EVALUATION OF CURVE DELINEATION SIGNS ON RURAL HIGHWAYS

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

The three post-mounted delineator systems currently used in the state of Virginia were tested at five sites for their effectiveness in controlling run-off-the-road accidents. The changes in speed and lateral placement noted with the systems in place were taken as drivers' responses to the systems. The study showed that drivers react most favorably to chevron signs on sharp curves $\geq$ 7 degrees and to standard delineators on curves < 7 degrees. It is suggested that state-wide use of delineators based on these findings will improve the safety and uniformity in delineation on the rural highway system.

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INTRODUCTION

Travel on rural roadways is noticeably different from travel on urban streets. On the former, vehicular speeds are generally higher; the lower average daily traffic (ADT) usually warrants a more narrow, less well-marked road surface; and the severity of accidents is greater than for urban highways.[1]

Several studies have pointed out that a high proportion of the accidents that occur on rural curves happen at night and usually involve a single vehicle that runs off the road.[1,2] For a majority of the rural roadways, those with an ADT of less than 2,100, single-vehicle, run-off-the-road (ROTR) accidents have been reported to account for more than 40% of all accidents, with nearly half of these involving a personal injury or fatality.[1,2]

Post-mounted delineators (PMDs) of various shapes, colors, and types have been used throughout the United States in an attempt to reduce the number of ROTR accidents. These markings have proven to be effective, especially at night or during adverse weather conditions when roadway markings may be covered.[3]

These delineators are retroreflective devices mounted in series at the side of the roadway to indicate the roadway alignment, and they are considered guidance devices, rather than warning devices.

The PMD has been shown capable of influencing the "subject's judgements of the sharpness of a road curve." This influence can be used to modify the pattern a driver follows through a curve, and thus promote safety on rural roadways.[1]

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CURRENT PRACTICE

Virginia

In the state of Virginia, the three basic types of delineation or alignment signs used on rural roadways are--

- the 3" x 8" (7.62cm x 20.32cm) reflector on a wooden post (ED-1),
- the 6" x 48" (15.24cm x 121.92cm) special striped delineator, and
- the chevron alignment sign (WI-8).

Figure 1 illustrates these sign types.[4]

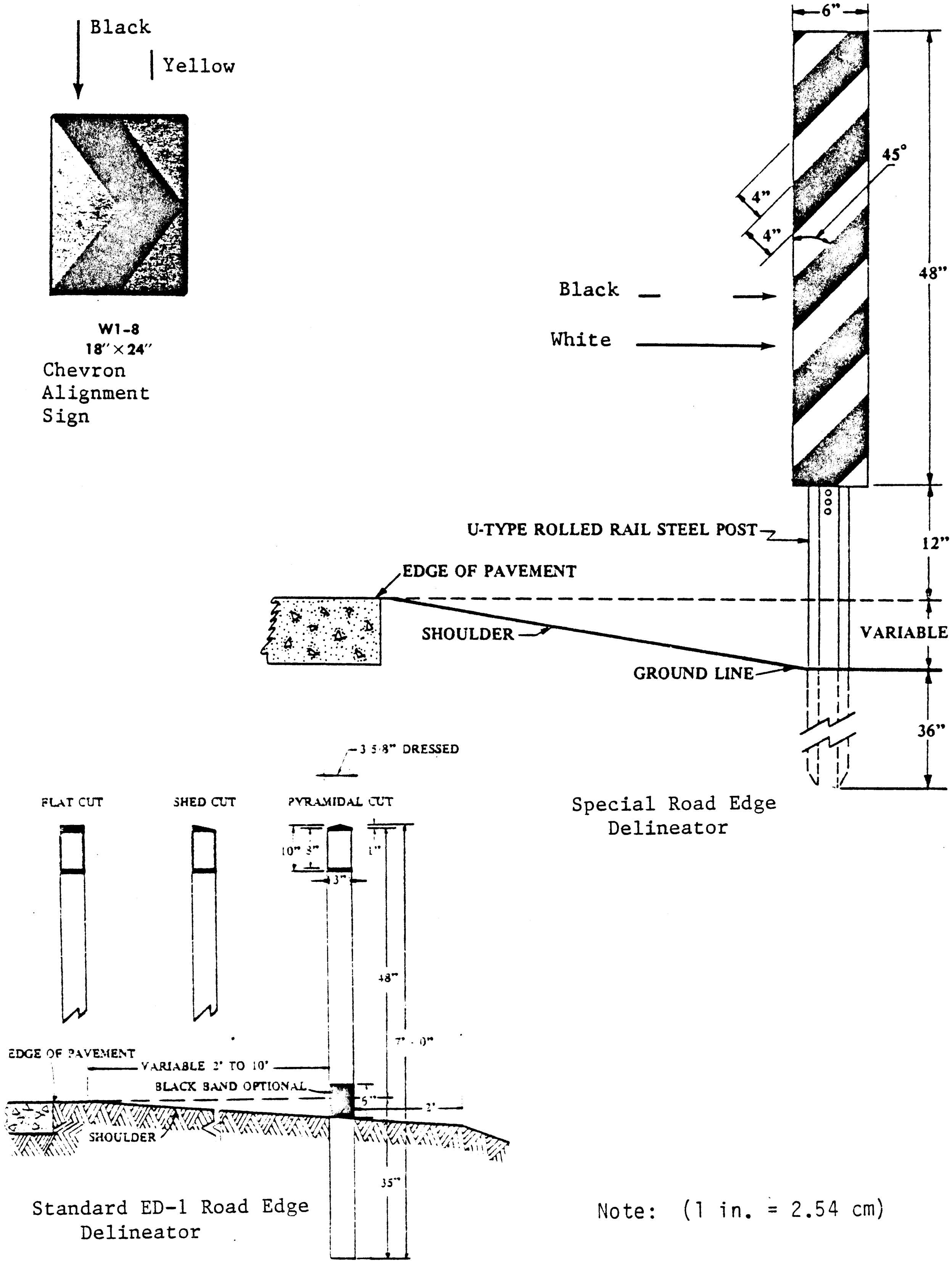
Two general approaches are used in selecting delineators for a site. The Manual on Uniform Traffic Control Devices (MUTCD) is an often quoted source for delineation selection for freeways and major roadways. This manual recommends spacing, location, and height for the delineators without recommending the type of delineator to be used. In fact, the MUTCD states that "Delineation is intended to be a guide to the vehicle operator as to the alignment of the highway; whatever is needed to provide that guidance in a clear and simple way should be installed."[5]

The second method of selection is local practice. A survey of each of the nine operating districts of the Virginia Department of Highways and Transportation found wide variations in the use of PMDs, as can be seen in Table 1. It should be noted that several districts are currently replacing some delineation signs in an effort to increase standardization.

The differences in delineator use from region to region may confuse motorists. These inconsistencies induce additional information loads on a driver, violate driver expectancy, and reduce the safety along affected routes. Rural roadways are much more affected by these inconsistencies than are freeway facilities.[6] If the different delineator types were installed according to the same criteria based on their effectiveness relative to given roadway conditions, it is conceivable that their positive influence on driver behavior would be improved.

Other States

A review of delineation practices in other states has revealed many of the same problems and practices that exist in Virginia. Several states are involved in studies to determine the safest delineation systems for rural roadways, and though their results have not yet been finalized, the following conclusions can be drawn from their data.



Note: (1 in. = 2.54 cm)

Figure 1. Alignment signs used in Virginia.

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Table 1

DELINEATION SYSTEM APPLICATION IN VIRGINIA

District	Chevrons	Night Arrows	Special (6" x 48") (15.24 cm x 121.92 cm)	Standard (ED or D Type)	Responsibility
Bristol	No district policy; very little use	Extensive use on sharp curves or where accident rates indicated need	Extensive use on medium sharp curves	Used on normal curves following MUTCD	Traffic Engineering Office
Culpeper	Three always visible; judgment determines need	Used on very sharp curves, usually with 25 MPH speed restrictions	Used on curves with limited shoulder space; seldom used	Used as an extension of tangent system on gentle curves	Traffic Engineering Office
Fredericksburg	Used where problems exist; posted on every other post where standard delineators already exist	Being replaced by chevrons	Not used	Used where problems might exist following MUTCD	Traffic Engineering Office
Lynchburg	Used on curves 5° or greater with one chevron visible at all times	Seldom used	Used on curves less than 5° but more severe than normal curves; judgment determines need	Used on normal curves following MUTCD	Traffice Engineering Office
Northern Virginia	Used on all curves; judgment determines spacing	Being replaced by chevrons	Not used except at hazards on curves	Not used	Traffic Engineering Office; usually a Tech. Supervisor
Richmond	Used on critical curves with accident history; two sizes used, downsized chevrons used after entering a curve	Not used	Being replaced by chevrons	Used on medium curves following MUTCD	Resident Engineers; however, "what is on the truck often determines selection"
Salem	Used on sharp curves, three chevrons visible at all times	Used on sharp curves; being replaced by chevrons	Used on sharp curves; being replaced by chevrons	Not used	Field supervisors and Traffic Engineering Office
Staunton	Used at special locations with high accident or run-off-the-road rates; three chevrons visible at all times; a double chevron is used on 90° curves of extreme sharpness	Used on the the sharpest curves more often than chevrons	Used on normal curves	Very few used	Local supervisor or Traffic Engineering Office
Suffolk	Major emphasis within district; three chevrons visible at all times	Used on very sharp or deceiving curves	Installed on curves 10° or greater; none recently installed	Not used	Traffic Engineering Office

1. Large chevrons are not very effective and show little effect on speed, braking, or lateral placement within the curve.(1)
2. Standard delineators in an MUTCD configuration positively affect speed, braking, and lateral placement and are particularly effective on sharp rural curves.(1)
3. Rural curves with PMDs have a much lower nighttime ROTR accident rate than curves of similar characteristics without vertical delineation. Tests have shown the reduction rate to be 50% or more.(7)
4. Long-term effects of PMDs are much less than the initial effect during the first few weeks. This suggests adaptation by local drivers. Since accidents on rural roads often involve drivers unfamiliar with the roadway geometry, this result does not negate the safety benefits of vertical delineators.(1)

National Studies

In the files of the Transportation Research Board Committee on Visibility there is a working paper dated July 27, 1964, and entitled "Subjects Needing Research, Study of Development Relating to Night Visibility in Highway Use." It poses 24 questions such as, "What are the relative advantages and disadvantages of various highway delineators and roadway edge markings?"(8)

In a 1973 TRB presentation, it was noted that more than 90% of the states used some form of PMD; however, it was also reported that there was little agreement among the states as to the proper placement and use of the varying delineator types. The talk concluded by calling for an evaluation of delineator techniques and the uniformity of national use.(9)

During the late 1970s and early 1980s some effort to evaluate the various types of PMDs was begun. To assist in this effort, the Offices of Research and Development, FHWA, U. S. DOT, initiated projects with eight state highway agencies. By March 1982, the first draft of the results of these projects was available. The draft noted that "It is not possible to state that the installation of post delineators under all conditions will result in a reduction in the number of run-off-the-road type accidents. The data that were collected indicate a trend toward reducing run-off-the-road accidents with the installation of post delineators."(7)

The studies reviewed for that report showed some evidence that lateral placement was less variable with the delineator and that this effect was also somewhat improved for closer spacing.(7) Of the three delineator types generally used in Virginia, only two were included in this national study. The chevron was studied as currently used and the standard was tested and placed upon a U-channel post. The special 6" x 48" (15.24cm x 121.92cm) delineator was not tested.(7)

The chevron was noted as being especially useful in delineating a horizontal curve that occurs just over the crest of a vertical curve. This, however, might depend upon the placement of the delineator; Virginia practice places the top of the chevron sign at 4' (1.2m), not 7' (1.8m) as was done in the test. It was also noted that chevron signs are highly visible both day and night and have the important advantage of indicating direction.[7]

The draft report noted the tendency to always have 3 chevron signs visible and acknowledged the spacing formula used by West Virginia, which calls for a chevron spacing of two times the normal delineator spacing.

Standard U-channel delineators were mentioned as having an advantage of being relatively easy to install because they are now commonly used and their installation is easily understood by sign and road crews.

The disadvantage of standard delineators were that they provide very little driver guidance information under normal daylight conditions and that their height limits their visibility where horizontal and vertical curves occur together.[7]

The report concluded that delineators do reduce accidents and that most sites on which they are used will show some reduction in nighttime ROTR accident rates. Chevron signs were especially mentioned as making a significant difference in the total fatal accident rate.[7]

OBJECTIVE AND SCOPE

The purpose of this study was to determine where current practice in the placement of the available types of delineator signs could be improved through providing uniformity. The focus was only on the effects of different post-mounted delineators on driver behavior. Standard 4-inch (10.16-cm) pavement markings were in place at all test sites. Selected delineation strategies were evaluated and recommendations developed for selecting the type of sign best suited for given roadway and environmental conditions after the decision has been made to use vertical delineation at a site.

RESEARCH METHOD

Performance Measures

Studies on driver reactions to delineation systems placed on roadways generally rely upon changes in vehicle movement as indicators of the reactions. The two most obvious changes in movement are vehicle speed and placement. The path a driver takes through a curve is dependent upon his perception of the curve and how best to traverse it. Because this positioning changes as the vehicle moves through the curve, it is desirable to record the placement and speed of the vehicle at several locations throughout the maneuver.[1,10]

The vehicle speed is an indication of the apparent severity of the curvature of the roadway. Slow speeds entering the curve indicate that the driver is aware that the curve exists. Fast speeds at the start of the curve with slower speeds near the middle indicate braking by the driver, probably because the curve is sharper than he has perceived it to be. Acceleration in the curve would indicate that the driver has perceived the curve to be sharper than it actually is.

The path of the vehicle through the curve is also a good indication of the perceived sharpness. Movement across the centerline may indicate that the curve is not as sharp as it looks. This centerline encroachment may also be caused by objects along the shoulder of the road that the vehicle's driver perceives to be a threat.

Vehicles traveling very close to the right-hand edge of the road may indicate that the curve is sharper than it appears. This occurrence may also be an indication of a high ADT that causes drivers to feel unsafe driving near the centerline.[1,10]

A satisfactory delineation system is one that will produce uniform speeds and placement throughout the curve. It will negate the need for excessive braking in the curve,and the absence of a change in speed within the curve is a prime indication that the driver of the vehicle has correctly perceived the curvature of the road. Also, it will minimize encroachments on the centerline and edgeline and thereby leave most of the vehicles driving in the center of the lane.[1]

On some roads, vehicle type could be an important third item that should be recorded. These sites would be located where exceptionally large numbers of heavy trucks are present or where continuous grades reduce the speeds of these trucks but not those of other vehicles. Since large trucks are a very small percentage of the normal traffic on most rural roads, the data for trucks were not studied separately.

Statistical Method

The effectiveness of different delineation treatments was measured using the chi-squared goodness-of-fit test. Here performance data for the marked roadway were compared with those obtained while the curve was unmarked.

The purpose of this analysis was to determine the value of statistical similarity for the delineation treatments as compared to the unmarked roadway. The larger the value of α that was obtained, the more similar the data for the two tests. A small value of α indicated that the delineation treatment had significantly altered the driver's path and/or speed through the curve. For example, an α value of 0.10 means a 10% level of significance, which in turn indicates a significant change in driver performance in the curve.

The results of this statistical evaluation showed that there was no significant change in speeds after the delineators were installed. Most values were in the 0.90 range. However, there were significant changes in the lateral placement of vehicles. For this reason the placement changes were taken as the critical elements in the study with the changes in speed being noted for additional information.

Delineation System/Technique Selection

Delineation systems vary from exotics such as ascending and descending patterns, in and out patterns, and sign mix patterns to the more traditional systems currently used in Virginia.[1] Since this investigation was intended mainly to test the systems used in this state, only three conventional systems were investigated (see Figure 1). The only variation made was that the wooden posts used with the standard road edge delineators were not painted. This decision to use treated, but unpainted, posts was supported by a study involving the possible use of untreated posts which found very little difference between visibilities for the two types of posts.[1] The MUTCD recommended spacing and placement for standard delineators was used as is often done in Virginia.

The most effective placement pattern for chevrons has not yet been determined. Most districts in Virginia use their own judgement in determining the placement and spacing of the chevron signs. The placement varies from one sign always being visible to at least three signs being visible. It was decided that since most of the districts recommend that three chevron signs be in sight, such a pattern would be used. In examining the MUTCD placement patterns, it was noted that the recommended spacing for standard delineators generally provided that four to six delineators would be in view of a driver.[2] Using this information it was decided to space chevrons at a distance twice that recommended by the MUTCD for traditional delineators. This spacing proved adequate for this study.

Field Data Collection

To record the speed and lateral placement of the vehicles moving through the curve, a Leopold and Stevens traffic data recorder (TDR) was used. Eight tapeswitches were used to record data at the beginning and near the midpoint of the curve. The switches were temporarily placed from the edge of the centerline to the shoulders of the road and secured with 4" (10.16cm) industrial tape designed for such use. The leads from the switches were connected to the TDR concealed off the roadway.

The switches were placed on the roadway in a predetermined pattern as is illustrated in Figure 2. Using a spacing of 6' (1.83m) between matching channels (switches) allowed a variation in placement of 3/4" (1.9cm) with less than a 1% change in speed or lateral placement, an important factor in field installations.[12] As an automobile's tires crossed the first

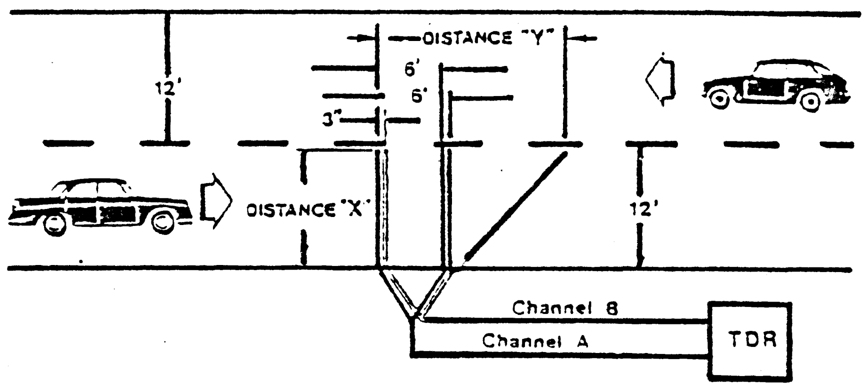

Figure 2. Configuration for data collection using two TDR channels per lane.

and second switches, their circuits were opened. The third switch closed the first circuit to generate the time from switch 1 to switch 3, and with it the vehicle's velocity. The fourth switch, which was laid at a 45° angle to facilitate field measuring and placement, closed the second circuit to generate the time from switch 2 to switch 4. The placement of the vehicle was then calculated using the following formula developed by Leopold and Stevens.[13]

Lateral placement = 6 * Tan (Theta) ((S1/S2)-1),

where

6 = distance in feet separating the speed detector switches,
θ = angle of the lateral placement switch = 45°,
S_1 = speed of the vehicle measured by the speed switch, and
S_2 = speed of the vehicle measured by the lateral placement switch.

Input from the tapeswitches was recorded on cassette tapes and the data processed on a computer. The output included volume, velocity, and vehicle type information for ten zones in each lane.

Zones 1 through 9 were of equal width, while zone 10 represented vehicles which encroached more than 1' (0.3048m) across the centerline. At the sites tested, zones 1-9 were each 8" (20.3cm) wide (Figure 3).

By using this zoneal width, it could be concluded that vehicles in zone 10 represented possible head-on collisions, while zones 8 and 9 represented possible sideswipe accidents. Zones 8 through 10 (zones 7 through 10 at the narrowest sites) were considered to be the centerline encroachment zones. Any vehicles in these zones were considered to be candidates for multi-vehicle collisions.

The data by lane zone allowed trace data to be determined for average vehicles. This vehicle trace, combined with the velocity averages, was used to determine the effectiveness of the delineation treatments. That the use of average trace data tends to overshadow individual vehicle performances, especially at the two extremes, is of some concern for the high velocities but of no concern for the low velocity area.[1]

Selection of Sites

Two groups of roadway sites were used. Sites in the first group were already marked with PMD devices and were used to study the data collection system as well as to obtain base data (pretest program), the second group were intially free of any vertical delineation and were used in the actual testing program. Data were collected at each pretest site once, while they were taken at each test site seven times. The first collection was while the test site was still unmarked. Then, the site was studied with each vertical delineation device in place to determine short-term effects and then several weeks later for long-term effects.

The criteria shown in Table 2 were used in selecting the sites. Using these criteria, a listing of candidate roads and locations was accumulated through interviews with highway officials. Each road or site was then evaluated to determine its suitability for testing.

Technical data for each curve were obtained from the headquarters of the district in which it was located, and these were used to group the sites by length of curve, degree of curvature, and degree of grade. The pretest program showed that vehicle placement was not significantly different in curves with different grades, so grade was not initially considered as a major influence on vehicle placement.

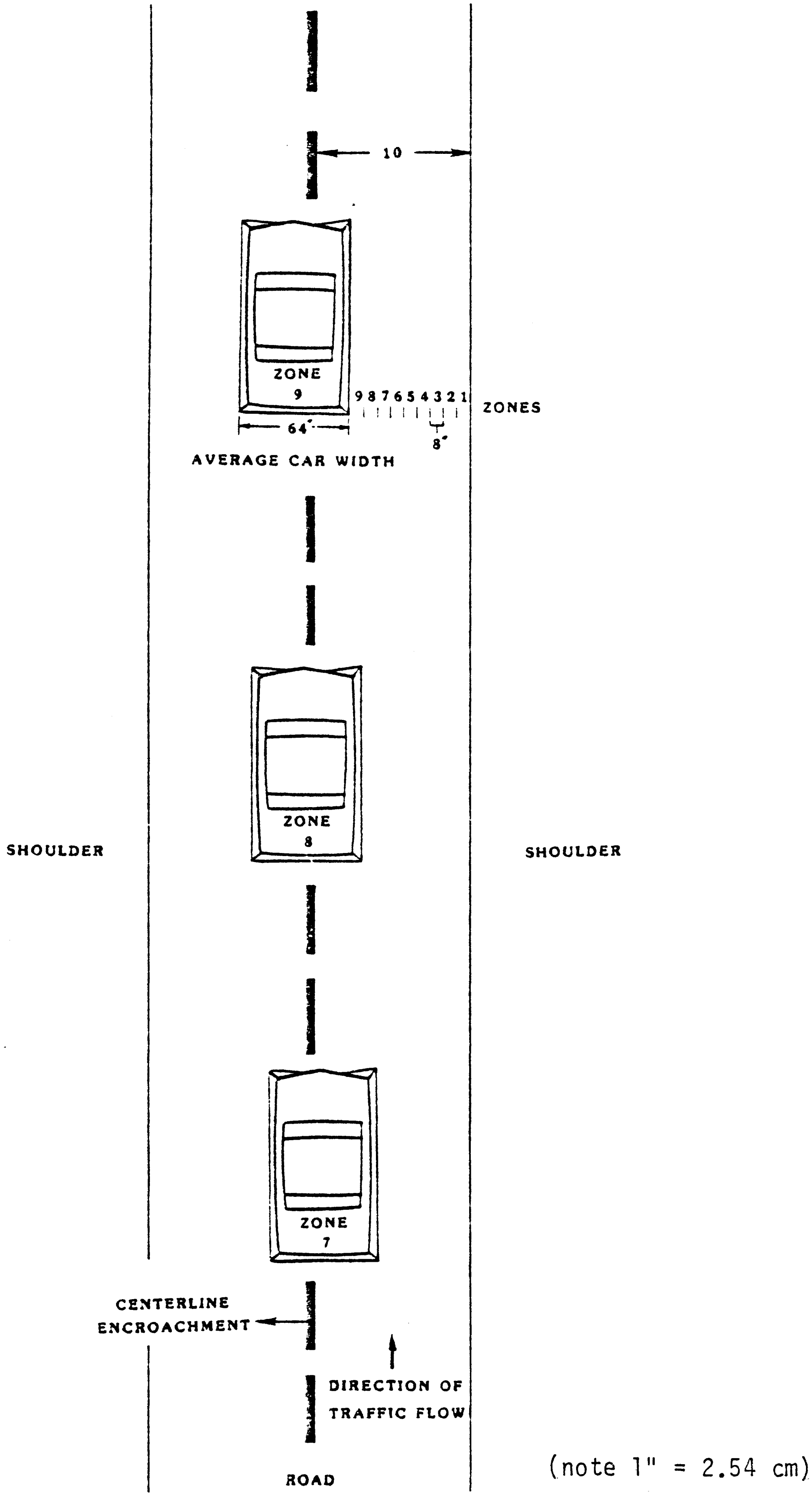

Figure 3. Illustration of lane zones

Table 2

CRITERIA FOR TEST SITE SELECTION

- Proper signing using current spacing and erection techniques (pretest)
- No delineation devices (test)
- No obstacles (driveways etc.) on shoulder
- Accident history
- ADT 1,000-3,000
- Pavement markings
- Located within 1-hour drive of Charlottesville
- Rural location
- All curves in same construction district to simplify project
- Roadways carry at least some out-of-state traffic
- Standard pavement markings at centerline and edge of pavements

In the field evaluation of a test site, a vehicle was driven through the curve several times, the site was examined for signs of heavy braking or ROTR incidents, and a series of photographs was made. Table 3 identifies the sites chosen for the pretest and test phases of the study.

Data Collection Problems and Classifications

The data collection technique used has a number of advantages over other methods. The most important advantage of the TDR system is that it can be secured with a chain and lock and left in the field, while several prior studies of this kind had to rely upon observations by research personnel.[1,10] The TDR allows long-term data collection without worrying about personnel needs. Figure 4 shows the traffic data recorder equipment.

Table 3

DESCRIPTION OF STUDY SITES

Site #	Route	County	Curve Location	Horizontal Curvature	Radius of Curvature	Length of Curve	Lane Width	Grade	ADT 1982	Treatment
Pretest Sites										
1	20	Albemarle	0.6 mi. south of I-64	10° 16'	558'	237'	12'-11"	---	3,440	Unmarked
2	231	Albemarle	5.0 mi. north of Rte. 22	8°	716'	311'	9'-2"	-4%	2,600	Existing - Special
3	20	Albemarle	7.6 mi. south of I-64	8°	716'	225'	11'-0"	---	3,440	Existing - Special
4	20	Orange	South of Rte. 616	4° 30'	1273'	240'	9'-1"	---	3,990	Existing - Standard
5	20	Albemarle	Albemarle/Orange County Line	12°	477'	200'	9'-0"	-5%	2,180	Existing - Chevron
6	33	Greene	9.6 mi. west of U.S. 29	11°	521'	323'	9'-0"	-6%	2,860	Existing - Chevron
7	33	Greene	9.7 mi. west of U.S. 29	7°	819'	387'	9'-0"	+5%	2,860	Existing - Chevron
8	231	Albemarle	6.9 mi. north of Rte. 22	4°	1433'	470'	8'-10"	-2%	2,600	Existing - Special
Test Sites										
9	20	Albemarle	6.8 mi. south of I-64	12°	478'	215'	10'-4"	+2%	3,440	All
10	33	Orange	At Rtes. 652 & 664	5°	1146'	824'	9'-4"	---	3,005	All
11	231	Albemarle	5.5 mi. north of Rte. 22	5°	1146'	748'	9'-8"	+4%	2,600	All
12	22	Albemarle	East of Rte. 783	8° est.	700' est.	300'	9'-7"	-2%	1,530	All
13	208	Louisa	South of Rte. 642	4°	1433'	583'	10'-3"	-4%	2,740	All

Note: (3.05 ft. = 1 m)

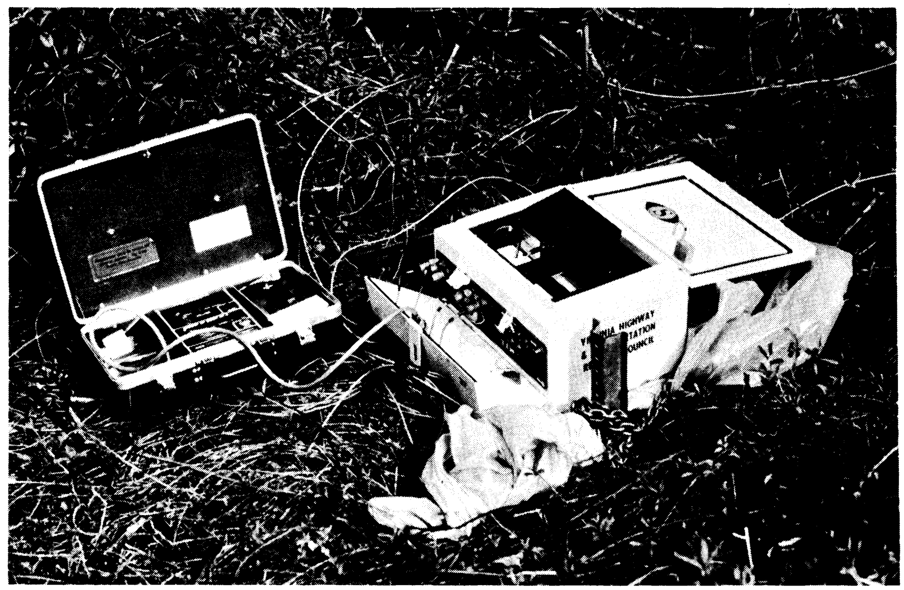

Figure 4. Traffic data recorder
and portable programmer.

The second advantage of the TDR system is that the collected data can be directly inputted into a computer for analysis, thus saving time and eliminating much of the possibility for human error.

On the minus side, the most significant shortcoming of the system is that it is nearly impossible to use under cold or wet conditions because of the inability of different tapes to stick to the roadway surface. This caused some problems, the most significant of which was the forced cancellation of the short-term standard delineation test at site 9 and the resulting delay of further testing for several months.

Another problem stems from the system's use of an electric circuit to register vehicle passes. On one occasion, a heavy dew shorted the circuit and caused the loss of nearly three hours of data. This occurred even though all of the circuit connections were wrapped in plastic bags.

Further experimentation with industrial tapes might reveal a tape suitable for use in wet weather. This, along with all-weather circuit connectors, would allow data collection without regard to weather conditions.

Another weather related problem with the TDR is its inability to transfer data to the cassette tape at low temperatures, even temperatures at the levels prevailing during many spring and fall evenings.

Another source of trouble with the TDR system is the sensitivity of the CASSETE FORTRAN program which reports the traffic performance measures by reading and interpreting the data from the cassette.(13) This sensitivity requires that a perfectly "clean" cassette tape be used.(12) Furthermore, should the TDR accidentally place any extraneous data on the tape, or the transfer of data from the TDR to the tape be incomplete, the programs may reject the data or interpret them incorrectly.

The number of variables which might affect the way a driver traverses a curve creates the third, and probably most difficult to compensate for, source of problems. The list of these variables is long, including:

- time of day
- roadway grade
- radius of curvature
- length of curve
- lane and road width
- existing pavement markings
- shoulder width (if any)
- nature of adjacent lane
- intersecting roadways or driveways
    - in curve
    - before curve
    - after curve
- ADT volumes
- average speeds of traffic
- delineator spacing (if any)
- delineator type and number (if any)
- condition of delineators
- weather conditions
- sight distance

All of these variables cannot be controlled in a study of this type. Those relating to physical characteristics of the roadway can be reported and compared, but this still leaves a number that are continuously changing.

The testing program was conducted from early spring to midsummer, a period that encompasses all levels of vegetation development along the shoulder of the road. This greenery, in many cases, reduced the sight distance and caused the shoulders to look more narrow and dangerous than before. At site 11, where the shoulder was clear of trees, the spring growth stood chest high and partially obscured some of the delineation signs. This is a problem often found in areas where the shoulders are not mowed regularly.

A further source of difficulties encountered during the testing phase was the occasional differences in the totals for vehicle counts and vehicle types at the two sensor locations on the road. Since none of the curves had intersecting roads, the counts and types of vehicles should have been the same for both sensors. This problem was usually caused by the TDR misinterpreting the axle counts from one or the other set of sensors.

These differences were easy to correct, but the task often proved to be very time consuming. A visual inspection was made of the data for each vehicle as reported by the VEHICLE program.

Vehicles were matched by their time of arrival and the axle counts were corrected where necessary. The data for stragglers and other vehicles, such as those with speeds below 15 mph (24km/hr), and those with negative lateral placement, were unusable and were omitted from the analysis.

Even with these problems, using the TDR proved to be an easy and successful means of obtaining the data in the quantity needed.

SITE EVALUATIONS

Preliminary Observations

The sites designated 1 through 8 in Table 3 were used for the pretest phase of this study conducted to test the TDR equipment and to determine if the data obtained would allow meeting the study objectives. The data showed some similarities in driver response characteristics for the different delineation treatments.

As an example, Table 4 shows the zone-by-zone percentages of vehicle travel and average speeds for special pretests at sites 8 and 2. The data are statistically similar for both placement and speed; α = 0.250 and α = 0.950, respectively, which indicates that two sites with different physical characteristics may induce similar driver responses for the same type of delineation signing.

There were also similarities between two of the chevron marked sites. Here, the zonal placements were not as significantly alike (α = 0.025), but the average speed, placement, and centerline encroachment of sites 5 and 7 resembled each other.

Even though these data do not conclusively show that vehicle paths at sites with the same delineation systems are similar, they do show that the patterns are similar at some sites.

In studying the data and site characteristics, it is not the similarity that is worth noting, but the general trends shown in the vehicle data. The consistency in average lateral placement and speed alterations shows that drivers react in a predictable manner to the different delineation techniques.

Table 4

EXAMPLE OF DATA SIMILARITIES FOR SITES 8 AND 2

Zone	Zonal Distribution - Day (percent)		Average Zonal Speed - Day (mph)	
	Site 8	Site 2	Site 8	Site 2
Beginning of Curve				
1	1.6	2.4	51.7	49.2
2	13.8	14.2	53.3	52.3
3	26.9	26.4	52.4	51.6
4	29.4	31.9	54.2	53.5
5	17.7	18.4	53.4	52.6
6	5.8	3.9	52.5	54.4
7	3.6	2.1	54.4	54.8
8	0.7	0.3	54.4	54.3
9	0.1	0.3	65.0	57.0
10	0.5	0.3	44.6	53.0
Middle of Curve				
1	0.3	0.6	47.0	48.1
2	3.0	2.7	48.6	48.2
3	6.9	8.5	48.1	49.5
4	22.0	16.0	52.3	52.2
5	24.8	24.5	53.1	52.6
6	19.7	20.4	53.9	53.8
7	16.7	18.8	53.9	54.1
8	4.5	4.5	55.1	55.0
9	1.2	2.6	54.2	57.4
10	0.9	1.5	58.6	57.6

Note: 1 mph = 1.6 km/hr.

Table 5, which gives the results of seven tests at the beginning of the curve on site 10 during daylight (6 a.m. to 8 p.m.) and nighttime (8 p.m. to 6 a.m.), demonstrates how the data can show trends in driver reactions. The data are broken down into the ten zones for each test and include an additional total for possible centerline encroachments. Depending upon the lane width, the possible encroachments would occur in one of the last three or four zones. At this site, vehicles in zones 7 through 10 experienced encroachments. Centerline encroachments increased during all of the tests.

The percentages in Table 6 show a general trend for vehicles to travel away from the edge of the road with the delineation signing in place. The averages and variances in Table 6 more clearly show the change. Again, all of the tests of the delineation systems show similar movements; in this case, a strong movement away from the edgeline. Also, there was a slight increase in the placement variance, which is used to determine how defined the new path through the curve is.

Table 7 shows how the vehicle speeds were affected by the new delineator signs. As can be seen, all of the systems induced an increase in speed during the day. The increase in speed with the chevrons was much less and possibly indicates that the drivers perceived the chevron signs as an obstruction close to the traveled way more than they did the other delineators. Also, the speed variance increased greatly for the chevron signs while the other delineators caused a decrease. This again points to the possibility that drivers were apparently not as comfortable with the chevrons as they were with the other delineator systems.

Main Tests

Sharp Curves

Two of the five curves studied in depth, sites 9 and 12, are considered to be sharp (curvature > 7°). The data from both indicate that chevron signs are the most favorable form of delineation at these places. The data for site 9 show that the chevrons produced the lowest probable centerline encroachment of the three delineation systems, and, on the average, a traveled path was closest to being centered in the lane. The placement variability was also lower than for the other systems.

The speeds at site 9 also indicated that chevrons performed best on this curve. The average speeds were slightly higher than for the other systems, a maximum of 2%, but the speed variances were among the lowest found.

The data taken at site 12 showed much the same trends. The centerline encrochment was lower for the chevrons, and the average vehicle path was the most desirable, especially at the middle of the curve where it was about one-half foot further away from the centerline. The placement variance was about average for the three systems studied.

Table 5

EXAMPLE OF VEHICLE PLACEMENT BY PERCENTAGES
BEGINNING OF CURVE - DAY
Site 10

		Curve Treatment					
Zone	Unmarked	Standard Short-Term	Standard Long-Term	Special Short-Term	Special Long-Term	Chevron Short-Term	Chevron Long-Term
1	0.1	0.1	0.1	0.1	0.1	2.0	0.1
2	3.4	1.4	0.6	0.8	1.3	2.4	2.6
3	13.7	9.5	5.7	7.1	6.1	7.1	7.9
4	31.6	23.0	22.4	24.5	24.2	21.6	21.8
5	28.5	30.3	29.0	29.1	31.8	28.3	30.7
6	14.9	19.6	24.4	22.5	18.8	20.5	19.9
7	5.8	11.3	13.3	12.0	12.5	13.0	13.2
8	0.9	3.2	3.1	2.5	3.4	3.2	2.7
9	0.8	1.2	0.7	0.6	1.0	1.3	0.8
10	0.3	0.5	0.6	0.9	0.8	0.7	0.4
Possible Centerline Encroachment	7.8	16.2	17.7	16.0	17.7	18.2	17.1
Total Volume for test period	924	862	975	932	912	709	978
Chi-square	-	0.05	0	0	0	0	0.005

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Table 6

Example of Lateral Placement and Variability Data - Site 10 (feet)

	Beginning of Curve			
	Day		Night	
Curve Treatment	L.P.	Var.	L.P.	Var.
Unmarked	2.75	0.75	3.21	0.87
Standard Short-term	3.08	0.86	3.50	0.86
Standard Long-term	3.19	0.80	3.69	1.10
Special Short-term	3.12	0.82	3.78	1.24
Special Long-term	3.14	0.87	3.79	1.12
Chevron Short-term	3.08	1.15	3.75	1.23
Chevron Long-term	3.08	0.86	3.72	1.13

Note: (3.05 ft. - 1 m)

Table 7

Example of Vehicle Speeds and Variability Data - Site 10 (mph)

	Beginning of Curve			
	Day		Night	
Curve Treatment	Speed	Var.	Speed	Var.
Unmarked	51.8	46.2	53.3	41.0
Standard Short-term	53.0	44.9	52.8	43.6
Standard Long-term	53.6	43.6	53.4	46.2
Special Short-term	53.0	44.9	51.6	47.6
Special Long-term	52.9	42.3	52.6	33.6
Chevron Short-term	52.1	77.4	51.0	57.8
Chevron Long-term	51.9	56.3	52.4	54.8

Note: (1 mph = 1.6 km/hr.)

The chevrons at site 12 were not as successful in dealing with excessive speed as they were at site 9. The speeds averaged about 50 mph (80km/hr), greatly above the 35 mph and 40 mph (56km/hr and 64km/hr) recommended by two signs in the area. For the chevrons, the daylight speeds were slightly lower than for the other systems, while the nighttime speeds were greater by as much as 2 mph (3.2km/hr). The speed variances for the chevrons were also slightly greater during the day, but at night they were about the same as for the other two systems.

Gentle Curves

At sites 10, 11, and 13 the standard and special delineators provided the best delineation, usually with the standard delineators being preferred.

At site 10, the standard delineators produced the lowest levels of centerline encroachment and an average lateral placement that was slightly better than those of the special delineators or the chevrons. During the daylight, the chevron produced the best lateral placement. However, at night that for the standard delineators, which had a much smaller variance, was the best of the three systems tested.

The speed data for site 10 showed the special delineator treatment to be superior; the vehicle speeds were above average and the speed variance was lower than that of the other two systems. The standard delineators proved to be the second most effective system in terms of speeds and speed variances.

The testing at site 11 showed that the chevron signs produced some of the lower centerline encroachment figures, especially at the middle of the curve. There was very little difference between the standard and special delineator treatments.

In average vehicle placements, no one system seemed to have a major advantage over the others. The special delineators caused the average vehicle path to be slightly closer to the center of the lane than did the other systems. The variance in vehicle placement for the special delineators was also the lowest, which indicated that the delineators were more uniformly accepted at this site.

The speeds recorded at this site changed little from one delineation system to another. The chevron sign produced the slowest speeds, but the speeds were very variable.

The standard and special delineators produced nearly the same speeds and variances; however, the changes over time for the two systems were opposite, with the speeds increasing for the standard delineators and decreasing for the special delineators. For both types of delineators, the speed variances decreased, with the special delineators producing the largest decrease.

Site 13 was the most difficult of the test sites to analyze, because of the loss of the data for the special delineator short-term test and the repaving of the roadway before the chevron long-term test.

The vehicle placement and speed data, however, do show that the standard delineators produced the lowest levels of centerline encroachment. They also resulted in low levels of vehicle placement variance and produced a vehicle path near the center of the traveled lane through the curve. The placement variance results for the special delineators indicated that they are more effective in producing uniform traffic movements at night than the standard delineators, but the average lateral placement for them was much closer to the centerline. The chevron signs produced the highest variances in placement, but a lateral placement similar to that of the standard delineators.

The chevrons did a much better job as judged by the average speeds. They induced the lowest variance of speed of all of the systems at site 13. The standard delineators showed good variances during the day, but had the largest ones during the night, and they also produced the lowest speeds during the day and the highest at night.

The results for the special delineators were always satisfactory but never the best. This may indicate that they are the most appropriate delineation treatment should only one type be used in the state, because they produce no extreme changes in vehicle paths while still providing suitable guidance through the curve.

This general preference for standard or special delineators for these less sharp curves follows the guidelines which most of the state's districts use. It would seem that the use of these two signs is correct for those sites with a curvature of less than 7°.

Discussion of Findings

All of the Virginia highway districts follow the MUTCD spacing guide for standard and special delineators, so the only problem found in the state related to spacing was one with the chevron signs. This project used the system practiced in West Virginia; that is, the regular MUTCD spacing was doubled for the chevron signs.[7] This spacing proved to be successful in providing guidance without using an excessive number of signs.

Based on the data obtained from the field tests, along with information obtained in the survey of state delineation practices, it would seem that a simplified delineation policy can be developed. For moderate curves ($< 7^{\circ}$) where delineation is deemed to be necessary, the use of standard delineators spaced as recommended by the MUTCD appears to be the most satisfactory choice.

This choice does present some problems, the most significant being that the Salem, Suffolk, and Northern Virginia districts reported no current use of these delineators. Another problem is that many such curves are marked in other ways. However, this should be of little concern since the use of delineators already varies from site to site. The use of only standard delineators will eventually result in a more uniformly marked highway system.

For curves ($\geq 7^{o}$), chevrons tend to give better delineation information to the driver. All districts reported the use of chevron signs on these curves. The major difference in chevron use is in the spacing policy followed in the districts. Using a spacing of twice the MUTCD recommendation will greatly simplify this matter. This spacing allows two to three signs to be visible throughout the curve, about the average of the numbers suggested by the various state districts, and has been found by several other states[7] to be the best spacing.

Previous studies have tended to question the acceptability of chevron signs. They generally have reported that the signs induce an excessively large number of centerline encroachments along with little if any change in vehicle speeds.[7] This was not found to be true with all of the five sites studied in this project. Chevrons produced less centerline encroachment than the standard or special delineators while still providing smaller vehicle placement variances at the sharper curves. Likewise, speeds were also decreased in these curves.

These data are supported by recent studies on the use of chevron signs. A possible explanation for this change in driver reaction is that when the first tests were performed, chevron signs were a very new delineation technique. Many drivers had never seen the signs before and were confused as to their meaning. With chevrons gaining wide acceptance, drivers are more familiar with the signs and are now capable of interpreting their meaning.

A second factor, and possibly a more important one, is chevron sign spacing. When first used, chevrons were used much as a normal delineator would be. This close spacing and large sign size combined to form a wall-like effect alongside the roadway. Drivers tended to move away from this effect and over the centerline. Spacing the chevrons at twice the normal distance tends to eliminate the wall effect while still providing guidance through the curve.

RECOMMENDED GUIDELINES

Many of Virginia's highway districts have been moving toward the use of different delineator systems for sharp and gentle curves, and this policy is supported by the findings of this study.

This study has determined that drivers do react to vertical delineation along the roadway and that this reaction is related to the layout of the curve. Delineation systems used in curves should be matched to the expected driver responses based upon such factors as the curvature of the road and sight distance. To ease this decision-making process, the following recommended guidelines are offered for curves deemed to require delineation because of the degree of curvature, not other factors such as the presence of interesections or hazards on the roadway shoulder.

For curves $< 7^{\circ}$, the use of standard edge delineators (ED-1) is recommended. The spacing should conform to that in Table 8.[4] The height of the delineator post should be 4' (1.22m) above the pavement and the post should be located 6' to 8' (1.83m to 2.44m) from the edge of the pavement.[5]

For curves $\geq 7^{\circ}$, the use of chevron alignment signs (WI-8) is recommended. These signs should be erected 6' to 8' (1.83m to 2.44m) from the edge of the road at a top-of-the-sign height of 4' (1.23m). The chevrons should be spaced twice the distance of the standard delineators as is shown in Table 8.

The purpose of this study was to compare the existing PMD systems against one another. However, now that it has been shown that delineation signing can alter a driver's path through a curve, the most effective pattern should be developed. Testing in this area has already been carried out, but the results of these studies have been mixed, with some spacing and height changes showing improvements.[9,10]

The type of signpost used is also of some concern. A study is currently under way to determine the most cost effective post system.[7]

Table 8

SUGGESTED SPACING FOR HIGHWAY DELINEATORS ON HORIZONTAL CURVES

(Distance in Feet Rounded to the Nearest 5 Feet)

Radius of Curve (in feet)	Spacing on Curve for Standard Delineators (in feet) (S)	Spacing on Curve for Chevron Signs (in feet) (C)
50	20	40
150	30	60
200	35	70
300	50	100
400	55	110
500	65	130
600	70	140
700	75	150
800	80	160
900	85	170
1,000	90	180

Spacing for specific radii not shown may be interpolated from table. The minimum spacing should be 20 feet. The spacing on curves should not exceed 300 feet. In advance of or beyond a curve, and proceeding away from the end of the curve, the spacing of the first delineator is 2S, the second is 3S, and the third 6S but not to exceed 300 feet. S refers to the delineator spacing for specific radii computed from the formula $S = 3\sqrt{R-50}$. The spacing of chevron signs should be twice that used for standard highway delineators. C refers to the chevron spacing for specific radii computed from the formula $C = 7\sqrt{R-50}$.

Source: Reference 4

Note: 3.05 ft. = 1 m.

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