Potential Improvements in Roadway Delineation for Older Drivers

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Safe driving requires that the moving vehicle follow a proper path on the roadway. Inadvertent excursions can lead to disaster: head-on collision with an approaching vehicle, sideswipe of a passing vehicle, or an overturn or collision with a hazardous roadside object. To avoid such disasters, the driver must be able to (a) sense in advance required changes in direction resulting from horizontal curvature or an intersection turn and (b) accurately follow the desired path, thus maintaining safe edge-of-pavement and intervehicle clearances. Each of these tasks—identified herein as guidance and tracking, respectively—relies extensively on visual stimuli. The kinds of stimuli that are most important differ between intersection and nonintersection locations.

Guidance through intersections is accomplished almost exclusively with traffic control devices such as route markers and direction and street signs. With the intended movement chosen and attention properly directed, the driver steers toward the appropriate departure leg. Tracking on the approach and departure legs is largely based on the location of lane boundaries, usually defined by the physical edge of the pavement or the curb or gutter line; by pavement stripings, including centerlines, lane lines, and edgelines; and by channelizing devices. Within the intersection proper, the driver gains useful tracking clues by following leading vehicles, by the location of channelization, and occasionally by a dashed lane line extending through the intersection.

At nonintersection locations, guidance comes largely from the visual perspective of the road ahead and the location of parallel elements such as lines of trees, fencing, utility poles, parked cars, lighting standards, and bridgerail or guardrail. Traffic control devices such as chevron alignment markers, post-mounted delineators, raised or recessed pavement markers, curve warning signs, and centerline, lane-line, and edgeline markings are also important, often critically so at night and during other periods of restricted visibility and when speeds are high. For tracking, the driver relies on nearby features; contrasts in color, texture, and shape between pavement and shoulder; curb and barrier edges; and pavement striping. Under high traffic volumes, car following is likely a dominant tracking and guidance aid. The vibration and noise of an inadvertent excursion onto a properly textured shoulder also serve to alert the inattentive driver to potential danger and redirect attention to the tracking task.

The purpose of this paper is to identify special difficulties of the older driver in performing these guidance and tracking tasks at nonintersection locations, to determine whether these difficulties can be eased by the installation or enhancement of delineation devices, and to identify conditions in which such installation or enhancement appears warranted. Intersections and signing are treated by Hauer and Mace in other papers in this volume.

The discussion in the following sections draws heavily on the material presented in Chapter 3, Safety of Older Persons in Traffic, of Volume 1 and on other papers in this volume by Mortimer, McKnight, Hauer, Mace, Bailey and Sheedy, Kanouse, and Schieber.

THE OLDER DRIVER

The typical aging person suffers a deterioration in at least three functions important to safe and carefree driving: sensory (visual), cognitive, and psychomotor. Unlike more complex driving tasks such as emergency maneuvering or freeway merging, guidance and tracking at nonintersection locations probably place critical demands only on vision; the cognitive function becomes important only for complex guidance tasks and high-speed travel. Typically, though, the changes in direction necessary for guidance and tracking are small and continuous; they do not demand quick thinking and fast and strong response.

Specific visual capabilities essential to guidance and tracking have not been accurately identified. However, for travel on two-lane roadways at night, resistance to glare and quick recovery from its effects are obviously essential to both tasks. Visual acuity (the ability to see details clearly) and contrast sensitivity (the ability to discriminate small-contrast differences in larger objects or features) are probably the most critical visual elements for identifying distant features essential to the guidance task. Tracking requires the identification of more closely located features, typically outside the point of visual fixation, and as a consequence relies heavily on peripheral vision. Unfortunately, deterioration of each of these vital visual functions is a frequent consequence of the aging process *(1)*. The deterioration is often dramatic and, with exception of visual acuity, largely uncorrectable.

One anticipated consequence of visual deterioration in aging drivers is certainly an increase in the rate of their involvement in guidance- and tracking-related crashes, in the context of this paper at nonintersection locations. For two-lane highways, these include both head-on and single-vehicle run-off-roadway crashes; for multilane highways, sideswipe and single-vehicle run-off-roadway crashes. Nighttime would be expected to exacerbate the consequences of impaired vision.

Past research establishes a conclusive association between driver age and crash measures such as the number of fatalities per mile of travel: crash rates have been positively associated with age for older drivers. Other research has shown the deleterious effect of visual impairment on crash rates *(2)*. However, crash research has not been sufficiently refined to attempt direct correlations between the rates of guidance- and tracking-related crashes and age or vision. At the same time, the typical types of crashes in which the older driver is involved are clearly known. They occur in urban areas during the daylight hours. They are multivehicle crashes involving turning, merging, pulling into traffic, lane changing, backing up, and the like. Not infrequently, the older driver fails to yield the right-of-way or to observe traffic signs or signals. The typical older-driver crash is obviously not of the type expected from failures in the guidance and tracking tasks.

The absence of a clearly defined link between the patterns of guidance- and tracking-associated crashes and driver age or vision may stem from inadequacies of crash and exposure data bases or by lack of a concerted attempt to seek such a link. However, it is almost certainly related to adaptive and compensatory behavior of the aging driver. As a consequence of visual deterioration, older drivers are expected to find guidance and tracking tasks becoming increasingly difficult with time. As a result, they alter their patterns of behavior, driving less at night, avoiding unfamiliar routes, venturing less frequently into unaccustomed territory, and avoiding peak traffic conditions. In short, aging drivers may selectively avoid driving situations that they believe will be difficult and dangerous.

DELINEATION

A "bare" roadway—one devoid of traffic control devices—is seldom adequate for supplying essential input for guidance and tracking tasks, even for the most competent motorists. A striped centerline is considered essential for almost all two-lane roadways *(3)*. It provides essential delineation, acts to assure adequate separation between opposing or passing vehicles, and provides a convenient mechanism for identifying no-passing zones. In addition, the horizontal curve, hidden from view by the roadway geometry, is the genesis of one of the more common signs along rural secondary roadways—the diamond-shaped curve warning sign. Such signs—long considered essential to proper guidance—are frequently supplemented by delineation devices such as post-mounted delineators or chevron alignment markers. Interestingly, roadways of the highest standards, Interstate highways and other freeways, make most extensive use of delineation devices: centerlines, lane lines, and edgelines (all reflectorized for enhanced nighttime visibility); raised or recessed pavement markers for enhanced wet-weather visibility; post-mounted delineators at roadside for use when other devices are obscured by ice or snow and for general advance direction; and, as necessary, the chevron alignment marker at critical locations.

The extensive use of such devices reflects not only the common belief that enhanced delineation is essential to safe and comfortable driving at night and during other periods of impaired visibility but also an expanding body of research that has validated its operational and safety benefits *(4, 5–8)*. The Federal Highway Administration's study of delineation techniques, conducted in the mid-1970s, provides an indication of crash benefits *(7, 9)*:

- Highways with centerlines had lower crash rates than those without delineation treatment. For example, application of a painted centerline to two-lane sections without prior delineation was found to reduce the overall crash rate by up to 1.5 crashes per million vehicle miles. The reduction was approximately 30 percent for the entire sample of highways.
- Highways with raised pavement marker centerlines had lower crash rates than those with painted centerlines. The average reduction in crash rates was approximately 0.5 crash per million vehicle miles.
- Installation of post-mounted delineators lowered crash rates for sections with or without edgelines. The reduction in crash rate resulting from the installation of these delineators averaged 1.0 crash per million vehicle miles.
- The application of edgelines generally resulted in a decrease in crash rates. The reduction was greatest for tangent sections, averaging approximately 0.7 crash per million vehicle miles.

The significance of the foregoing estimates is demonstrated by a cost-effectiveness analysis that justifies the application of striping and post-mounted delineators for a wide range of conditions including minimum traffic volumes of 1,000 vehicles per day or even less in some cases. Raised pavement markers, as a substitute for painted centerlines, become cost-effective at larger volumes, 3,000 or more vehicles per day.

Because of the difficulty of performing investigations that rely on crash data, much delineation research has been based on observations of its operational effects, including such measures as speed, speed change, lateral placement, and frequency of out-of-lane excursions. Although there is limited evidence of correlation between such measures and crash experience *(4, 5)*, definitive relationships have yet to be developed, and researchers sometimes disagree as to the appropriateness of specific measures. At the same time, the controlled nature of operational experiments contributes to more reproducible and sensitive results, and researchers who have applied such methods generally agree on the merits of improved delineation.

Possible effects of enhanced delineation on the operational behavior and crash patterns of older drivers have not been objectively studied. Research currently under way may eventually yield significant new insights on the kinds of delineation enhancements likely to most greatly benefit the older driver *(1)*. For the moment, however, some reasoned speculation is necessary. The greatest crash savings from improved delineation are expected when the vision or visibility is least. Certainly, for example, crash savings are greater at night than during daylight, and a few investigations suggest more beneficial effects for the driver whose vision has been impaired by alcohol consumption *(10–12)*. It seems reasonable to conclude, therefore, that enhanced delineation would more favorably affect the older driver than possibly more average segments of the driving population. Present research supports this view by postulating that older drivers suffer greater degradation in the ability to detect pavement markings and other horizontal targets than younger drivers, especially in poor visibility conditions *(1)*. Yet to be tested, however, is whether unsafe driving behavior is induced by the sense of security stemming from enhanced delineation—the selection of speeds too fast for conditions and driving ability, tracking too close to (or too far from) a conspicuous edgeline, increased travel during periods of reduced visibility, and so on.

ENHANCEMENT OF DELINEATION

For the Older Driver

Given that the typical older driver has diminished ability for safe and comfortable steering, and that enhanced delineation has proven beneficial to vehicle guidance and tracking tasks, it is logical (a) to seek to identify circumstances in which delineation improvements might be justified, largely on the basis of benefits accruing to the population of older drivers and, in such circumstances, (b) to specify the nature of improvements likely to be cost-effective. An objective analysis of this type requires quantification of the lifetime costs of the delineation improvements as well as the safety benefits likely to be realized by the population of drivers, including the subset of older drivers. The latter requires not only an estimate of the reduction in crash rate but also an estimate of the exposure to crash risk. Although quantification of lifetime costs of delineation devices is a task that can be accomplished with relative ease, the scientific basis for quantification of crash rate improvements is limited, and little is known about exposure of older drivers to delineation-related risk.

Although a quantitative evaluation is thus not feasible, a qualitative assessment can indeed be made. Older drivers typically travel at reduced speeds and drive at times (daytime and better weather) and in places (urban streets instead of rural highways) not demanding greatly enhanced delineation for safe driving. Like other drivers, their rural travel is probably concentrated on Interstate highways and other freeways, facilities for which existing delineation treatments are most advanced and therefore in need of little, if any, enhancement. Furthermore, the established patterns of older-driver crashes and violations are not of a type thought to be correctable by enhanced delineation, at least not at nonintersection locations. On the basis of such considerations, it seems unnecessary to attempt to give priority to delineation improvements on the basis of special needs of the older driver.

Travel patterns of the older driver will almost certainly change in the future, and the aging population can be expected to seek to maintain the high level of mobility achieved during their middle years. Fewer self-imposed restrictions on personal travel can be expected: the older driver is likely to travel more at night, take more long-distance trips, more frequently select unfamiliar routes, and travel more often during adverse weather. In short, older drivers will be more frequently exposed to the kinds of conditions for which enhanced delineation is beneficial. Fortunately, the installation of delineation devices is relatively quick and inexpensive; thus, future enhancements to better accommodate the changing population of drivers can easily be made.

For All Drivers

As has been noted, centerline striping is applied to most paved, two-lane highways. The first enhancement to this basic delineation pattern is usually the addition of edgelines. Painted edgelines are relatively inexpensive and have been found to be cost-effective from a safety perspective when daily volumes exceed 1,000 vehicles. Their use has been recommended for all major roads wider than 20 ft *(9)*. Recent interest has focused on the use of edgelines wider than the standard, 4-in. width *(13)*. These wide edgelines offer the potential for extensive cost-effective application *(14)*.

Unfortunately, published crash studies have not produced conclusive findings on the incremental safety effect of wider-than-standard edgelines (see Appendix). A joint study by FHWA and seven participating states is designed to rectify this situation when its findings are published in early 1989. In the interim, a tentative assessment can be made based on existing knowledge of the safety effects of standard edgelines, results from operational studies of wide edgelines, and the crash studies that have examined wide edgelines. The current state of knowledge is summarized as follows.

1. The presence of edgelines has a small but measurable effect on traffic operations *(5, 6, 10–12, 15–17)*. On horizontal curves, for example, edgelines

• Reduce the disparity between daytime and nighttime operating speeds and generally increase nighttime speeds,

• Reduce the frequency of excessive turning curvature,

• Move vehicles away from the pavement edge toward more central positions within the lane of travel,

• Reduce the frequency of shoulder encroachments, and

• Reduce the variability in vehicle position and speed. Operational effects are more pronounced at night than during the day.

2. When applied to centerline-marked roadways, the addition of standard edgelines reduces crash risk *(5, 7, 11, 18–20)*. Although reductions in the frequency of all types of crashes as large as 60 percent have been reported *(11)*, a more likely expectation for the normal roadway would be within the range of 10 to 15 percent. Reported reductions in excess of this range most probably reflect experimental deficiencies—such as regression-to-the-mean effects common in before-and-after studies—or applications to highways having greater than normal incidence of delineation-related crashes, or both.

3. Studies of the effects of edgelines on crash severity have yielded mixed findings *(11, 18, 19, 21)*. However, beneficial effects, if any, are likely due to changes in the mix of crash types rather than an attenuation of the consequences of specific crash events. Such effects could be countered, however, by the increased nighttime speeds induced by edgelining.

4. Although there is some indication that relative benefits of edgelines on straight or gently curving roads may exceed those on more demanding sections *(7, 19)*, research has not been sufficiently refined to pinpoint the confounding effects of many roadway and roadside variables. Edgelines are likely to have maximum beneficial impact in these situations: following

• Poor existing demarcation between pavement and shoulder surfaces;

• Hazardous shoulder or roadside conditions, or both;

• Hazardous horizontal curves, particularly when preceded by straight or gently curving sections;

• Sudden changes in pavement width and the approaches to narrow bridges;

• Large nighttime traffic volumes and high speeds;

• Frequent occurrence of fog or mist; and

• Frequent and severe glare from opposing headlights.

5. Prior research has not defined conditions in which the application of edgelines may have harmful effects. However, these are likely to include narrow roadways, particularly those without centerline markings. Although edgeline applications on 20-ft pavements have not been found to result in safety decrements, most states have prohibited their use on pavements narrower than 22 ft *(4)*, a precaution likely to be a prudent one. Narrower roadways with an abnormally high incidence of delineation-related crashes can likely be better treated by widening or by the installation of raised or recessed pavement markers on the centerline or, possibly, post-mounted delineators off the shoulders.

6. Although one study has documented an increase in crashes following the application of 8-in. edgelines on some types of highways, accompanied by a decrease on others *(22)*, there seems to be no logical basis for arguing that, under normal circumstances, wide edgelines are more hazardous than narrow ones. No such claim has been found in the literature. To the contrary, operational and safety effects of edgelines would logically appear to be continuous functions of their widths, although the incremental effect of each inch of width would likely diminish as width increased. Studies showing a reduction in crash risk following wide edgelining generally support such an assertion (*23*; R. Kelly, Spokane County, Washington, unpublished data; N. D. Nedas, letter to W. Hoversten, California Department of Transportation, July 18, 1985). Reductions are expected to be quite small, however—almost certainly less than 5 percent for typical highways. Although research under way may more accurately assess the quantitative benefit, changes as small as those anticipated are difficult to quantify from records of crash history.

7. The performance of drivers suffering from alcohol impairment is improved by the presence of edgelines *(10–12)*. Although the effects of edgelines on older-driver performance have not been directly tested, an improvement is, by inference, expected.

8. For 8-in. edgelines to be a cost-effective replacement for 4-in. edgelines when the daily traffic exceeds 1,000 vehicles, crashes need only be reduced by an amount of 0.7 percent or less *(14)*. Such a small reduction seems to be well within the expected range, and 8-in. edgelines appear to be a cost-effective application on all two-lane, rural highways warranting such delineation. However, applications on lanes narrower than 11 ft should be considered experimental and carefully monitored.

In view of the foregoing findings and at least until more conclusive crash data become available, 8-in. edgelines should be used in lieu of standard, 4-in. edgelines on two-lane, rural highways. Although this finding is not based on benefits accruing specifically to older drivers, older drivers will share—probably proportionally more—the safety benefits with others who travel these highways during periods of impaired visibility.

RECOMMENDED RESEARCH

Findings of this study suggest that only minor gains in the safety of older drivers are likely to be realized through the widespread adoption of enhanced delineation techniques. Accordingly, motivation for the refinement and extension of knowledge on this subject is not as compelling as it is for others. Two matters however, do warrant additional investigation. The first is the travel and crash patterns of older drivers. A critical study should search for situations in which the older driver is most in need of help that can be rendered by changes to the design and operation of the street and highway system. In the context of delineation, validation would be sought of the finding reached herein that major safety gains are unlikely through the enhancement of delineation. The second is the response of older drivers to a variety of delineation treatments. The primary objective of such a study would be simply to confirm that enhanced delineation improves the performance of older drivers and that abnormally conspicuous delineation does not induce unsafe driving behavior. Effects of lane width and shoulder and roadside conditions as measures of risk in improper tracking should be included in the investigation.

CONCLUSIONS AND RECOMMENDATIONS

Ample evidence suggests that harmful effects of visual degeneration typical in older drivers can be alleviated by the installation or improvement of pavement striping and other delineation devices. At the same time, available evidence is not sufficiently precise to quantify the safety gains that older drivers can expect from enhanced delineation. It does appear, however, that the typical trip made by the older driver is taken on streets and at times when any benefits of improved delineation would be marginal. Furthermore, crash and violation histories of older drivers do not suggest predominant patterns of unsafe behavior of a type correctable by improved delineation.

Nevertheless, the older driver—along with all others—derives some benefit from improved delineation. It is incumbent upon those who operate and maintain the nation's streets and highways to provide delineation treatments in accord with the highest standards of accepted practice *(3, 24, 25)* and to assure that such treatments are satisfactorily maintained and replaced as necessary. One promising enhancement for two-lane rural highways having pavement widths of 22 ft or more is to replace standard edgelines with wider, 8-in. ones. Where older drivers make up an unusually large portion of the traffic stream, additional consideration should be given to the incremental enhancement of delineation treatments, either at spot locations—such as sharp curves, narrow bridges, construction zones, lane drops, and sudden changes in pavement width—or on extended highway segments.

APPENDIX

Studies in New Mexico *(22)* and Virginia *(23)* are among the most recent and probably the most frequently cited in conection with the safety effects of wide edgelines. Both studies concluded that wide edgelines were not beneficial. The researchers recommended, respectively, that "this treatment be discontinued on rural highways" and that "wide edgelines not be considered as a countermeasure." Actually, in Virginia wide edgelines were associated with a reduced frequency of run-off-road crashes; however, the reduction was not statistically significant. In New Mexico, although there was an overall negative effect of wide edgelines on run-off-road crashes, a favorable experience was found on the federal-aid primary subset of the sampled mileage. Unfortunately, statistical testing procedures were not used to evaluate the significance of the New Mexico findings.

In both New Mexico and Virginia the sampled mileage of treatment and control highways was quite limited; neither study addressed the sample size that would likely be necessary to detect, with acceptable risk for error, any beneficial effect of edgelines. Because that effect is likely to be a small one and because highway crash data are so highly variable, it is likely that sample sizes considerably in excess of those used in New Mexico and Virginia would be necessary. The purpose of this Appendix is to examine the sample sizes necessary to keep the risk of error within satisfactory bounds for studies such as these.

For simplicity, the experimental plan selected for investigation was a before-and-after design with both treatment and control sites. Further, it was assumed that the treatment and control sites would be individually matched so that paired comparisons could be made. The following quantities would be observed in such a study.

TB_i = number of crashes at treatment site i in the before period,
TA_i = number of crashes at treatment site i in the after period,
CB_i = number of crashes at paired control site i in the before period, and
CA_i = number of crashes at paired control site i in the after period.

Computed quantities would include the following:

δT_i = $TB_i - TA_i$, the reduction in crashes at treatment site i,
δC_i = $CB_i - CA_i$, the reduction in crashes at control site i, and
δ_i = $\delta T_i - \delta C_i$, the improvement observed with site pair i due to treatment.

For such an experiment, the required number *(n)* of site pairs in the sample can be determined as follows *(26)*:

$$n = \frac{(z_{1-\alpha} + z_{1-\beta})^2}{d^2}$$

where

z = normal variate,
α = level of significance,
β = probability of committing an error of the second kind, and
d = $(m_T - m_C)/\sigma$, in which the first term is the value of the positive average difference that is desired to be detected and σ is the standard deviation of the population of signed differences, δ_i.

$$\begin{aligned} m_T &= \text{Exp}\{\delta T\} \\ &= \text{Exp}\{TB - TA\} \\ &= \text{Exp}\{TB\} - \text{Exp}\{TA\} \end{aligned}$$

where Exp{ } is the expected value of the quantity in braces. The difference in crash frequency due to wide edgelines is expected to be quite small. A 1 percent difference is chosen because that is the approximate level at which wide edgelines are cost-effective. Accordingly,

$$m_T = 0.01\ \text{Exp}\{TB\}$$

Because no change in crash frequency is expected at the control sites,

$$\begin{aligned} m_C &= \text{Exp}\{\delta C\} \\ &= \text{Exp}\{CB - CA\} \\ &= 0 \end{aligned}$$

For maximum accuracy, σ should be estimated from results of actual crash studies. However, the following is considered to be a reasonable approximation. First, the variances in the crash frequencies are assumed to be identical, that is, Var$\{TB\}$ = Var$\{TA\}$ = Var$\{CB\}$ = Var$\{CA\}$, where Var{ } represents the variance of the braced quantity. Then

$$\begin{aligned} \text{Var}\{\delta T\} &= \text{Var}\{TB - TA\} = \text{Var}\{TB\} + \text{Var}\{TA\} - 2\ \text{Cov}\{TB,TA\} \\ &= 2\ \text{Var}\{TB\}\ (1 - r_1) \\ \text{Var}\{\delta C\} &= \text{Var}\{CB - CA\} = \text{Var}\{CB\} + \text{Var}\{CA\} - 2\ \text{Cov}\{CB,CA\} \\ &= 2\ \text{Var}\{TB\}\ (1 - r_1) \end{aligned}$$

$$\begin{aligned} \text{Var}\{\delta\} &= \text{Var}\{\delta T - \delta C\} = \text{Var}\{\delta T\} + \text{Var}\{\delta C\} - 2\ \text{Cov}\{\delta T, \delta C\} \\ &= 2\ \text{Var}\{\delta T\}\ (1 - r_2) \\ &= 4\ \text{Var}\{TB\}\ (1 - r_1)\ (1 - r_2) \end{aligned}$$

where Cov{ } is the covariance of the braced quantities and r_1 and r_2 are correlation coefficients. In the absence of actual data, the correlation coefficient r_1 is assumed to equal 0.50 and r_2, 0.25. Thus,

$$\text{Var}\{\delta\} = 1.5\ \text{Var}\{TB\}$$

and

$$\sigma = (\text{Var}\{\delta\})^{0.5} = 1.22\ (\text{Var}\{TB\})^{0.5}$$

Although Var{*TB*} is not known, it can be treated parametrically by expressing it as a fraction of the mean as follows:

$$\text{Var}\{TB\} = k\ \text{Exp}\{TB\}$$

where k is some constant fraction. Then

$$\sigma = 1.22\ (k\ \text{Exp}\{TB\})^{0.5}$$

and, finally,

$$d = \frac{0.01\ \text{Exp}\{TB\}}{1.22\ (k\ \text{Exp}\{TB\})^{0.5}}$$

As stated earlier, the experiment being considered in this investigation is a before-and-after experiment with paired treatment and control sites. For purposes of estimating the required sample size, the following assumptions are made:

- Extent of crash data: 2 years before and 2 years after treatment;
- Length of each site: 5 mi;
- Traffic volume: 2,000 vehicles per day;
- Crash rate: 5 crashes per million vehicle miles; and
- Mean and variance of accidents: Based on the above, the mean number of crashes in the 2-year before period is 36.5; the variance is largely unknown but might be expected to be about one-fourth the mean, yielding a standard deviation of about 3.0 crashes; the crash frequency in a 2-year period at virtually all sites would thus range from 28 to 46 (mean ± 3 times the standard deviation).

The typical crash investigation of a feature such as wide edgelines might involve 10 to 30 test pairs (100 to 300 mi of roadway in the context of the foregoing example). The level of significance is commonly 0.05. Given the assumptions just made, the probability of not being able to detect a real 1 percent crash effect for this typical experiment is very large, about 87 to 91 percent (Figure A-1). Therefore, the researcher is almost assured in advance of being unable to detect a beneficial effect as small as 1 percent with such limited mileages of treatment and control sections. In fact, if the effect sought is a small one such as 1 percent, no purpose would be served in performing the study unless the sample size were much larger.

Figure A-2 extends the analysis to much larger numbers of test pairs and to a wide range in variances. The probabilities of not detecting 1-percent effects remain quite large except for large sample sizes and unrealistically low crash variances. Some improvement is possible by increasing the level of significance, that is, the risk of committing an error of the first kind. Figures A-3 and A-4 demonstrate the effects of increasing the level of significance to 0.20. These illustrations also demonstrate that trade-offs are necessary in realistic experiments between the risks of committing each of the two types of errors on one hand and sample size on the other.

Of more specific interest to the current investigation, required sample sizes for levels of significance ranging from 0.05 to 0.20 and for a 40 percent

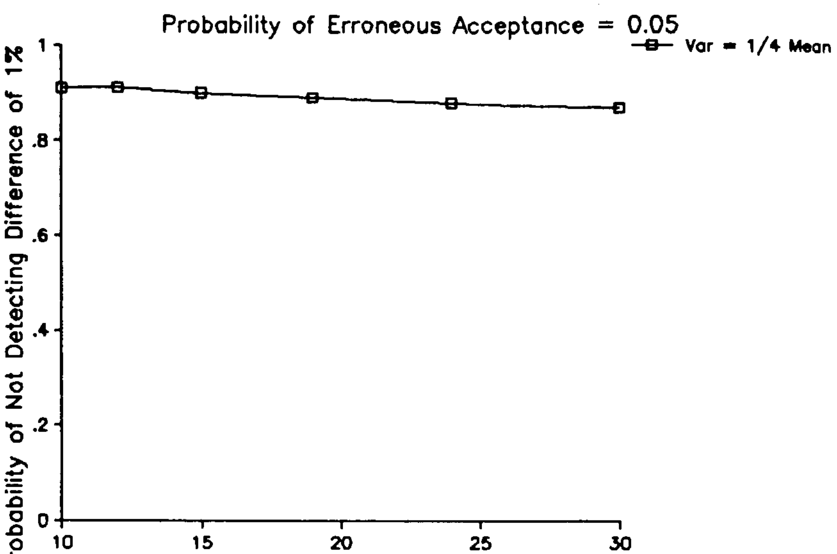

FIGURE A-1 Large probability of failing to detect a significant crash improvement with small sample size.

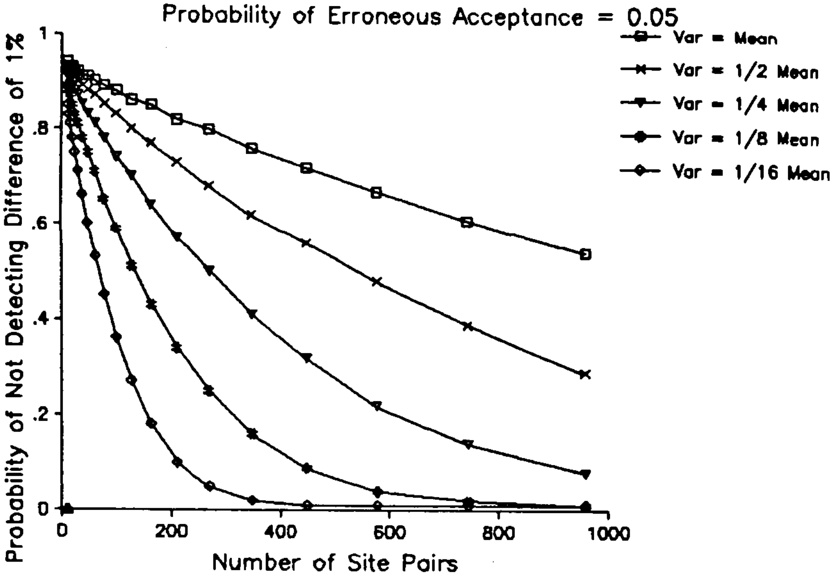

FIGURE A-2 Significance of sample variability and sample size on the experimental plan.

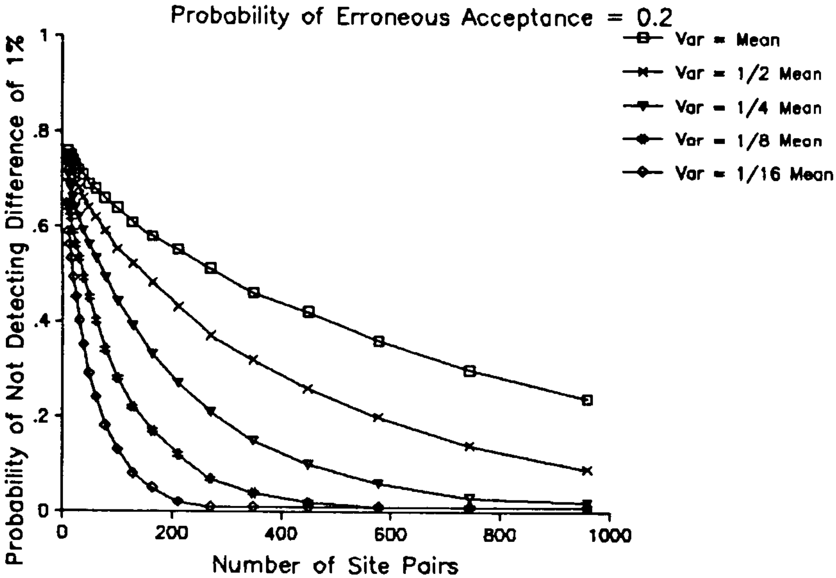

FIGURE A-3 Reduction in required sample size for a larger level of significance.

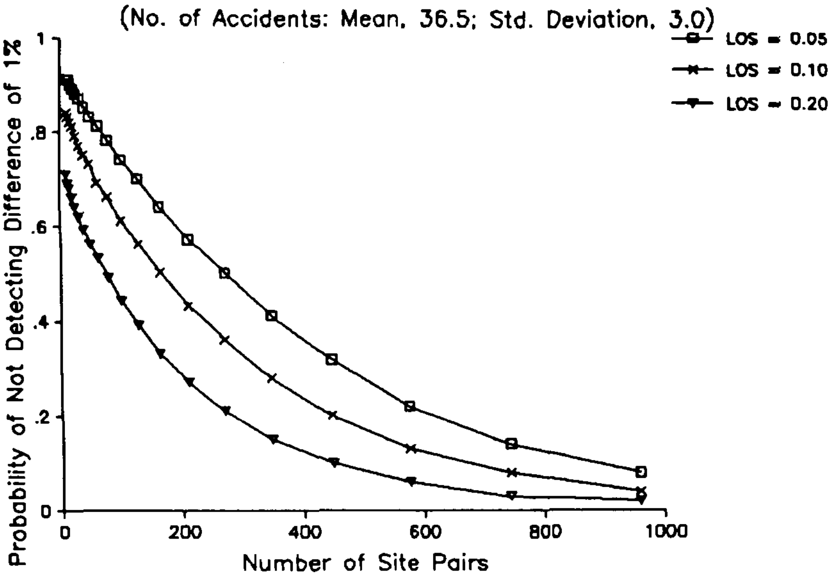

FIGURE A-4 Comparative effects of level of significance on sample size.

probability of not detecting a significant crash reduction effect at the 1 percent level are as follows:

	Level of Significance		
	0.20	*0.10*	*0.05*
No. of site pairs	125	240	360
Total no. of miles	1,250	2,400	3,600

Even at a level of significance as large as 20 percent, the required sample size greatly exceeds that used in the New Mexico and Virginia studies.

In summary, wide edgelines were found to have had a beneficial effect on run-off-road crash experience on federal-aid primary highways in New Mexico and, although not significant in the statistical sense, on Virginia highways. On other New Mexico highways, the observed effect of wide edgelines was detrimental to highway safety. Most important, however, neither the New Mexico nor the Virginia study seems to have been designed to detect small crash effects of the magnitude sufficient for cost-effective application of wide edgelines. Therefore, the findings of these studies, although adding valuable information to the rapidly accumulating bank of evidence, must be considered inconclusive.

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