GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. E-20-676 Misc GTRI/GIT DATE 9/22/82

Project Director: Dr. Paul H. Wright School/Lab Civil Engineering

Sponsor: Insurance Institute for Highway Safety

Type Agreement: IIHS Project No. 6861

Award Period: From 10/1/82 To ~~10/31/83~~ ~~6/15/84~~ 9-15-85 (Performance) ~~11/30/83~~ 7/15/84 (Reports)

Sponsor Amount: Total Estimated: $ 43,693 Funded: $ 43,693

Cost Sharing Amount: $ ______ Cost Sharing No: ______

Title: Evaluation of Low-Cost Techniques for Reducing Run-Off-The-Road Crashes

ADMINISTRATIVE DATA

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Defense Priority Rating: N/A

Military Security Classification: ______
(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Sponsor; however, none proposed.

COMMENTS:

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 6/11/86

Project No. E-20-676 School/~~Lab~~ CE

Includes Subproject No.(s) N/A

Project Director(s) Paul H. Wright GTRC / ~~GIT~~

Sponsor Insurance Institute for Highway Safety

Title Evaluation of Low-Cost Techniques for Reducing Run-Off-The-Road Crashes

Effective Completion Date: 9/15/85 (Performance) 10/15/85 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [XX] Final ~~Invoice~~ or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No. Continued by Project No.

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Other A. Jones
R. Embry

FORM OCA 69.285

E-20-676

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May 15, 1986

MEMORANDUM

TO: Office of Contract Administration

FROM: Dr. Paul H. Wright, CE

SUBJECT: Final Report, Project E-20-676

In response to Dean Sangster's memorandum of May 8, 1986, I wish to advise that the sponsor of subject Project requested that the "final report" be submitted on computer tape. This was done before the due date of the report. A technical paper describing the results of that work has been written and submitted to the Transportation Research Board for publication. A draft version of that paper is forwarded herewith for your records.

Attachment

E-20-626

4548C
November 13, 1985

Effects of Chevrons, Post-Mounted Delineators, and Raised Pavement Markers on Driver Behavior at Roadway Curves

Paul Zador
Howard S. Stein
Paul Wright
Jerome Hall

November 1985

This work was supported by the Insurance Institute for Highway Safety.

ABSTRACT

Previous research has shown that in single vehicle crashes drivers tend to run off the road in the direction opposite the curve; i.e., they miss the curve. This study examined short- and long-term effects of commonly used curve delineation treatments on the speed and the placement of vehicles traveling on curves on rural two-lane highways in Georgia (46 sites) and in New Mexico (5 sites). Vehicle speed and placement distributions at sites modified with the addition of chevrons, post-mounted delineators, and raised pavement markers, and unmodified control sites were compared in terms of 10th percentile, 90th percentile, and mean values before and after modification.

Except for the chevrons in Georgia, at night the modifications tended to shift the speed distributions upward, with an average speed increase of 1-3 ft/sec. Overall, at night vehicles moved away from the centerline with chevron signs; they moved further away when raised pavement markers (about 0.5 ft) were used. In contrast, when post-mounted delineators were used, vehicles moved toward the centerline. The modifications also resulted in slight reductions in speed variability and in placement variability for chevrons and raised pavement markers. There was also little change in the typical driver curve following behaviors of corner cutting or curve lengthening. Few of the changes varied systemically by curve alignment or grade, and there was little evidence that short-term changes erode over time.

Although drivers did change their behavior in response to the delineation modifications, there was no clear evidence that any one of the devices is superior to the others. The primary benefit of clearly delineating curves may simply be that it helps drivers better recognize that they are approaching a curve.

E-20-676

INTRODUCTION

Research has shown that roadway curves are often a factor in vehicle crashes especially on rural roads (1,2,3). During 1983, over 25 percent of fatal highway crashes occurred on curves and 40 percent of these crashes were also on grades (4). Detailed analyses of single vehicle crash sites show that vechicles most commonly leave the roadway on the outside of the curve; this is particularly true for left curves (1,2,3,5). Curves on roadways have also been shown to be more hazardous for drivers who are not familiar with the route (5).

The most common countermeasure to reduce crashes on curves is to improve the delineation of the roadway with roadway markings or signs. A survey of state highway agencies found that chevron signs, raised pavement markers, post-mounted delineators, and curve warning signs were the low-cost countermeasures most often used and judged most effective in reducing crashes (although there has been little documentation of their actual effect) (6). Improving roadway delineation is also strongly supported by the U.S. Department of Transportation, which has allocated several hundred million dollars for funding these activities over the last decade (7).

The choice of specific low-cost countermeasures at a given site should be guided by scientific evidence of their expected effects on crashes as well as by engineering considerations of implementation and cost. These effects could vary with road geometry and design in complex ways that are not well understood. Because crash studies for comparing delineation modifications while controlling for other factors are time consuming and expensive, the effects of delineation modifications are more often studied in terms of the change in driver behavior they produce.

Literature Review

Research on the effects of delineation modification on roadway curves has concentrated on studies of factors in driver perception/ visibility and driver behavior. Studies of driver visibility requirements and perception of curved roadway sections have typically involved either driver simulations or driver evaluations of static pictures of curves. These studies have found that as the range of driver visibility decreases, delineation becomes more important (8). Also several studies found that drivers have more trouble perceiving information about left curves compared to right curves (9,10,11,12).

Other studies have looked at how actual driving performance is affected by both novel and conventional roadway delineation treatments. Some studies of novel treatments have shown that painted markings that create an optical illusion of either increasing speed or roadway narrowing can affect driver performance and reduce crashes (13,14,15). However, painted markings can wear rapidly and their visibility is diminished during rain. Consequently, use of these novel markings is limited.

Before reviewing studies of driver performance with supplemental delineation systems, it is important to understand how drivers typically negotiate curves. Most drivers attempt a "corner cutting" or "curve lengthening" strategy (16,17). They do not steer a circular path around the curve but try to follow a straighter path by flattening the curve.

However, at some point drivers tend to steer a path that is sharper than the actual curve radius (16,18).

Thus the actual curves drivers follow differ significantly from the center path that is traditionally assumed to be followed on circular curves. With a more straight path, drivers may exceed the speed and the side friction limitations that were assumed in the design of the curve. If all this occurs at the same point along the curve where the curvature of the driver's path is sharper than the actual curvature, the vehicle will begin to slide laterally on the road. Among the many unanswered questions is whether delineation should assist in this curve following behavior or attempt to influence drivers contrary to their normal behavior to follow a more circular path around curves. Also intepretation of the changes in driver behavior resulting from changes in delineation is not well understood. However, most researchers have interpreted a decrease in the variability in speed and/or lateral position variables to be a major benefit derived from improved delineation (19,20,21).

The Federal Highway Administration (FHWA) conducted a large field evaluation of conventional and modified delineation systems including painted centerlines and edgelines, and supplemental systems such as raised pavement markers and post-mounted delineators (20). The first phase of this study evaluated driver performance at 10 curves and found that vehicle placement far in advance of the curve was similar to vehicle placement at the beginning of the curve but that at the midpoint of the curve, the vehicle placement was significantly different. For left-turning curves vehicles were closer to the centerline and for right-turning curves they were closer to the edgeline. In the present study, both of these behaviors are recognized as "corner cutting" or "curve flattening."

In the second phase of the study, the speed and placement of vehicles were measured at several points along four curve sections and several tangent sections. Traffic was observed at each section with several variations of delineation treatments several days after modifications occurred. Compared to a baseline condition (centerline and edgeline), nighttime midcurve speeds of vehicles traveling in both directions were <u>lower</u> with supplemental delineation using raised pavement markers and post-mounted delineators, separately and in combination. The speed reductions were significantly lower (2.1 to 3.7 ft/sec) for left-turning vehicles for all the delineation modifications. Nighttime vehicle placement changes were almost always toward the edgeline for vehicles traveling in either direction. The changes were significant for raised pavement markers, and raised pavement markers in combination with post-mounted delineators, and they were larger for left-turning vehicles (0.3 to 1.1 ft). The standard deviation of vehicle placement was significantly less for three of four supplemental delineation modifications for left-turning vehicles (.29 to .16 ft/sec).

This study also found that vehicle placement relative to the centerline and the difference in placement variability along a section were the two most important explanatory variables in predicting crash rates. The study recommended the use of raised pavement markers over post-mounted delineators on high-hazard curves because the raised pavement markers serve as both far and near delineation. It also encouraged the use of one-way raised pavement marker systems and multicolor directional coding of raised pavement markers.

Two other studies of driver performance evaluated the effects of chevron signs, other post-mounted delineators and raised pavement markers; both concluded that driver performance was the most favorable on sharp curves when chevrons were used. In an Australian study, 36 drivers traveled a closed test track at night that had varying delineation modifications (edgelines, raised pavement markers, post-mounted delineators, and chevron signs) (16). (Note: Drivers were on left side of road.) This study found that with chevrons drivers followed a better path around the curve (defined as the ratio of the vehicle's instantaneous radius to the actual curve radius). With chevron signs, drivers negotiated curves with the lowest frequency of this ratio less than 0.85 i.e., sharper than actual curves. This study also reported drivers utilizing a corner cutting strategy. Chevron signs were reported as facilitating this strategy, although this was not consistently true for post-mounted delineators. On right curves with chevrons, drivers had an average midcurve placement closest to the centerline. On left curves vehicle placement with chevrons did not differ significantly from the edgeline/centerline condition. However, with post-mounted delineators (both sides of roadway) drivers were closest to the centerline, which is contrary to the corner cutting strategy. Analysis of the mean speeds found that chevrons (with and without edgelines) resulted in higher speeds than with other delineations; for example, the mean speed with chevrons without edgelines was 66 ft/sec compared to 58 ft/sec with post-mounted delineators. However, mean nighttime speeds with chevrons were not faster than daytime speeds.

The other study evaluated several curve delineation signs (chevrons, road edge delineators, and special large striped road edge delineators) placed at five left curves in Virginia (22). Speed and placement of vehicles were measured at the beginning and middle of the curve. The data showed drivers were using a corner cutting strategy, with an average 0.63 ft difference between the placement at the beginning of unsigned curves compared with the middle of these curves. The data also showed an increase in possible centerline encroachments with all of the delineation signs. Although the study recommended the use of chevron signs for sharp curves, closer examination of the data indicates that it is very difficult to identify consistent differences in driver response to the three types of delineation for any of the placement and speed variables for all curves during the night.

The most important factor in evaluating these delineation modifications, regardless of actual changes in driver behavior, is their effect on crashes. Many studies have found reductions in crashes and lower crash rates for roadways and curves with these supplemental delineation systems (23,24,25,26,27). However, these reductions can not be quantified because most of the studies are cross-section analyses and/or do not properly control for other factors that influence crashes such as differences in roadway design (curvature and grade) and traffic volumes.

The objective of the present study was to compare changes in curve following behavior by drivers caused by the three most common types of low-cost countermeasure: chevron signs, post-mounted delineators, and raised pavement markers. These devices were independently installed at curves that varied systematically in direction and degree of curvature, and steepness of grade. Past studies have not evaluated whether the effectiveness of these devices differs by curve geometry and direction. A traffic data recorder collected vehicle speed and position data at two points along each curve section both before and after the installation of these devices. Changes in driver behavior were compared for the sites modified with the three types of delineation devices and a matched set of unmodified sites observed during similar time periods.

METHODS

Rural roadway sites were modified by Georgia and New Mexico Department of Transporation following procedures in the Manual on Uniform Traffic Control Devices with respect to the type, size, location, and spacing of the countermeasures. Specific procedures used for modifying the sites with the three types of countermeasures are described below.

Raised pavement markers. Standard 4 x 4 inch amber stimsonite markers were installed at the selected sites on both sides of the double yellow centerlines. Reflectorized Type 1 markers, visible to both directions of traffic, were used. The markers were installed with two-part epoxy in a sloped 52 inch groove (26 inch length each direction) so that the top of the marker was flush with the original surface. The markers were usually spaced 80 ft apart; along the sharper curves, where at least three markers could not be seen at one time using usual spacing, they were spaced 40 ft apart. The markers were installed throughout the entire length of the curve.

Post-Mounted Delineators. Standard 3 inch diameter round, white stimsonite delineators were installed on metal posts along the outside of the curves. The delineators were installed on both sides of the posts to be visible to drivers traveling in both directions. The delineators were placed approximately 4 ft above the near roadway edge and 7 ft wide, from the edge of the pavement. Where shoulders were less than 7 ft in width, the delineators were placed as close as practicable to the shoulder edge. The delineators were spaced so that drivers would see at least three delineators at one time.

Chevron Signs. Standard 18 x 24 inch Chevron alignment signs were placed along the outside of the curves to be visible to drivers traveling in both directions. The signs were positioned so that motorists would always have at least three in view. The signs were offset 7 ft from the pavement or as close as practicable to the shoulder edge where the shoulder was less than 7 ft wide. The signs were mounted at a height of approximately 7 ft.

Traffic Data Recorder

A special traffic data recorder (TDR) was constructed by the University of New Mexico Engineering Research Institute to measure the speed and placement of vehicles as they traveled along the road. The TDR consisted of an arrangement of electronic cables on the roadway (see Figure 1) and a Rockwell AIM-65 microprocessor with a printer that interpreted and printed the actuations of the cables. The first cable (spanning the road in the direction of travel) alerted the TDR of an approaching vehicle and counted the total traffic in both directions.

The next two cables were placed a fixed distance apart to serve as a "trap" for measuring vehicle speed. Once the speed was known, the placement of the vehicle's right front tire could be computed from a fourth cable placed at a 45 degree angle to the second and third cables. Vehicle position, speed, and placement, and the time of the vehicle and traffic counts were printed onto a paper tape after the vehicle cleared all the cables.

Preliminary testing of the TDR by placing it at several points along a curve indicated that, at about 100 ft before the beginning of the curve, drivers had yet to begin adjusting for the upcoming curve. Over the next 200 ft most of the change in placement occurs and the vehicle path is defined. Several studies have examined the speed and placement of vehicles at the center of the curve; however, because drivers tend to flatten out curves, the major effects of the different delineation treatments might be to influence the initial adjustments drivers make when they begin to negotiate the curve. Therefore, two TDRs were set up for each day/night observation period; one 100 ft before the beginning of the curve and one 100 ft after the beginning of the curve.

Only vehicles that were isolated from all other traffic, either following or oncoming, for at least 2.5 seconds were analysed in this study. At 70 ft/sec, the approximate average speed encountered in the study, the measurement error for an individual vehicle had a standard deviation of about 1.3 percent or 0.9 ft/sec. Thus, the standard deviation for an average speed based on 100 individual measurements was about 0.1 ft/sec. The comparable figure for the standard deviation of an average placement was about 0.01 ft.

Experimental design

There were 46 observation sites in Georgia and 5 in New Mexico. All sites were located on two-lane rural highways. The sites in Georgia represented a nearly complete factorial design* with four factors: modification (M), direction of turn (T), vertical alignment (G), and sharpness of curve (C). There were four levels of treatment (control, chevron, post-mounted delineator, and raised pavement marker), two directions of turn (left and right), three types of vertical alignment (grade $< -2°$ or down, $-2° \leq$ grade $\leq 2°$ or level, and $2° >$ grade or up), and two levels of sharpness of curve (less sharp or more sharp within the grade and turn class). Because only a small number of New Mexico sites were available for experimentation, only chevrons were tested there.

Figure 2 displays the joint distribution of all sites using the reciprocals of the curvature as the horizontal and the gradient as the vertical coordinates. This figure shows that there was a good mix of alignment combinations in all treatment groups.

Table 1 presents roadway characteristics of these sites by direction of curve and modification type. The data indicate that there were differences in the physical layout of the roadways. For example, the average superelevation rate of the unmodified left curves is almost half the rate of any other grouping. The average speed limits for left curves varied, but the average speed limits for right curves were similar. In addition, the chevron and raised pavement marker sites had

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*Two sites had to be eliminated from the analyses because of modifications that were not part of the experiment.

the fewest curve warning signs on the approach to the curve, whereas only one unmodified site was without any type of signing (e.g., curve warning, speed limit).

Observations were taken at each modified and control site shortly before and shortly after (several weeks) the modifications were put in place. To determine the long-term effects of the modifications, a third set of observations were taken approximately 6 months after the modifications at about a third of the Georgia and at all New Mexico sites. During each of the three observation periods, data were recorded for about a 100-150 or more vehicles during the day and for a similar number of vehicles during the night (defined as the time of sunset).

Statistical Analysis

The effects of the modification on curve following behavior were investigated using the following seven variables:

V1	Approach speed, measured 100 ft upstream from the beginning of the curve, ft/sec;
V2	Curve speed, measured 100 ft downstream from the beginning of the curve, ft/sec;
D1	Vehicle placement 100 ft upstream from curve, distance from centerline of road to right wheel of vehicle measured in conjunction with V1, ft;
D2	Same as D1 but measured in conjunction with V2, ft;
DE	Estimated deceleration, computed as $(V2^2 - V1^2)/400$, ft/sec^2,
D	Average placement, computed as (D2 + D1)/2, ft; and
Δ *D*	Change in placement between the two traps, computed as (D2 - D1).

The distribution of each of the variables was summarized using four statistics: mean, standard deviation, 10th percentile, and 90th percentile. These statistics were estimated for day and night data separately by site and by period of observation.

Changes in these statistics before modification compared to the first period after modification were analyzed using the GLM procedure developed by the SAS Institute (28). The same model was used to analyze changes in all of the variables. In this model, the dependent variable, for example the average approach speed (MV1), was represented in terms of main effects for turn direction (T), vertical alignment (G), sharpness of curve (C), and their interactions with the modification factor (M):

$$MV1_{mtgc} = A + B_m + C_t + D_g + E_c + F_{mt} + G_{mg} + H_{mc} + Error_{mtgc}$$

where

m = 0 for no modification,
  = 1 for chevrons,
  = 2 for post-mounted delineators,
  = 3 for raised pavement markers;
t = 1 for left curves,
  = 2 for right curves;
g = 1 for downhill grades,
  = 2 for level grades,
  = 3 for uphill grades; and
c = 1 for less sharp curves,
  = 2 for more sharp curves.

The short-term modification effects due to chevrons in New Mexico were tested for statistical significance using a t-test for comparing the changes between corresponding before-modification and after-modification site averages. This method of paired t-tests was also used to compare short-term and longer effects by modification groups in both Georgia and New Mexico.

RESULTS

Initial Vehicle Speed and Placement

Speed and placement observations for V1, V2, D1, and D2 are summarized prior to modification for the night data in Table 2. All values in this table are based on the average values of the variables for the sites. Both the average speed and the average vehicle placement varied relatively little among the different modification groups (Table 2.a). The range for approach speed was from 70.9 ft/sec to 76.5 ft/sec and for curve speed from 69.1 ft/sec to 74.1 ft/sec. For all modification groups, the curve speeds were a few ft/sec below the approach speeds. Average vehicle placements ranged from 7.4 ft to 7.9 ft at the first speed trap and from 7.6 ft to 8.0 ft at the second trap.

The average speed and placement at the first trap varied little by grade (Table 2.b). However, at the second trap, 100 ft into the curve, the average speeds were more than 1 ft/sec lower at uphill curves than at level or at downhill grades, and vehicles moved away from the centerline by about 0.5 ft between the two traps at uphill and at level curves but drew closer to the centerline by 0.2 ft at downhill curves.

For both left and right curves and at both speed traps, sharper curves had lower average speeds than less sharp curves. The average differences were about 3 ft/sec for left and about 6 ft/sec for right curves (Table 2.c). The average vehicle placement relative to the centerline was reduced by about 1 ft for left curves and was increased by about 1.4 ft for right curves, which indicates a considerable amount of corner cutting or curve flattening among drivers.

Short-term Effects of Roadway Delineation Modification--Georgia Data

To show the effects of the countermeasure modifications for the Georgia data, the statistically significant changes are summarized in Table 3.a for standard deviations and in Table 3.b for the 10th percentiles (L), the means (M), and the 90th percentiles (H).

Figure 3 graphically displays the means of the speed and placement observations before and after the modifications by time of day, direction of turn, and modification. Figures 3.a-3.c present results for chevrons, post-mounted delineators, and raised pavement markers; Figure 3.d presents the data for the unmodified sites. Data for left-turning curves are on the left side and data for right-turning curves are on the right side of each figure. Speed averages are shown as bar charts separately for approach and curve speeds. Vehicle placement averages are displayed horizontally at the bottom (D1) and top (D2) of a pair of vertical reference lines running parallel to the centerline but displaced 7 and 8 ft to the right, respectively. Note when referring to these figures that the scales used for vehicle placement and velocity are arbitrary.

The reader will find it helpful to refer to these figures throughout the subsequent description of the results.

The presence of corner cutting or curve flattening behavior is clearly shown for all conditions on Figure 3. On the approach to the curve drivers are much closer to the centerline than at the trap 100 feet into the curve. By shifting their initial position away from the centerline and angling their vehicles in the direction of the curve, drivers reduce (or cut) the sharpness of the curve that the vehicle will travel. This maneuver also lengthens the portion of the roadway on which the vehicle travels a curved path. Under nearly all conditions, vehicles traveled slower and nearer to the centerline during the night than during the day.

Changes in Standard Deviation. As Table 3.a shows, short-term changes in the standard deviations varied significantly by modification at night for the placement 100 ft before the curve, the average placement, and the deceleration. There were no significant main effects for these variables for daytime observations. Figure 4 shows these changes in the standard deviations for vehicle placement 100 feet before the curve and for vehicle deceleration. The standard deviation in placement at curve approach was reduced by about 0.1 feet with chevrons and raised pavement markers and increased by about 0.1 ft. with post-mounted delineators. The changes in the average placement (not shown) were similar in direction and in magnitude to those at the curve approach. Estimated average short-term changes in the standard deviation of the deceleration showed a reduction of almost 0.2 ft/sec^2 for post-mounted delineators and increases of about 0.15 ft/sec^2 for chevrons and raised pavement markers. Also, at night all modifications, particularly chevron signs, resulted in an overall reduction in the standard deviations of curve speeds, however, this effect failed to reach the conventional level of statistical significance ($t = 2.50$, $p = 0.076$). There was no systematic pattern of significant changes in the standard deviations associated with the modification by alignment interactions.

Changes in Mean and Percentiles. As can be seen from Table 3.b, the estimated short-term changes in mean and 90th percentile speeds exhibited significant variations by type of modification during both time periods and at both speed traps. The corresponding estimates are plotted in Figure 5 for the night observations only; the daytime changes were similar. The estimated mean approach speeds (left side of Figure 5) were reduced by about 0.6 ft/sec with chevrons, increased by about 1.1 ft/sec with raised pavement markers and by about 2.3 ft/sec with post-mounted delineators. For the modifications where the mean speed was reduced (particularly chevrons) the reductions were even greater for the 90th percentile speed. The pattern of changes in measurement of curve speed (right side of Figure 5) is similar to the pattern of changes in approach speeds. This is consistent with the finding that there were no statistically significant changes in the corresponding deceleration variables.

Table 3.b also shows that the estimated short-term changes in mean and 10th percentile vehicle placement exhibited significant variations by type of modification during both time periods and at both speed traps.

Figure 6 displays these estimated changes for night observations. The largest changes in vehicle placements occurred following the installation of raised pavement markers: On average, the 10th percentiles of the placement distributions shifted about 0.3 ft away from the centerline at the first trap and about 0.7 ft at the second trap. The corresponding changes in the mean placements were about 0.4 ft and 0.7 ft, respectively. Chevrons also caused the vehicle placement distributions to shift away from the centerline, but these shifts were generally less pronounced. Overall, post-mounted delineators shifted the placement distributions towards the centerline, but the average magnitude of these shifts was quite small except for the 10th percentile placement value of about -0.3 ft at the second speed trap. Vehicle placement changes at sites with post-mounted delineators also differed by direction of curve (although not statistically significant from changes noted for other treatments). The vehicles on left curves moved toward the centerline and on right curves they moved away from the centerline. In both cases, this movement was away from the delineators, which were on the outside of the curve.

The pattern of changes in average placements were similar to those given in Figure 6 for the 10th percentile; mean and 90th percentile and are not displayed separately. The relative placement changes over the speed trap were not pronounced enough to cause significant changes in any of the statistics based on $\Delta D = D2 - D1$.

Interaction of Modification with Curve Alignment. In addition to the main modification effects, some of the modification-by-alignment interactions are statisically significant. As an illustration, Figure 7 shows the modification effect on mean placement by grade of curve (left figure) and by sharpness of curve (right figure). Neither these nor any of the other significant interactions appear to have a clear intepretation.

Short-term Effects of Chevrons--New Mexico Data

The New Mexico data was limited to five sites modified with chevron signs. The short-term effects were to increase both speeds, V1 and V2, at night. There was a 3.2 ft/sec increase in approach speed that was statistically significant based on paired t-test comparisons ($t = 3.27$, $p = 0.03$), and a 2.6 ft/sec increase in curve speed that was not ($t = 2.26$, $t = 0.09$). (It should be recalled that, overall, chevrons did not increase speeds in Georgia). As in Georgia, at night vehicles moved away from the centerline after the installation of chevron signs; however, these changes were not statistically significant.

Long-term Effects of Delineation Modification--Georgia and New Mexico Data

Finally, to assess the long-term effects of the countermeasure modifications the averages of short- and long-term changes in the two speed measurements by type of modification are given in Figure 8.* For the Georgia data the results are based on only those sites where three sets of measurements were taken; there were four such sites per treatment group. All five sites in New Mexico had three sets of measurements. The corresponding data for placement averages are shown in Figure 9.*

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*Note that these results are not directly comparable with the results based on all Georgia survey sites discussed earlier.

Comparisons of long- and short-term differences in the speed and placement averages show three situations that were statistically different. Average curve speeds for the untreated group of curves differed by 1.7 ft/sec ($t = 3.85$, $p = 0.03$) and for raised pavement markers approach speed increased by 2.3 ft/sec ($t = 4.4$, $p = 0.02$) and curve speed by 2.0 ft/sec ($t = 7.2$, $p = 0.01$).

SUMMARY AND DISCUSSION

The short- and long-term effects of three commonly used delineation modifications on curve following behavior on rural roads in Georgia and New Mexico were examined. The principal findings of this research are: (1) all delineation modifications affected driver behavior at night as measured by speed and placement; (2) few systematic differences were found in the effects by type of modification or roadway alignment; and (3) these effects did not change over time. The presence of delineation modifications significantly influenced vehicle speeds and placements compared to measurements taken at unmodified sites. There were changes at the unmodified sites although they were almost always small and unsystematic compared to those at the modified sites. Because most run-off-the-road crashes occur because drivers miss the curve, the main benefit from any of the these delineation modifications may simply be that the driver is alerted that he or she is approaching a curve.

The short-term results showed installation of post-mounted delineators produced the largest speed increases (about 2 ft/sec to 2.5 ft/sec at night). Speed increases of about 1 ft/sec at night occurred with raised pavement markers. The results for chevrons were not consistent; speed decreased by about 0.5 ft/sec at night in Georgia but increased by about 3 ft/sec in New Mexico. The long-term measurements provided no evidence for the erosion of any of these short-term speed changes.

A recent survey of state highway officials found that speed reductions are commonly thought to be the best surrogate for evaluating the effectiveness of measures taken to prevent run-off-the-road crashes (6). On this basis, only chevrons could be advocated for use as countermeasures. However, the present study shows that, although night speeds increase with post-mounted delineators and raised pavement markers (and with chevrons in New Mexico), the resulting speeds always remain below the daytime speeds. It could be argued that these speed increases simply reflect driver adaptation to increased information about nighttime rural roadway conditions and are, therefore, advantageous.

Vehicle placements at night were also affected by the modifications. Generally, vehicle paths were shifted away from the centerline on curves where raised pavement markers and chevrons were installed and toward the centerline when post-mounted delineators were used, although the latter effect was present only for right curves. Changes in vehicle placement were largest at sites with raised pavement markers. The magnitudes of the shifts were about the same at both speed traps except where raised pavement markers were used when the shift atthe second trap exceeded the shift at the first trap by about 0.2 ft regardless of the direction of the turn. These results can be interpreted in terms of changes in corner cutting behavior. For left curves, corner cutting involves first a shift away from the centerline before the curve; for right curves, the first shift is toward the centerline. The direction of these shifts is then reversed as the vehicle travels through the curve (cf. Figure 3). Thus the modifications had no effect on corner cutting behavior except when raised pavement markers were used. On right curves, raised pavement markers slightly increased corner cutting both during day and night, and on left curves raised pavement markers reduced it at night and increased it during the day.

The present and earlier studies all clearly demonstrated drivers' preference for the corner cutting strategy. Corner cutting can reduce the lateral acceleration through a curve and thereby reduce peak friction demand, but it may also bring vehicles closer to the roadway boundaries and reduce their margin of safety. However, to assess the relative importance of these factors requires the use of crash data, and previous analyses of the relation between crash frequency and implementation of delineation devices have been unable to quantify their effects or examine potential differences among devices.

The size of the changes in vehicle speeds and placements measured in this study compare well with results from other studies, but there are some inconsistencies in the directions. For example, the FHWA study (20) found that midcurve speeds were often significantly lower with raised pavement markers and post-mounted delineators whereas in the present study speeds increased with the installation of these devices, particularly post-mounted delineators. However, both studies found that raised pavement markers had the largest effect on vehicle placement--vehicles moved away from the centerline. The Australian study found that speeds were significantly higher with chevron signs (16), but in the present study only the New Mexico sites experienced a significant short-term speed increase. All the studies suggest that delineation modifications tend to increase the uniformity of both vehicle placement and speed, and this is the most clearly identifiable benefit of supplemental delineation.

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TABLE 1

Average Roadway Characteristics of Georgia Sites by Modification Type and Direction of Curve

Modification	Lane Width (ft)	Shoulder Width (ft)	Superelevation at Curve (Percent)	Speed Limit (MPH)
a. *Left Curves*				
No Modification	11.8	9.1	2.5	52
Chevron signs	12.2	11.4	5.2	51
Post-mounted delineators	11.9	9.0	6.4	45
Raised pavement markers	11.8	7.5	4.8	48
b. *Right Curves*				
No Modification	12.2	14.8	4.9	53
Chevron signs	12.0	10.1	5.3	51
Post-mounted delineators	12.3	6.4	6.9	53
Raised pavement markers	12.2	11.7	5.3	52

TABLE 2

Average Values of Initial Measurements by Site Characteristics At Night
(Standard deviation in parenthesis)

		Vehicle Speed (ft/sec)		Vehicle Placement (ft)	
		100 ft Before Curve	100 ft Into Curve	100 ft Before Curve	100 ft Into Curve
		V1	V2	D1	D2
a. By Modification Type					
No Modification	(N=12)	76.5(4.0)	74.1(4.3)	7.4(1.1)	8.0(1.0)
Chevrons, GA	(N=10)	70.9(5.2)	69.1(5.6)	7.8(0.8)	7.8(1.3)
Chevrons, NM	(N= 5)	73.6(5.3)	71.9(6.0)	7.9(1.3)	7.6(2.4)
Post-mounted delineator	(N=12)	74.0(4.8)	71.5(5.2)	7.4(1.0)	7.8(1.0)
Raised pavement markers	(N=12)	72.2(7.7)	69.4(9.2)	7.5(0.9)	7.6(1.0)
b. By Grade					
Uphill	(N=15)	73.0(5.6)	69.9(6.8)	7.5(0.7)	8.0(1.2)
Level	(N=19)	73.7(5.9)	71.6(5.9)	7.6(0.9)	8.0(1.3)
Downhill	(N=17)	73.7(6.0)	71.9(6.8)	7.6(1.2)	7.4(1.1)
c. By Curvature (Georgia data only)					
Left - Moderate	(N=12)	75.5(5.4)	73.1(5.8)	8.1(0.6)	7.4(0.7)
Left - Sharp	(N=11)	72.8(6.1)	70.6(7.2)	8.1(0.6)	6.7(1.2)
Right - Moderate	(N=11)	76.0(3.8)	73.8(4.2)	7.0(0.7)	8.4(0.7)
Right - Sharp	(N=12)	70.1(6.4)	67.2(7.3)	6.7(0.8)	8.2(0.9)

TABLE 3

Short-term Effects of Roadway Delineation Modifications in Georgia on Vehicle Speed and Placement[1]

a. Changes in Standard Deviation

Speed and Placement Variable[2]	Time of Day	Modification Main Effects	Interactions		
			Curve Direction	Grade	Curve Sharpness
D1	Day	-	-	*	-
	Night	*	-	-	-
D2	Day	-	*	*	-
	Night	-	-	-	-
V1	Day	-	*	*	*
	Night	-	-	-	-
V2	Day	-	-	*	*
	Night	-	-	-	-
DE	Day	-	-	-	*
	Night	*	-	-	*
D	Day	-	-	-	-
	Night	-	*	-	-
ΔD	Day	-	-	*	-
	Night	*	-	-	-

b. Changes in 10th Percentile (L), Mean (M) and 90th Percentile (H)

		L	M	H	L	M	H	L	M	H	L	M	H
D1	Day	-	-	-	-	-	-	-	-	-	-	-	-
	Night	*	*	-	-	-	-	*	*	*	-	*	*
D2	Day	-	-	-	-	-	-	-	-	-	-	-	-
	Night	*	*	-	-	-	-	-	-	-	-	-	-
V1	Day	-	*	*	*	-	-	-	-	-	-	-	-
	Night	-	*	*	-	-	-	-	-	-	-	-	-
V2	Day	-	*	*	-	-	-	-	-	-	-	-	-
	Night	-	*	*	-	-	-	-	-	*	-	-	-
DE	Day	-	-	-	-	-	-	-	-	-	-	-	-
	Night	-	-	-	-	-	-	-	-	-	-	-	-
D	Day	-	-	-	-	-	-	-	-	-	-	-	-
	Night	-	-	-	-	-	-	-	-	-	-	-	-
ΔD	Day	-	-	-	-	-	-	-	-	*	-	-	-
	Night	*	*	*	-	-	-	-	-	-	-	-	*

1. An asterisk (*) indicates F statistic is significant at .05 level; a dash (-) indicates it is not.
2. See text page 11 for definitions of the variables. Briefly, D1 and D2 are distances from centerline 100 ft before and after the curve; V1 and V2 are the corresponding speeds; DE is deceleration, D is the average placement; and ΔD is the change in placement.

FIGURE 1

Layout of Cables for Traffic Data Recorder

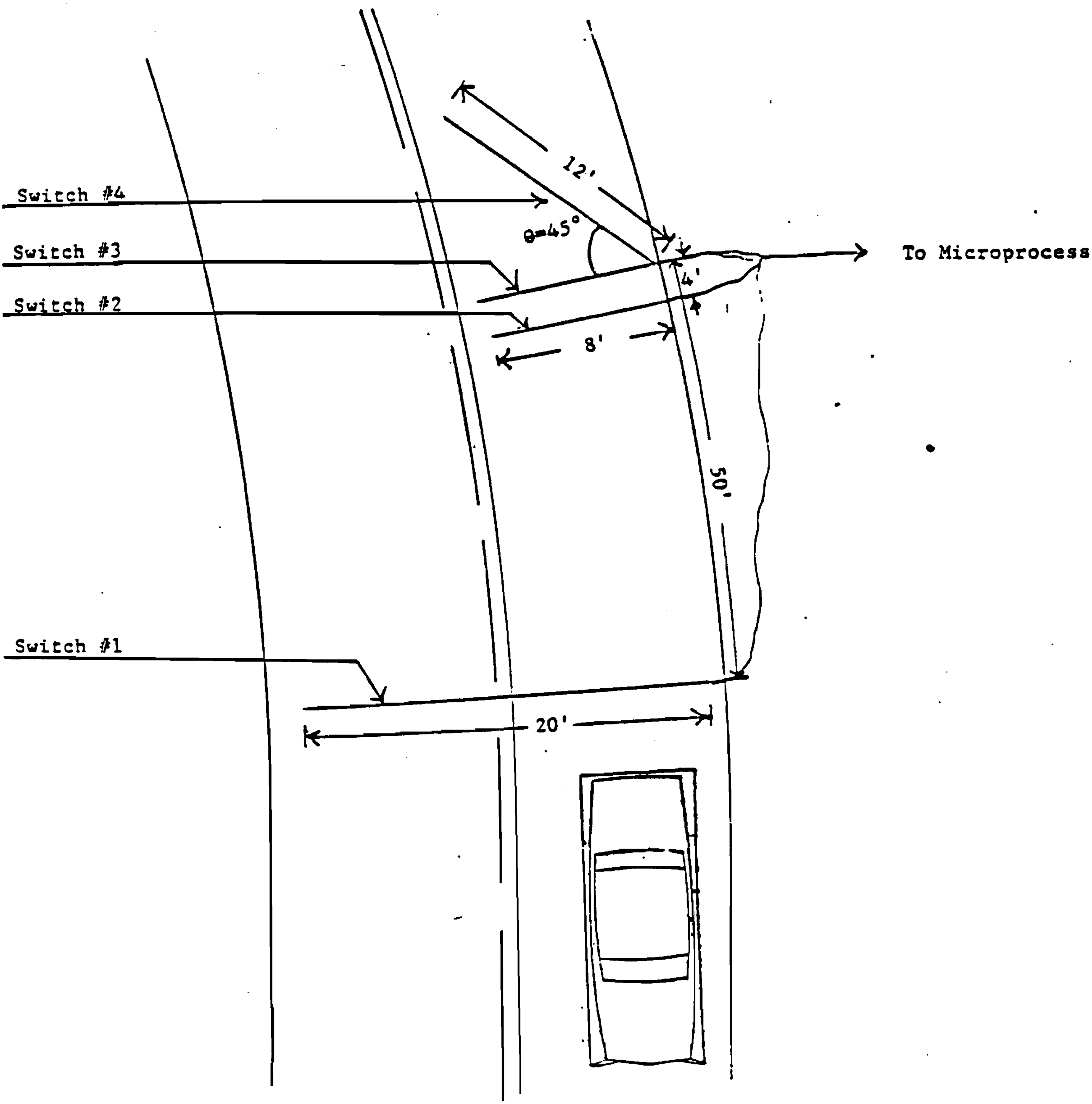
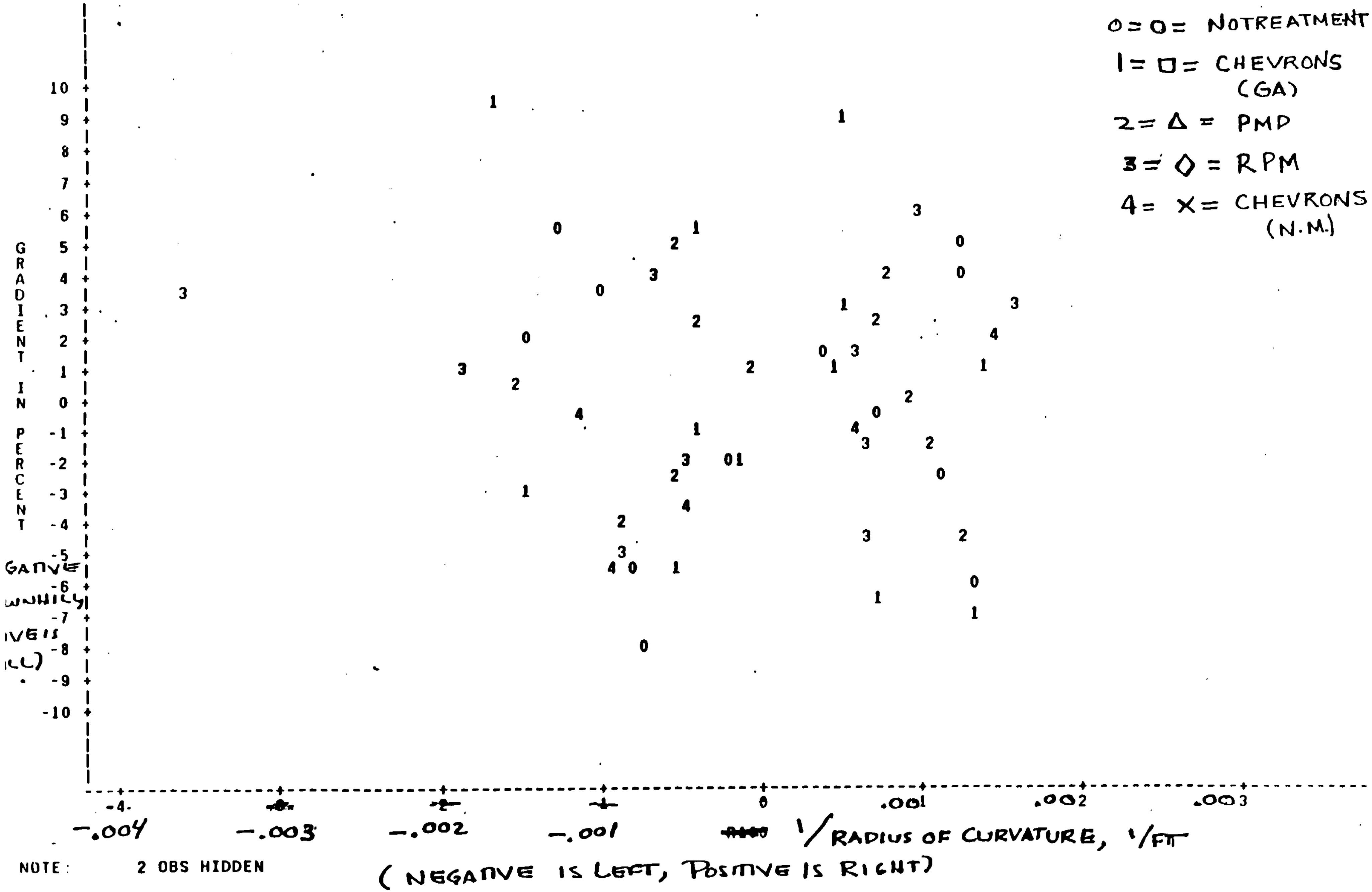


FIGURE 2

Distribution of Sites by Curvature, Grade, and Treatment



NOTE: 2 OBS HIDDEN

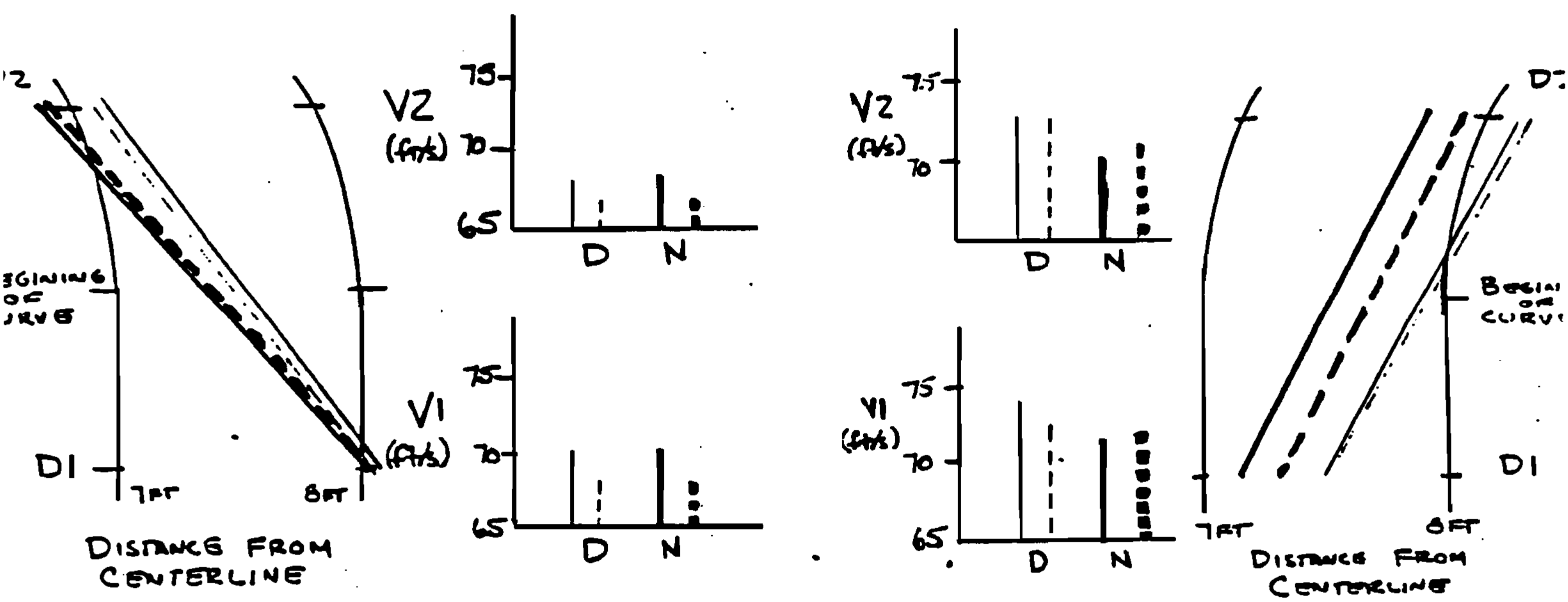
FIGURE 3

Mean Speed and Placement Observations Before and After

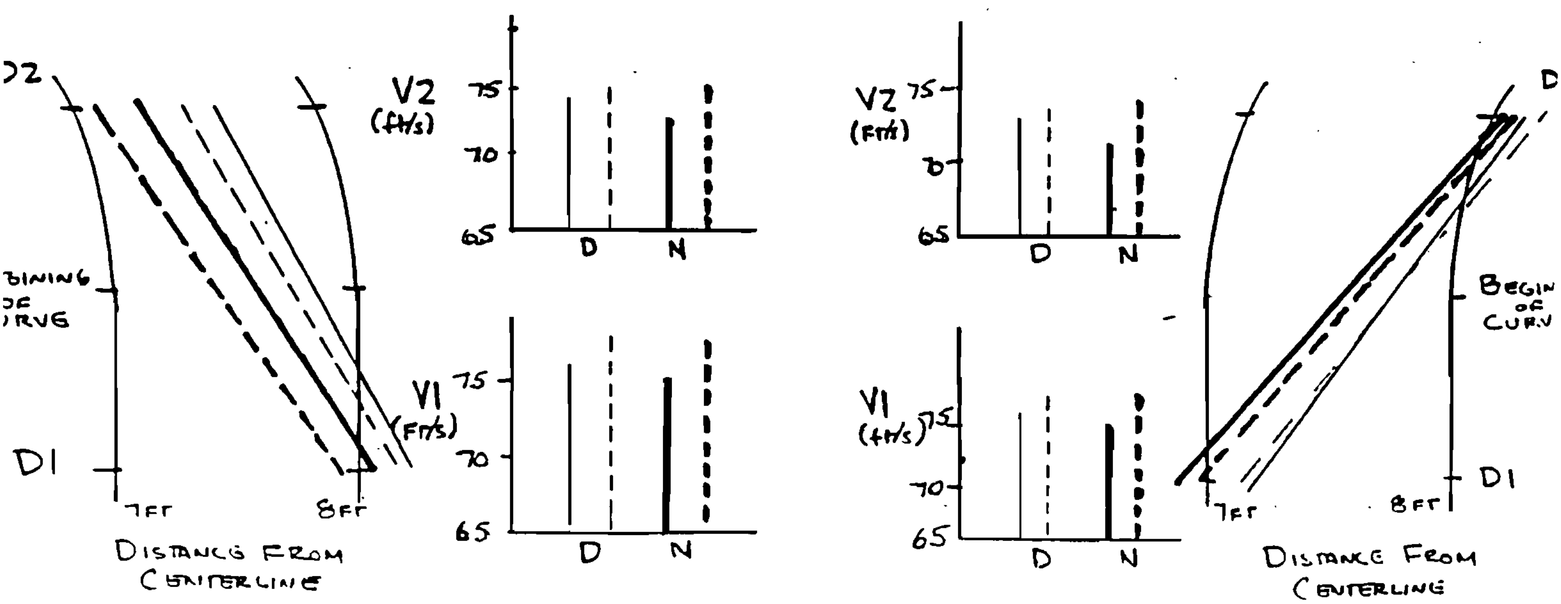
Modification by Time of Day, Direction of Turn, and Treatment

3.A Chevron Signs

Left Curves | Right Curves



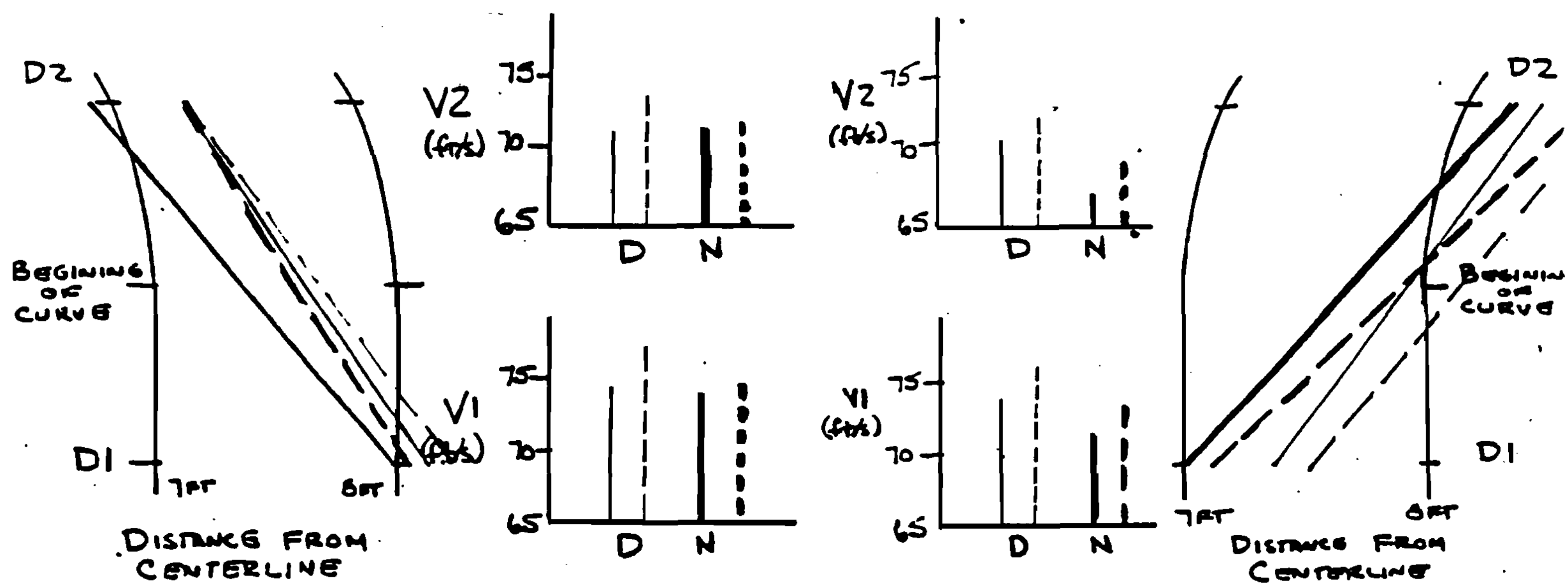
3.B Post-Mounted Delineators



3.C Raised Pavement Markers

Left Curves

Right Curves



3.D No Modification

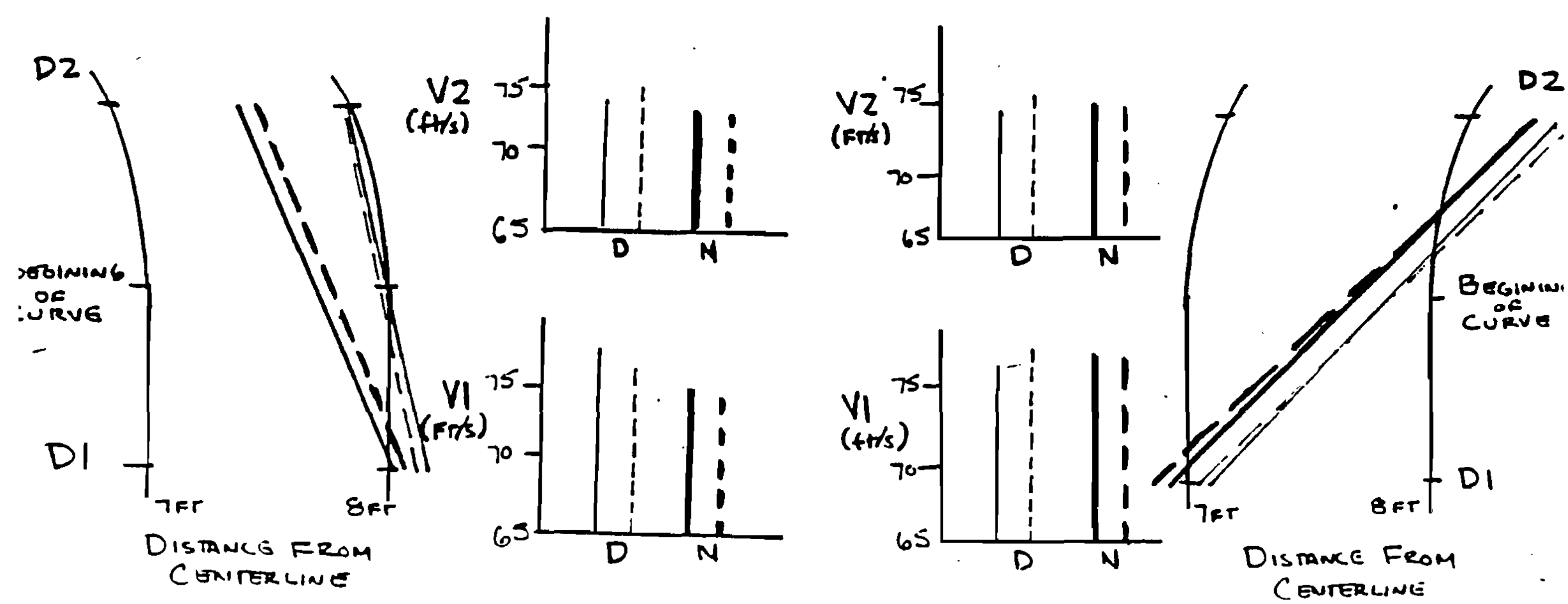
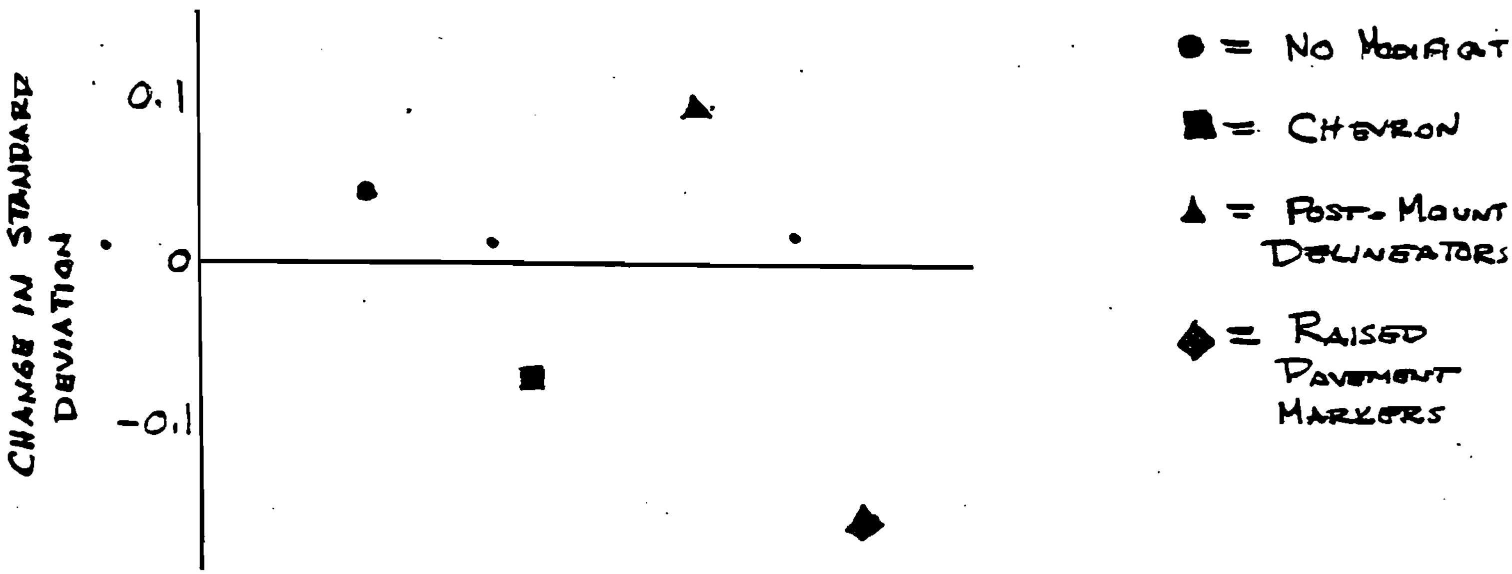


FIGURE 4

Estimated Short-Term Changes in Standard Deviations of Variables by Treatment Type at Night for Georgia Sites

1. Vehicle Placement 100 Feet Before Curve



2. Deceleration

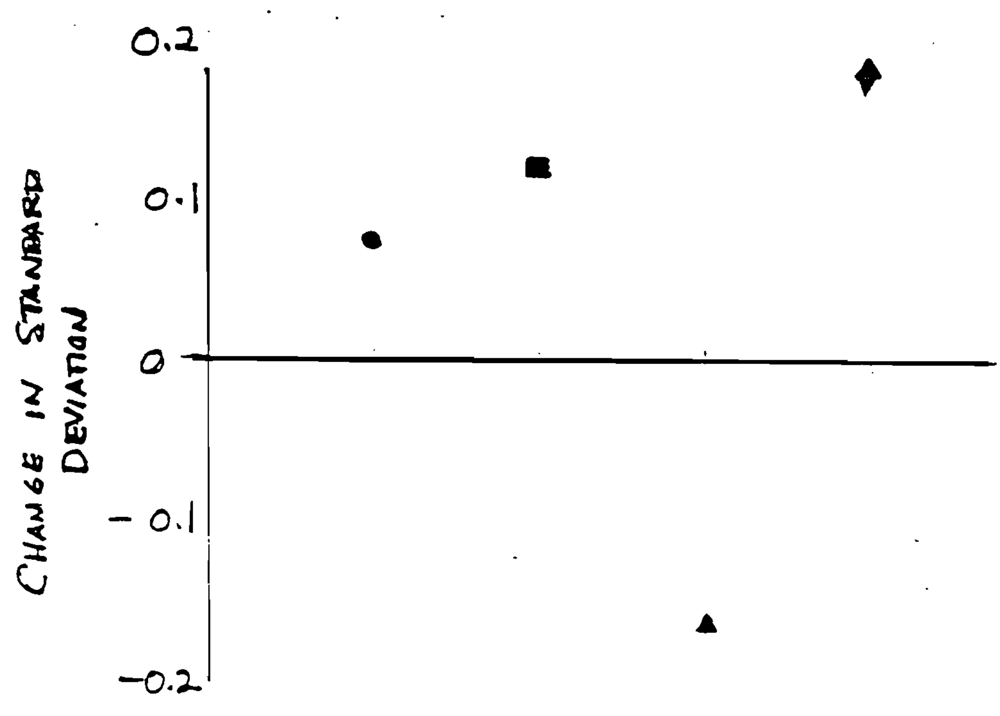


FIGURE 5

Estimated Short-Term Changes in the 10th Percentile (L),

Mean (M), and 90th Percentile (H) Values of Speed Measurements

by Treatment Type at Night for Georgia Sites

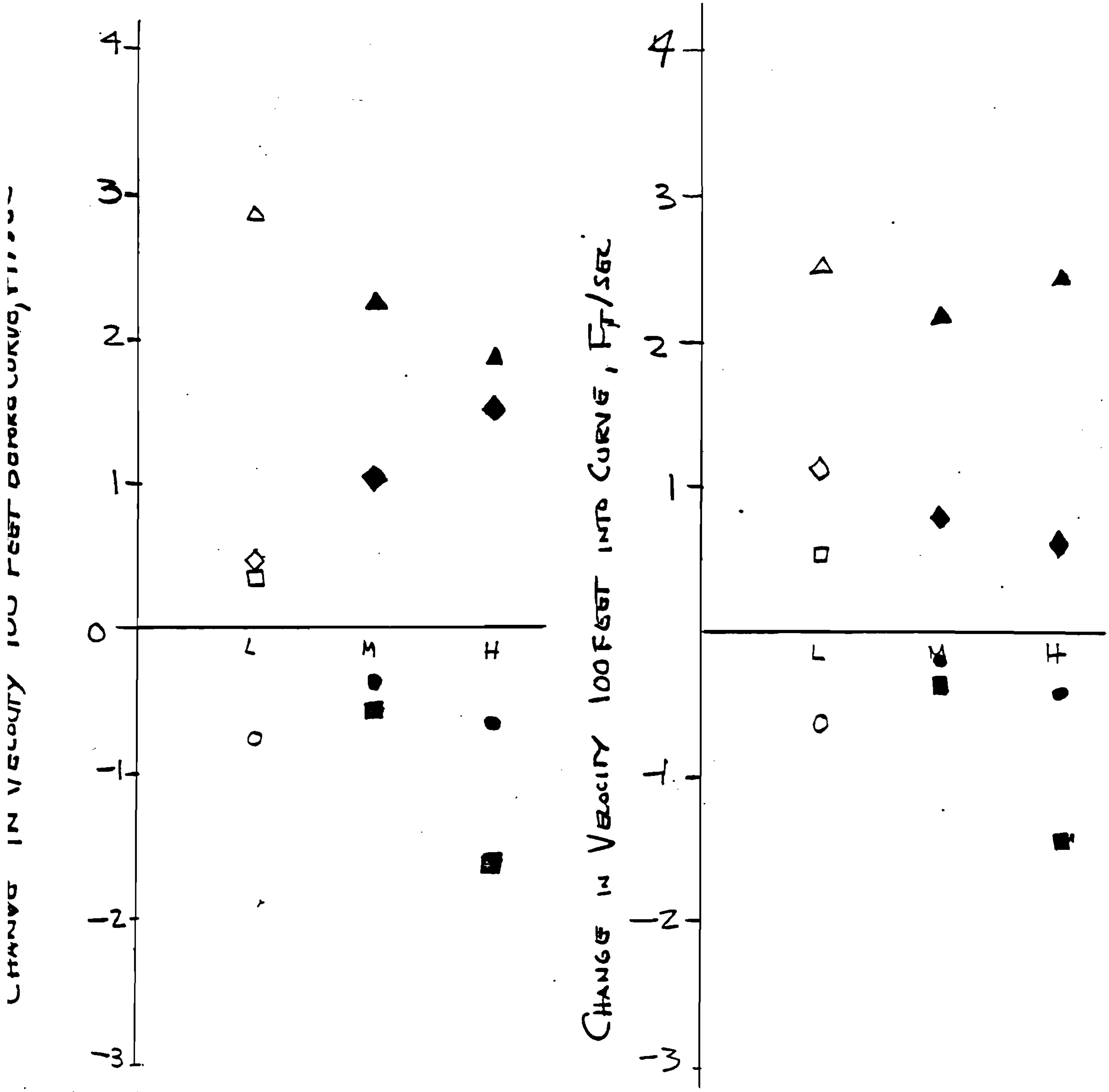
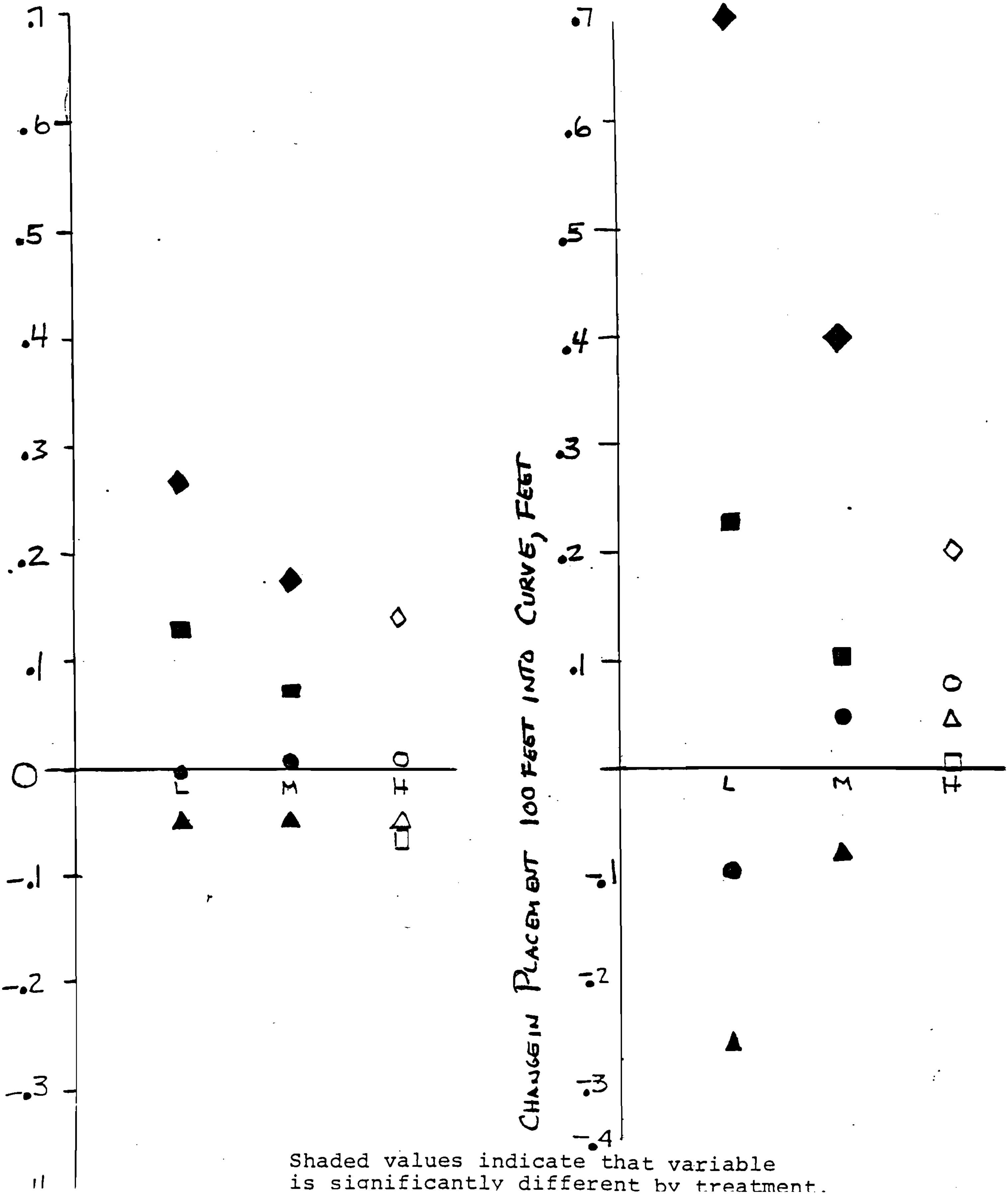


FIGURE 6

Estimated Short-Term Changes in 10th Percentile (L), Mean (M), and 90th Percentile (H) Values of Vehicle Placement Measurements by Treatment Type at Night for Georgia Sites



Shaded values indicate that variable is significantly different by treatment.

FIGURE 7

Estimated Short-Term Changes at Night in Mean Vehicle Placement 100 ft Before the Curve by Treatment and Geometric Condition at Georgia Sites

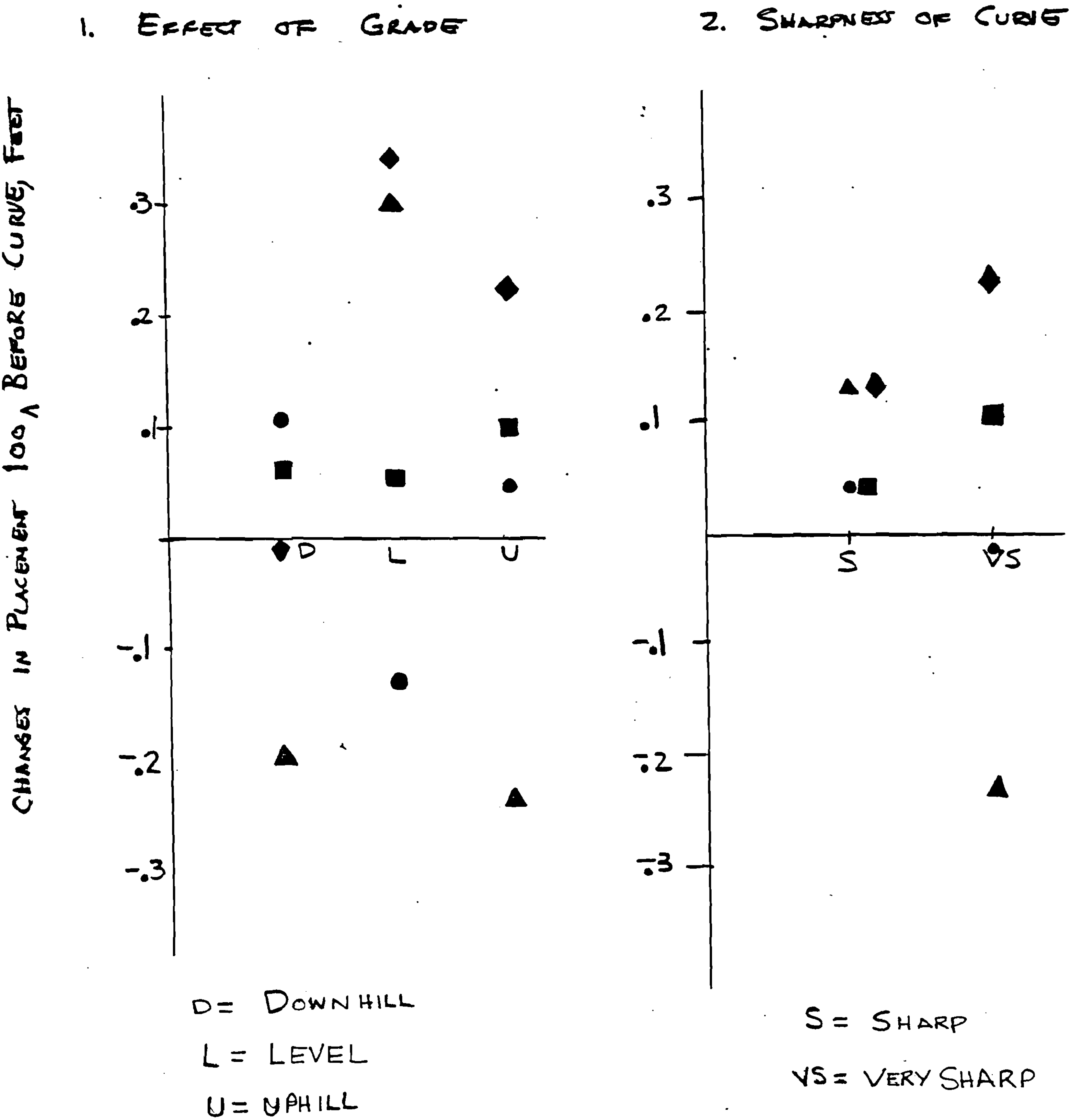


FIGURE 8

Comparison of Short-Term and Long-Term Changes in Vehicle Speed

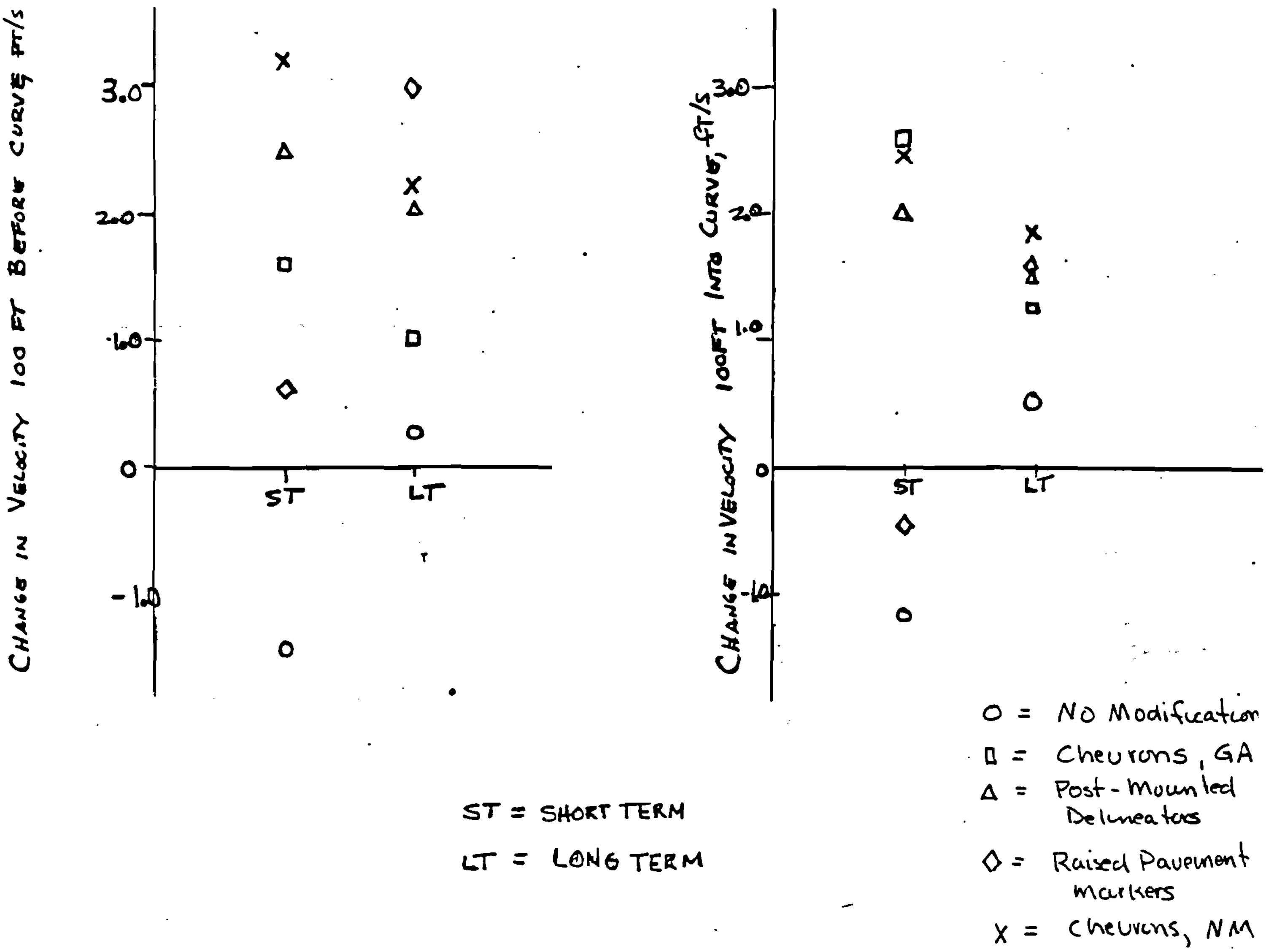


FIGURE 9

Comparison of Short-term and Long-Term Changes in Vehicle Placement