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THE EFFECT OF LANE AND SHOULDER WIDTHS ON ACCIDENT REDUCTIONS ON RURAL,TWO-LANE ROADS

by

Charles V. Zegeer
Director of Traffic and Transportation Engineering
Goodell-Grivas, Inc.
Southfield, Michigan

and

Robert C. Deen
Assistant Director

and

Jesse G. Mayes
Research Engineer Chief

Division of Research
Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

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C. V. Zegeer, R. C. Deen, and J. G. Mayes

ABSTRACT

The purpose of the study was to determine the effect of lane and shoulder widths on accident benefits for rural, two-lane roads and also to determine the expected cost-effectiveness of widening lanes and shoulders. Information concerning geometrics, accidents, and traffic volumes was obtained for over 25,000 km (15,000 miles) of roads.

Run-off-road and opposite-direction accidents were the only accident types found to be associated with narrow lanes and shoulders. Wide lanes had accident rates 10 to 39 percent lower than for narrow lanes. Wide shoulders (up to 2.7 m (9 feet)) were associated with the lower accident rates. Criteria based on a cost-effectiveness approach were developed for selecting highway sections for widening.

INTRODUCTION

A question facing highway engineers is whether to widen lanes and shoulders on existing rural roads to provide improvements in rideability, capacity, and safety. Limited funds compel the implementation of those improvements which are most cost effective. Before lane and shoulder improvements are implemented, the relationship between widths of lanes (and shoulders) and accident experience on different types of roads should be ascertained.

Design standards for pavement (driving lanes) and shoulder widths most often are dependent on traffic volume and design speed *(1, 2)*. Standards for the paved surface (pavement plus shoulders) also have been set for two-lane roads on the basis of an economic analysis of construction, maintenance, and accident costs *(3)*.

Previous studies resulted in a variety of findings concerning the effects of pavement width on accidents. Little or no information exists on the economic benefits (if any) expected from wider lanes and shoulders. The purpose of this study was to answer some of the questions regarding the safety benefits due to pavement and shoulder widening.

Lane Width and Safety

On 5.5-m (18-foot) pavements, cars pass oncoming trucks at clearances averaging only 0.8 m (2.6 feet). On 6.1-m (20-foot) pavements, average clearances are 1.1 m (3.5 feet). When a truck meets an oncoming truck, clearance distances are less. Trucks overtaking other trucks remain centered in their lanes only when lanes are 3.7 m (12 feet) wide or greater. Clearances for cars overtaking other cars are only 0.7 m (2.3 feet) on 5.5-m (18-foot) pavements and 1.5 m (4.8 feet) on 7.3-m (24-foot) pavements *(4)*.

In Illinois, the widening of a 5.5-m (18-foot) pavement to 6.7 m (22 feet) caused a reduction from 143 to 89 accidents per million vehicle-kilometers (230 to 140 accidents per 100 million vehicle-miles), a 39-percent reduction *(5, 6)*. In Louisiana, it was concluded that narrow lanes contribute significantly to injury and fatal accidents and wet-weather accidents. There, accident rates on rural roads decreased from 1.5 accidents per million vehicle-kilometers (2.4 accidents per million vehicle-miles) on 2.7-m (9-foot) lanes to 1.1 on 3.1-m (10-foot) lanes and 0.9 on 3.4- and 3.7-m (11- and 12-foot) lanes *(6, 7)*.

Shoulder Width and Safety

Several previous studies involving rural, two-lane roads have included correlations of shoulder width with accident occurrences. Considerable variation in findings have been cited. A study in Oregon concluded that total accidents increase with increasing shoulder width, except for roads with AADT's of 3,600 to 5,500 *(8)*. Shoulders over 8 feet (2.4 m) experienced significantly more accidents than 0.9- to 1.2-m (3- to 4-foot) shoulders *(9)*. In Connecticut, all accident types decreased with increased shoulder width for AADT's between 2,600 and 4,500. A reverse correlation existed for AADT's less than 2,600 in another study *(10)*. Only a slight correlation was noted between shoulder width and accidents in Louisiana *(7)*.

Others have found a definite benefit from wide shoulders. In California, about twice as many injury accidents occurred on roads with 0.3- to 0.9-m (1- to 3-foot) shoulders than for shoulders over 1.8 m (6 feet) (for most AADT ranges) *(11)*. In New York, reductions in accidents were observed as shoulder width increased, especially in the 2,000-6,000 AADT range; no correlation was found for AADT's below 2,000 *(12)*. In another study in New York, it was concluded that 1.2- to 1.5-m (4- to 5-foot) shoulders were adequate on roads of good alignment, but shoulders over 2.4 m (8 feet) wide were preferred on roads with poor geometrics *(13)*.

A number of studies on shoulder widths indicate a lack of correlation with accidents on two-lane roads where AADT's are below 2,000. Wide shoulders appear to be most beneficial where AADT's are between 3,000 and 5,000. Shoulders 1.2 to 2.1 m (4 to 7 feet) wide were preferred to wider ones. Others suggested that shoulders as wide as 3.1 to 3.7 m (10 to 12 feet) were the safest.

However, the economic justification for widening shoulders has not yet been determined for rural, two-lane roads. Several geometric variables were found to be significant in accident occurrences in some of the studies. Lane width, access control, conflict points per mile, cross slope of shoulder, traffic volumes, and sight distance were all mentioned as variables having more of an effect on accident experience than shoulder width.

Shoulder Stability

To derive full benefits from shoulder improvements, it is very important for the shoulders to be stable. Shoulders should support vehicle loads in all kinds of weather. The possibility of a vehicle skidding out of control or turning over is increased when the shoulder is soft or is covered with loose gravel, sand, or mud.

In a study of cost effectiveness of paved shoulders in North Carolina, a significantly lower accident experience and severity index were associated with paved shoulders on two-lane roads when compared with unpaved shoulders on similar highway sections. Shoulders 0.9 to 1.2 m (3 to 4 feet) wide were predominant in that study. Paving of shoulders was cost effective (based only on accident reductions) in some cases within 10 to 20 years and varied according to traffic volume *(14)*.

Shoulder stabilization on two-lane roads in Ohio resulted in a reduction of 38 percent of all accidents and 46 percent of injury and fatality accidents. The criteria for stabilizing shoulders was a minimum of 45 percent of the accidents being run-off-the-road and head-on collisions *(15)*.

Capacity Considerations

Relationships between lane width, shoulder width lateral clearance, and capacity can be obtained from the Highway Capacity Manual *(16)*. Expected increases in capacity due to wider lanes or shoulders can be estimated from such relationships.

PROCEDURE

To compare accident occurrences for various lane and shoulder widths, two different procedures may be followed. The first, subject to several shortcomings, would involve conducting an analysis of before-and-after accidents for sections which were widened. First, a very limited sample size for such an analysis is normally available. Second, such improvements often include other improvements such as delineation, skid resistance, realignment, and shoulder leveling which also affect the accident experience to an unknown extent. Third, additional traffic may be generated by such improvements and, therefore, affect accidents. The other procedure may be termed a "comparative analysis" since it compares accident experiences for existing highway sections where geometric and accident data are known. Sections of similar geometrics can be grouped for analysis. This technique usually allows for a large data base without relying on improved sections and therefore was selected for use in this study.

The accident records consisted of nearly 17,000 accidents reported in 1976 and investigated by state, county, and city police agencies and stored on computer tape. Highway traffic and geometric data were also obtained from computer tape. Data from both sources were coded by county number, route number, and milepost. Accident summaries were carefully merged with the traffic and geometric data on a third computer tape.

Only rural highways classified as state primary, state secondary, or rural secondary routes were selected. Also, only two-lane roads were considered, since most four-lane highways did not warrant an in-depth investigation at this time.

Highway sections containing abrupt changes such as major intersections and changes in roadway width or access control were considered undesirable since they were believed to bias the data. Therefore, all nonuniform sections of road were omitted. Using the above criteria for selection of a test sample, a total of 25,670 km (15,944 miles) of roads were included in the analysis. A total of eight classifications based on AADT (Table 1) were used.

Information input included the location (county, route, and milepost), lane width, shoulder width, AADT, road classification, pavement type (bituminous or concrete), shoulder type (bituminous, dense-graded aggregate, or other), number of lanes, access control (full, partial, or permit), and number of public approaches (access points). A computer program was then written which matched accident records with each 1.6-km (1-mile) section of highway. The number of accidents for each section was summarized according to several geometric features, weather conditions, severity of accidents, and types of accidents.

Certain other variables were not available. These included skid number, shoulder slope, and number and degree of vertical and horizontal curves. Because of the large data sample (about 26,000 km (16,000 miles)), much of their influence on accidents was minimized when sections were grouped for analysis. Also, the classifications of accidents by type (rear-end, run-off-road, opposite-direction, driveway-related, etc.) allowed for the exclusion of most accidents which were unrelated to lane and shoulder widths.

After accident data were summarized, relationships between accidents and various geometric characteristics were determined. Several hundred summary tables were generated which gave cumulative accident numbers for each lane width, shoulder width, AADT, highway classification access control, etc. This allowed for the use of control variables to determine the true effect of lane and shoulder widths on accident experience. All accident rates were expressed as combined averages to insure data stability.

LANE WIDTH AND ACCIDENTS

For this analysis, lane widths were rounded to the nearest 0.3 m (1 foot). Accident and traffic volume statistics for lane widths of 2.1 to 4.0 m (7 to 13 feet) are cited in Table 2. Accidents were classified as either run-off-road, opposite-direction (head-on or sideswipe collision between opposing vehicles), rear-ends, passing situations, driveway and intersection, or collisions with pedestrians, bicycles, animals, and trains. The most common accidents, considering all lane widths, were run-off-road, opposite-direction, and rear-end. Accident rates were the highest for run-off-road and opposite-direction accidents for narrow lanes and decreased steadily as lane width increased. Accident rates for other accidents generally increased as lane widths increased, indicating that the only accidents which would be expected to decrease with lane widening were the run-off-road and opposite-direction accidents.

Injury and fatality rates for each lane width were also computed. Rates of property damage and injury accidents decreased as lane width increased, corresponding to the overall accident rate for various lane widths. No changes in fatality rate occurred as lane width changed. Also, the percentage of injury and fatal accidents increased slightly and then decreased as lane width increased. No definite relationship was found between lane width and accident severity.

SHOULDER WIDTH AND ACCIDENTS

Of the total sample, about 70 percent of the test sections had no shoulders. Only paved or dense-graded aggregate shoulders were considered as shoulders since grass and soil are not suitable driving surfaces; and, therefore, these surfaces normally do not function as shoulders.

Because of the small sample sizes for some shoulder widths, considerable differences were found in accident rates. Shoulder widths were categorized as no shoulder, 0.3 to 0.9 m (1 to 3 feet), 1.2 to 1.8 m (4 to 6 feet) , 2.1 to 2.7 m (7 to 9 feet) and 3.0 to 3.7 m (10 to 12 feet) -- as shown in Table 3. The poor relationship between shoulder width and all accidents was expected before controlling for other factors such as lane width and volume. The small sample of locations for shoulder widths greater than 0.9 m (3 feet) may also be a factor.

Accident types and rates were summarized for various shoulder widths. As with lane width, the run-off-road and opposite-direction rates decreased as shoulder width increased to 2.7 m (9 feet). There was a slight increase in rate for 3.0- to 3.7-m (10- to 12-foot) shoulders. Accident rates for categories other than run-off-road and opposite-direction tended to remain fairly constant or increased slightly as width of shoulder increased.

Rates for property-damage, injury, and fatal accidents were calculated. As before, rates for each type generally decreased as shoulders widened, but the percentage of injury and fatal accidents did not show any trends. No reduction in average accident severity, therefore, may be expected from shoulder widening.

LANE AND SHOULDER WIDTH COMBINATIONS

An analysis was made of accident rates for various combinations of lane and shoulder widths. For all accidents (Table 4), rates on roads with no shoulders decreased from 2.9 to about 0.5 as lane widths increased from 2.1 to 3.7 m (7 and 12 feet). For other shoulder widths, accident rates generally decreased with increasing lane width, although the relationships were not as pronounced.

For the same lane widths, accident rates tended to decrease as shoulder width increased. Overall, the decrease in accident rate was greater for increases in lane widths than for equivalent increases in shoulder widths. Using only run-off-road and opposite-direction accidents (Table 5), more uniform decreases in accident rates were found in most cases than when all accidents were included. Again, increases in lane widths resulted in a greater reduction in accident rates than for the same widening of shoulder.

These analyses appear to indicate a greater accident savings can be realized by lane widening than by shoulder widening. While little reduction in accidents may be gained by increasing a 6.8-m (22-foot) road to a 7.4-m (24-foot) pavement, the added width would provide slightly better service to users in terms of capacity and safe driving speed.

OTHER HIGHWAY FEATURES

The previous summaries of accidents by lane and shoulder widths were analyzed to determine the possible influence of other highway features on the accident experience. The effect of traffic volume, highway type, and access control on accidents were examined in detail.

This analysis was intended to quantify that portion of the change in accident rates which can be attributed to lane and shoulder width. For example, the average accident rate on roads with 2.1-m (7-foot) lanes was 2.58 accidents per million vehicle-kilometers (4.16 per million vehicle-miles) compared to a rate of 1.28 per million vehicle-kilometers (2.08 per million vehicle-miles) for lanes 3.4 m (11 feet) wide. This difference may be partially due to the wider lanes and partially to other unidentified causes. For example, narrow roads usually have less access control and lower volumes than wider roads. Both of these factors may be a primary cause of the higher accident rate for narrower roads. Therefore, a separate analysis of the effects of some of these other highway features on accident experience was preformed.

Traffic Volume

The number of accidents per kilometer (0.6 mile) increased considerably with AADT (Figure 1). The relationship between traffic volume and accident rate is shown in Figure 2 for all sections (over 24,000 km (15,000 miles)) of rural, two-lane roads. In this case, the rate decreased significantly as the AADT increased, particularly for AADT's above 1,000.

It appears from Figure 2 that lower accident rates are assoicated with higher volumes. However, higher volumes were also associated with higher classes of roads which normally have wider lanes and shoulders and less and more gradual curvature than lower-volume facilities. To determine how accident rates were affected by volume alone, summaries were made of rates as a function of volumes for specific highway types and lane widths. To also control other geometric variables, only routes with no shoulder and with 2.5 or fewer public approaches (access points) per kilometer (4.0 per mile) were included. No clear relationships were found. Rates for each classification and lane width remained roughly the same or fluctuated slightly as AADT increased. This may be expected since all accident types were included in the calculation of accident rate.

Previous research has shown that single-vehicle accidents are affected differently than multi-vehicle accidents as AADT increases. This was verified by data reviewed in this study (Figure 3). Results may be different for test sections containing an intersection. The probable reason that the rate of run-off-road (single-vehicle) accidents decreased as AADT increased is that vehicles tend to be driven slower since passing may not be possible. On low volume roads, vehicles are not able to caravan (follow each other in groups), and unfamiliar motorists may take curves at excessive speeds, particularly at night or in the rain. At night, motorists sometimes follow tail lights ahead of them which help warn of sharp curves.

Since the rate of run-off-road accidents decreases as both lane width and AADT increase, the effect of lane width alone on the rate of run-off road accidents was determined. The rate of run-off-road accidents was plotted versus AADT for different lane widths (Figure 4). By controlling for the other variables, the slopes of the lines indicate the effect of AADT on rates, and the vertical distances between lines indicate the effect of lane width on rates. Most of the decrease (72 percent) in accident rate was related to volume changes, and 28 percent resulted from wider pavements.

The effect of traffic volume on opposite-direction accidents was also determined with respect to various pavement widths (Figure 5). The wider pavements were associated with about 76 percent of the decrease in the rate of opposite-direction accidents (Table 3). As can be seen in Figure 5, the greatest reduction in accident rate per foot of widening can be achieved by widening the narrow-width pavements (4.3- to 4.9-m (14- to 16-foot)) to medium-width (5.5- to 6.1-m (18- to 20-foot)) pavements. The effect of volume on accident rates was determined in a similar manner in the analysis of shoulder widths.

Access Points

Another geometric feature thought to have some influence on accident rates was the effect of access points per kilometer (mile). This is the number of public approaches or minor entrances onto the highway which could adversely affect accident rates.

More access points per kilometer (mile) were associated with higher accident rates for virtually all lane-width categories, as shown in Figure 6. However, only about six percent (1,600 km (1,000 miles)) of the sample had 3.1 access points per kilometer (five or more access points per mile). Those sections were distributed evenly throughout the test sections.

Highway Classification

Another control variable which was studied included the effect of highway classification on accident rate. Rates were compared for each lane width for rural secondary, state secondary, and state primary routes while the other variables were controlled. For 2.7-m (9-foot) lanes, rates were generally higher for rural secondary routes and lower for state primary routes. For 3.0-m (10-foot) lanes with low AADT's, a similar trend was found. However, as AADT increased, rates became highest for state primary routes. This could indicate that 3.0-m (10-foot) lanes are not acceptable for state primary roads with high volumes. For 3.4-m (11-foot) lanes, no obvious differences were found in accident rates between state secondary and state primary routes.

ACCIDENT SAVINGS

Savings due to accident reductions were the only benefits included in the economic analysis. Lane and shoulder widths were shown previously to have an effect on only run-off-road and opposite-direction accidents. Other accident types did not decrease as a function of wider lanes and shoulders. Thus, average costs were computed only for these two categories.

Of all run-off-road and opposite-direction accidents, 40.3 percent involved injuries or fatalities, compared with only 19.6 percent for the other types of accidents. The percentage of fatal and A-injury accidents was nearly three times as high for run-off-road and opposite-direction accidents than for all other types.

The severity index was computed using a formula developed in a 1973 study *(17)*:

$$SI = [9.5(K + A) + 3.5(B + C) + PDO] / N$$

in which SI = severity index,

K = number of fatal accidents,

A = number of A-type injury accidents,

B = number of B-type injury accidents,

C = number of C-type injury accidents,

PDO = number of property-damage-only accidents, and

N = total number of accidents.

The combined severity index of the run-off-road and opposite-direction accidents was 2.74, compared to 1.74 for the other accidents.

The average cost per accident was computed for use in the calculation of expected accident savings. Accident costs reported by the National Safety Council for 1976 *(18)* were used:

Death -- $125,000,

Nonfatal, disabling injury -- $4,700, and

Property-damage accident -- $670.

The average cost of a run-off-road or opposite-direction accident was $5,569 compared to $2,199 for other accident types on rural, two-lane roads.

Lane Width

The expected reduction in accident rate was computed and plotted for various degrees of lane widening (Figure 7). The values represent reductions in the combined rate of run-off-road and opposite direction accidents after controlling for other highway and traffic variables. Note that very little additional benefit is realized by widening a lane beyond 3.4 m (11 feet). The relationship for percentage reduction in run-off-road and opposite-direction accidents for various degrees of pavement widening was determined (Table 6). For example, on an average section of rural, two-lane road, widening lanes from 2.4 to 3.4 m (8 to 11 feet) would be expected to reduce run-off-road and opposite-direction accidents by 36 percent.

Shoulder Width

The expected reductions in combined accident rates for run-off-road and opposite-direction accidents were computed in a similar manner. No additional benefit is obtained on rural, two-lane roads by widening shoulders to over 2.7 m (9 feet). The percentage reduction in run-off-road and opposite-direction accidents for various shoulder widening was calculated after controlling for access control, highway classification, AADT, and lane width (Figure 7). For an average section of rural, two-lane highway, widening the shoulders (both sides of the road) from 0.5 to 2.5 m (1.6 to 8.2 feet) should reduce run-off-road and opposite-direction accidents by 16 percent.

IMPROVEMENT COSTS

Costs (average for Kentucky) associated with pavement widening were determined from historical records of costs (Table 8) *(19)*. Costs per kilometer for 1 meter of widening ranged widely and depended on the increase in pavement width. All pavements were assumed to require a full-width overlay. Costs for shoulder widening (Table 9) also varied, depending on the amount of widening. All shoulders were assumed to require stabilization and surfacing.

Widening (lane and shoulder) normally utilizes existing rights of way. Major reconstruction projects which involve right-of-way acquisition were not considered here. Because of the great variation in terrain and soils throughout Kentucky, the costs differed considerably. Adequate room may be available on some roads to widen the pavement for shoulders but would be insufficient on others. The costs given here are average values based on past contract prices adjusted to 1976 dollars. Note that such costs were considerably different from similar construction costs in other states, due to differing types of terrain, construction techniques, etc.

COST-EFFECTIVENESS ANALYSIS

To determine the cost-effectiveness of lane and shoulder widening, benefit-cost ratios can be used to priority rank the projects. Average statewide costs based on past contract prices in Kentucky (Tables 8 and 9) were used. More exact costs should be used for a particular project whenever available. Benefits should be computed in terms of present-worth based on the following formula:

$$B_{pw} = (C_a)(R)(N)(PWF)$$

in which B_{pw} = present-worth benefits expected from a highway improvement (in dollars), R = annual percentage reduction in opposite-direction and run-off-road accidents due to widening (see Tables 6 and 7),

C_a = average cost of each accident affected by the improvement ($5,569 for opposite-direction and run-off-road accidents),

N = annual number of accidents influenced by improvements, and

PWF = present-worth factor used to convert benefits to present values.

The present-worth factor is based on the interest rate, AADT growth factor, and expected service life of the improvement. The interest rate selected was eight percent. An exponential growth factor of four percent was assumed for the AADT's on rural, two-lane roads in Kentucky to reflect recent volume trends. This was also in agreement with traffic growth nationwide from 1975 to 1976 on all non-interstate routes *(20)*. Lane and shoulder widening projects were considered to have a 30-year life, assuming proper maintenance. A recent study in Idaho included benefits and costs from pavement widening and assumed a useful service life of 30 years *(3)*. The appropriate present-worth factor (17.62) was selected *(21)*.

Based on the equation given previously, calculated benefits depend on the percentage of accident reduction. Estimates of present-worth benefits may be obtained from Figure 8. To determine how much lanes or shoulders should be widened to obtain the optimal benefits per dollar spent, plots of benefit-cost ratios versus number of accidents similar to that in Figure 9 were developed. Figure 9 illustrates benefit-cost ratios expected when 2.1-m (7-foot) lanes are widened to 3.4 m (11 feet). As stated before, little if any additional benefits accrue by widening a pavement to more than 3.4 m (11 feet) on rural, two-lane roads. It is noted that approximately five accidents per year would prequalify a section in terms of accident benefits (benefit-cost ratio of 1.0). Similar analyses for other initial widths of lanes were also plotted. Such plots indicate that widening pavements to at least 3.4 m (11 feet) may be optimal, based on cost-effectiveness, for all existing lane widths.

If a two-lane highway with lane widths above 3.0 m (10 feet) has at least five run-off-road and (or) opposite-direction accidents per year, shoulder widening should be considered. Since shoulder widths were grouped for purposes of accident analysis, average shoulder width in each group was used in the economic analysis.

For pavements without shoulders, the optimal shoulder widening, in terms of benefit-cost ratios, would be 1.5 m (5 feet) (Figure 10). Slightly more than five accidents per year would be required to result in a benefit-cost ratio above 1.0. For 0.6-m (2-foot) shoulders, widening to 1.5 m (5 feet) would be more cost-effective than widening to 2.4 m (8 feet).

For this study, all 1.6-km (1-mile) sections with at least two opposite-direction or three run-off-road accidents were selected from the sample data. The average statewide accident rate was then computed for run-off-road and opposite-direction accidents on rural, two-lane roads. For 1976, this statewide average rate was 1.02 accidents per million vehicle-kilometers (1.65 accidents per million vehicle-miles) and was used to select highway sections with critically high accident rates determined by the Rate-Quality Control Method *(23)*.

IDENTIFYING SECTIONS FOR IMPROVEMENT

The next step involved the identification and ranking of sections of highway for consideration of widening. There were 350 sections (1.6 km (1 mile) each) with critically high accident rates. A priority listing of the top 631 highway sections based on widening needs was made.

The next step was to determine what improvements, if any, should be recommended at the highest priority locations. For this, a detailed study of all accident reports was recommended for each section under consideration. A field inspection should follow.

For those sections for which widening is recommended, a benefit-cost analysis will show which improvements would be the most cost effective. Based on the projected benefits and costs for widening of each section, priority listings can be prepared for lane-widening and shoulder-widening projects.

It is recommended that each year 1.6-km (1-mile) sections with 3.1 or more accidents per kilometer (five or more per mile) involving run-off-road or opposite-direction and having narrow lanes or shoulders be identified. These locations should then be analyzed for cost-effectiveness and ranked separately as lane and shoulder widening projects. Those qualifying for widening should be field investigated; cost estimates should be prepared for all widening alternatives. These projects should then be considered along with other safety improvement projects for implementation.

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Table 1. DISTRIBUTION OF TEST SITES BY TRAFFIC VOLUME AND BY ROUTE TYPE

AADT	NUMBER OF 1.6-km (1-mile) TEST SITES			
	STATE PRIMARY	STATE SECONDARY	RURAL SECONDARY	TOTAL
0 - 500	38	1,462	6,283	7,783
501 - 1,000	175	1,730	1,124	3,029
1,001 - 2,500	969	1,884	369	3,222
2,501 - 5,000	794	604	47	1,445
5,001 - 7,500	180	124	6	310
7,501 - 10,000	66	47	1	114
10,001 - 15,000	18	13	0	31
15,001 - 20,000	3	7	0	10
Total	2,243	5,871	7,830	15,944

Note: 1 mile = 1.609 km

Table 2. LANE WIDTHS AND ACCIDENTS

LANE WIDTH (m)	SAMPLE SIZE (km)	NUMBER OF ACCIDENTS	ACCIDENT PER km	AVERAGE AADT	ACCIDENT RATES	
					PER MILLION VEHICLE-km	PER MILLION VEHICLE MILES
2.1	637	123	0.19	205	2.58	4.16
2.4	4,518	1,143	0.25	304	2.28	3.66
2.7	13,273	6,652	0.50	729	1.88	3.03
3.0	4,082	4,947	1.21	1,862	1.78	2.87
3.4	1,268	2,017	1.59	3,410	1.28	2.06
3.7	981	1,743	1.78	3,970	1.23	1.97
4.0	61	135	2.21	4,483	1.35	2.17
Total	24,820	16,760	0.68	1,099	1.68	2.71

Notes: 1 mile = 1.609 km
1 foot = 0.3048 m
This table was generated before controlling for the effects of traffic and other highway variables

TABLE 3. SHOULDER WIDTHS AND ACCIDENTS

SHOULDER WIDTH (m)	SAMPLE SIZE (km)	NUMBER OF ACCIDENTS	ACCIDENTS PER km	AVERAGE AADT	ACCIDENT RATES: PER MILLION VEHICLE-km	ACCIDENT RATES: PER MILLION VEHICLE MILES
None	17,887	8,790	0.49	751	1.79	2.89
0.3 - 0.9	6,661	6,610	0.99	1,578	1.72	2.77
1.2 - 1.8	163	370	2.27	3,566	1.74	2.81
2.1 - 2.7	138	188	1.36	3,693	1.01	1.62
3.0 - 3.7	553	964	1.74	4,088	1.17	1.88
Total	25,402	16,922	0.67	1,074	1.70	2.73

Notes: 1 mile = 1.609 km
1 foot = 0.3048 m
This table was generated before controlling for the effects of traffic and other highway variables

TABLE 4. ACCIDENT RATES FOR VARIOUS COMBINATIONS OF LANE AND SHOULDER WIDTHS ON RURAL, TWO-LANE HIGHWAYS (ALL ACCIDENTS)

	SHOULDER WIDTH									
	NO SHOULDER		0.3 to 0.9 m 1 to 3 feet		1.2 to 1.8 m 3 to 6 feet		2.1 to 2.7 m 7 to 9 feet		3.0 to 3.7 m 10 to 12 feet	
LANE WIDTH (m)	RATE*	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS
2.1	2.92	286	1.06	110		0		0		0
2.4	1.84	2,460	2.13	344		1		1		0
2.7	1.38	6,032	1.19	2,185	0.83	9	0.76	6		4
3.0	1.14	1,384	1.01	1,080	0.74	23	0.64	8	0.64	12
3.4	0.64	382	0.63	275	0.50	31	0.32	21	0.52	38
3.7	0.48	168	0.67	87	0.61	27	0.44	34	0.56	261

* Accidents per million vehicle-kilometers
Note: 1 mile = 1.609 km
1 foot = 0.3048 m

TABLE 5. ACCIDENT RATES FOR VARIOUS COMBINATIONS OF LANE AND SHOULDER WIDTHS ON RURAL, TWO-LANE HIGHWAYS (RUN-OFF-ROAD AND OPPOSITE-DIRECTION ACCIDENTS)

	SHOULDER WIDTH									
	NO SHOULDER		0.3 to 0.9 m 1 to 3 feet		1.2 to 1.8 m 4 to 6 feet		2.1 to 2.7 m 7 to 9 feet		3.0 to 3.7 m 10 to 12 feet	
LANE WIDTH (m)	RATE*	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS
2.1	3.16	286	1.21	110		0		0		0
2.4	2.24	2,460	2.52	344		1		1		0
2.7	1.97	6,032	1.78	2,185	1.81	9	1.14	6		4
3.0	1.87	1,384	1.70	1,080	1.93	23	1.84	8	1.58	12
3.4	1.16	382	1.37	275	1.37	31	0.53	21	1.37	38
3.7	1.19	168	1.51	87	1.40	27	1.13	34	1.16	26

* Accidents per million vehicle-kilometers
Note: 1 mile = 1.609 km
1 foot = 0.3048 m

TABLE 6. REDUCTIONS IN RUN-OFF-ROAD AND OPPOSITE-DIRECTION ACCIDENTS DUE TO LANE WIDENING

LANE WIDTH (m)		PERCENTAGE REDUCTION IN ACCIDENTS
BEFORE	AFTER	
2.1	2.4	10
2.1	2.7	23
2.1	3.0	29
2.1	3.4	39
2.4	2.7	16
2.4	3.0	23
2.4	3.4	36
2.7	3.0	10
2.7	3.4	29
3.0	3.4	23

Note: 1 foot = 0.3048 m

TABLE 7. REDUCTIONS IN RUN-OFF-ROAD AND OPPOSITE-DIRECTION ACCIDENTS DUE TO SHOULDER WIDENING

SHOULDER WIDENING (m)		PERCENTAGE REDUCTION IN ACCIDENTS
BEFORE	AFTER	
None	0.3 to 0.9	6
None	1.2 to 1.8	15
None	2.1 to 2.7	21
0.3 to 0.9	1.2 to 1.8	10
0.3 to 0.9	2.1 to 2.7	16
1.2 to 1.8	2.1 to 2.7	8

Note: 1 foot = 0.3048 m

TABLE 8. COSTS PER MILE OF PAVEMENT WIDENING

PAVEMENT WIDTH (m)		GRADE AND DRAIN	SUBGRADE	OVERLAY	OTHER	TOTAL	COST PER FOOT OF WIDENING
BEFORE	AFTER						
4.3	5.5	$ 93,943	$14,900	$19,764	$5,200	$133,807	$33,452
4.3	6.1	113,079	22,350	21,960	6,647	164,036	27,339
4.3	6.7	132,216	29,800	24,156	8,093	194,265	24,283
4.3	7.3	151,352	37,250	26,352	9,540	224,494	22,449
4.9	6.1	93,943	14,900	21,960	5,529	136,332	34,083
4.9	6.7	113,079	22,350	24,156	6,976	166,561	27,760
4.9	7.3	132,216	29,800	26,352	8,423	196,791	24,599
5.5	6.7	93,943	14,900	24,156	5,858	138,857	34,714
5.5	7.3	113,079	22,350	26,352	7,305	169,086	28,181
6.1	6.7	74,807	7,450	24,156	4,741	111,154	55,577
6.1	7.3	93,943	14,900	26,352	6,188	141,383	35,346
6.7	7.3	74,807	7,450	26,352	5,070	113,679	56,840

Note: 1 foot = 0.3048 m
1 mile = 1.609 km

TABLE 9. COSTS PER MILE OF SHOULDER WIDENING

SHOULDER WIDENING (EACH SIDE) (m)	GRADE AND DRAIN	SHOULDER STABILI-ZATION	SHOULDER SURFACING	TOTAL	COST PER FOOT OF WIDENING
0.3	$19,832	$ 3,568	$ 1,834	$ 25,234	$12,617
0.6	26,965	7,136	3,668	37,769	9,442
0.9	34,445	10,704	5,502	50,651	8,442
1.2	42,274	14,272	7,336	63,882	7,985
1.5	50,451	17,840	9,170	77,461	7,746
1.8	58,106	21,408	11,004	90,518	7,543
2.1	65,761	24,976	12,838	103,575	7,398
2.4	73,416	28,544	14,672	116,632	7,290

Note: 1 foot = 0.3048 m
1 mile = 1.609 km

Table 10. NUMBER OF ACCIDENTS AND ACCIDENT RATES*
FOR VARIOUS LANE WIDTHS

LANE WIDTH (m)	TYPE OF ACCIDENT: RUN OFF ROAD		OPPOSITE DIRECTION		REAR END		VEHICLE PASSING		DRIVEWAY AND INTERSECTION		PEDESTRIAN, BICYCLE, ANIMAL, OR TRAIN		OTHER OR NOT STATED			TOTAL	
	NO.	RATE	NO.	RATE	NO.	RATE	NO.	RATE	NO.	RATE	NO.	RATE	NO.	PER-CENT	RATE	NO.	RATE
2.1	58	1.22	54	1.13	6	0.12	1	0.02	2	0.04	2	0.04	0	0	0.00	123	2.59
2.4	576	1.15	368	0.73	56	0.11	15	0.03	36	0.07	54	0.11	38	3	0.07	1,143	2.27
2.7	3,399	0.96	1,160	0.33	459	0.13	244	0.07	344	0.10	427	0.12	619	9	0.17	6,652	1.88
3.0	2,189	0.79	720	0.26	591	0.21	220	0.08	310	0.11	256	0.09	666	13	0.24	4,947	1.78
3.4	728	0.46	190	0.12	417	0.27	133	0.09	205	0.13	94	0.06	250	12	0.16	2,017	1.28
3.7	555	0.39	192	0.14	373	0.26	97	0.07	195	0.14	95	0.07	236	14	0.17	1,743	1.22
4.0	32	0.32	10	0.10	32	0.32	11	0.11	26	0.26	7	0.07	17	13	0.17	135	1.35
Total	7,532		2,694		1,934		721		1,118		935		1,826	11		16,760	

* Accidents per million vehicle-kilometers
Based on accidents on 15,426 sections 1.6 km in length
Note: 1 mile = 1.609 km
1 foot = 0.3048 m

TABLE 11. INJURY AND FATALITY ACCIDENTS FOR VARIOUS LANE WIDTHS

LANE WIDTH (m)	NO. OF 1.6-km SECTIONS	NUMBER OF ACCIDENTS			ACCIDENT RATES*			PERCENT INJURY AND FATAL ACCIDENTS
		PROPERTY DAMAGE	INJURY	FATAL	PROPERTY DAMAGE	INJURY	FATAL	
2.1	396	86	36	1	1.81	0.76	0.02	30.1
2.4	2,808	728	396	19	1.45	0.79	0.04	36.3
2.7	8,249	4,068	2,449	135	1.15	0.70	0.04	38.8
3.0	2,537	3,180	1,685	82	1.14	0.61	0.03	35.7
3.4	788	1,348	644	25	0.85	0.41	0.02	33.2
3.7	610	1,154	553	36	0.81	0.39	0.02	33.8
4.0	38	107	28	0	1.07	0.28	0.00	20.7
Total	15,426	10,676	5,791	298	1.07	0.58	0.03	36.3

* Accidents per million vehicle-kilometers
Note: 1 mile = 1.609 km
1 foot = 0.3048 m

TABLE 12. NUMBER OF ACCIDENTS AND ACCIDENT RATES* FOR VARIOUS SHOULDER WIDTHS

SHOULDER WIDTH (m)	TYPE OF ACCIDENT: RUN-OFF ROAD		OPPOSITE DIRECTION		REAR END		VEHICLE PASSING		DRIVEWAY AND INTERSECTION		PEDESTRIAN, BICYCLE, ANIMAL, OR TRAIN		OTHER OR NOT STATED			TOTAL	
	NO.	RATE	NO.	RATE	NO.	RATE	NO.	RATE	NO.	RATE	NO.	RATE	NO.	PER-CENT	RATE	NO.	RATE
None	4,032	0.82	1,666	0.34	870	0.18	341	0.07	503	0.11	490	0.10	888	10	0.18	8,790	1.80
0.3 - 0.9	3,024	0.79	884	0.23	785	0.21	281	0.07	444	0.12	362	0.09	830	13	0.22	6,610	1.72
1.2 - 1.8	77	0.37	38	0.18	66	0.31	21	0.10	59	0.28	17	0.08	92	25	0.44	370	1.75
2.1 - 2.7	50	0.27	15	0.08	44	0.24	8	0.04	35	0.19	11	0.06	25	13	0.14	188	1.01
3.0 - 3.7	317	0.39	106	0.13	215	0.26	62	0.07	105	0.12	59	0.07	100	10	0.12	964	1.17
Total	7,500		2,709		1,980		713		1,146		939		1,935	11		16,922	

* Accidents per million vehicle-kilometers
Note: 1 mile = 1.609 km
1 foot = 0.3048 m

TABLE 13. INJURY AND FATALITY ACCIDENTS FOR VARIOUS SHOULDER WIDTHS

SHOULDER WIDTH (m)	NO. OF 1.6-km SECTIONS	NUMBER OF ACCIDENTS			ACCIDENT RATES*			PERCENT INJURY AND FATAL ACCIDENTS
		PROPERTY DAMAGE	INJURY	FATAL	PROPERTY DAMAGE	INJURY	FATAL	
None	11,117	5,546	3,087	157	1.13	0.63	0.03	36.9
0.3 - 0.9	4,140	4,235	2,254	111	1.11	0.59	0.03	39.4
1.2 - 1.8	101	248	117	5	0.48	0.55	0.02	33.0
2.1 - 2.7	86	142	44	2	0.46	0.24	0.01	24.5
3.0 - 3.7	344	626	320	18	0.42	0.39	0.02	35.1
Total	15,788	10,797	5,822	293				

* Accidents per million vehicle-kilometers
Note: 1 mile = 1.609 km
1 foot = 0.3048

TABLE 14. ACCIDENT RATES FOR VARIOUS COMBINATIONS OF VOLUME, HIGHWAY CLASSIFICATION, AND LANE WIDTHS

HIGHWAY CLASSIFICATION AND AADT	LANE WIDTH 2.4 m		LANE WIDTH 2.7 m		LANE WIDTH 3.0 m	
	RATE**	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS	RATE	NO. OF 1.6-km SECTIONS
RURAL SECONDARY						
0 to 500	2.02	1,876	2.02	2,969	2.42	147
501 to 1,000	2.64	157	1.88	530	2.20	75
1,001 to 2,500	2.29	27	2.27	142	1.47	40
2,501 to 5,000			2.25	10	1.70	11
5,001 to 7,500						
7,501 to 10,000						
STATE SECONDARY						
0 to 500	2.22	237	1.81	793	2.24	108
501 to 1,000	2.70	93	1.92	777	1.64	209
1,001 to 2,500	2.47	27	1.93	381	1.70	287
2,501 to 5,000			2.15	33	1.72	70
5,001 to 7,500					1.63	14
7,501 to 10,000						
STATE PRIMARY						
0 to 500	1.25	6	1.88	25		
501 to 1,000	1.68	52	2.08	168		
1,001 to 2,500	1.58	112	2.33	104	0.98	26
2,501 to 5,000	1.65	7	1.91	10	1.37	53
5,001 to 7,500						
7,501 to 10,000						

* Includes only those sections with no shoulders and less than 3.1 access points per kilometer (5 per mile)
** Accidents per million vehicle-kilometers
Note: 1 mile = 1.609 km
1 foot = 0.3048 m

TABLE 15. NUMBER OF ACCIDENTS BY TYPE AND SEVERITY

TYPE* OF ACCIDENT	RUN-OFF-ROAD AND OPPOSITE-DIRECTION ACCIDENTS		OTHER ACCIDENTS		PERCENTAGES	
	NUMBER OF ACCIDENTS	NUMBER OF INJURIES	NUMBER OF ACCIDENTS	NUMBER OF INJURIES	RUN-OFF-ROAD AND OPPOSITE-DIRECTION ACCIDENTS	OTHER ACCIDENTS
Property Damage	14,000	0	32,130	0	59.7	80.4
C-Injury	2,730	4,516	3,446	5,844	11.6	8.6
B-Injury	3,876	6,391	2,720	4,509	16.5	6.8
A-Injury	2,436	3,543	1,468	1,963	10.4	3.7
Fatality	422	494	202	225	1.8	0.5
Total	23,464	14,944	39,966	12,541	100.0	100.0

* Property damage -- no injuries sustained
C-injury -- no visible injuries, but complaints of pain
B-injury -- bruises, abrasions, swelling, or limping
A-injury -- bleeding wound, distorted member, or person carried from scene
Fatality -- one or more deaths

TABLE 16. REDUCTIONS IN ACCIDENT RATES DUE TO SHOULDER WIDENING

SHOULDER WIDTH BEFORE WIDENING (m)	SHOULDER WIDTH AFTER WIDENING (m)		
	0.3 to 0.9	1.2 to 1.8	2.1 to 2.7*
None	0.09**	0.25	0.36
0.3 to 0.9		0.16	0.27
1.2 to 1.8			0.11

* No further reductions in accident rates to more than 2.7 m due to widening shoulders
** Accidents per million vehicle-kilometers

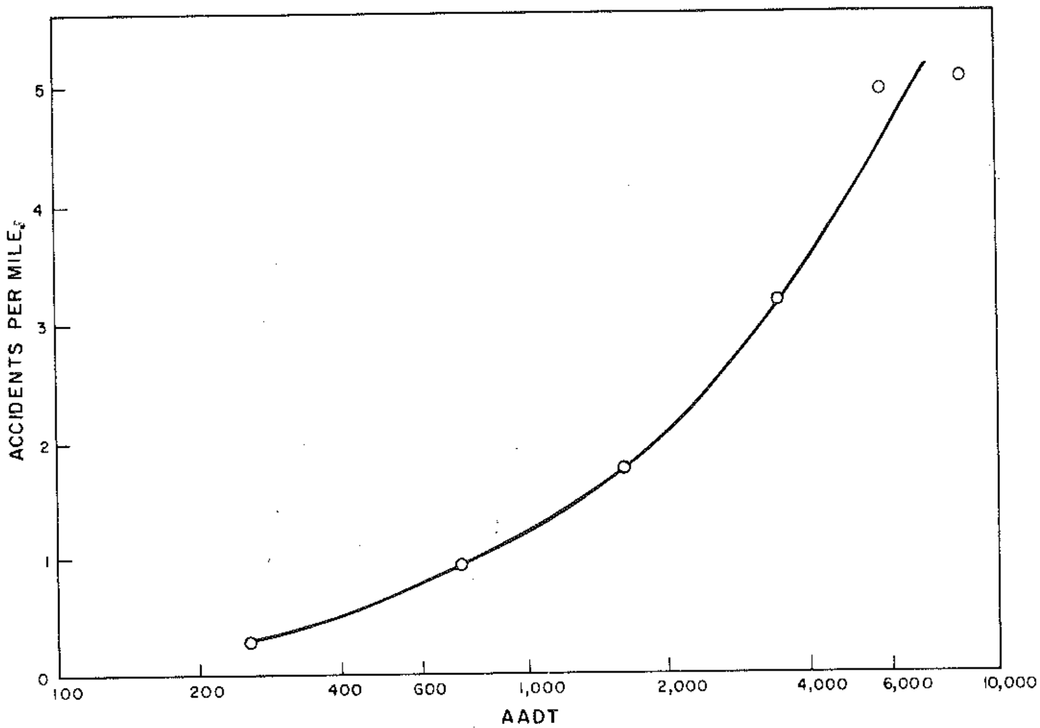

Figure 1. Relationship between Accidents and Traffic Volume, All Accidents.

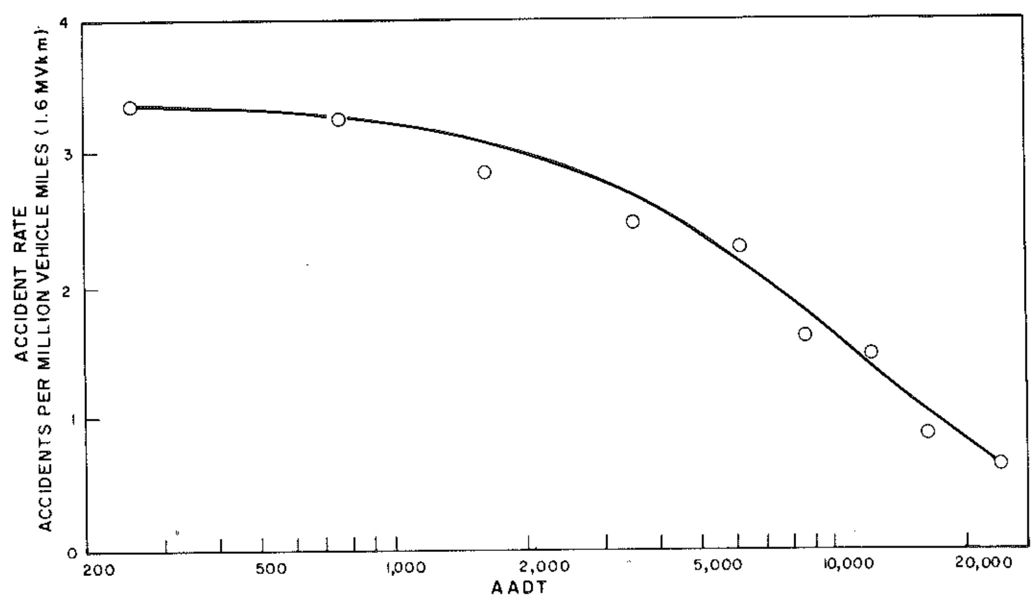

Figure 2. Relationship between Accident Rate and Traffic Volume, All Accidents.

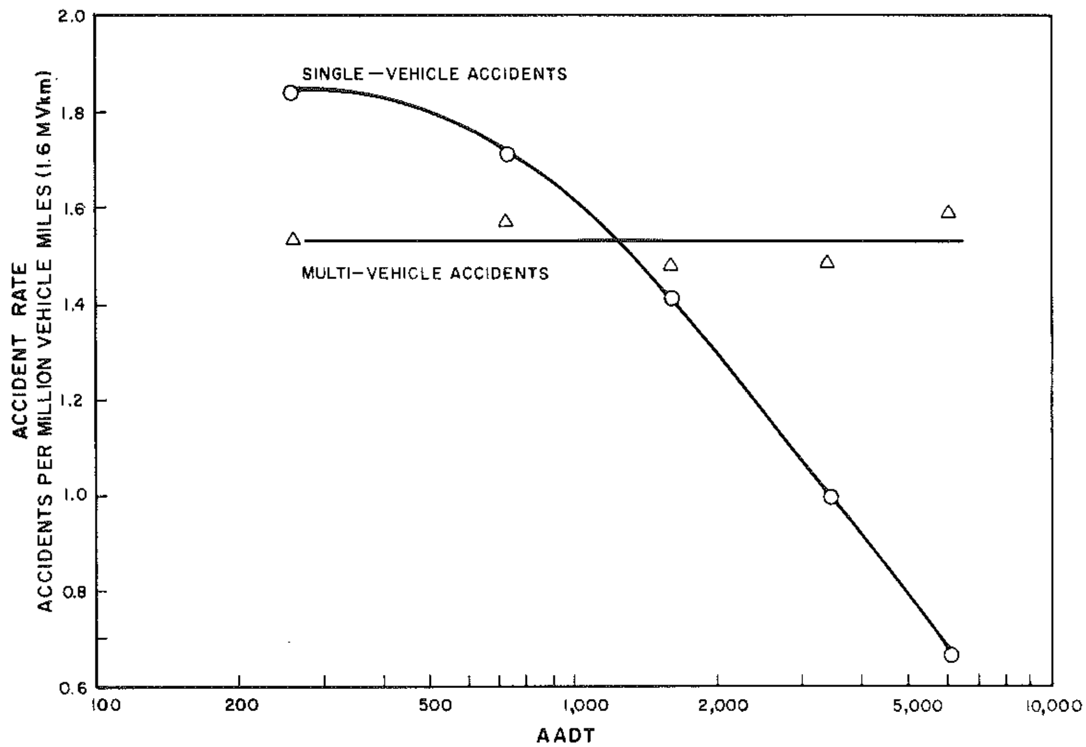

Figure 3. **Effect of Traffic Volume on Single-Vehicle and Multi-Vehicle Accident Rates.**

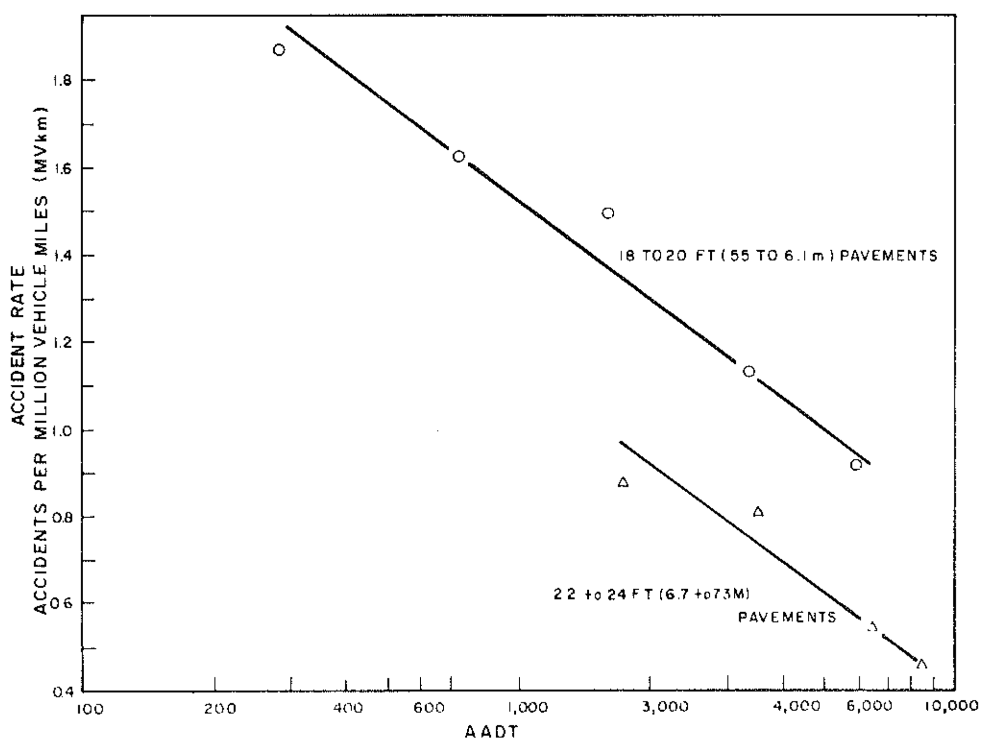

Figure 4. **Rates of Run-off-Road Accidents by Lane Width, Various Traffic Volumes.**

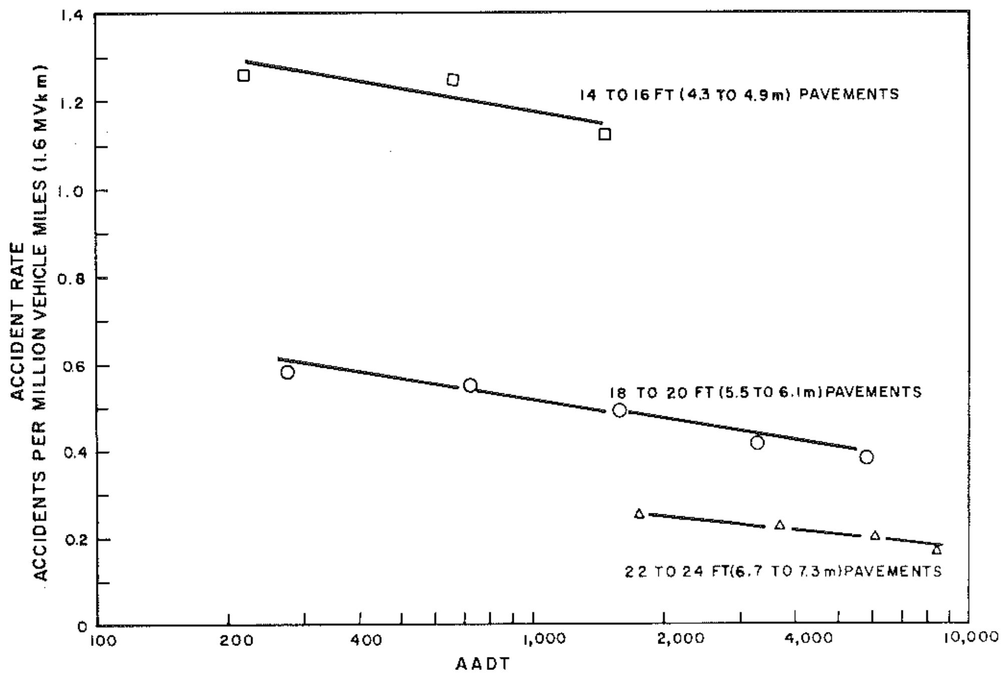

Figure 5. Rates of Opposite-Direction Accidents by Lane Width, Various Traffic Volumes.

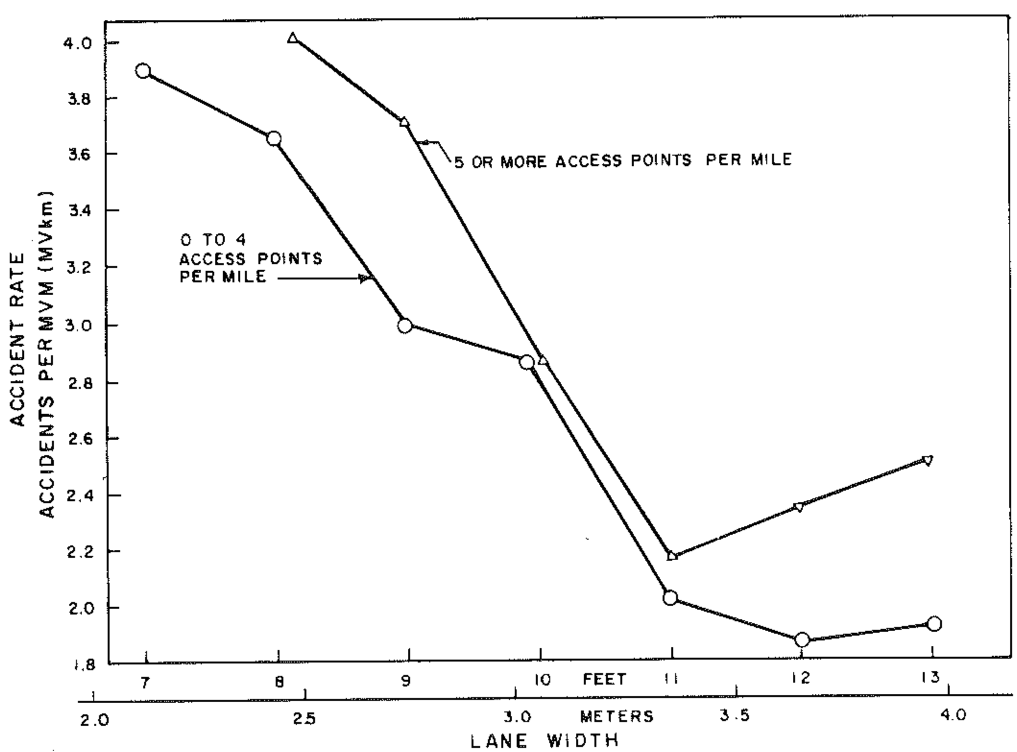

Figure 6. Effect of Access Points per Kilometer on Accident Rates, Various Lane Widths.

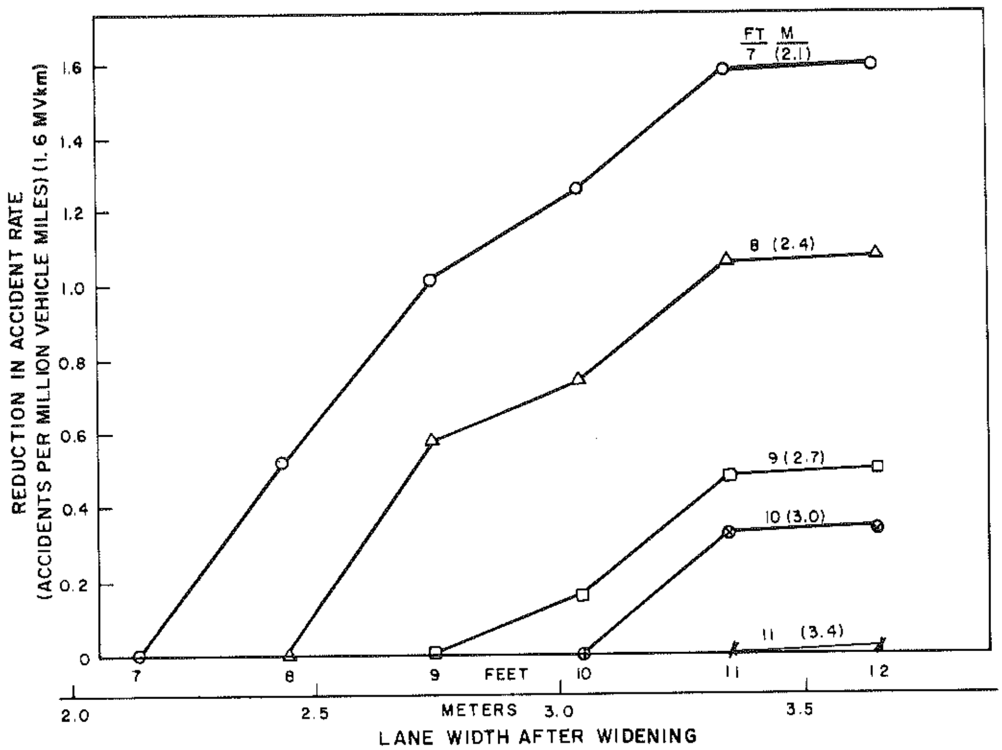

Figure 7. Reduction in Accident Rate due to Lane Widening.

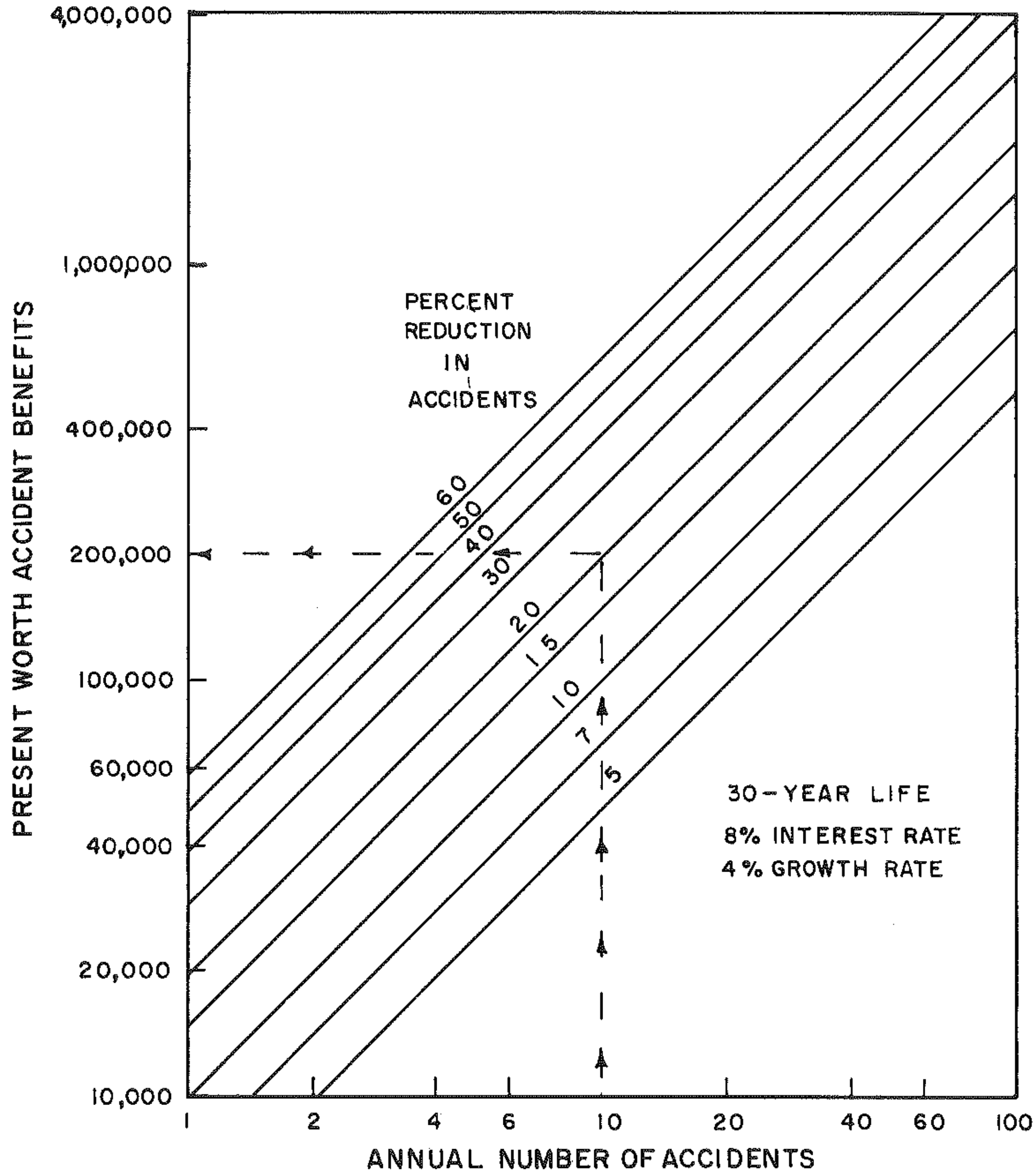

Figure 8. **Present-Worth Benefits for Various Accident Histories and Percentages of Accident Reduction.**

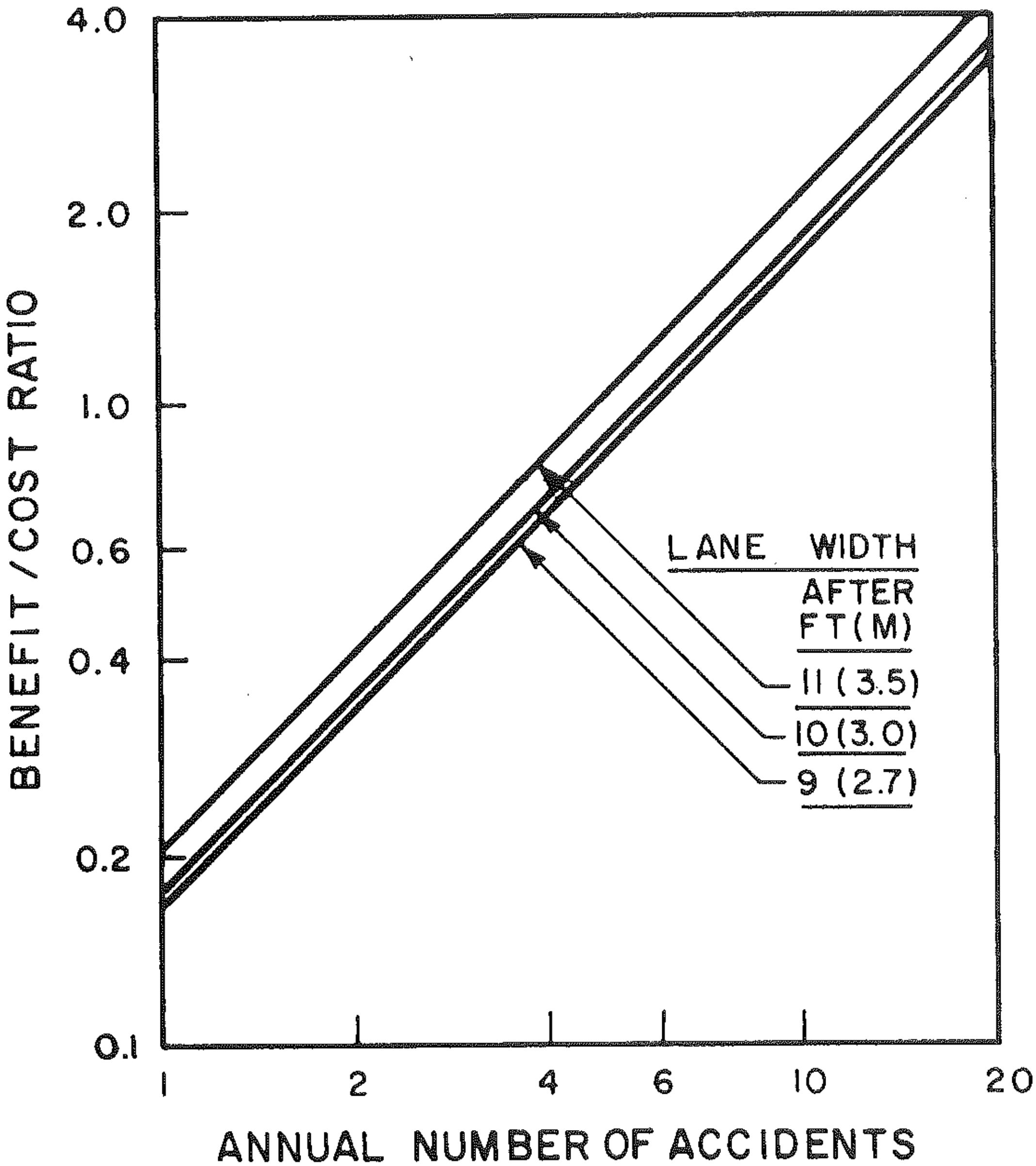

Figure 9. Benefit-Cost Ratios for Widening 2.1-meter (7-foot) Lanes.

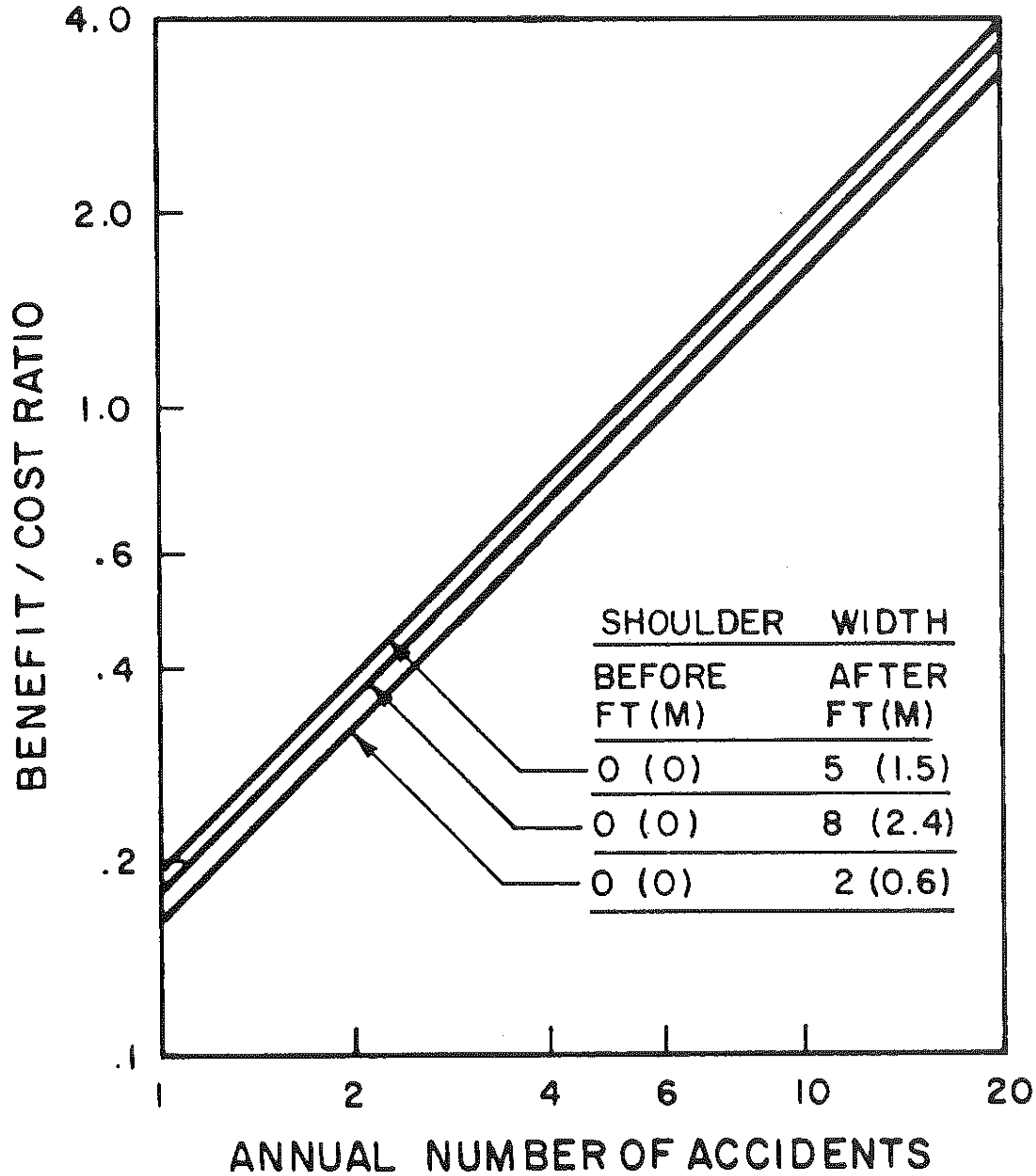

Figure 10. Benefit-Cost Ratios for Adding Shoulders.