

These Digests are issued in the interest of providing an early awareness of the research results emanating from projects in the NCHRP. By making these results known as they are developed and prior to publication of the project report in the regular NCHRP series, it is hoped that the potential users of the research findings will be encouraged toward their early implementation in operating practices. Persons wanting to pursue the project subject matter in greater depth may obtain, on a loan basis, an uncorrected draft copy of the agency's report by request to the NCHRP Program Director, Highway Research Board, 2101 Constitution Ave., N.W., Washington, D.C. 20418

## Roadway Delineation Systems

 An NCHRP staff digest of the essential findings from the final report on NCHRP Project 5-7, "Roadway Delineation Systems," Prepared by James I. Taylor, The Pennsylvania State University, and Robert S. Hostetter, Institute for Research, State College, Pennsylvania.

### THE PROBLEM AND ITS SOLUTION

Vehicles running off the road constitute a substantial portion of the accidents on the nation's highways. This research presents information that will assist highway and traffic engineers in providing improved pavement and roadway delineation systems to aid drivers in guiding their vehicles. Thus, the safety aspects of the highway will be improved and the driving task will be eased, especially during adverse weather conditions and at night.

Recommendations for applications of delineation treatments at horizontal curves, no-passing zones, pavement width transitions, merge and diverge areas, turns, and stop approaches are provided. Uses of pavement markings, post delineators, and raised pavement markers were investigated in considerable detail. In addition, attention was also directed toward colored pavements, rumble strips, indirect delineation by means of contrasting shoulders, and systems of delineation treatments.

This research produced the following:

1. A comprehensive state-of-the-art summary, synthesizing information gathered from the literature and interviews with highway engineers from various states and several foreign countries.
2. A definition of the driver's delineation requirements in various highway geometric situations.
3. The formulation of several basic concepts of delineation, with field test data to substantiate their validity.

4. An assessment of the effectiveness of various techniques for the evaluation of delineation treatments and systems.
5. A set of Guideline Forms for use by highway engineers in the decision-making process regarding future delineation treatments.
6. Recommendations for delineation of a number of "classic" geometric situations.

The agency's final report is structured such that it is easily approachable from the situation-specific standpoint. It is relatively simple to proceed from one section to another and derive the information pertinent to a specific situation. That is, if the problem is to delineate a horizontal curve, one can easily assess the delineation requirements for this situation, determine the current practices and state-of-the-art, and locate the project findings and recommendations relevant to this situation. This research stands alone and does not have to be combined with the results of other research to be useful. The research results are defined explicitly enough to permit direct application to practice.

### FINDINGS

This project encompassed a large number of laboratory and field experiments to validate basic roadway delineation concepts and to compare alternative treatments in various geometric situations, both day and night. The findings from these individual studies are included in the final report, complete with descriptions of the experimental designs, the data, and the statistical analyses employed. The general findings and conclusions of the research follow:

- (1) The literature review, the discussions with other researchers and practicing highway engineers, and the studies conducted within this project all indicate that the major benefits derivable from delineation, in terms of accident reduction potential, can be obtained through more consistent widespread application of standard treatments. Data from external long-term investigations indicate that statistically significant reductions in accident rates can be obtained through the application of delineation treatments where there were previously none--i.e., presence vs absence of specific delineation treatments can be related to accident rates.
- (2) Establishment of a Delineation Task Force is likely to be the single "best move" by any state highway department in the field of delineation. This Task Force is essentially a diagnostic team, and the advantages and limitations of this approach are outlined in the project final report. The group should meet at regular intervals, and be continuing in nature. This will permit evaluation of large numbers of diverse test installations and, perhaps most important of all, provide the impetus for continuing study of delineation problems within the state.
- (3) Reliance has been and will remain on subjective evaluation methods, because the accident reduction potential is nearly the same for all treatments in the same class, and the non-accident factors are subjective by nature. The lack of a valid, reliable, and data-feasible cost-effective methodology is a further constraint on objective evaluation. Cost-effectiveness techniques can be used as aids in the decision-making process, but it will

be difficult to arrive at convincing benefit/cost ratios if only direct "hard" benefits are included. In general, it will be better to use an approach similar to that in the Guideline Forms described under "APPLICATIONS" than to attempt to assign dollar values to the various indirect, intangible benefits.

- (4) Major changes in delineation treatments in specific situations can produce measurable changes in intermediate effectiveness criteria. The intermediate measures include erratic maneuvers and the means and variances of various traffic performance measures, such as speeds, lateral placements, and points of brake application. It is hypothesized that the installation of treatments that reduce the number of erratic maneuvers and/or the variances of the traffic performance measures (indicating more uniform driving performance) will lead to a lower accident frequency. Hence, the relative effectiveness of major alternatives in delineation treatments can be evaluated through these intermediate measures.
- (5) The intermediate effectiveness criteria are not sensitive enough to measure the effects of minor variants within treatments (spacing, brightness, most color codes, differences in materials, etc.). Diagnostic teams and driver surveys inherently evaluate factors other than accident reduction (e.g., driver ease and comfort, message clarity, aesthetics). Thus, it is possible to use these techniques to determine the relative "effectiveness," in terms of these latter factors, of minor variants in the treatments.
- (6) In designing and specifying delineation treatments and systems, there should be far greater concern for compliance with basic roadway delineation principles than with minor variations in the treatments.
- (7) Inasmuch as variants in treatments do not measurably affect their effectiveness as accident reduction measures, least-cost solutions should receive more attention. More expensive variants of the treatments must be, and may well be, justified on other bases.

## APPLICATIONS

As a result of this research, the following specific concepts and conclusions are presented. These recommendations can be applied by traffic and maintenance engineers when designing new or upgrading old roadway delineation systems. The applications presented are ready for direct implementation and they have already been translated into the working tools familiar to the highway engineer. The research results have been evaluated sufficiently to insure a high probability of success when applied to practice.

The two principal products, "Guideline Forms" and "Treatment Recommendations," will be of immediate use to highway and traffic engineers.

### Guideline Forms

A methodology for arriving at solutions to delineation problems has been developed, and specific checklists and worksheets for each of the "classical"

geometric situations are provided in the final report. A schematic diagram summarizing the interrelationships among the various informational inputs and Guideline Forms is shown in Figure 1.

Due to the wide variety of situations, treatment properties, and indirect benefit considerations inherent in the selection of delineation systems, the methodology must rely on subjective judgments--hard data simply do not exist to formalize and quantify the complex interrelationships.

The Guideline Forms are constructed in such a manner that they can be used to arrive at solutions to problems ranging from state-wide policy down to treatment of a specific site. They will aid in selecting one treatment from many (e.g., pavement parkings, post delineations, raised pavement markers, colored pavements); selecting configurations of a specific treatment (e.g., post delineators: one-side vs both-sides, amber vs crystal, alternative spacings); or selection of treatment systems (e.g., use of pavement markings and post delineators vs raised pavement markers).

### Treatment Recommendations

The recommendations, much abbreviated for this Digest, are presented by geometric situation with the exception that comments that are relevant across several situations (e.g., regarding edge lines) are included in the first section--Tangents.

#### Tangent and General Situations

##### Pavement Markings

- , The gap-to-gap ratio for center lines should be increased from the present standards.
  - , A savings in paint material costs would result.
  - , England has used a 3-ft mark with a 24-ft gap for several years. (See Fig. 2.) This pattern was derived through laboratory simulation tests to study visual acceptance by drivers. It was also ascertained that the "flicker" rate for this pattern was satisfactory.
  - , A study within the project, using a 5-ft mark with a 35-ft gap (retaining the basic 40-ft module), with and without edge lines, indicated no meaningful changes in vehicle speeds or lateral placements. (See Fig. 3.)
  - , From a human factors standpoint, the number of mark "ends" observed is of relatively more significance than the length of the marks--i.e., the shorter marks are almost as strong, because the number of "ends" per unit length of roadway is the same as for the standard patterns. In fact, the English pattern, with its shorter module, provides more "ends" with approximately the same amount of paint as used in the experimental study--approximately 1/3 of the paint in the standard pattern.
  - , The adoption of a "weaker" broken-line pattern in areas where it serves only to mark the center line of the road

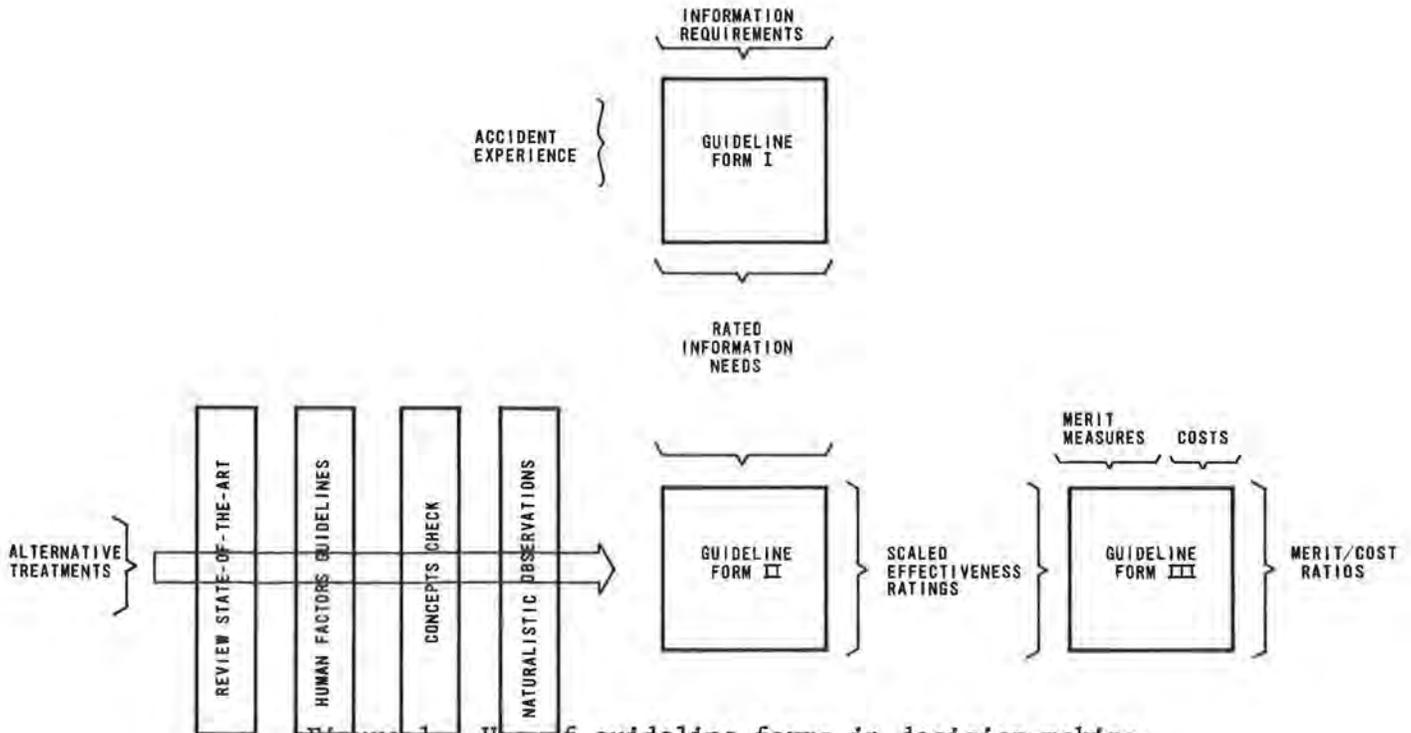


Figure 1. Use of guideline forms in decision-making.

will permit the use of "stronger" broken lines in areas where special caution may be required but crossing the line is still permitted. (See Fig. 4.) This concept has been used extensively and successfully in England and some other European countries. A 4-in. line, with 20-ft mark to 10-ft gap is suggested for the United States.

- Continuous edge lines should be placed on all roads over 22 ft in width, where traffic volumes justify the expenditure. It is particularly important where shoulders are bad. Long-term research studies tend to indicate that a reduction in accident experience will be achieved with the installation of edge lines, but the studies are far from conclusive. In this matter, however, there seems little doubt that the public will demand the edge lines, and the expenditures should be made even if comparable savings from accident reduction cannot be assured.
- The present 4-in. width should be retained for center lines and edge lines in the general case.
- Various widths of lines were installed in a study in England--they concluded that the 2-in. line was unacceptable from an appearance standpoint; the minor irregularities in alignment showed up clearly, and the lines appeared wavy. On the other hand, 6-in. lines just provided "more of the same" when compared to the 4-in. lines and the additional paint costs did not seem justified.
- Eight-inch lines, solid and broken, could be used for special applications where crossing is permitted, but the driver should be aware that he is entering a non-standard zone--e.g., climbing lanes (See Fig. 5 ), approaches to lane-drop exit



Figure 2. Broken center line pattern, England (3-ft mark; 24-ft gap).



Figure 3. Test broken center line pattern (5-ft mark; 35-ft gap).



Figure 4. Change in strength of broken center line pattern, England.



Figure 5. Use of 8-in. broken line for climbing lane situation.

ramps, etc. A pattern of 10-ft mark, 10-ft gap is recommended.

- For the wide two-lane roads encountered in the West, the 4-ft median being tested in Texas appears to have considerable merit. (See Fig. 6.) No research in this area was conducted within the project.
- Under present-day relative cost conditions, the use of thermoplastic paints is restricted to special situations. They can be used in high wear areas particularly where periodic absence due to wear cannot be tolerated. Most of these situations occur in urban areas, rather than on rural highways.
  - The strongest arguments for thermoplastics are that they are available for a larger percentage of the time than painted lines, and that traffic need not be interrupted as frequently as with paint lines.
- Drivers prefer a two-line delineation system to a single line. This, in part, explains the strong preference for edge lines. Hence, no matter what treatment is used as a center line, it will be desirable to use a second line--either an edge line or a line of post delineators.

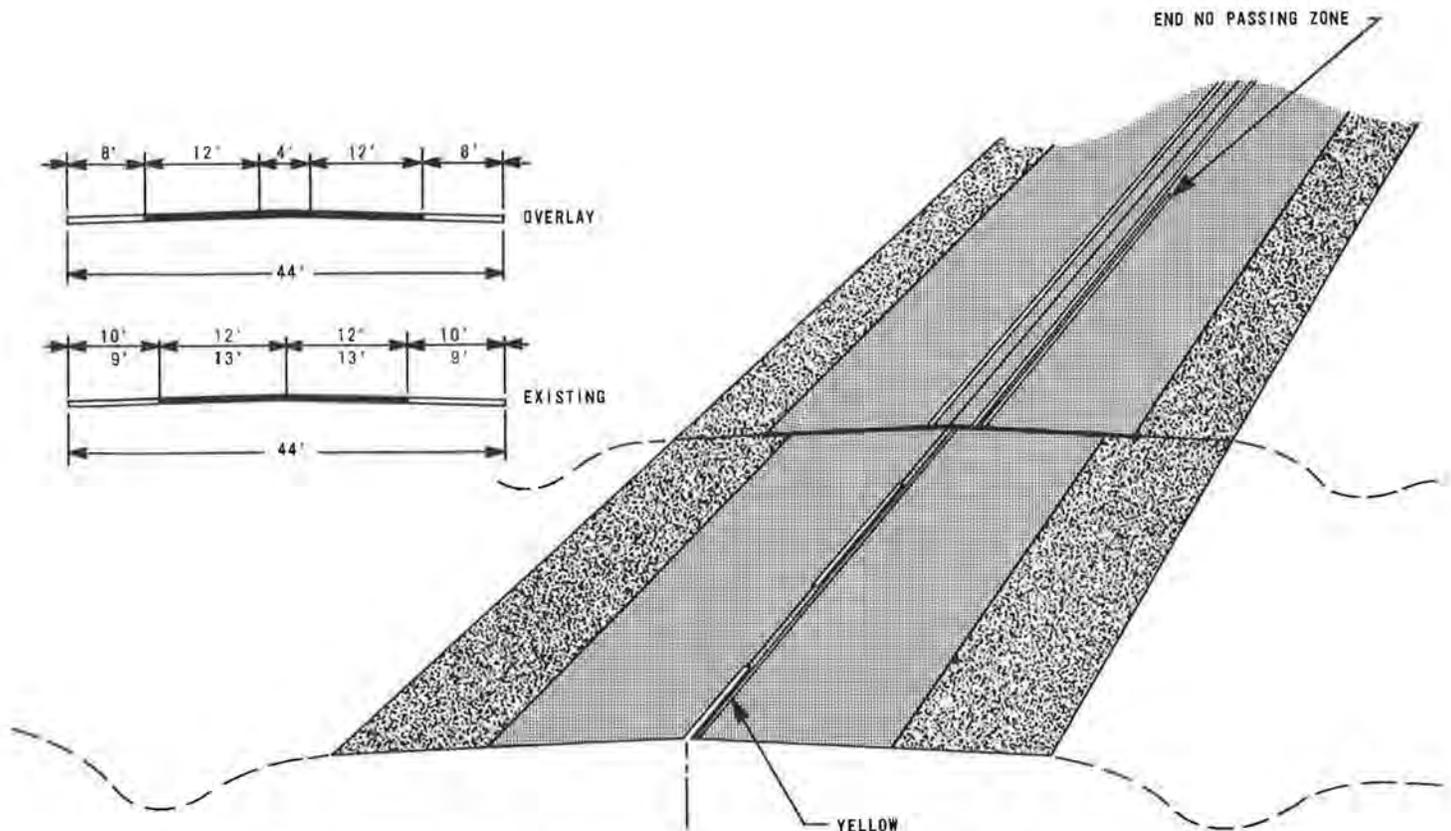


Figure 6. Pavement marking technique for wide two-lane roadways, Texas.

### Post Delineators

- , Post delineators should be installed along the right side of two-lane rural roads. A spacing of 400 ft is adequate, as the delineators serve simply as indicators that the roadway alignment is straight immediately ahead. A further stipulation is that three delineators should be visible at all times; this may necessitate somewhat closer spacing on winding, hilly roads.
- , Crystal, or white, delineators should be used on tangent sections.
- , The standard retro-reflective delineators, usually amber, should be removed from culvert markers, etc. ("negative" delineation) when the crystal delineators are used for "positive" delineation, as recommended above.
  - , The tops of the posts should be painted with reflectorized paint. This will make the posts visible to maintenance crews, but, because of their low intensity, they will not detract from the positive delineation pattern for the average driver.
- , The "negative" delineators should not be removed when the positive delineation pattern is not employed. Even though not standard in application, they do give the driver some indication of the roadway alignment ahead.
- , Guardrails on tangent sections need not be marked in a special manner if the general positive delineation pattern is in force (additional markers at the ends of the guardrails will not be distracting if they are in line with the others and are crystal in color).
  - , Again, if the general positive delineation is not being used, marking of the guardrails is a good idea.
  - , The "paddles" used in some states for daytime delineation are of limited usefulness, and should not be installed. In daylight these serve little purpose, as there are enough other natural cues to inform the driver of the roadway alignment. In addition, they are aesthetically unattractive--without them, the post delineators are nearly invisible during the day (as they should be). (See Fig. 7.)
  - , Emphasis should be shifted to the use of post delineators on rural roads, instead of on high-type facilities. Sudden changes of alignment and uncertainty of the roadway path are most prevalent on the two-lane roads.

### Raised Pavement Markers

- , Standard pavement paint lines should be simulated (pattern and color) when raised pavement markers are used for daytime conditions.



Figure 7. Paddles for daytime delineation (use is discouraged).

- Ceramic markers are the most effective during the day.
- A spacing of 3 or 4 ft will simulate a solid line (or the solid part of a broken line). (See Fig. 8.)
- It is not necessary to simulate broken lines with raised pavement markers at night; solid lines should appear "solid" at night, as well as during the day, however.
  - For lane lines and other broken lines, a spacing of 80 ft is sufficient; this can be reduced to 40 ft in "warning" areas where crossing is permitted, but discouraged.
  - High-intensity markers (e.g., Stimsonite 88) spaced at 24 ft will give the appearance of a solid line at night (see Fig. 9); a spacing of about 6 ft is required if low-intensity markers are used. The first type derive their strength from brightness; the latter type from density.

- , An acceptable pattern of raised pavement markers for right edge lines has not been reported in the literature, and the project's experiments did not include consideration of the markers for right edge lines.
- , The principal advantage of raised pavement markers is that they provide both near and far delineation; limited somewhat by the vertical profile of the road.
  - , As compared with painted lines for near delineation, the principal advantage is the increased visibility, particularly on rainy nights. In areas where snowplows operate, the standard types are destroyed. Snowplowable markers are available. To date, the purchase and installation costs are relatively high, and service lives are not adequately documented. Development is continuing.
  - , As "far" delineation, the principal advantage over post delineators is the correspondence of the line of raised pavement markers to the road surface; the principal advantage of post delineators is that they are visible over longer distances, particularly at crest vertical alignments.

### Horizontal Curves

#### Pavement Markings

- , No changes in the standard markings at horizontal curves are suggested, except that if a more open broken-line pattern is adopted, a warning line (increased mark-to-gap ratio) could be used at gentle curves and on approaches to the no-passing areas on curves.
- , If pavement width is sufficient, the addition of edge lines (on roads where they do not exist on the tangents) will improve lateral placement characteristics, with possible reduction in accident experience.
- , Pavement markings are good near delineation devices, but supplemental treatments with longer visibility distances are required to supply anticipatory information.
- , A two-line system is desirable for near delineation on horizontal curves. This could consist of two pavement lines (center line and edge line) or a combination of pavement markings and some other treatment.

#### Post Delineators

- , The most effective pattern, from the visual standpoint, is the use of post delineators on the outside of curves only. (See Fig. 10.)
  - , Amber delineators are recommended for right curves (left side of roadway) and crystal for left curves (right side of roadway).

- , When post delineators are used on both sides, the pathway will be much clearer if the two-color system is used.
- , It is possible that many drivers would learn the color code with time, and recognition of the direction of the curve will increase their anticipatory information. Continued use of amber delineators at culverts, etc., on both sides of the roadway weakens this code considerably.
- , A post delineator spacing of  $3 \sqrt{R-50}$  on curves is adequate.
- , Maintaining maximum delineator brightness is not really critical in terms of provision of direct accident-reduction information--the necessary driver actions can easily be taken after delineation is visible, if nominal brightness is still available. However, increasing anticipatory information will ease the driving task, and benefits from this factor will result. This should not be construed to imply that cleaning is unimportant, as heavy dirt films can reduce the brightness below an acceptable value.
- , Consistent application is desirable--post delineators should be used at all curves over  $5^\circ$ .

#### Raised Pavement Markers

- , No change is necessary from the patterns of raised pavement markers used on tangent sections, other than the use of solid lines in no-passing areas of curves. Again, a stronger line (derived through closer spacing) than on the tangent could be used at gentle curves and approaches to solid-line sections.
- , Raised pavement markers can be a very effective supplemental treatment on curves on two-lane roads where the expense may not be justified on the tangent sections. (See Fig. 11.)
  - , They serve as far delineation, with good visibility distance and correspondence to the roadway path.
  - , They are excellent near delineation treatments, providing strong improvements in lateral placement patterns.
- , The color of the raised pavement markers should be the same as the pavement markings they are supplementing.
- , Where raised pavement markers have been used, they have been popular with the driving public.

#### Rumble Strips

- , On sharp curves where an accident problem exists, use of transverse rumble patches is recommended. (See Fig. 12.)
  - , Patches consisting of a series of transverse spray thermoplastic strips, 6 in. wide with 6-in. spacings, are effective and not objectionable.

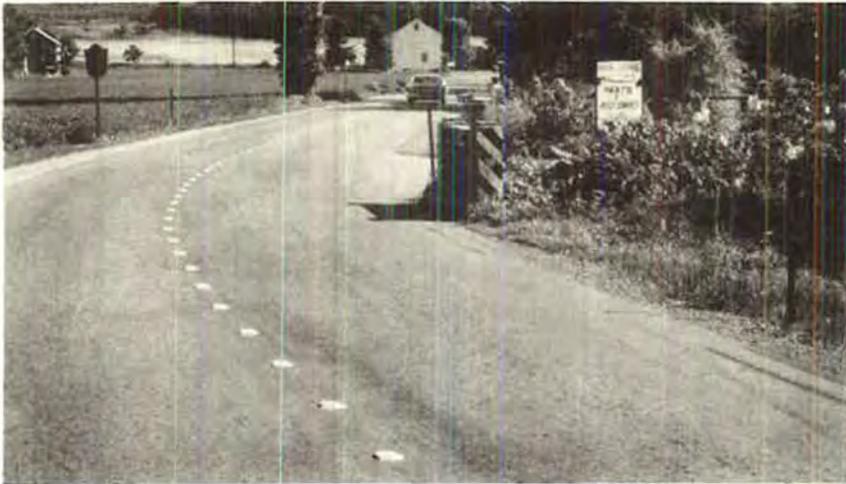


Figure 8. Simulation of solid line with raised pavement markers.

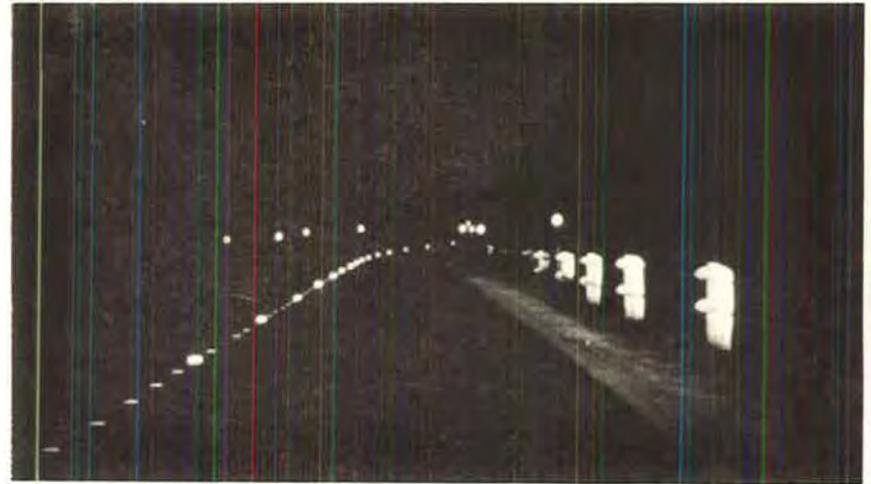


Figure 9. Non-reflectORIZED raised pavement markers spaced at 4 ft, with high-intensity markers spaced at 24 ft.



Figure 10. Post delineators at horizontal curve to the left--outside only.

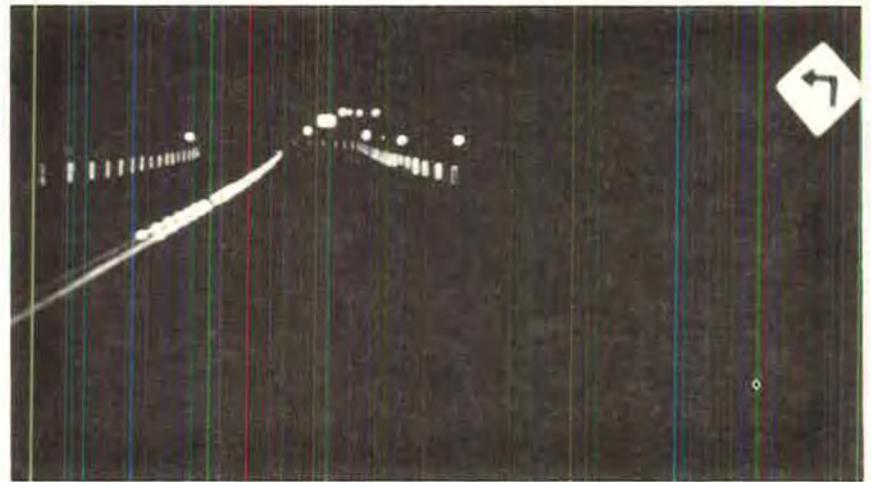


Figure 11. Raised pavement markers at a horizontal curve.

- , These lines hold up well under snowplowing.
- , A set of three of the "patches" on each approach is suggested.

### No-Passing Zones

#### Pavement Markings

- , Use of the transitional marking is recommended--i.e., a relatively open broken line should be used where passing is permitted, changing to a stronger line on the approach to a no-passing area, and then finally to a solid line. (See Fig. 4.)

#### Raised Pavement Markers

- , The colors of the markers used should agree with those used for standard painted pavement markings, so that the treatment can be easily and unmistakably identified.

### Pavement Width Reductions

#### Pavement Markings

- , Painted arrows in the lane being dropped are recommended.
- , Edgelines should be continued, or added if non-existent on the approach.
- , The use of heavy lines (8 in. wide, with 10-ft mark and 10-ft gap) will be helpful on approaches to the lane-drop ramp situation. (See Fig. 13 for concept; dimensions are not those given here.)

#### Post Delineators

- , Shortening of the spacing of post delineators in the area of the pavement width reduction will emphasize a feeling of constriction, and changing the color (from crystal to amber under present usage) will provide advance warning of change.
- , Use of post delineators on both sides of the road will further emphasize constriction, and promote slower and more attentive approaches.

#### Colored Pavement

- , Solid yellow-colored pavement is effective in moving traffic off the paved areas during daylight hours. The principal problem is low visibility at night, and degradation of color with weathering.

#### Rumble Strips

- , Transverse rumble strips can be used to outline the taper area where a reduction in pavement width occurs--i.e., rumble would be felt when drivers left the proper path.
- , The rumble strip treatment should be used primarily as a supplement, where problem persists after other treatments have been installed.

## Merge and Diverge Areas

### Pavement Markings

- , Discontinuous lanes (such as acceleration and deceleration lanes) should be separated from the through lanes with heavy broken lines--e.g., 8 in. wide; 10-ft mark with 10-ft gap. (See Fig. 13.) Thermoplastic markings should be given consideration for this application, as heavy wear will be encountered.
- , The heavy markings should be carried clear across the throats of exit and entrance ramps. This is especially important when ramps enter or leave a curve section of highway, as these lines can provide continuity of the edge line for the through driver.
- , The heavy broken line should also be used on the last 500 ft before the gore of other diverge areas, and on the first 500 ft of merged roadway, to indicate lane changing is discouraged, but not forbidden.
- , Painted gore markings at exit ramps should be heavier than standard lines--8- or 12-in. lines are suggested. (See Fig. 14.)

### Post Delineators

- , Delineators on ramps should have a different color from those used for the through lanes. Amber is generally used, but has the disadvantage that it is used for other purposes as well. Hence, the message is not unique and other cues are required before a driver is certain of the "message." Several states have experimented with blue post delineators (and raised pavement markers) for delineation of ramp areas, and are generally satisfied with the results.
- , Through-way delineation should be strengthened in exit ramp areas--i.e., the post delineators added to the left side of the roadway if there are none. Frequently, only the standard tangent delineation is used and it is difficult to discern the through-way in the presence of the much stronger exit ramp delineation.
- , An important cue in exit ramp situations is the color change at the point of the gore.
- , Similarly, a change in color of the post delineators is an important cue at the end of a merging area, as it indicates that the conventional cross-section has been reestablished.

### Raised Pavement Markers

- , Where they can be used, raised pavement markers are an excellent treatment for diverge gore areas. (See Fig. 15.) They may be color coded to indicate a changing situation.
- , It is important to delineate the edge line of the through road on the approach to, and a short distance past, the gore or end of the merging lane to define the total geometry.
- , Raised pavement markers should be supplemented with post delineators on vertical crest sections, which occur rather frequently in merge-diverge situations.



Figure 12. Rumble strips at a horizontal curve.



Figure 13. Pavement markings at lane-drop exit ramp, England

15



Figure 14. Wide painted gore markings.



Figure 15. Raised pavement markers; diverge gore area.

### Colored Pavements

- Colored pavements can be used to indicate desired pathways in complex situations. They will improve driver performance when they are clearly visible.

### Systems

- Diverge areas are particularly suitable for the application of delineation "systems." It is possible to color code pavement markings, post delineators, raised pavement markers, and signs to differentiate the two possible routes to follow through the diverge area.

### Turns

#### Pavement Markings

- If the open broken-line pattern is adopted for the general center line, the warning line (greater mark-to-gap ratio) could be used to provide warning of the upcoming intersection. The solid line would still be used in the immediate intersection area.
- The previously described heavy broken line should be used to separate discontinuous lanes from through--e.g., between left-turn slot and through lanes.
- Pavement arrows give clear messages as to permissible movements at upcoming intersections. They should be used wherever there is any uncertainty as to the desired or permissible movements.

#### Post Delineators

- The spacing of post delineators should be decreased to 50 ft for the last 500 ft on the approach to intersections where turning maneuvers are heavy, to indicate need for extra caution. A change in color of the delineators in the intersection area from those used on the approach roadway is not recommended, as color change should be reserved to indicate transition sections (e.g., merge-diverge area, pavement width transition, stop approach).

#### Raised Pavement Markers

- Spacing between raised pavement markers should be reduced in line with the recommendation for strengthening painted lines on the approach to intersections.
- Closely spaced crystal raised pavement markers should be used between left-turn slots and through lanes, in areas where these markers can be used. A double row is suggested. It may be desirable to omit the raised pavement markers for the first 100 ft of the left-turn slot to permit traffic to get into the slot without crossing the markers themselves.

### Colored Pavements

- The use of colored pavements for left-turn slots is of marginal value. The best feature is that the use of colored pavement appears to discourage through traffic from entering the left-turn slot.

## Stop Approaches

### Pavement Markings

- , As in several situations mentioned previously, adoption of the open broken-line system will permit changing the center line to a warning pattern preceding the solid line on stop approaches.
- , Addition of edge lines where none exists on the approach roadway will promote a feeling of restriction, and the change will alert drivers to a changing situation.

### Post Delineators

- , Post delineators at progressively shorter spacings (from 200 ft or more down to 10 ft) on the approach to STOP signs was found effective in reducing approach speeds.
- , Crystal post delineators were found to be at least as effective as red delineators at a stop approach treatment. Hence, crystal is recommended.
- , Post delineators, at progressively shorter spacings, may be added to the left side of the roadway to strengthen this treatment message.

### Raised Pavement Markers

- , The use of raised pavement markers, at progressively shorter spacings, on approaches to STOP signs is recommended.
- , Because red raised pavement markers have been used to designate "wrong way" on some freeway sections and ramps, they should not be used at stop approaches. Crystal should be used, relying on the spacing change for stimulus rather than the color.
- , The addition of raised pavement markers to the edge line for the section over which closer spacings on the center line are utilized will provide a useful "tunnel" effect.

### Colored Pavement

- , Red-colored pavement was shown to be effective in reducing approach speeds in situations where good visibility can be obtained. When daytime run-the-STOP-sign accidents are a problem, red-colored pavement may be an effective treatment, but it is not likely to be sufficient at night.

### Rumble Strips

- , Although rumble strips are not suggested as a general treatment, they are very effective for special problem areas--particularly in situations where the driver does not expect a STOP sign, such as after a long stretch of through roadway.

The results of this study will be published as NCHRP Report 130, "Roadway Delineation Systems," estimated to be available in May 1972.