2. Dash or skip designs are more permissive in interpretation than continuous designs, regardless of the symbology used.

3. Solid (or filled) diamonds appear more prohibitive than diamond outlines.

4. Line stroke width appears to have little impact on subjects' reactions to buffer-zone designs.

5. Color tends to add a degree of prohibitiveness to design meaning but generally is a secondary determinant of subject response.

6. The paired-comparison forced-choice and questionnaire techniques provide different types of information about buffer-zone design, and the data are highly complementary, resulting in a Spearman rank correlation of $r_s = 0.93$.

7. Several design characteristics must be further defined before design recommendations can be advanced. Included are delineation-zone width, effect of spacing or density of symbol (rungs in crosshatch), and driver perception of where a vehicle can be stopped relative to the delineated zone.

8. Any design recommendations emanating from laboratory study should be evaluated in an operational setting.

ACKNOWLEDGMENT

The research reported in this paper was conducted by BioTechnology, Inc., under contract to the Federal Highway Administration. Alfred Klipple of the Traffic Systems Division, FHWA Office of Research, served as contract technical manager. The Institute for Research, State College, Pennsylvania, was subcontractor.

REFERENCES

1. J. H. DuPree and R. H. Pratt. A Study of Low-Cost Alternatives to Increase the Effectiveness of Existing Transportation Facilities: Results of Survey and Analysis of Twenty-One Low-Cost Techniques. R. H. Pratt Associates, Inc., Silver Spring, MD, Jan. 1973.
2. R. F. Pain and others. Signing and Delineation for Special-Usage Lanes. Federal Highway Administration, U.S. Department of Transportation, Interim Rept. FHWA-RD-78-205, Vol. 1, Dec. 1977.
3. J. P. Guilford. Psychometric Methods. McGraw-Hill, New York, 1954, Chapter 7.
4. K. G. Courage and others. Traffic Control of Carpools and Buses on Priority Lanes on Interstate 95 in Miami. Federal Highway Administration, U.S. Department of Transportation, Rept. FHWA-RD-77-148, Aug. 1977.

Publication of this paper sponsored by Committee on User Information Systems.

Study of Width and Density of Delineation Design Elements for Special-Use Lanes

BEVERLY G. KNAPP AND RICHARD F. PAIN

The results of a two-part study that investigated the effects of varying roadway delineation width and the density of design elements within the roadway line on driver lane-change behavior are reported. The width study consisted of a controlled field experiment in which drivers indicated their decisions on whether to cross 1-, 2-, and 3-ft delineation treatments laid on a closed section of roadway. In the second part of the study, a laboratory experiment, the number of elements in the line design was varied by overlaying various drawings onto a highway scene and showing these slides to subjects to elicit their lane-choice responses. The designs tested were generated from previous work related to delineation treatments for high-occupancy vehicle lanes, which often operate as special-use lanes during rush hours and then revert to general use during off-peak hours. Delineation markings must thus appear prohibitive at one time and permissive at another. Width of line was found to have relatively little effect on the prohibitive or permissive meaning of delineation treatments. Density of design elements, however, was found to be an important determinant of permissiveness or prohibitiveness in that the widely spaced elements invited lane crossover more than densely spaced ones. The study findings appear to be applicable not only to delineation designs for special-use lanes but also as general design parameters in the application of roadway markings.

In a paper elsewhere in this Record, various delineation marking designs for highways and arterials were evaluated in terms of their permissive or prohibitive effects on driver lane-change behavior. These marking designs were developed for potential application as delineators between concurrent-flow, high-occupancy-vehicle (HOV) lanes and general-use traffic lanes. The intent of the study was to determine the levels of prohibitive or permissive meaning conveyed by various delineation designs by using a paired-comparison process, since the final design chosen must operate in one mode during HOV lane operation and another mode during off-peak hours (i.e., must be prohibitive to some vehicles at certain times and not at other times). The delineation treatments tested are given in Table 1.

In general, the earlier study established that dashed "skip" designs permit or elicit vehicle crossovers while solid, connected lines prohibit them. It was also found that colored lines are somewhat more prohibitive in meaning than a white version of the same configuration. The results experimentally defined some basic design parameters.

This paper discusses the effects of two other parameters--width and density of design image--that were not resolved.

The data given in Table 2 indicate how the concept of "element density" emerged from the earlier paired-comparison data. Element density is the actual number of elements, either diamonds or crosshatch strokes, within any given line segment. This concept emerged from the results of the first experiments in the form of "clusters" of delineation treatments, according to varying degrees of what subjects perceive as a "wide, thick look" versus a "thin, sparse look." Treatments 1, 2, 4, 8, 10, 13, and 14 are a cluster--a separated, thin look; treatments 3, 5, 9, 17, and 18 are connected but still thin; treatments 6, 7, 15, and 16 are wide and connected; and, finally, treatments 11 and 12 (the crosshatch lines) are wide and strictly prohibitive, with a very dense look. Width is simply the varying of the total horizontal image of the line itself--i.e., the width of the total delineation or buffer-zone treatment.

Table 1. Delineation designs tested.

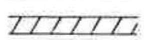
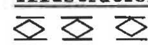
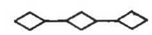
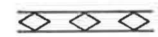
Treatment No.	Type	Illustration
1	Conventional dash	
2	Wide dash	
3	Broken-solid combination (white)	
4	Double dash (white)	
5	Conventional dash and MUTCD diamond (15-ft line, 25-ft gap), diamond every 1000 or 500 ft	
6	Diamond with solid line (white)	
7	Design 5 with filled-in (solid) diamond	
8	Diamond with dash line (white)	
9	Diamond with connecting line (white)	
10	Diamonds only	
11	Diagonal crosshatch (left slant)	
12	Diagonal crosshatch (right slant)	
13	Design 2 in bright yellow-green	
14	Design 2 in light blue	
15	Design 7 in bright yellow-green	
16	Design 7 in light blue	
17	Design 9 in bright yellow-green	
18	Design 9 in light blue	

Table 2. Clustering of delineation designs by appearance in relation to paired-comparison rankings.

Cluster	Appearance	Paired-Comparison Rank[a]	Treatment No.	Paired-Comparison Scale Value
1	Separated, thin look	1	1	1.3
				1.2
		2	2	1.10
		3	14	1.00
				0.9
		4	13	0.8
				0.7
		5	10	0.6
		6.5	4	0.5
		6.5	8	0.5
				0.4
				0.3
				0.2
				0.1
2	Connected, thin look	8	9	0.05
		9	3	0
		10	5	-0.1
		11	17	-0.2
		12	18	-0.3
				-0.4
3	Connected, wide look	13	6	-0.5
		14	7	-0.6
		15	16	-0.7
		16	15	-0.8
4	Connected, wide, dense, strictly prohibitive look	17	12	-0.9
		18	11	-1.0
				-1.1
				-1.2
				-1.3

[a]1 = most permissive; 18 = most prohibitive.

In order to study the effect on subjects' perceptions of these delineation treatments when the parameters of horizontal width and vertical image are varied according to stroke-element density, one treatment was selected from each of the clusters described above. Since the effect of color is tentative and would confound treatments of interest, only white designs were considered. The following designs were selected because they are relatively equidistant in ranking on the comparison scale:

Cluster	Treatment	Illustration
1	8	
2	9	
3	6	
4	11	

In attempting to design stimulus materials to study both width and density, it was determined that an artist's drawing that attempted to portray varying widths of 1-3 ft was not a perceptually good simulation of a driver's view, since the differences would be so obvious. Density, on the other hand, was well suited to display on stimulus slides similar to the ones used in the previous study. To reconcile this dilemma, it was decided to study the issue of width in a more realistic, controlled field setting and to simultaneously design a laboratory investigation of the density parameter, in which the slide technique would be used. Thus, two experiments were performed instead of one. The methodology, results, and discussion of each of these experiments--called the field study and the laboratory study--are presented separately.

FIELD STUDY

Method

The field study examined the width of the delineation markings for each of the four selected designs described earlier. For each design, widths of 1, 2, and 3 ft were paired against each other. A total of 12 test pairs resulted, three for each treatment: 1 versus 2 ft, 1 versus 3 ft, and 2 versus 3 ft. The dimensions for each width and design are given in Table 3.

The paired-comparison technique discussed by Guilford (1) was used here. Subjects were forced to indicate which delineation treatment of any given pair they would sooner cross, given a blockage in their center lane of travel. A blockage "set" was given subjects to more closely replicate the laboratory study. The stimuli here were actual delineation stripes laid out on closed sections of roadway. Subjects were driven through each of the 12 pairs and asked to indicate a "left" or "right" choice for each.

The pairs were laid out on closed sections of MD-32 and MD-100, off I-95 north of Washington, D.C. Each pair of treatments was laid out by using construction-grade, temporary white lane tape. The pairs were each 100 ft long and 12 ft apart, and each pair was separated by 400-500 ft of driving distance. Figure 1 shows some examples of these pairs as they were laid out on the roadway. The 12 pairs were laid out in random order on three sections of roadway, and placement of any given treatment on the left or the right was also counterbalanced.

The basic testing routine consisted of two parts:

(a) the experimental drive through the test course and (b) completion of a form that contained questions about the markings just seen. When a subject arrived at the appointed meeting station, he or she was greeted by an experimenter and taken for a ride as a passenger in the test car. The car used was a 1978 Plymouth Volare automatic, a standard-sized vehicle with ordinary viewing distance and height for most drivers. The subject was driven through each test pair and told to indicate on the answer sheet whether he or she would, as a driver, sooner cross the line to the left or the line to the right.

After the drive-through, subjects were returned to their point of origin, where they filled out the remainder of the test sheet, which showed drawings of each of the four delineation designs they had just seen. As in the earlier study, subjects checked which of six driving behaviors was appropriate for each treatment:

1. I can enter the right lane for passing and travel as I wish.
2. I can enter the right lane for turns or exit ramps only.
3. I would enter the right lane only for emergency repairs.
4. I should not use the right lane; it is reserved for special vehicles.
5. I should not use the right lane at all.
6. I have no idea whether I can enter the right lane or not.

Subjects were asked to rank each treatment from best to worst (1 to 4), according to how it conveyed the meaning of a special-use lane. The subjects were then paid, thanked, and dismissed.

The entire test run took 30 min or less. Driving speed through the test pairs was 35-40 miles/h, which allowed an exposure of several seconds for each, in a dynamic driving mode.

Thirty-four licensed drivers participated in the study, 17 males and 17 females. They ranged in age from 17 to 65; half were under 30 years of age, and half were over 30. They learned about the study through various types of publicity in the Baltimore-Columbia, Maryland, area.

Table 3. Width and design dimensions for each delineation treatment: field study.

Treatment No.	Buffer Width (ft)	Stroke Width (in)	Spacing of Design Elements
6	1	2	5 diamonds 20 or 25 ft apart[a]
8	2	4	5 diamonds 18 or 20 ft apart[a]
9	3	6	5 diamonds 15 or 17 ft apart[a]
11	1	2	2-in crosshatch strokes at 45° angle, 5 ft apart
	2	4	4-in crosshatch strokes at 45° angle, 5 ft apart
	3	6	6-in crosshatch strokes at 45° angle, 5 ft apart

[a]Diamond length-to-width ratio = 3:1.

Results

The paired-comparison data were summarized in four small tables of proportions, one for each delineation treatment, and traditional scale values were calculated. This follows the scaling procedure detailed by Guilford (1).

Figure 1. Sample stimulus pairs of delineation designs with varying line widths laid out on closed sections of roadway.

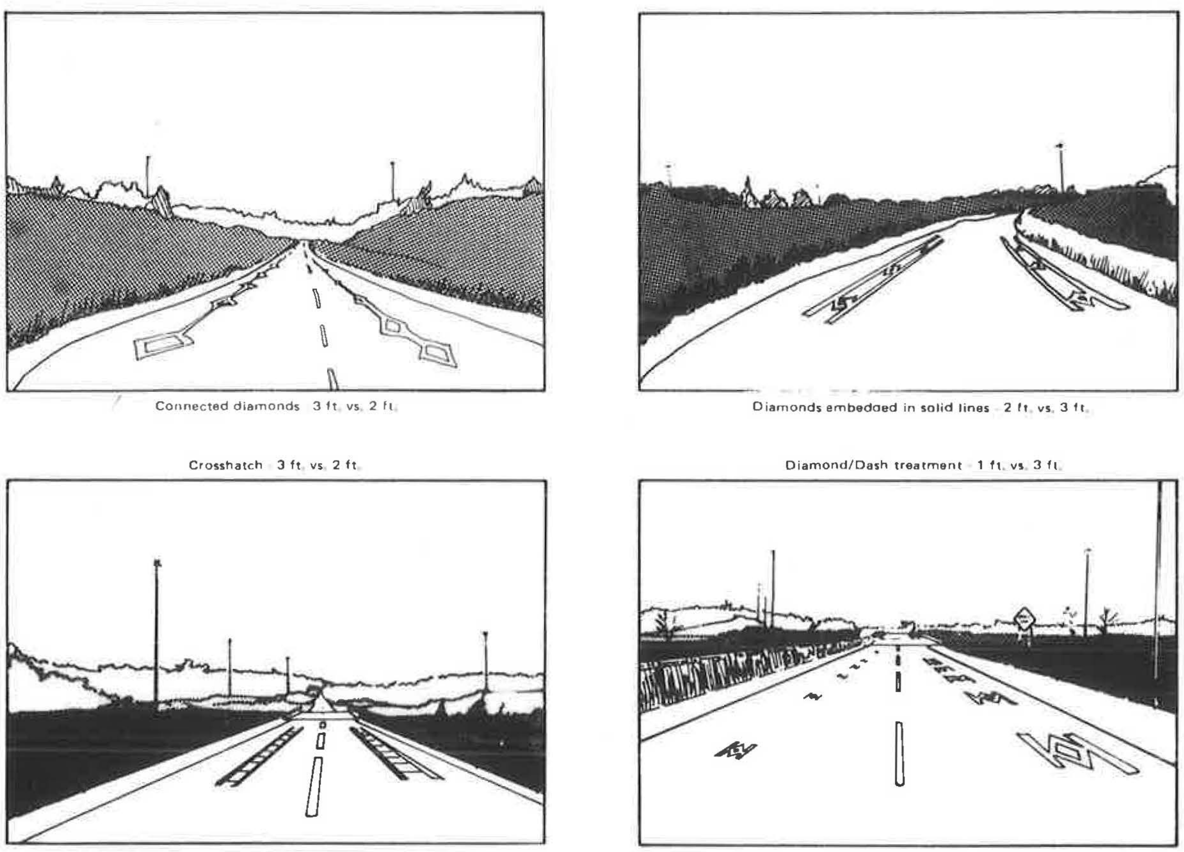
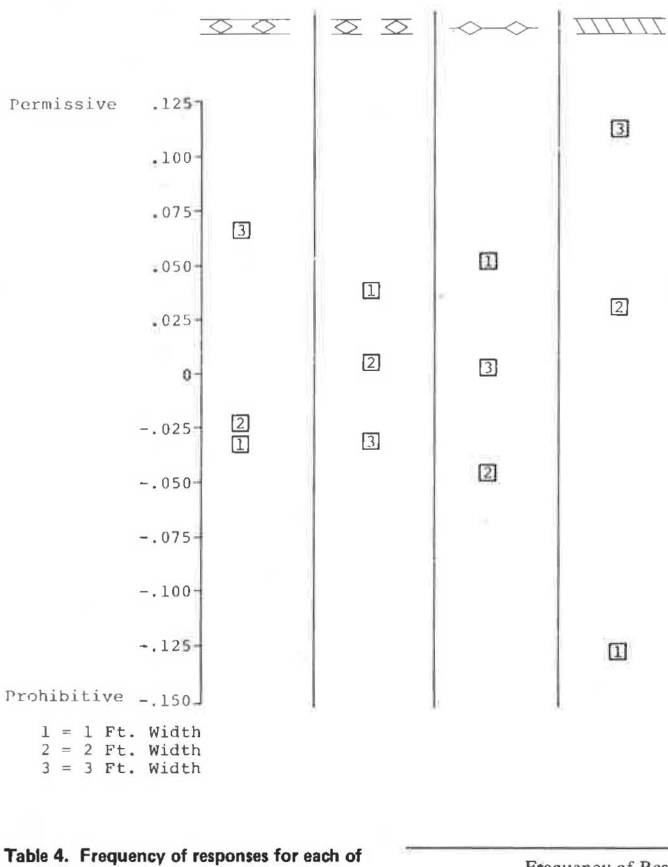


Figure 2 diagrammatically shows the scale values obtained for each of the four designs. Scale values are arbitrary numbers, amenable to transformation. However, the total distance between widths, even in the most separated condition--treatment 11 (the crosshatch design)--is not great in comparison with the wide scale obtained in the previous study (Table 2). In scanning across each treatment, the more crucial issue is whether any one width is more permissive or prohibitive than any other, and simple inspection reveals almost totally random results for the widths tested. So the 1-, 2-, and 3-ft widths have essentially the same effects, and thus the cost-effective, space-saving, 1-ft image is acceptable for use. In fact, it is desirable to avoid the wider widths because they may have a tendency to indicate to drivers a shoulder or breakdown area, especially the crosshatch design.

The data from the questionnaires replicate previous data quite well. Table 4 gives the frequency of response for each of the four treatments. The six questionnaire responses form a loose scale ranging from open, permissive connotations to assorted restrictions and ending with "Keep out" or "I don't know." The number of the behavior alternative (1, 2, etc.) is multiplied by the response frequency, summed for each row, and divided by N to yield a weighted mean. This indicates a ranking of permissiveness, since the lower the weighted mean, the more permissive is the meaning of the treatment. Thus, the dash-diamond treatment (treatment 8) is the most permissive delineation, followed in order by the connected diamonds (treatment 9), the crosshatch (treatment 11), and the solid lines with embedded diamonds (treatment 6).

Figure 2. Paired-comparison scale values: field study.



A final task for the test subjects was to rank order the four design treatments from best to worst (1 to 4) as delineation treatments for special-use lanes. In this case, the frequencies of selection for each rank per treatment are tabulated. Weighted rank sums are then computed (rank is multiplied by frequency and then summed for each treatment) to give an overall ranking for each design. Table 5 gives these rankings and the resultant ranking of the four designs based on these data.

This method of assessing the effectiveness with which a delineation design conveys the intended meaning clearly corroborates both the paired-comparison and questionnaire findings. Treatment 9 (the diamond design with a dash pattern) was judged least effective in conveying the meaning of special or restricted lane use. Treatment 6 (the double solid line with diamonds) and treatment 11 (the crosshatch design) were judged very similar in effectiveness. A closer look at the data for the crosshatch treatment reveals that many observers ranked this design as best but a surprisingly high number ranked it as worst. This suggests that the crosshatch may be so strongly prohibitive that the special-use connotation is masked for almost one-third of the subject drivers. During the test drive, many drivers volunteered the thought that they felt more comfortable with a "diamond look" to indicate special lane use and felt that they might belong in the lane only if there were some signs or other explanations as to what the diamonds meant.

LABORATORY STUDY

Method

The laboratory study was concerned with determining the effects of stroke-element density--i.e., whether the number of diamonds or line elements within a given area would affect the driver's decision as to whether to cross over the delineation line. The paired-comparison, forced-choice technique was again used. Eighteen delineation designs of varying densities were paired against each other, and subjects indicated which of each pair they would sooner cross.

The delineation treatments were drawn on acetate sheets and overlaid on an artist's rendering of a three-lane highway. The 18 treatments were generated by using the four basic designs tested in the field study. The ratio of number of elements to gap was considered at three levels for each of the four treatments: 12-ft spacing (ratio of 2:1), 24-ft spacing (ratio of 4:1), and 36-ft spacing (ratio of 6:1). The remaining 6 design treatments considered

Table 4. Frequency of responses for each of six driving behaviors for four delineation treatments: field study.

Treatment No.	Frequency of Response: Pass and Travel Freely	Turns and Exits Only	Repair or Emergency Lane	Special-Use Lane	Do Not Use	Don't Know	Weighted Mean
6	6	4	8	6	0	14	24.3
8	18	3	5	3	1	9	18.3
9	1	8	7	8	2	9	22.3
11	2	7	9	6	8	6	23.8

Table 5. Frequency of responses ranking each of four delineation treatments from best to worst: field study.

Rank	Treatment 6	Treatment 8	Treatment 9	Treatment 11
1	10	4	2	14
2	14	7	4	5
3	6	9	12	3
4	0	9	12	8
Weighted sum[a]	56	81	94	65

[a]Lowest number is closest to "best".

represent a breakdown of the crosshatch design by color (bright yellow-green and light blue) for the three element spacings. This was done to determine the impact of color on the prohibitiveness of the crosshatch design, which was perceived as strictly prohibitive by study subjects.

The acetate overlays were placed on the three-lane highway painting, each paired against each other. This yielded a total of 153 pairs, which were photographed as 35-mm slides. Figure 3 shows samples of these slides. The resulting stimulus slides were shown in random order to three groups of subjects by using a tachistoscope with a 1-s exposure and a 5-s stimulus interval. As each slide was presented, subjects simply checked on their response sheet "left" or "right" to indicate which line they would sooner cross to bypass a center-lane blockage.

In addition, subjects filled out a questionnaire on the four delineation designs they had just seen, answering the same questions given to subjects in the field study. Subjects were required to check which driving behaviors seemed appropriate for each design and to rank the designs from best to worst according to how well they connoted a special-use lane. The entire test procedure, slides and questionnaire, took about 25 min.

Twenty-eight subjects from the State College, Pennsylvania, area participated in the study. There were 17 males and 11 females, ranging in age from 18 to 59 years.

Results

The paired-comparison data were first summarized in a table of proportions and subsequently transformed to traditional scale values for each of the 18 treatments. Figure 4 shows the scale and where each of the treatments falls on it. The scale ranges from permissive (promoting crossover) to very prohibitive (discouraging crossover). Although the scale numbers are arbitrary, the distance between values is meaningful in clustering and ordering the designs.

Several conclusions are clearly evident from the scale data:

1. The dash design with the embedded diamonds (treatment 9) is perceived as the most permissive, and the diamonds connected by a single line (treatment 8) is the next most permissive. Both are characterized by a thin, broken look. All six of these treatments, regardless of element (diamond) density, are above the zero point, which indicates permissiveness. The crosshatch treatments (treatment 11) of varying density and color, as well as the diamonds embedded between two solid lines (treatment 6), all cluster below zero on the scale, which indicates that they act to prohibit lane change. This directly validates previous findings.

2. Within the scale separations for permissiveness and prohibitiveness by design, each design becomes more prohibitive within its own space as the density of stroke elements increases. Thus, the most open dash treatment, the diamond-dash combination (treatment 9), is at the very top; and the tightly spaced, white crosshatch ladder design is at the very bottom, well separated from the initial prohibitive cluster.

3. No appreciable effects or advantages can be seen in the use of color; it seems to promote some relative indecision but generally does not affect perceptions of permissiveness. Its merit apparently lies in its being a cue to the driver to associate it with other available information, such as signing. Several subjects commented on this point.

The questionnaire data were taken exactly as in the field study. Subjects first checked which of six driving behaviors was appropriate for each of the four delineation designs and then ranked these from best to worst according to how well they connoted a special-use lane. This was, in a sense, the final validation of results from previous studies. Although the data do not provide a perfect match, the differences do not appear to be meaningful.

Table 6 gives the frequency of responses to each of the six behavior statements by treatment design. Response frequencies for the six types of behavior again formed a loose scale, from permissive to prohibitive to "I don't know", and were again transformed into weighted means for each design. The most permissive designs were the diamond-dash combination (treatment 9) followed by the diamonds connected by a single line (treatment 8). More prohibitive was the embedded diamonds within two solid lines (treatment 6), and the most restrictive design was the crosshatch (treatment 11). All treatments with solid lines were perceived as restrictive in some way. Except for the diamond-dash treatment, the diamond options are more associated with a special-use lane. The dash design again diminishes the effects of the associative meaning of symbols and conveys the more important factor--namely, "The line is dashed, so I can cross it." The crosshatch image is strongly prohibitive: None of the respondents elected the pass-and-travel option in the presence of a crosshatch design, and most (46 percent) responded "Do not use." For all of the connected treatments, especially the crosshatch, one-quarter to one-third of the subjects indicated that the lane could be used for emergency repair, a factor that needs further study.

Table 7 indicates the frequency with which the four delineation treatments were assigned to each rank, from best to worst, and the weighted sums computed. This is the same procedure used in the field study.

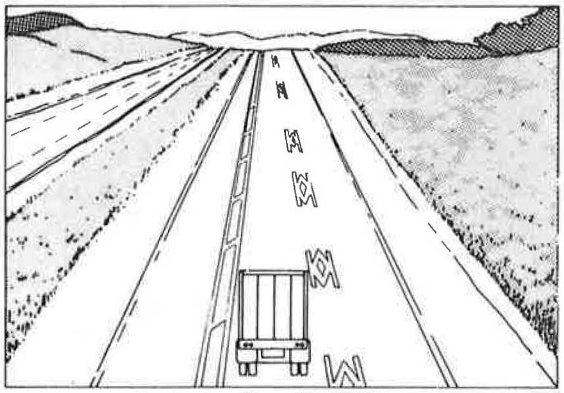
The crosshatch design (treatment 11) was ranked best of the four design alternatives, and the solid double lines with diamonds (treatment 6) a clear second. This is the reverse of the rankings from the field study. Is the switch in position a chance fluctuation, or is it related to the difference between real-life experience (full size and perspective) and exposure to artist-rendered image stimuli? Only further empirical work can provide the answer.

The single solid line with diamonds (treatment 8) was ranked third, and the dash pattern with diamonds (treatment 9) was ranked least effective in conveying the meaning of restricted or special use.

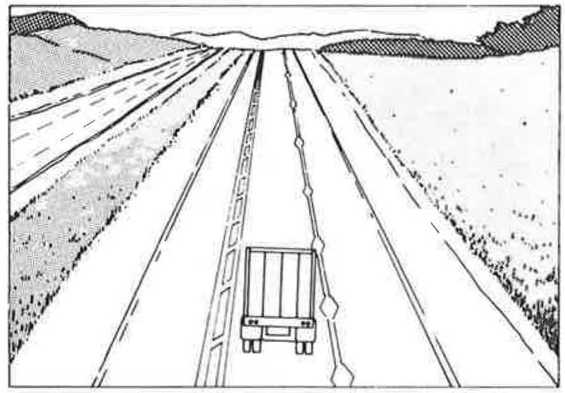
SUMMARY AND CONCLUSIONS

The two components of this study, the field setting and the laboratory setting, produced reliable findings regarding delineation width and element

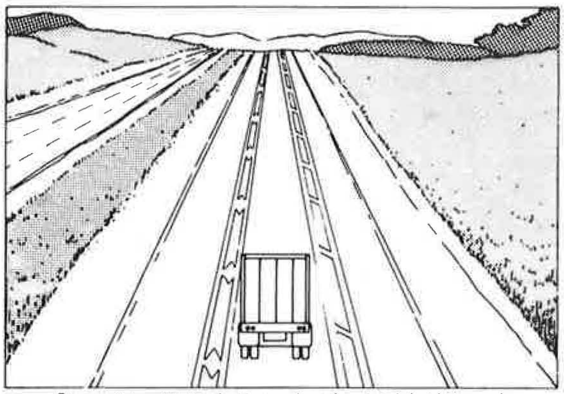
Figure 3. Sample stimulus pictures used to test the effectiveness of element density in delineation designs.



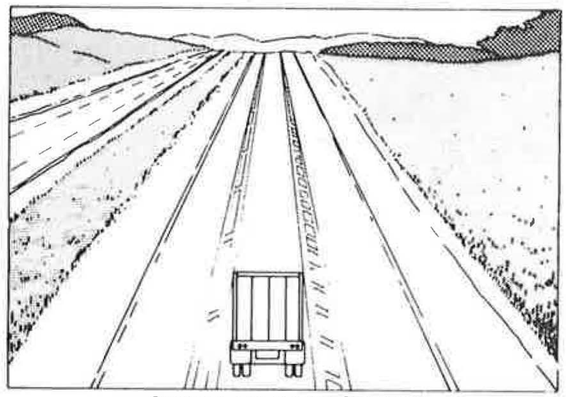
Crosshatch vs. Diamond Dash - Widest gaps



Crosshatch (mid-size gap) vs. Connected Diamond - Shortest gap

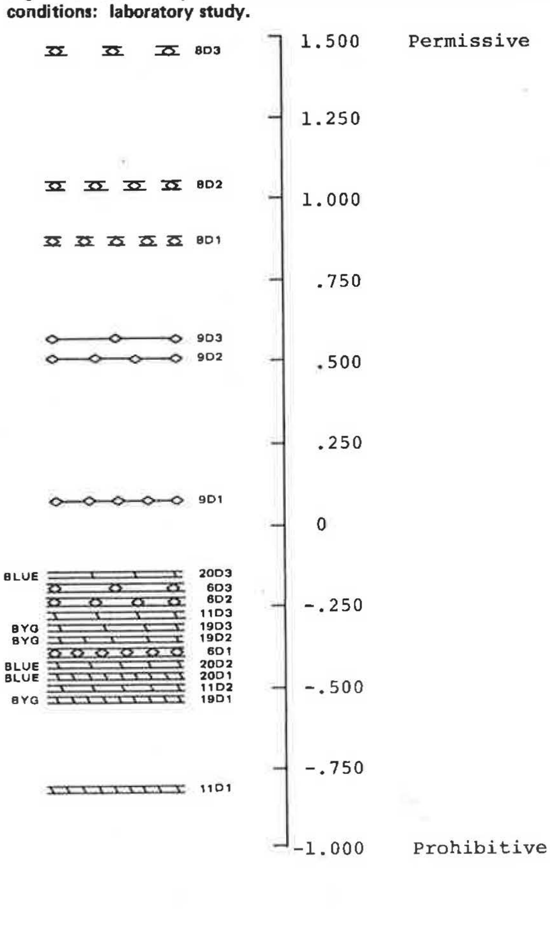


Diamonds in solid line (widest gap) vs. Crosshatch (mid-size gap)



Crosshatch - Widest gap vs. Shortest gap

Figure 4. Paired-comparison scale values for each of 18 delineation-treatment conditions: laboratory study.



density. In the field, 1-, 2-, and 3-ft widths were found to be relatively interchangeable in terms of design permissiveness and prohibitiveness. In the laboratory, element density was shown to be an important determinant of permissiveness in that the delineation treatments with more widely spaced elements tended to invite crossover more than the treatments in which the elements were closer together.

In addition to these primary findings, the questionnaire and ranking data produced highly complementary results. One part of the study validated the other, and both in turn validated the previous study. This is particularly meaningful because the subject samples were drawn from two different geographic areas and represented a wide range in age and an almost even male-female split. Given such a stratified random sample and reliable data, it is felt that the results can be applied not only as inputs to final delineation designs for special-use lanes but also as general design parameters in the application of roadway markings.

The conclusions drawn from each component of the study are presented separately below.

Field Component

1. There is no appreciable difference in the prohibitive effects of 1-, 2-, and 3-ft widths for the four delineation treatments tested.

2. The dash-diamond treatment is the most permissive in terms of driver tendency to cross. This replicates findings from a previous study that revealed the tendency of a skip design to promote crossover.

3. Striping with diamonds connected by a single

Table 6. Frequency of responses for each of six driving behaviors for four delineation treatments: laboratory study.

Treatment No.	Frequency of Response: Pass and Travel Freely	Turns and Exits Only	Repair or Emergency Lane	Special-Use Lane	Do Not Use	Don't Know	Weighted Mean
6	1	9	6	8	4	4	18.8
8	14	5	4	1	0	7	13.6
9	7	9	6	4	0	4	13.8
11	0	1	8	3	13	4	21.1

Table 7. Frequency of responses ranking each of four delineation treatments from best to worst: laboratory study.

Rank	Treatment 6	Treatment 8	Treatment 9	Treatment 11
1	5	1	1	2
2	14	6	1	4
3	4	15	10	0
4	1	6	17	3
Weighted sum[a]	53	82	100	41

[a]Lowest number is closest to "best".

line or with diamonds embedded between solid lines is seen as associated with a special-use lane.

4. The special-use association of the diamond is apparently diminished somewhat when the diamond is part of a skip design.

5. The crosshatch (or ladder) type of striping is most effective in prohibiting drivers' tendency to cross. This also replicates previous findings.

6. There is some difference among various observers as to whether the prohibitiveness of the crosshatch design is necessarily associated with the concept of the special-use lane. Further investigation of this is warranted.

Laboratory Component

1. The more elements per length of line in a delineation treatment, the more prohibitive the treatment is.

2. Designs with a broken, thin look remain the most permissive to drivers, regardless of the symbology used.

3. Solid, connected delineation lines with embedded diamonds or crosshatching are a highly effective prohibitor of lane change.

4. Color does not appreciably affect the prohibitiveness or permissiveness of delineation markings but could trigger associative meanings if accompanied by signing. Further testing is needed.

5. Questionnaire and ranking data on the four designs tested correlate well with the results from the paired-comparison trials and previous experimental studies.

6. The crosshatch design must be tested further in the field to determine its true effectiveness as a prohibitor of lane change and its potential for association with the concept of the special-use lane.

ACKNOWLEDGMENT

The research reported in this paper was conducted by BioTechnology, Inc., under contract to the Federal Highway Administration (FHWA). Alfred Klipple of the Traffic Systems Division, FHWA Office of Research, served as contract technical manager.

We also wish to thank officials of the Maryland Department of Transportation for their cooperation in allowing the use of closed sections of roadway off I-95N in Maryland.

REFERENCE

1. J. P. Guilford. Psychometric Methods. McGraw-Hill, New York, 1954, Chapter 7.

Publication of this paper sponsored by Committee on User Information Systems.