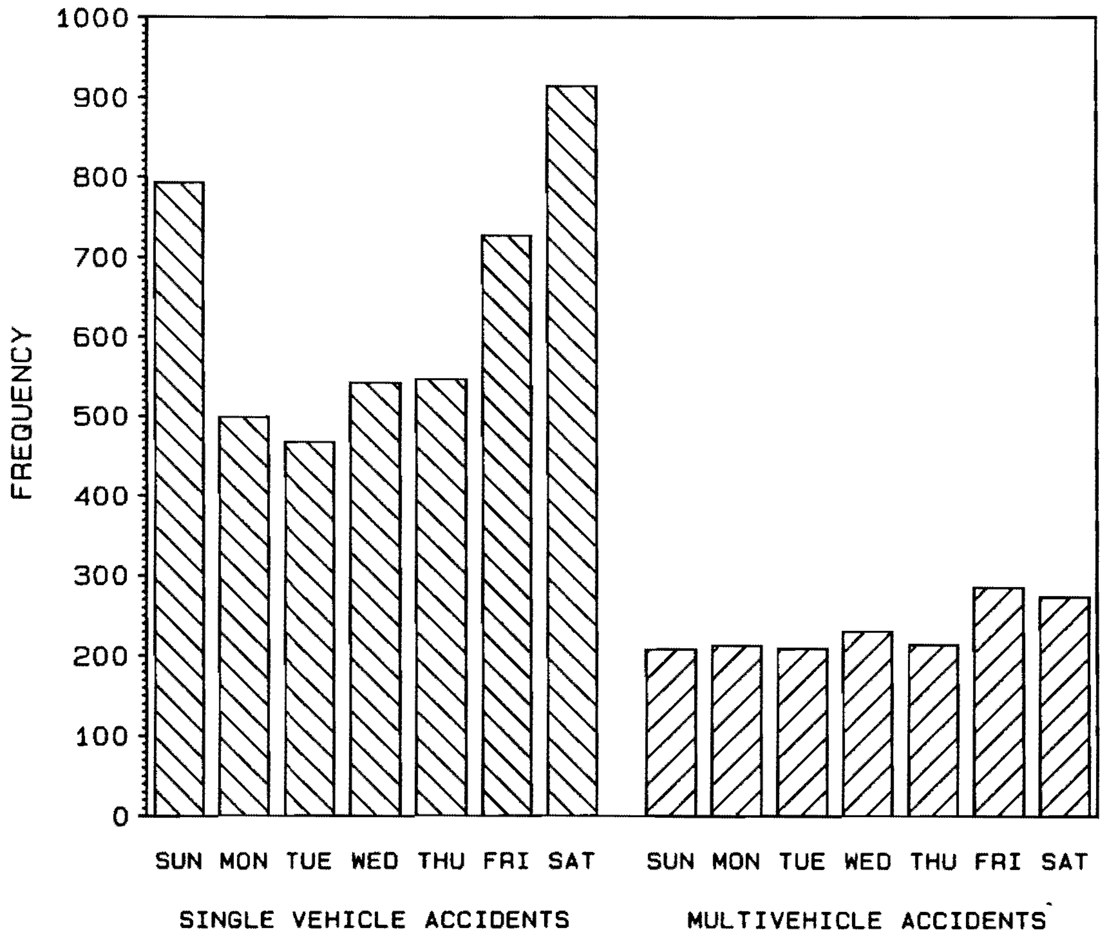

Figure 11: ACCIDENTS (N=6123) BY DAY OF WEEK

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

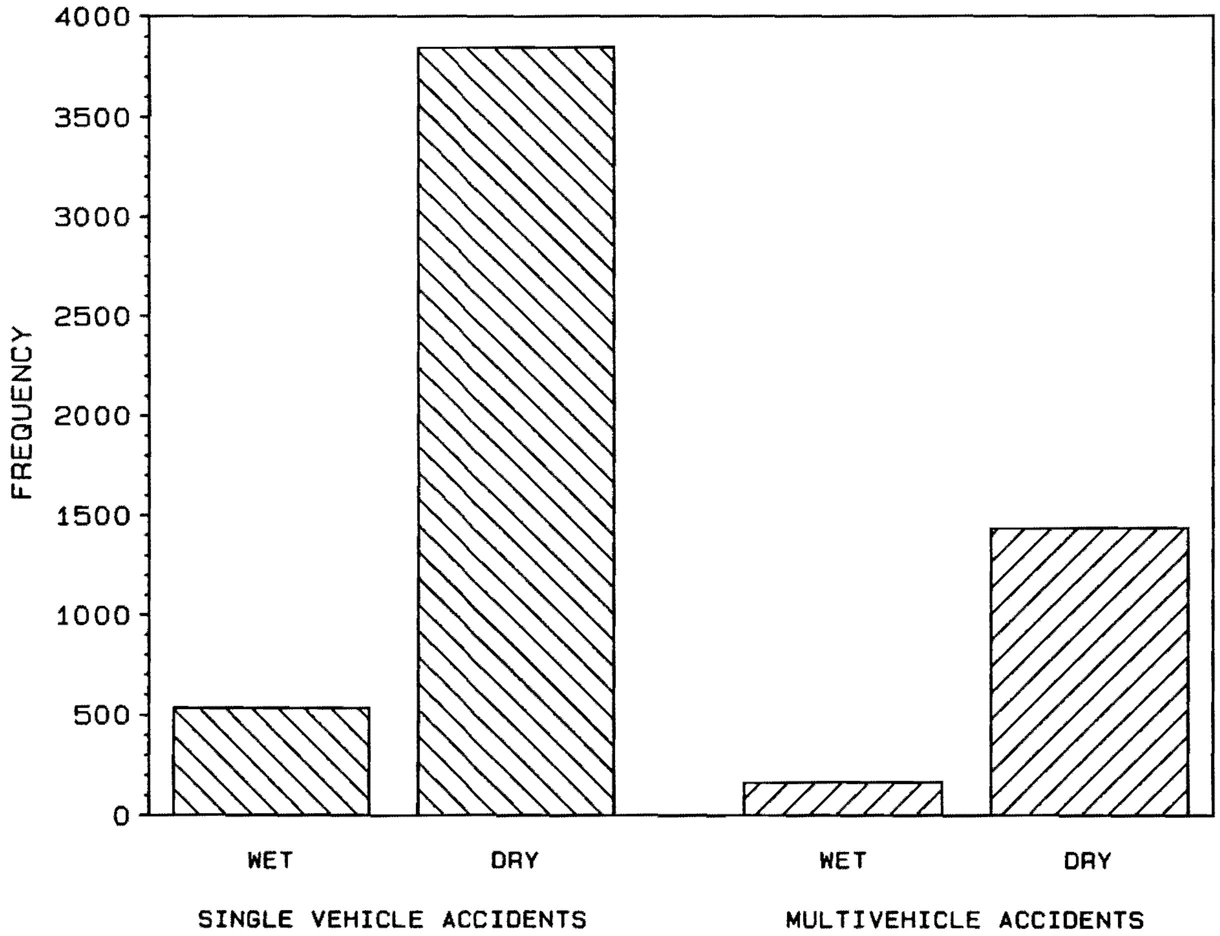

Figure 12: ACCIDENTS (N=6123) BY SURFACE CONDITION

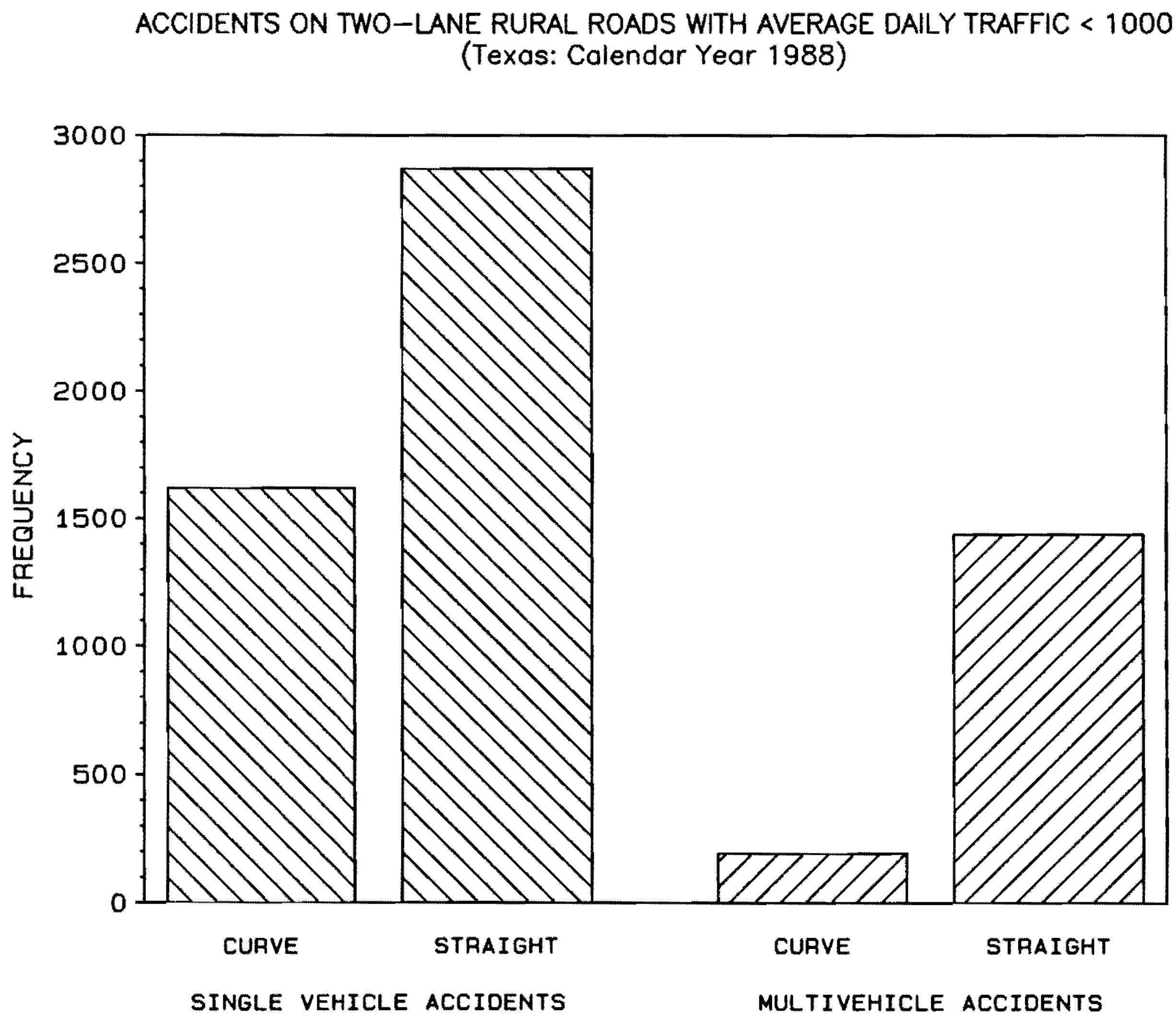

Figure 13: ACCIDENTS (N=6123) BY HORIZONTAL CURVATURE

ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

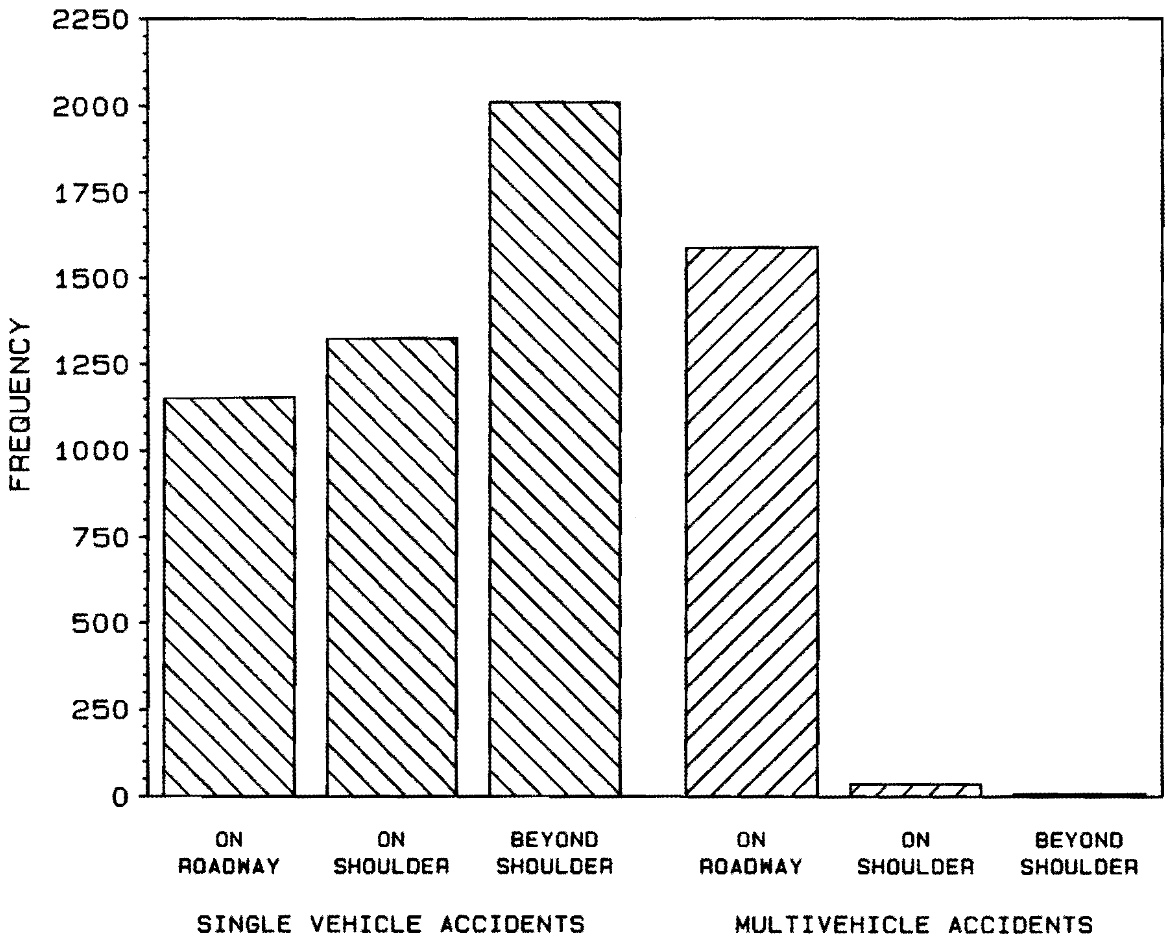

Figure 14: ACCIDENTS (N=6123) BY ROADWAY LOCATION

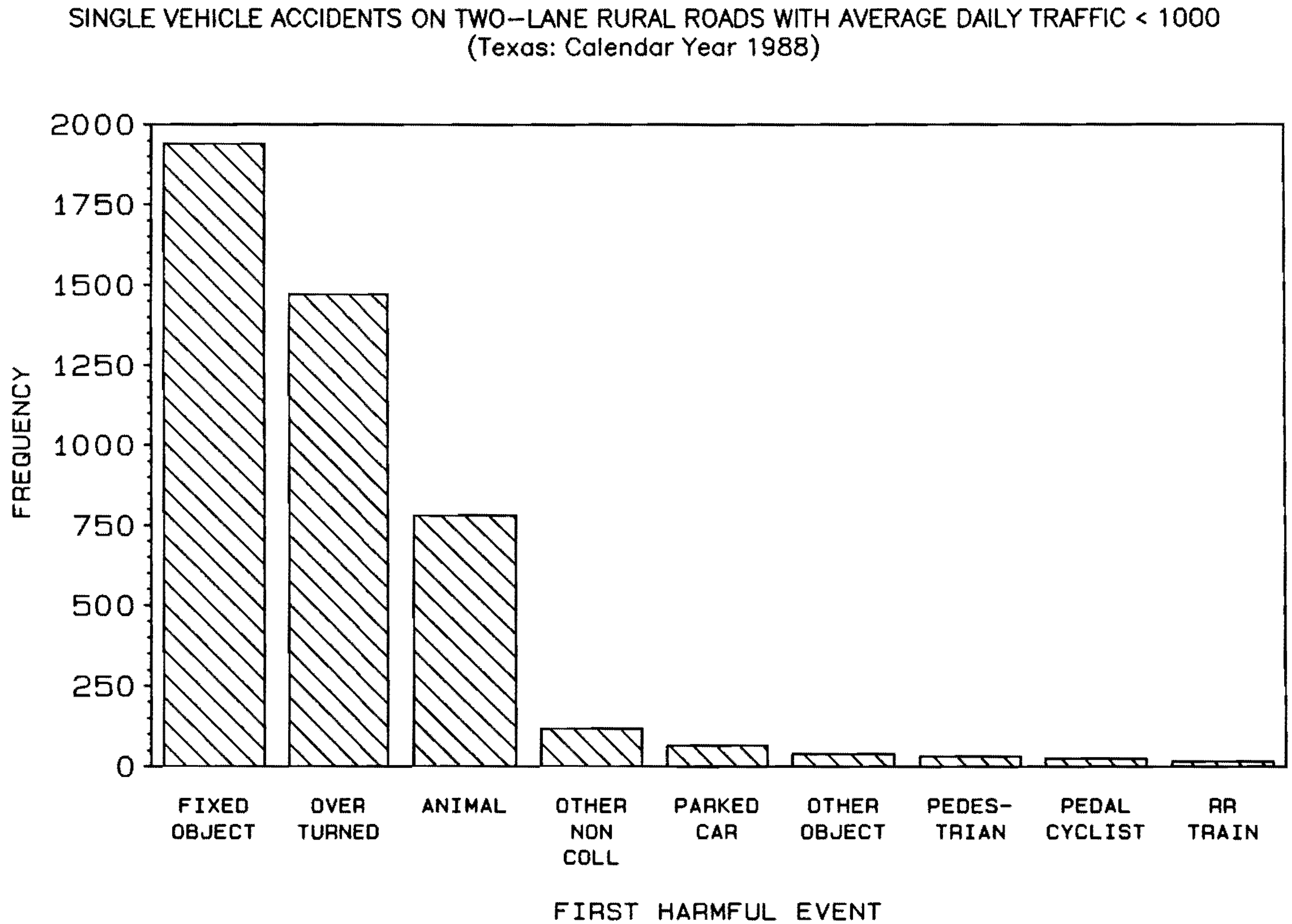

Figure 15: SINGLE VEHICLE ACCIDENTS (N=4490) BY FIRST HARMFUL EVENT

SINGLE VEHICLE ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

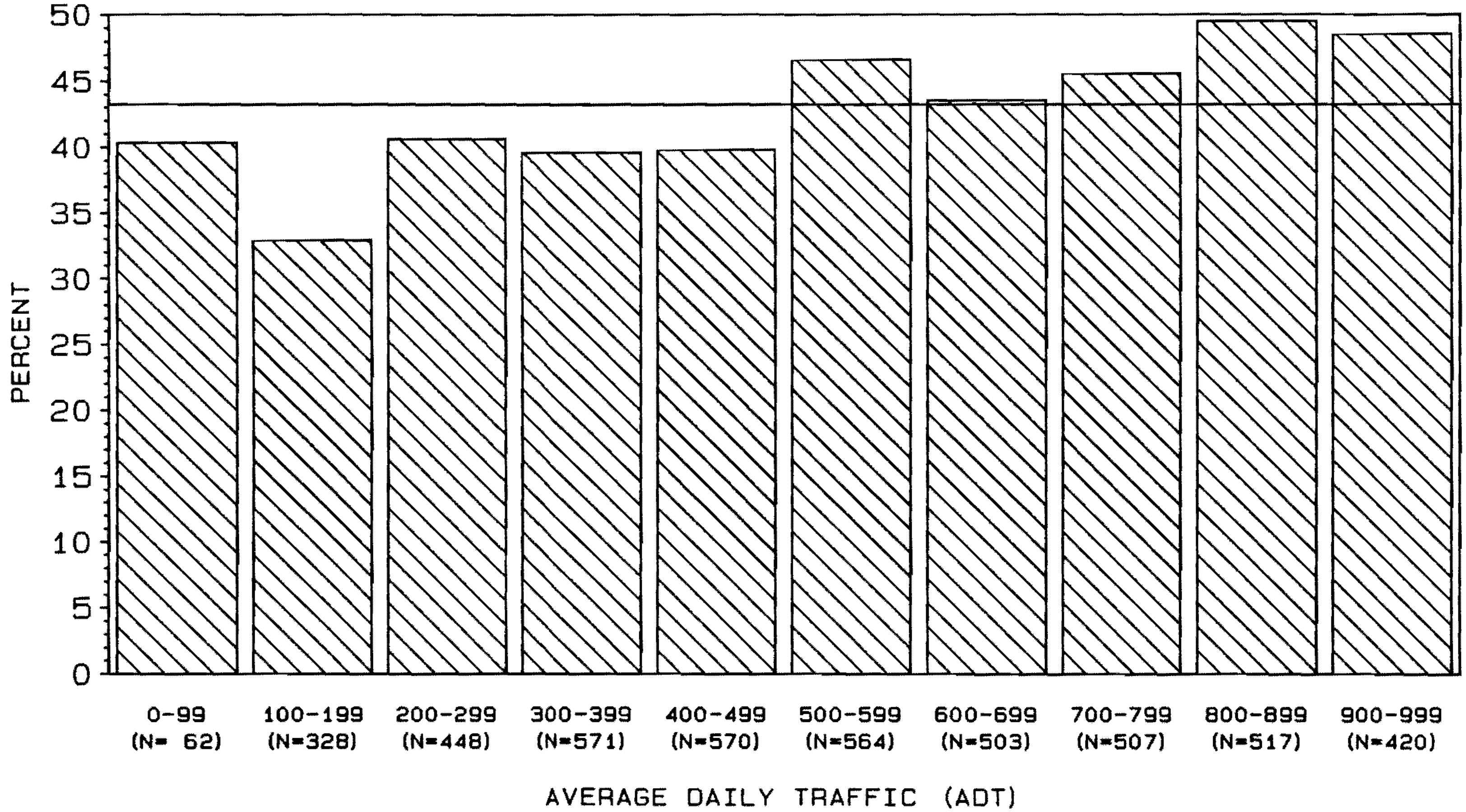

Figure 16: PERCENT OF SINGLE VEHICLE ACCIDENTS (N=4490) WITH "STRUCK FIXED OBJECT" LISTED AS THE FIRST HARMFUL EVENT, BY TRAFFIC VOLUME

SINGLE VEHICLE ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

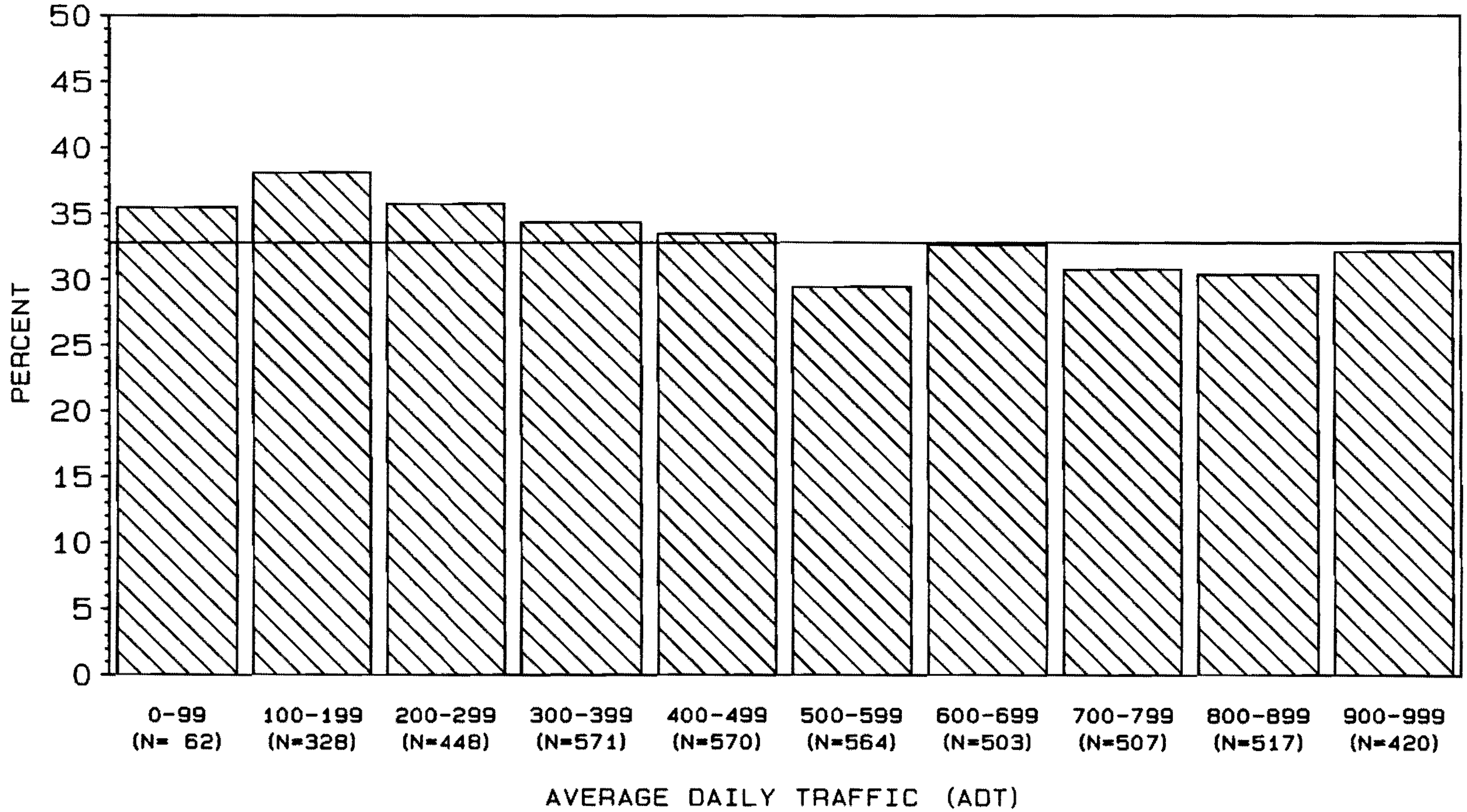

Figure 17: PERCENT OF SINGLE VEHICLE ACCIDENTS (N=4490) WITH "OVERTURNED"
LISTED AS THE FIRST HARMFUL EVENT, BY TRAFFIC VOLUME

SINGLE VEHICLE ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

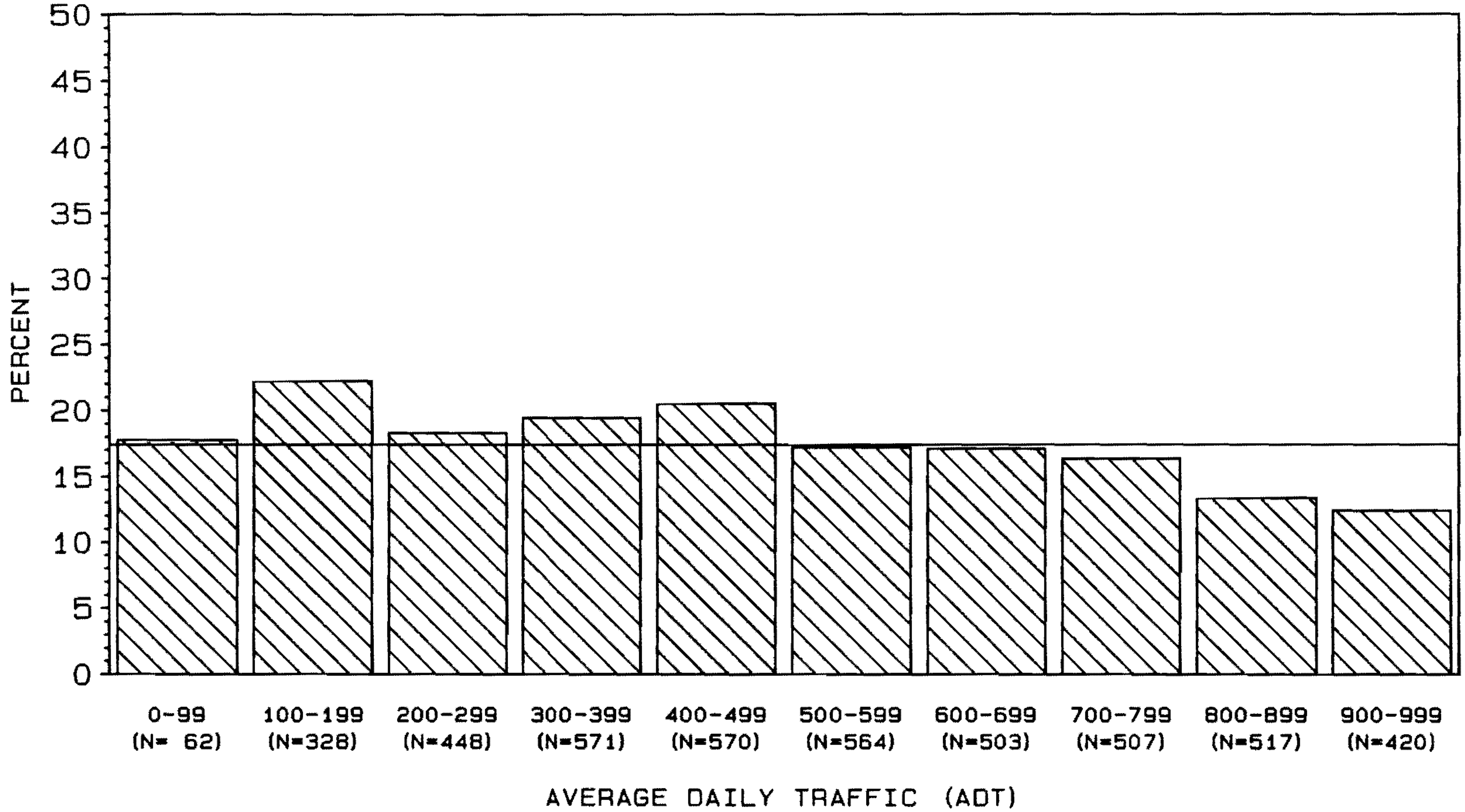

Figure 18: PERCENT OF SINGLE VEHICLE ACCIDENTS (N=4490) WITH "STRUCK ANIMAL" LISTED AS THE FIRST HARMFUL EVENT, BY TRAFFIC VOLUME

SINGLE VEHICLE ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

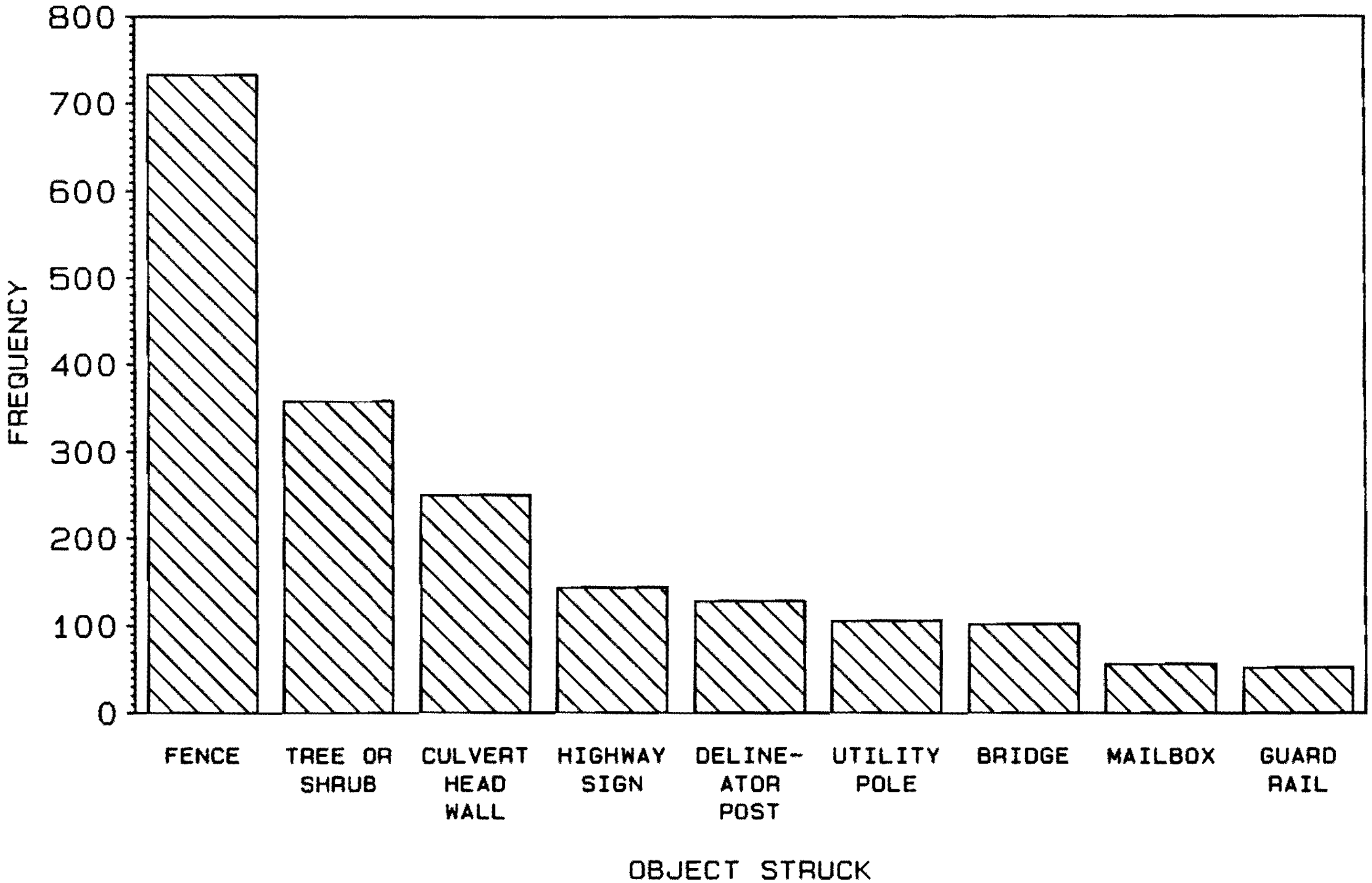

Figure 19: SINGLE VEHICLE ACCIDENTS (N=4490) BY NINE MOST FREQUENTLY STRUCK OBJECTS

SINGLE VEHICLE ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

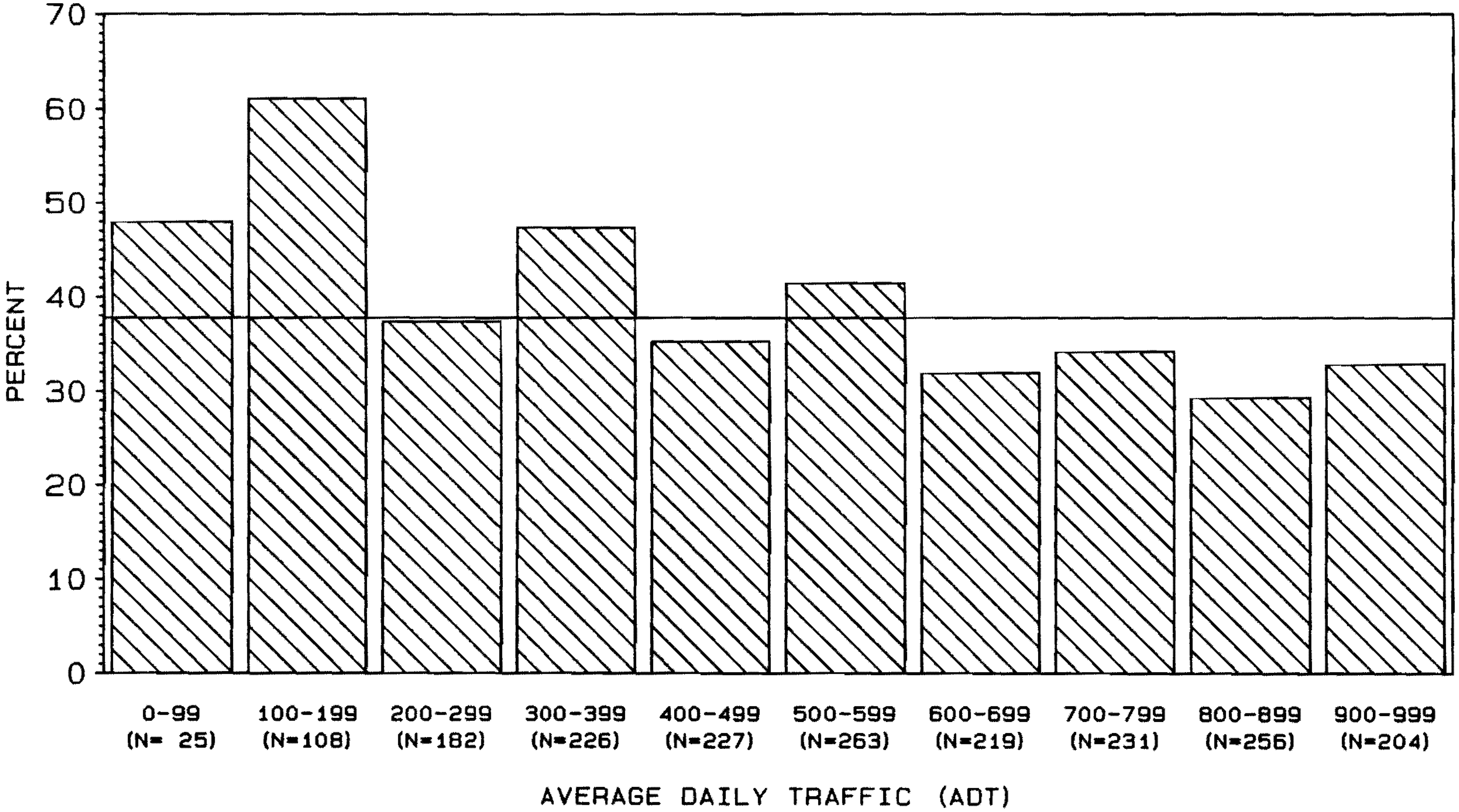

Figure 20: PERCENT OF SINGLE VEHICLE, FIXED OBJECT ACCIDENTS (N=1941) WITH "FENCE" LISTED AS THE OBJECT STRUCK, BY TRAFFIC VOLUME

SINGLE VEHICLE ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

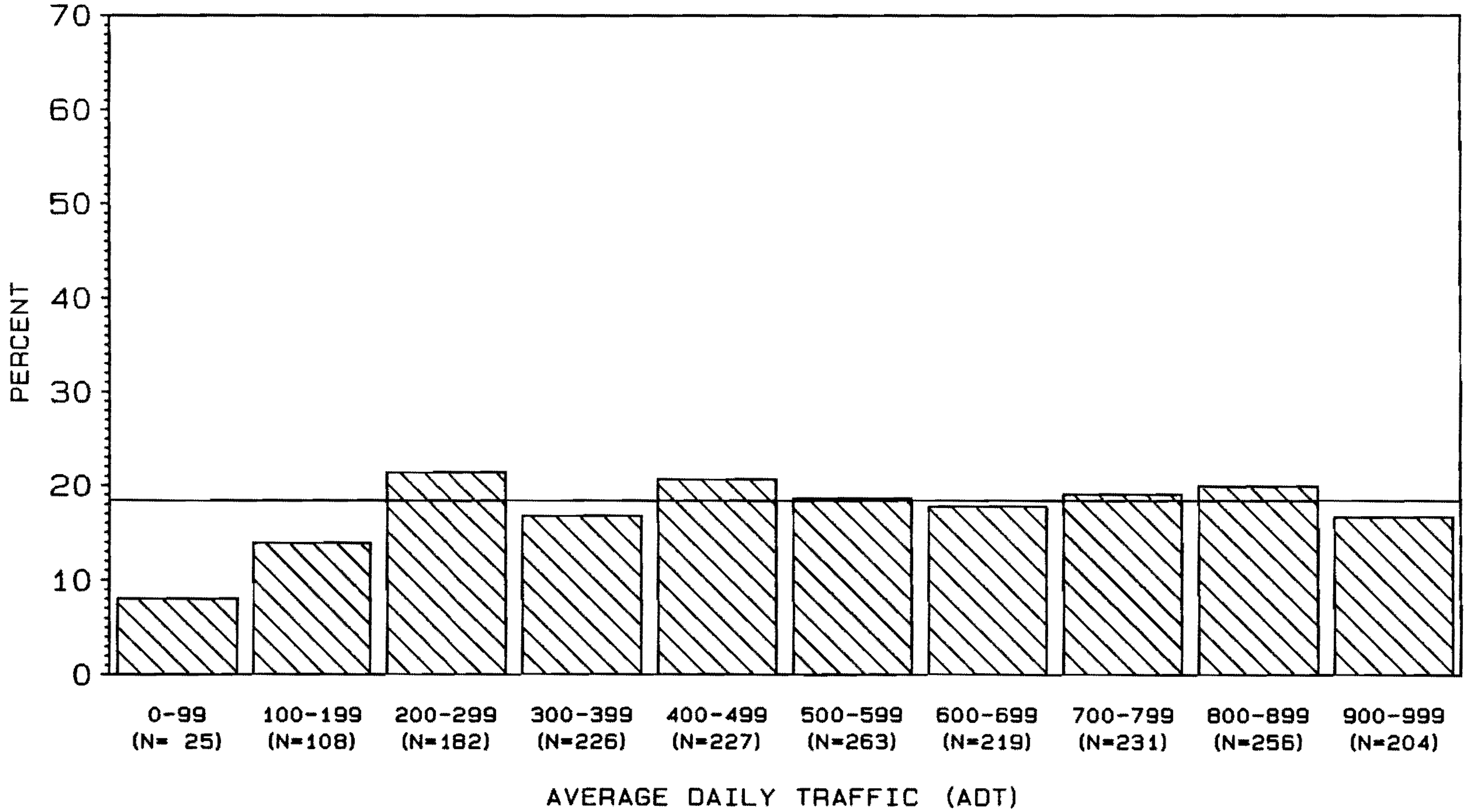

Figure 21: PERCENT OF SINGLE VEHICLE, FIXED OBJECT ACCIDENTS (N=1941) WITH "TREE OR SHRUB" LISTED AS THE OBJECT STRUCK, BY TRAFFIC VOLUME

SINGLE VEHICLE ACCIDENTS ON TWO-LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

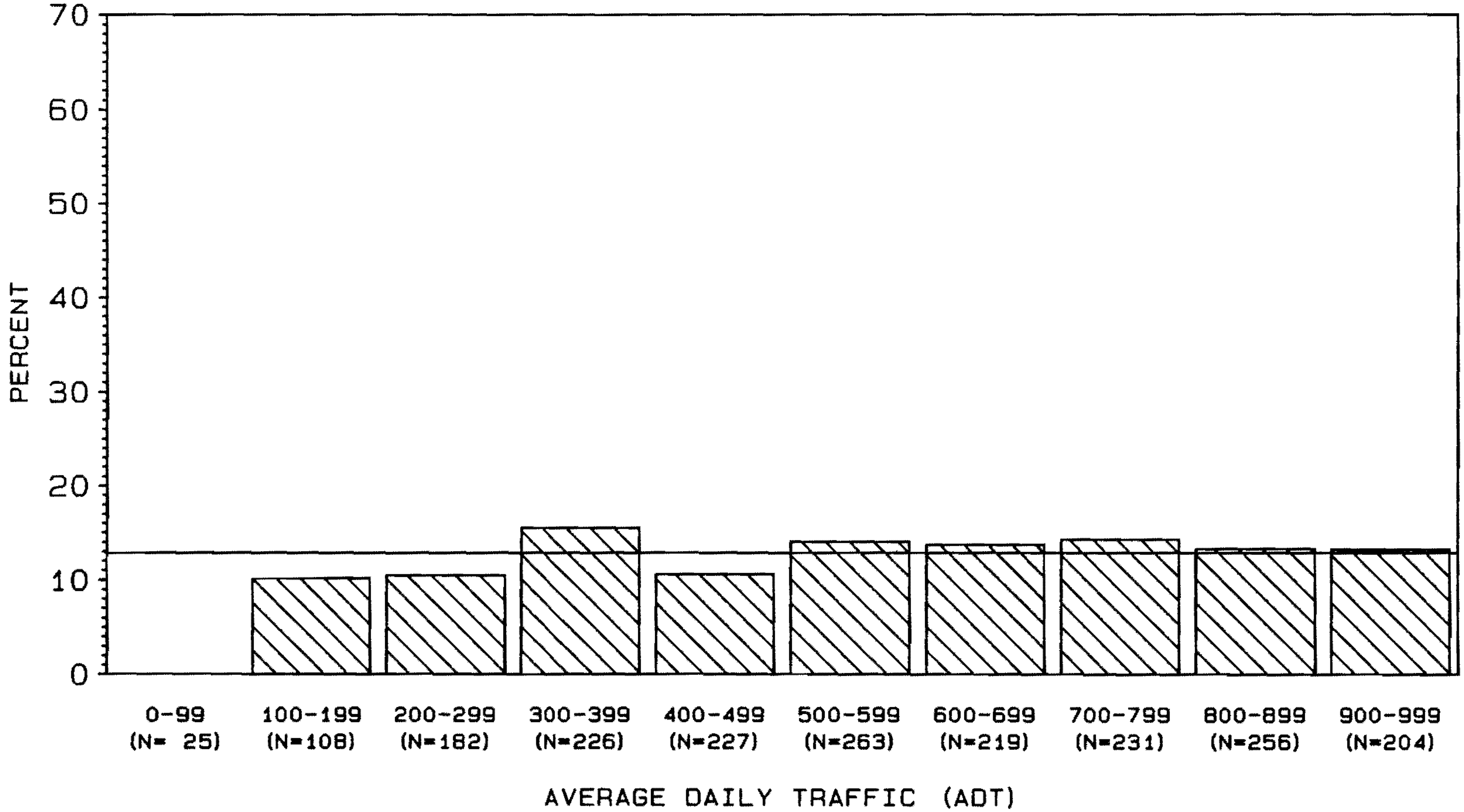

Figure 22: PERCENT OF SINGLE VEHICLE, FIXED OBJECT ACCIDENTS (N=1941) WITH "CULVERT HEADWALL" LISTED AS THE OBJECT STRUCK, BY TRAFFIC VOLUME

ACCIDENTS ON TWO–LANE RURAL ROADS WITH AVERAGE DAILY TRAFFIC < 1000
(Texas: Calendar Year 1988)

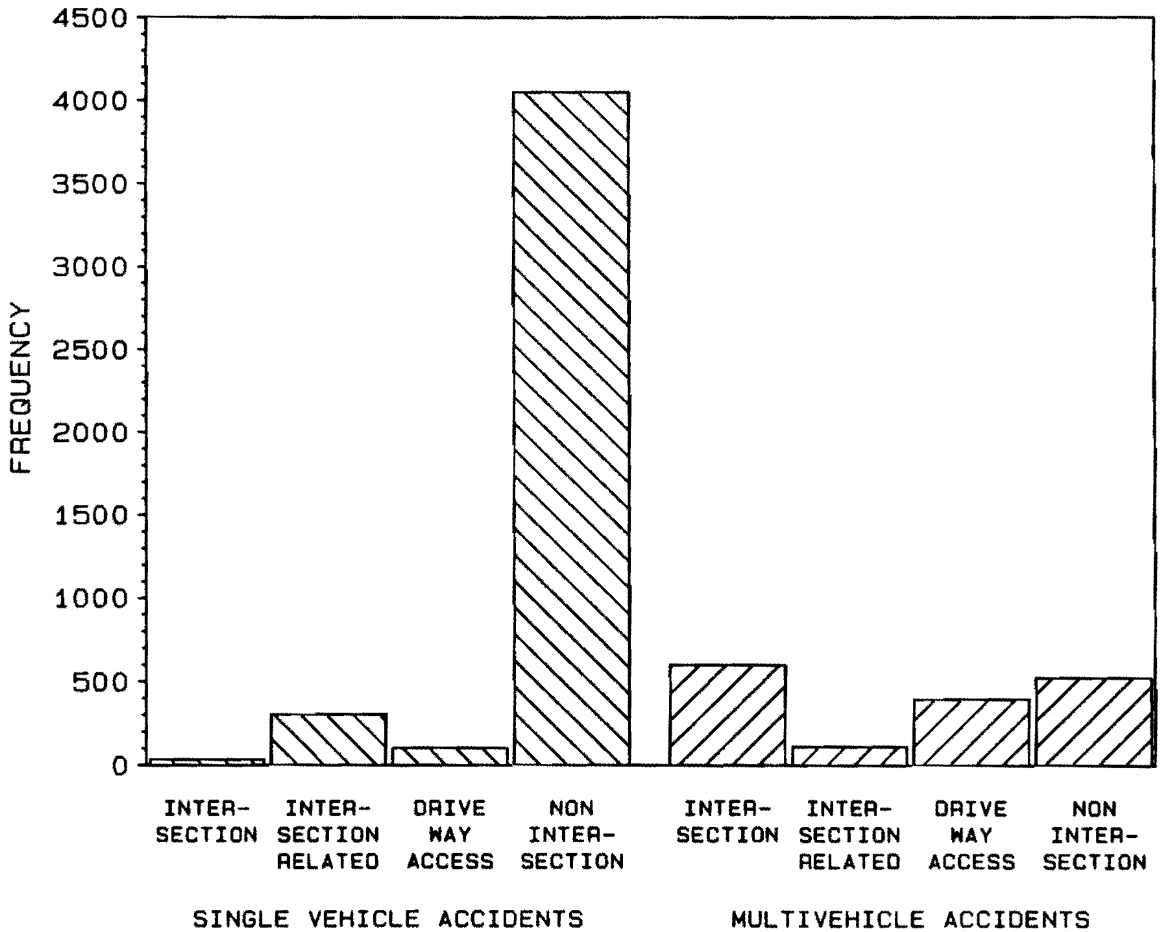

Figure 23: ACCIDENTS (N=6123) BY INTERSECTION INVOLVEMENT