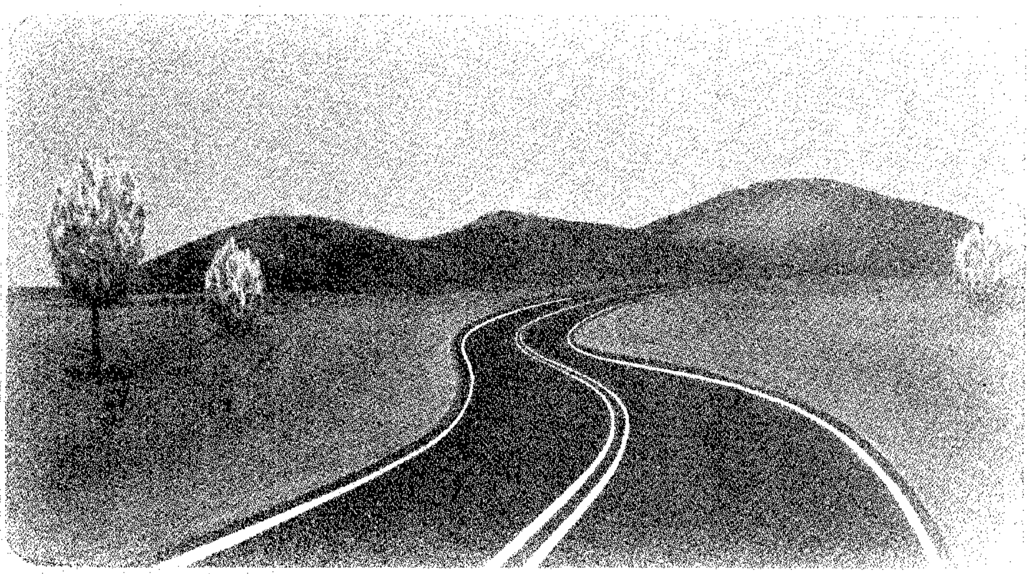
STATE OF THE ART ON ROADWAY DELINEATION SYSTEMS



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16. Abstract

Roadway delineation treatments and systems are those devices and techniques which individually or in combination provide guidance, regulatory, or warning information to drivers under various highway situations. This state-of-the-art report on roadway delineation systems constitutes an update to the National Cooperative Highway Research Program Report 130. In the first part of the report, studies documented since the publication of NCHRP Report 130 are reviewed. This review is organized under two headings; Delineation Situations and Delineation Treatments. Under the former heading, studies relative to the application of different delineation treatments and systems for various highway situations are evaluated. The latter heading contains reviews of the studies from the standpoint of materials, cost, maintenance, durability and environmental effects. Recommendations subject to ongoing research on delineation applications under different highway situations are given in the second part. A partially annotated bibliography is also included.

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FOREWORD

The Federal Highway Administration's Office of Research has underway a comprehensive delineation research program to determine motorist delineation requirements and to develop optimized delineation specifications for enhanced guidance. Three of the research studies addressing this program are: (1) Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments, (2) Driver's Visibility Requirements for Road Delineation and (3) Field Evaluation of Selected Delineation Treatments.

The purpose of this report is to update National Cooperative Highway Research Program Report 130, "Roadway Delineation Systems," which was a comprehensive state-of-the-art summary through 1970. Therefore, the literature review presented on pages 4 to 41 only refers to material published since 1970. This state-of-the-art was developed as a part of the first task of the "Cost-Effectiveness and Safety of Alternative Roadway Delineation Treatments" study and to the extent possible the same format has been maintained as utilized in NCHRP Report 130. Because this study has not progressed to the point where major new findings can be made based on this research, the recommendations given on pages 43 to 77 are essentially those reported in NCHRP Report 130 as modified to a minor degree by research studies since 1970. Research developed through this and companion efforts will be reported on at the completion of this study in the summer of 1977.

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INTRODUCTION

Roadway delineation treatments and systems are devices and techniques which individually or in combination provide guidance, regulatory or warning information to drivers. Delineation treatments currently in use include pavement markings, post delineators, raised pavement markers, colored pavements, rumble strips, and curbs. Additionally, indirect (but intentional) methods such as contrasting shoulders and reflectorized guardrails are also being applied. Certain roadside features such as parallel fence lines, rows of luminaires or lines of trees may also provide general guidance information to the driver (unintentional delineation).

By far the most prevalent and widely used delineation treatments are pavement markings which provide guidance to a driver with respect to his pathway in the near vicinity of the vehicle. Hence, pavement markings, raised pavement markers and colored pavements comprise delineation treatments utilized to satisfy "near delineation" needs of the drivers. Post delineators (and raised pavement markers to an extent) on the other hand, are primarily used to provide the driver with anticipatory information regarding the general roadway alignment far ahead. Such treatments are designed to satisfy the drivers' "far delineation" requirements.

Additionally, there are treatments which are utilized to provide regulatory or cautionary information to the driver. Under this category are treatments such as rumble strips and no-passing zone markings. Irrespective of the primary function of delineation treatments, utilized either individually or incorporated into a system, they aid drivers in maintaining the desired pathway at the desired speed.

Although delineation is an integral part of the roadway system and is required both during daytime and nighttime driving conditions, it is under nighttime driving or under reduced visibility conditions that roadway delineation systems obtain the maximum benefit. Generally under daylight hours the overall topography of the roadway and roadside provide the driver with sufficient tracking and guidance cues. However, under reduced visibility conditions the cues which are provided by the roadway are largely absent, and the driver relies very heavily upon delineation for guidance. Therefore, an important characteristic that is often required of a delineation treatment is effectiveness during nighttime and under inclement weather conditions. Other desirable properties of delineation treatments are durability under different roadway conditions, cost, and installation and maintenance ease.

The concept of roadway delineation dates back to 1883 when, as noted in a report published by the Organization for Economic Cooperations and Development (1975), Professor Macnie of the University of South Dakota prophesied that automobile vehicles would, in years to come, travel at 25 miles per hour over highways divided in the center by a white line to keep each stream of traffic in its place. Since this prophecy, roadway delineation treatment research has made significant progress.

It is not definitely known when and where the first traffic lines were used. Roads and Streets magazine (1936) reports on the earliest use of white line markings to divide the traffic stream. It is reported that in the State of Michigan, B. F. Goodrich Company, after investigating many claims, presented Edward N. Hines, Road Commissioner for many years of Wayne County, Michigan, with a plaque designating him as "Father of the Center Traffic Line."

In the early days of pavement marking applications, various techniques for marking the pavements were tried. In 1920, the Engineer of Maryland noted that the bituminous joint-sealer in concrete roads was of considerable use since it tended to divide the two streams of traffic and keep each to its proper side of the road. For a while white brick form permanent center lines were also used. However, as expected, the cost of such lines was extremely high. In one study, the cost of such lines was estimated to be $185 per lane mile (Sawyer, 1924). Another center line marking technique that was extensively utilized was adding color pigment to the concrete to achieve permanent traffic stripes. But it was the painted line which finally emerged as a standard pavement marking treatment.

The use of raised pavement markers is reported as early as the 1920's. The Highway Magazine (1927) had reported that Chicago used "rows of button-shaped metal studs set in the pavement to mark off safety zones and to form such messages as 'stop' and 'to right'." These metal studs were also installed along boulevards in the outlying sections of the city. Colored pavements, although considered mostly ineffective today, were reported to be in use in Tennessee and Kentucky as early as the late 1930's to "color and mark off an extra truck lane on long grades" (Concrete, 1941).

Apparently the first effort to systematically study delineation treatments, is reported by Mattimore (1925) where he listed physical properties of traffic paint which governed the quality of the paint and for which laboratory tests should be developed. The paint properties that he discussed encompassed consistency (suitability for machine application), spreading rate (uniform spreading without clogging), covering power (opacity), drying time, light resistance, visibility (day and night), and durability.

The first most comprehensive bibliography on pavement marking materials is contained in Highway Research Board Bulletin No. 57 (1952) which consists of a listing of 234 relevant research articles with annotations. An extensive review of the state-of-the-art of roadway delineation systems through the year 1970 is contained in NCHRP Report 130. The 1971 Manual on Uniform Traffic Control Devices (MUTCD) developed by FHWA contains a set of consistent delineation application guidelines based upon research conducted to the time of its publication.

PART I

LITERATURE REVIEW

DELINEATION SITUATIONS

Concepts and applications appropriate to general situations (such as edge lines) are presented first; applications at specific geometric situations (horizontal curves, pavement width transitions, diverging areas, merging areas) are then discussed.

Tangent and General Situations

General Treatment Studies

In 1973, Yu and Arnn (1973) reported the results of a survey of state highway department practices related to "roadside" delineation--roadside being defined as the edge of the pavement and/or the shoulder area. Major findings include:

(1) In response to a questionnaire survey as to which roadside delineation techniques are most commonly employed, the available choices ranked as follows:

 (1) Post-mounted delineators
 (2) Painted curbs
 (3) Lighting
 (4) Raised pavement-edge markers
 (5) Contrasting shoulders
 (6) Indirect methods.

(2) When asked for the dominant factors considered in selecting the proper roadside delineation technique, the available choices were ranked as follows:

 (1) Type of roadway
 (2) Traffic conditions of roadway
 (3) Physical conditions of roadway
 (4) Economic considerations.

(3) Most state highway department engineers generally agree with the 1971 MUTCD specifications for post delineator placement (spacing and distance from edge of pavement), but a number of minor modifications were suggested.

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Bolt, Beranek and Newman (1972) issued a report on the results of a questionnaire survey assessing drivers' understanding and preference for several of the delineation treatment applications included in the 1971 MUTCD . The researchers concluded that the respondents were able to interpret the intended meanings of the differing forms of road markings (i.e., broken lines, solid lines, and combinations) but, at least on the basis of the samples given in their questionnaire, drivers did not comprehend the proposed significance in white versus yellow pavement markings.

The researchers also queried driver understanding of the various proposals for color coding of post delineators (i.e., yellow for the left edge of the roadway, white for the right edge, blue for the right edge of ramps and speed-change lanes, and red to indicate to drivers that they are going in the wrong direction on a one-way roadway). The results of this survey indicated wide-spread confusion by the respondents as to the proper meaning of the proposed color codes. The authors concluded that establishment of reliable color codes will require an extensive public education effort and consistent widespread application.

In evaluating these results, it is important to recognize this survey was conducted soon after the 1971 MUTCD was issued, and widespread implementation of the new codes had not yet been obtained. Also, there were only 63 respondents in this study, all from the State of Massachusetts.

A continuing educational program to advise motorists of delineation color coding is also a recommendation of a study by UCLA researchers (Hulbert and Beers, 1970). Using their Driving Simulation Laboratory, they found that the majority of the test drivers were unaware that the reverse side of white raised reflective pavement markers on California highways is red; (i.e., that the reflectors will shine red if you are driving the wrong way). Also, they concluded the regular pattern of red markers California is now using to indicate wrong-way driving is the least effective of those studied in indicating to the motorist that "something is wrong." It was recommended that an irregular configuration which is not continuously repeated be used in lieu of the regular pattern.

Edge Lines

Data regarding the effect of edge lines on traffic on two-lane roads is provided in a study conducted in Maryland (Hassan, 1971). Spot speed and lateral placement were used as evaluation measures to assess the effectiveness of edge lines applied on two one-mile sections of rural roadway, one 18 feet wide and the other 24 feet wide. The edge line treatment produced effects on lateral placement similar to those reported in earlier studies; i.e., vehicles moved closer to the center line at night with the edge line treatment, but were unaffected during the day. The effect on vehicle speed was mixed; mean speeds were lower with edge lines for the 24 foot section, and higher for the 18 foot section.

Transverse Stripes

Patterns of transverse stripes have been applied in a number of specific situations (stop approaches, approaches to horizontal curves, approaches to construction zones, etc.), but are included under this discussion of "general treatments" because the desired effects are the same in nearly all cases--to alert drivers to a changing driving environment and, in most cases, to encourage lower vehicle speeds.

A series of transverse plastic pavement stripes (yellow) with gradually decreasing spacing (103 feet to 67 feet) was tested for its effectiveness in reducing speeds within a construction area in Michigan (Enusten, 1972). A speed survey, using loop detectors, showed that the effectiveness of this device in reducing speeds was minimal. This result is attributed to the prevalence of drivers familiar with the site. Enusten states that this treatment may be effective in alerting unfamiliar drivers in hazardous locations.

In this same study, Enusten (1972) reports on another application of transverse stripes--at the approach to a sharp curve on a two-lane, two-way rural highway. Yellow stripes were placed with a 37 foot spacing at the upstream end of the approach, reducing to 15 feet at the downstream end near the curve. Data obtained one year after installation indicated that the transverse stripes brought about a reduction in the mean speed and the speed variance.

In another phase of the study, hard plastic yellow rumble bars, 3/4 inch high, were installed along both edges of the transverse paint stripes. The rumble bars produced even lower speeds, but the variance in speeds increased and there were many complaints.

Transverse stripes and rumble bars were also installed at an approach to a loop ramp at a temporary freeway ending (Enusten, 1972). In this case, a less severe rumble bar of flexible polyvinyl chloride, 7/16-inch thick and 3-1/2 inch wide, was applied across the pavement in triple rows of variable spacing. Data collected one month after installation indicated the bars produced a significant reduction in speed without any change in the variance. However, it is not known what influence, if any, a sign warning motorists of the test had on the speed reduction.

A somewhat similar situation, at least in terms of driver information needs and potential delineation systems, is the approach to circle or rotary type intersections. A recent study in England (Denton, 1973), where roundabouts (traffic circles) are prevalent, indicated that yellow markings (2 foot bars) applied transversely and spaced exponentially from 20 feet to a minimum of 10 feet over a total approach distance of 1/4 miles, resulted in lower mean speeds near the intersection and reduced variance. (See Figure 1 for a diagram of the test installation.) Although there was a slight rise in the speeds one year after installation from those recorded one month after installation, the speeds at the later date were still significantly lower than the "before" speeds. Fourteen accidents were reported in the year prior to installing the pattern, and two in the sixteen months following installation. Unfortunately, a light pole was moved about the same time the pattern was installed, and the effects of the two changes cannot be clearly separated.

Horizontal Curves

The advantages to be derived from the addition of edge lines at horizontal curve sections on freeways were demonstrated in a recent study in Michigan (Roth, 1974). At four curve sites, 4-inch white edge

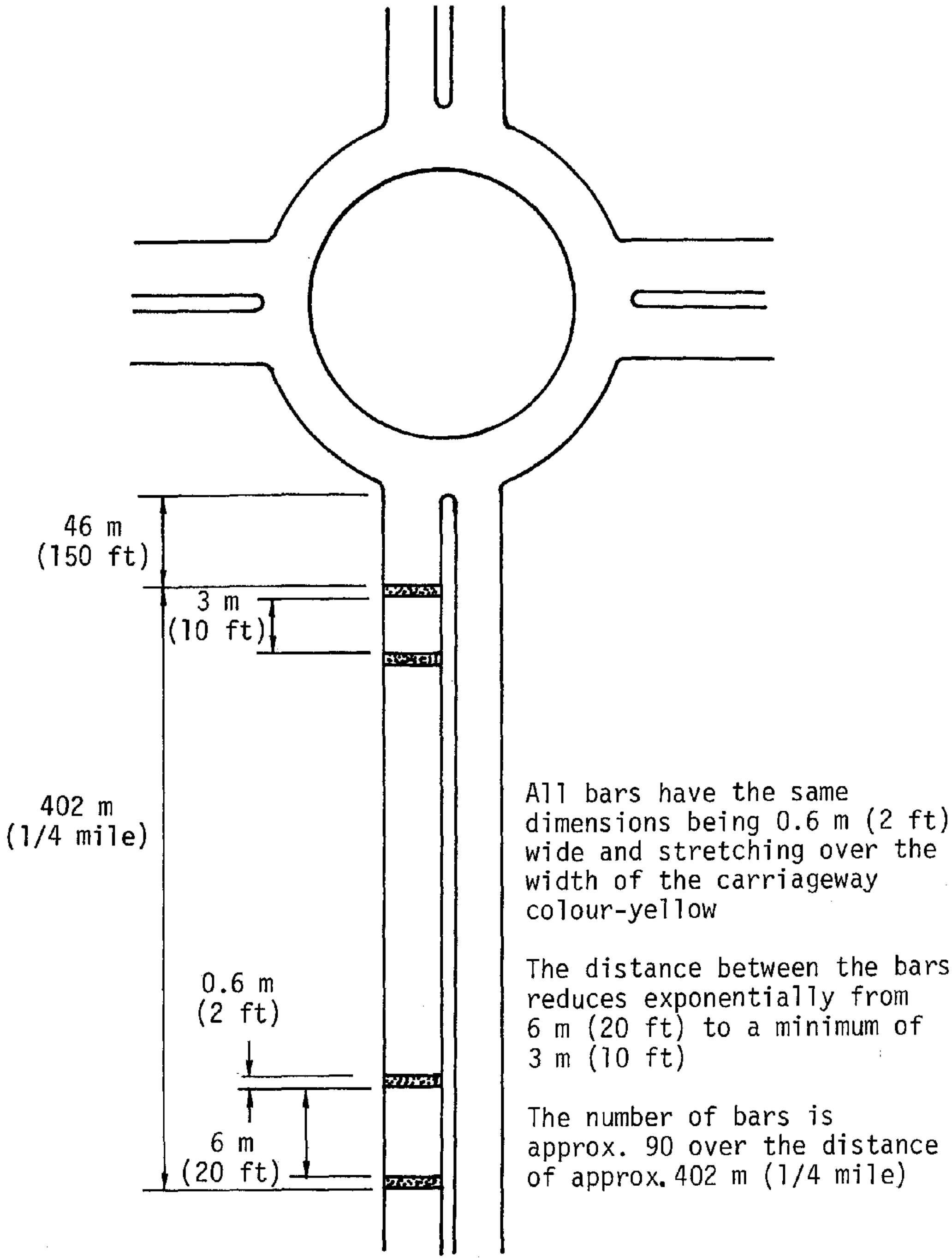


Figure 1. Bar Pattern at a Typical English Roundabout Site (Denton, 1973).

lines were painted along the right and left edges of divided freeway sections where the previous delineation treatment had consisted of lane lines and post delineators only. Speeds in the curves and the amount of center line straddling were reduced significantly.

Based upon the results of this study, Roth recommends that edge lines be used on freeway curves even if post delineators are present. In addition, he comments on an Arizona study that indicated painted edge lines and post delineators are equally effective on tangent sections. However, post delineators are favored on an economic basis. Roth concludes that the use of post delineators throughout curves and tangents, and the addition of edge lines at curves will "dramatize" alignment changes.

The Enusten (1972) study indicates that the installation of transverse stripes on the approaches to sharp curves will also result in reduced vehicle speeds.

Pavement Width Reductions

The most common example within this general class of geometric situations is the lane drop, frequently found at freeway exits. Recently, Kentucky evaluated the effectiveness of various types of raised markers as traffic guidance aids at three classes of lane drops--lane exits, lane splits, and lane terminations (Pigman and Agent, 1974). The types of markers used are shown in Figure 2; typical installations are shown in Figures 3 and 4. Major conclusions, based on results acquired at five lane drops, include:

(1) Raised pavement markers are an effective means of reducing erratic movements at lane-drop locations.

(2) No significant change in brake light rates resulted from the installation of raised pavement markers.

(3) While the raised pavement markers proved to be generally effective under both daytime and nighttime conditions, the reduction in erratic movements under nighttime conditions (44 percent) was greater than for daytime conditions (20 percent).

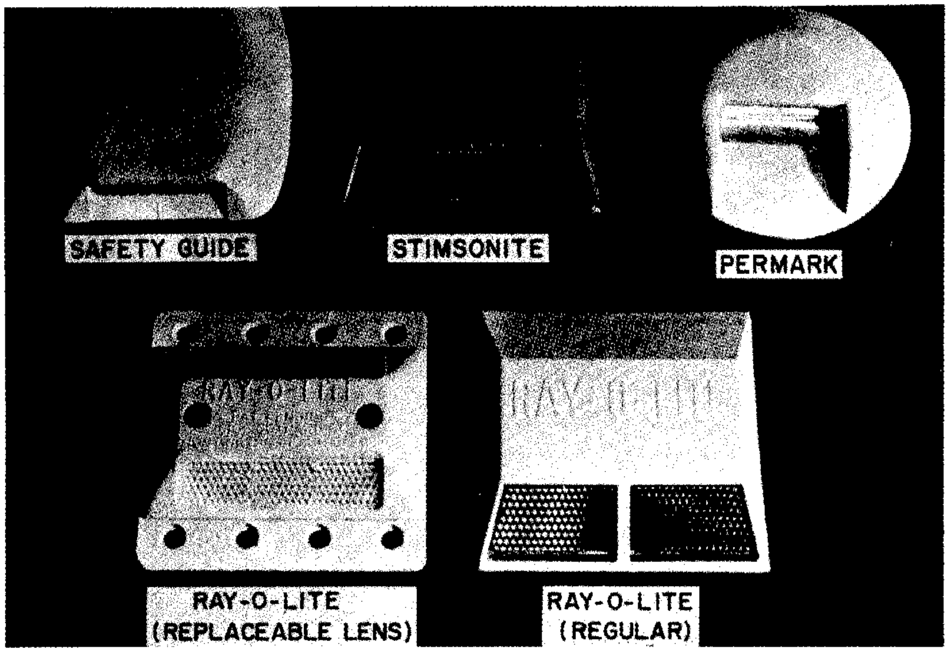


Figure 2. Types of Raised Pavement Markers (Pigman and Agent, 1974).

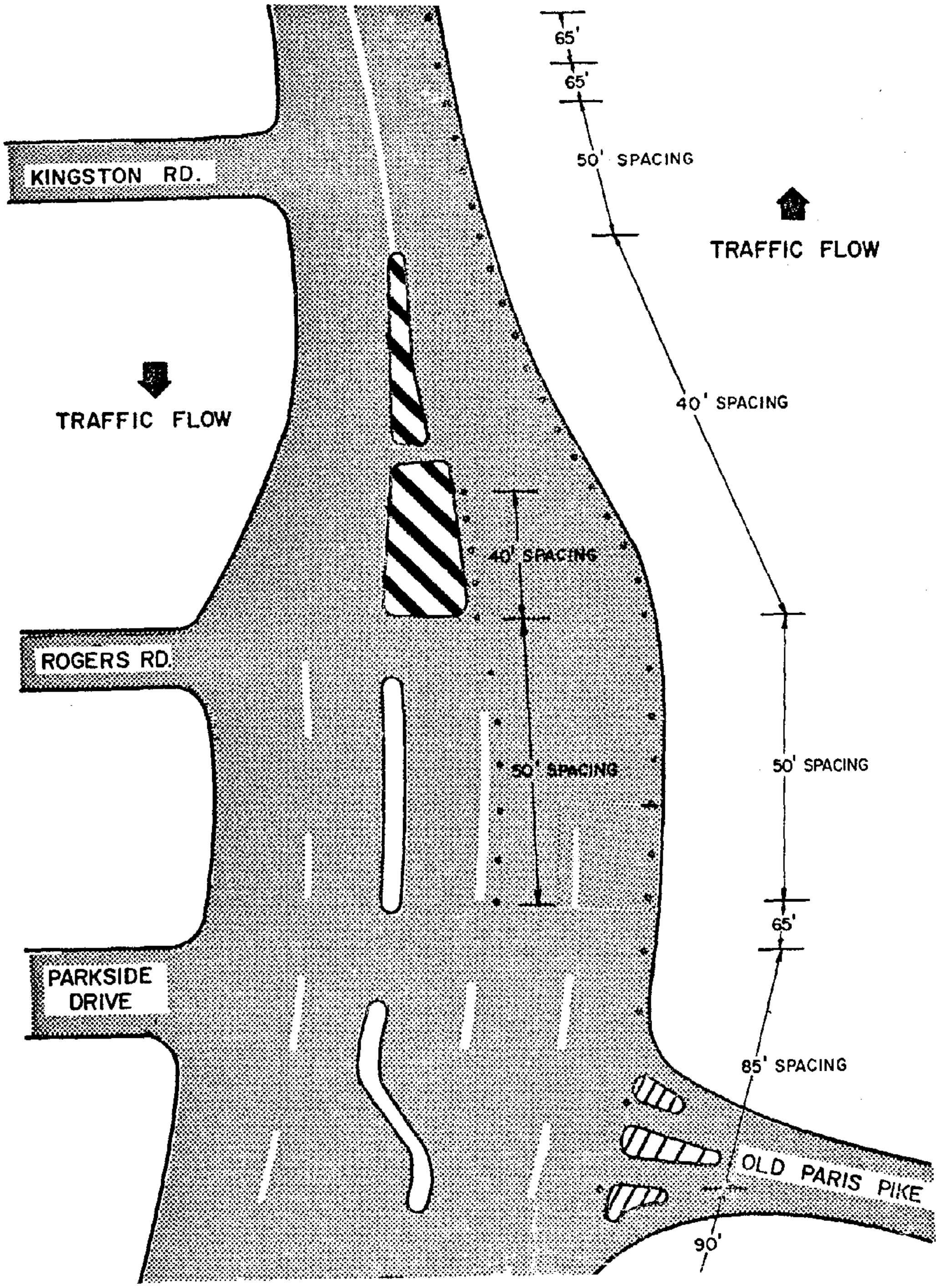


Figure 3. Arrangement of Raised Pavement Markers at US 27 - 68 (Paris Pike) NB Lane Termination, North of New Circle Road in Lexington. (Pigman and Agent, 1974)

NOTE: Crosshatching does not conform to MUTCD.

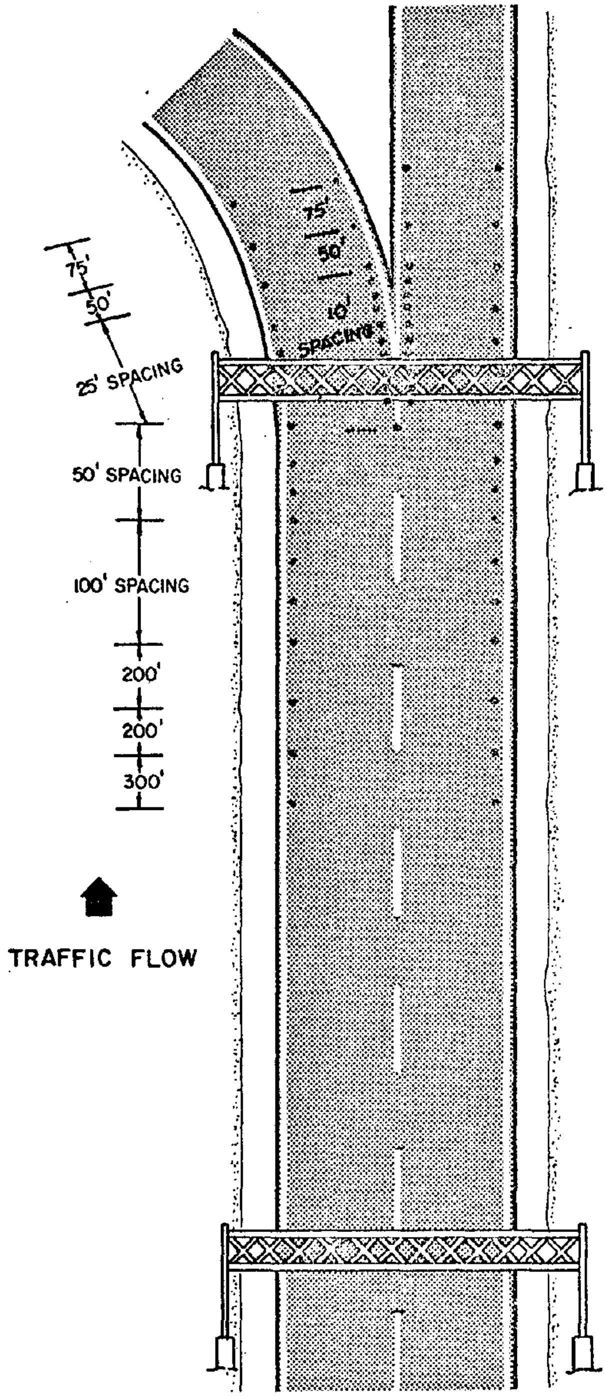


Figure 4. Arrangement of Raised Pavement Markers at I-75 Northbound - I-64 Eastbound Lane Split East of Lexington. (Pigman and Agent, 1974)

(4) The cost of the raised pavement markers and their installation was nominal, and their use at all lane-drop locations is recommended. (They suggest rubber-tipped snowplow blades be used where raised markers have been installed.)

Merge and Diverge Areas

In a National Cooperative Highway Research Program study, Taylor and McGee (1973) showed that strong delineation treatments at deceleration lanes and gore areas result in improved traffic operations and safety at freeway exits during periods of darkness. Delineation systems incorporating greater-than-normal numbers of post delineators and/or raised pavement markers, in addition to the standard paint markings, result in fuller use of the deceleration lanes and assist the motorists in identifying the mainline pathway and the exit ramp. Erratic maneuver rates were reduced significantly after the supplemental delineation treatments were installed (see Table 1). The recommended delineation system for exit ramp areas resulting from this study is illustrated in Figure 5.

Synthesis and Evaluation

The recent research reports dealing with the evaluation of delineation treatments as they affect traffic operations and safety tend to either confirm the recommendations presented in NCHRP Report 130, or provide information which can be incorporated as supplemental modifications. There appear to be no data or conclusions contradictory to these earlier recommendations. Of particular note in the more recent studies, are the following:

(1) The driving public does not comprehend the various color codes in use--at least as evidenced by questionnaire responses. (There is still some doubt whether or not they "use" the information without being able to verbalize the specific code--particularly the yellow/white paint markings and post delineator codes.) Perhaps most disappointing is the continuing, almost universal, evidence that drivers

Table 1. Summary of "Before" and "After" Erratic Maneuver (EM) Rates (Taylor and McGee, 1973)

Site No. and Identification	EM Rate (%) Before	EM Rate (%) After	Significant Change; Level of Confidence (%)
1 I-83S at Exits 27-28	1.17	0.86	> 95
2 US 322W to I-83N. I-83S, and I-283S			
Left Ramp	0.28	0.19	80
Right Ramp	0.51	0.39	80
3 I-283N to I-83N, I-83S, and US 322E			
Left Ramp	5.15	1.73	> 95
Right Ramp	2.39	2.36	< 50
4 I-79S at Exit 18	0.60	0.33	> 95
5 I-76E at Exit 14	0.20	0.08	> 95
6 I-76W at Exit 13	0.30	0.26	60
7 I-95S at I-695	0.80	1.50	> 95
8 Baltimore-Washington Expressway to Harbor Tunnel Thruway	0.39	0.21	> 95

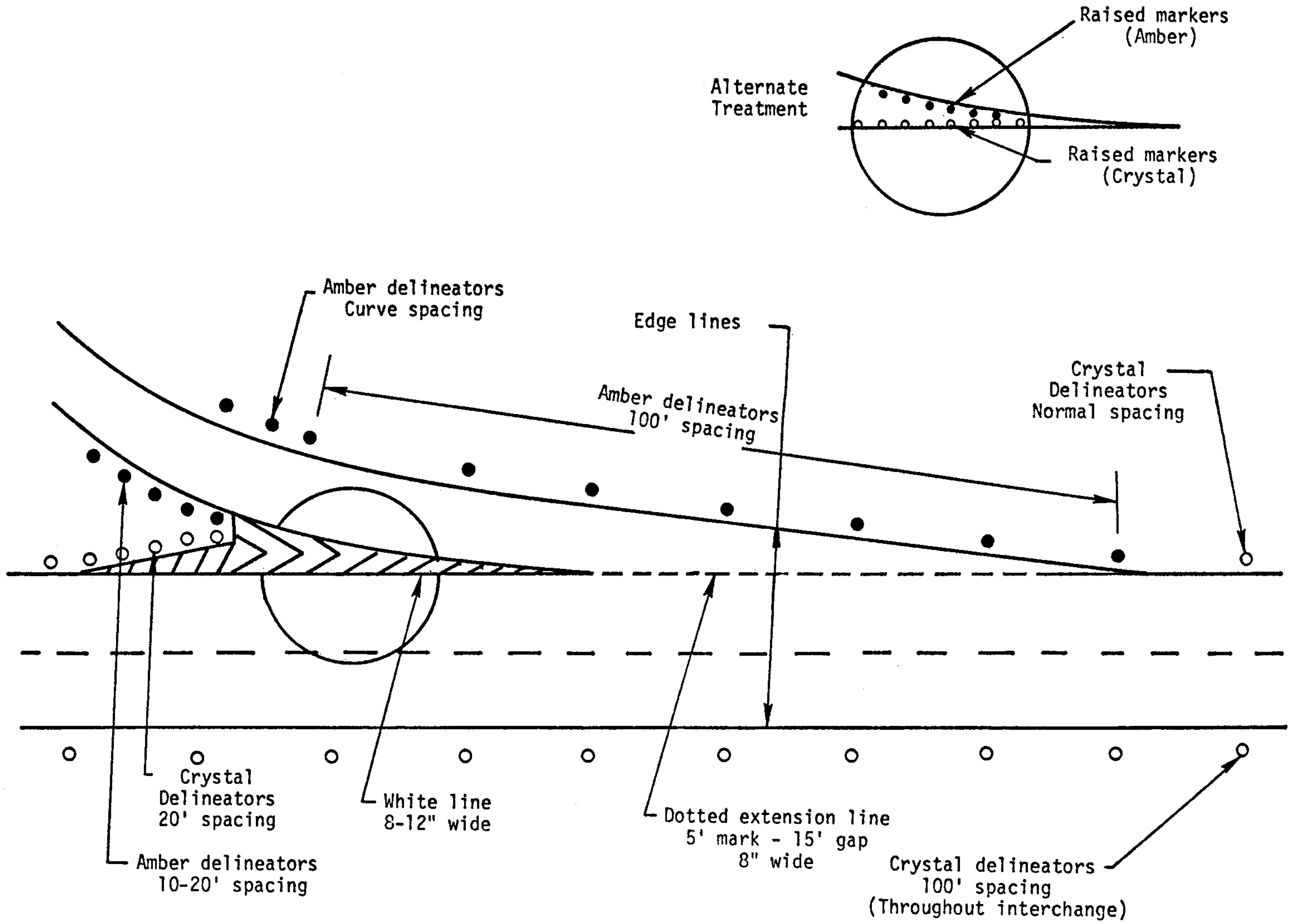


Figure 5. Recommended Exit Ramp Delineation (Taylor, McGee, 1973).

do not recognize red delineation as an indication they are going the wrong-way on a one-way facility, or that a "stop" or "avoid this area" message is intended. (Perhaps part of the problem is that red has been used for a number of messages, but the applications have been so limited that this would not appear to be a major experimental deficiency at this point.)

(2) Evidence that edge lines can produce "desirable" changes in traffic performance measures continues to mount. A direct relationship between these changes and accident experience has still not been demonstrated, however. There is some suggestion that edge lines at maneuver areas (such as horizontal curves, merge/diverge areas, lane drops, or stop approaches) may be a worthwhile investment in areas where continuous edge lines are not economically feasible (i.e., edge lines would not be applied on the tangent sections between maneuver areas). Further, edge lines and post delineator treatments on the median edges of divided highways appear to provide the same benefits as when applied at the left-hand side of the roadway on two-lane highways--particularly on curves to the right.

(3) In before-and-after studies, strengthening the delineation treatments at freeway exits has been shown to reduce erratic maneuvers and encourage better use of the deceleration lane. Supplemental post delineators, raised pavement markers, and dotted paint lines separating the mainline from the deceleration lane have all been investigated, and are believed to be effective in improving traffic operations and safety.

(4) A number of applications of transverse line patterns have been reported in recent years. In all cases, the intent was to alert drivers to some changing roadway environment and elicit slower vehicle speeds. Effectiveness in reducing

average speeds tends to be directly related to the tactile severity of the lines (some were paint only, other raised plastic stripes). The ratio of unfamiliar to familiar drivers seems also to be an important factor (the familiar drivers being less affected).

A revised set of the recommendations originally proposed in NCHRP Report 130, incorporating the more recent research results and observations of the project staff, are given in Part II.

DELINEATION TREATMENTS

Presented in this section is recent information (since 1970) on the physical aspects of the various delineation treatments in use or under development and testing. Each treatment will be discussed separately, with a discussion of materials, maintenance, and costs where appropriate.

Pavement Markings

Materials

Noteworthy results of recent tests of standard paints and thermoplastic marking materials include:

(1) Field tests in Missouri indicate that chlorinated rubber-alkyd paint is better in wear resistance than their dispersion resin-varnish paint. Further, the rubber-alkyd paint generally ranks with the best of the high heat paints tested (from five manufacturers) (Missouri, 1972). These findings are similar to those cited in NCHRP Report 130 for earlier tests in New York State.

(2) On the basis of field evaluations of various paint film thicknesses and application rates for reflectorizing beads in Mississippi, Lanz and Davis (1971) recommend that traffic paint be applied at 15 mils wet film thickness, and should contain reflectorizing glass beads at a maximum of 6 pounds per gallon. The film thickness can be reduced to 10 mils wet if a good base of paint is present, or paint is starting to build up on the surface. Glass beads having a high index of refraction, as well as beads that were bi-symmetrically treated, provided the best reflection. The authors note, however, that none of the paint and bead combinations studied were effective delineators in moderate or heavy rains.

(3) In a study encompassing plain and textured beaded stripes and four types of retroreflective raised pavement markers installed on Interstate 85 north of Atlanta, Georgia, Tooke and Hurst (1973) arrived at the following conclusions:

(a) The wet night visibility characteristics of the best raised pavement markers are superior by a large factor to the best continuous line systems.

(b) Surface texturing improves the wet night visibility of continuous line systems. This, however, may be accompanied by a loss in daytime brightness and uniformity. They note that none of the continuous line systems, textured or not, can be considered fully adequate for safe wet night delineation of Interstate System roadways.

(c) The desired level of intensity for a raised pavement marker is presently obtainable in prismatic or lens-type retroreflectors.

(d) The durability and visibility retention of hot spray applied thermoplastic is outstanding when compared with the performance of extruded thermoplastic.

(4) In tests comparing thermoplastic markings with standard paint lines for the Kentucky Department of Highways, Rahal and Hughes (1970) arrived at the following conclusions:

(a) Freshly placed thermoplastic stripes are definitely more visible on wet nights than are paint stripes. Even though visibility of thermoplastics is reduced with time, they remain more visible on wet nights than paints. The two are about equally visible under dry daylight conditions.

(b) Durability of the thermoplastics is "superior" when placed on bituminous concrete surfaces, and "good to poor" on portland cement concrete surfaces.

(c) Thermoplastics may prove economical when placed on bituminous concrete surfaces having relatively high volumes of traffic. It would be necessary to place greater emphasis on factors other than durability in order to justify use of thermoplastics on portland cement concrete surfaces, regardless of traffic volumes.

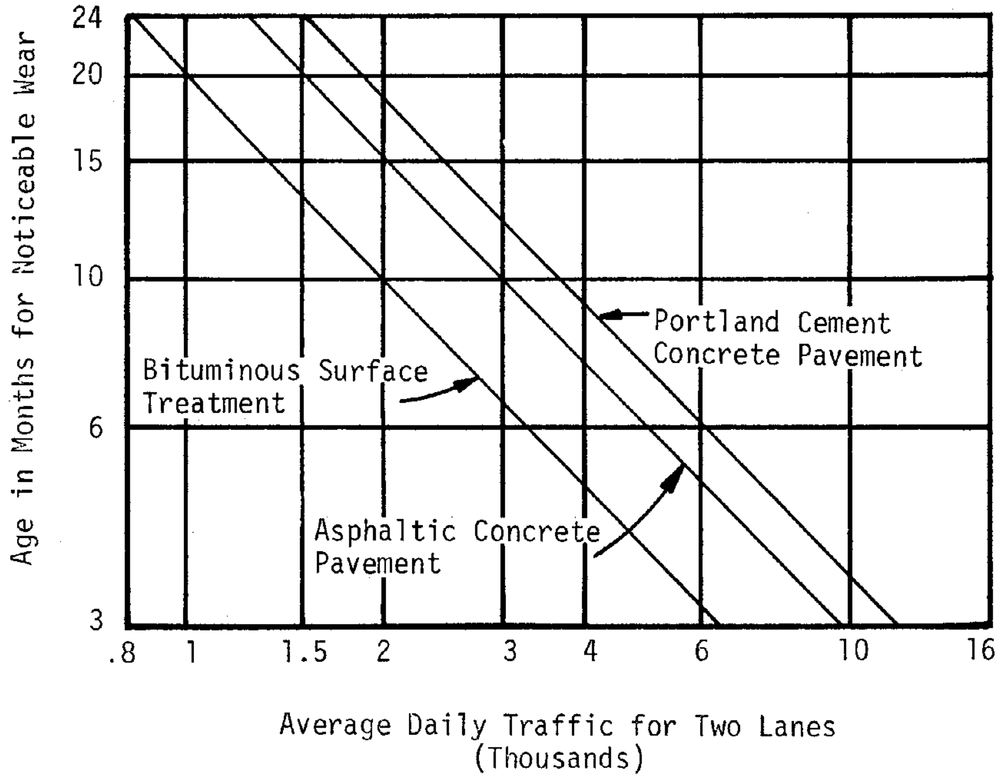
(5) Evaluation of a new floating type of traffic bead by the Colorado Division of Highways shows that these small uniformly-graded beads are superior in both brightness and durability to the coarser traffic beads that the State has been using. Although the new beads cost approximately two cents per pound more than the old type, they may be applied at 4 pounds per gallon and will be as brilliant and durable as the old larger-sized beads applied at 6 pounds per gallon; hence, a net savings in bead costs will result (Colorado, 1970).

(6) The results obtained in a study in Alabama indicate that "drop-on" beads generally result in better night visibility than reflectorized traffic paint with premixed glass beads, particularly during the early life of the striping. However, it is noted that the best performance is obtained with reflectorized paint and approximately two pounds of "drop-on" beads (Holman, 1971).

Maintenance and Service Life

Studies in Mississippi on road marking materials indicate that thermoplastic markings have an average life of ten years, and because of this longer life they are the least expensive over a ten-year period when compared to paint and raised pavement markers (Lanz, 1972).

In another study by Lanz (1973), the effective life of the standard traffic paint line in Mississippi was found to be a function of traffic volume and surface type, as shown in Figure 6.



Road Width: 24 Feet
Paint Thickness: 15 Mils
Bead Amount: 6 Pounds/Gallon

Figure 6. Conditions for Noticeable Traffic Stripe Wear (Lanz and Davis, 1973).

Cabrera and O'Flaherty (1973) have investigated the mechanism by which "chipping" failures in reflectorized road marking materials are initiated. They indicate that this failure mechanism is associated with the presence of glass beads in the binder. This suggests, they feel, that the optimum beak content and gradation in terms of durability of a road marking may very well be different from the optimum beak content/gradation for reflectivity; the relationship between these two optimums may vary with differing traffic and environmental conditions.

Costs

In recent years the costs of all types of pavement markings have risen considerably, largely due to the increased cost of the oil by-product ingredients. Several studies and reports have addressed this problem. Unfortunately, the situation has still not stabilized, and notice should be taken of the dates of the various studies before conclusions are drawn. Excerpts from recent reports follow:

(1) The most recent data found in the literature search was that available from a study in the District of Columbia, where the durability and costs for three types of markings were evaluated (VanVechten, 1974, and Flanakin, 1975). Table 2, extracted from the Flanakin report, indicates that thermoplastic markings are the most cost-effective material, at least for the District. (Note that in terms of the definition of cost-effectiveness given in the footnote to Table 2, the lower the cost-effectiveness number the more favorable the material.)

(2) NCHRP Synthesis 17 (1973) includes a tabulation of the costs of contract marking (paint and thermoplastic) in seven jurisdictions; this table is reproduced here as Table 3. It is obviously not a comprehensive review, but does provide an indication of the range of costs.

Table 2. Pavement Marking Costs, Service Life, and Cost Effectiveness of Materials Used in Washington, D.C. (Flanakin, 1975)

Markings and Properties	Conventional Paint	Instant Set	Thermoplastic By D.C. Forces	Thermoplastic By Contractor
Crosswalks and Stop Lines				
Cost per linear foot	8¢	12¢	32¢	43¢
Service life	1.7	2.6	20.0	20.0
Cost Effectiveness	4.8	4.8	1.6	2.1
Lane and Center Lines				
Cost per linear foot	1.8¢	1.9¢	19¢	26¢
Service life	1.7	2.6	20.0	20.0
Cost Effectiveness	1.06	0.7	0.95	1.30

Note:

1. SERVICE LIFE is a measure of the number of vehicles per line that have passed over the material when the marking is no longer serviceable on account of having lost its luster or its reflectivity (night visibility) or having been worn completely from the surface in the wheel paths.

2. COST EFFECTIVENESS is the ratio of the cost per linear foot of marking to the service life expressed in millions of vehicles per lane of traffic.

3. Cost of instant set markings is based on hot paint at $4.00 per gallon. This cost is expected to increase to $6.50 by mid-1975. This will increase the cost effectiveness parameter to more than 1.00.

Table 3. Some 1971 Costs of Contract Marking (Lanz and Davis, 1973)

State	Material	Color	Quantity (Feet)	Quantity (Meter)	Cost ($/Foot)	Cost ($/Meter)
New Jersey	Traffic Paint	White	17,557,414	5,351,500	0.013	0.043
		Yellow	1,337,583	407,695	0.013	0.043
Oklahoma	Thermoplastic	White	225,000	68,580	0.015	1.033
		Yellow	17,000	5,182	0.285	0.935
S. Carolina	Thermoplastic[1]	White	502,134	153,050	0.130	0.427
District of Columbia	Thermoplastic	White	96,362	29,371	0.566	1.857
Illinois	Thermoplastic	White	908,626	276,949	0.350	1.148
		Yellow	122,700	37,399	0.350	1.148
Florida[2]	Thermoplastic	White	1,792,481	546,348	0.140	0.459
Arizona	Thermoplastic	White	595,000	181,356	0.120	0.394

[1] Sprayed.

[2] Combination of contractor-supplied equipment and state forces.

(3) In a 1972 report from California on an evaluation of grooved traffic stripes (see Figure 7), it is stated that the "most recent figures" show the average annual cost per year for restriping standard paint lines to be $53 per mile over an extended period (Shelly, Rooney and Chatto, 1972). The grooved line was found to give no better performance than the standard line in mountainous areas with snowplowing, and to be relatively less effective than raised pavement markers in areas where there was no snowplowing. Since the raised pavement markers cost only slightly more, the grooved stripes were not recommended for either situation. (See Table 4 for relative cost figures.)

(4) In a 1973 report, it is stated that the estimated average annual cost over a ten year period of one mile of thermoplastic center line (with paint edge stripes and reflective markers) is $180 in Mississippi (Lanz, 1973). If the center line were painted, the long-term cost would increase by about three percent.

Post Delineators

In the review of the literature since 1970, only one study of post delineators was uncovered. A field study conducted in Australia utilized experiments using low-beam headlights to show that dirt accumulation and aging significantly affected the nighttime visibility of post delineators (type unknown). Reductions in reflectivity by as much as 18 times were noted. The corresponding reduction in visibility is from approximately 1,000 feet when new, to less than 100 feet (Hills, 1972).

Raised Pavement Markers

The state-of-the-art with respect to raised pavement marker materials has advanced noticeably within the past few years. While a fully satisfactory, all-purpose marker has yet to be developed, progress has been made toward that goal. For the most part, however, the markers noted in NCHRP Report 130 are still being utilized where feasible. Advancements in the state-of-the-art are:

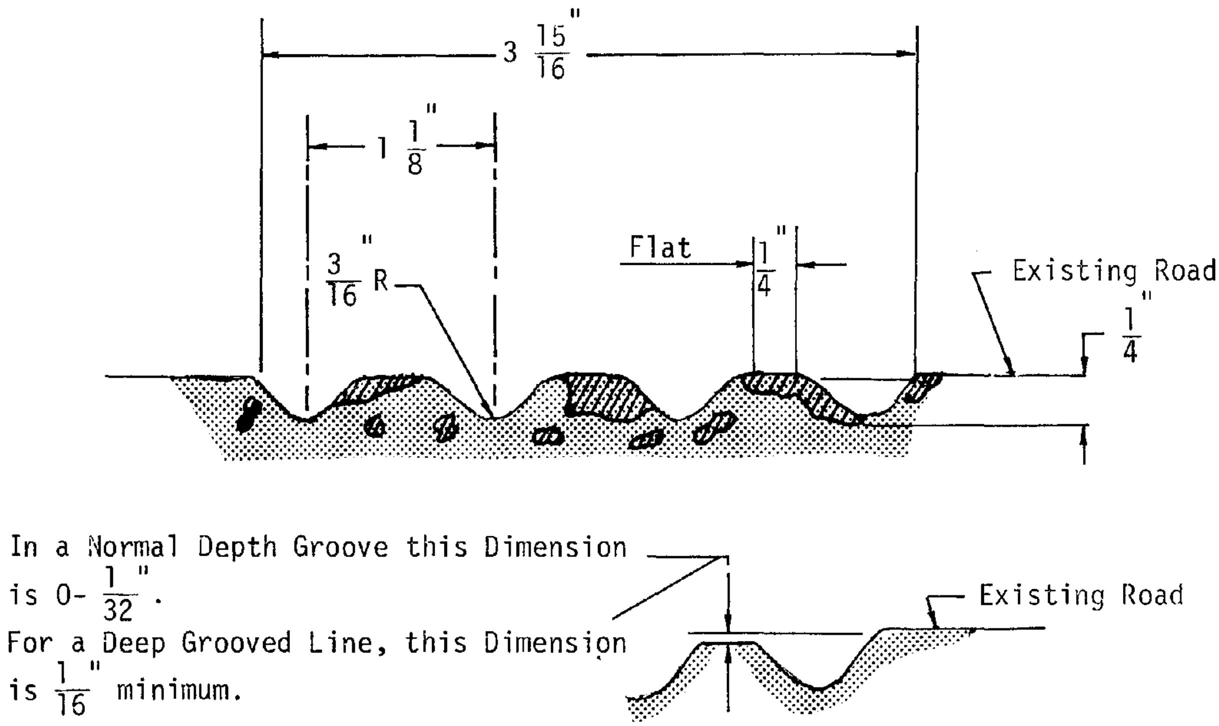


Figure 7. Grooved Traffic Line Cross Section
(Shelly, Rooney and Chatto, 1972).

Table 4. Comparative Costs (per mile) of Painted Line, Grooved Line, and Raised Markers (Shelly, Rooney, and Chatto, 1972)

	Initital Cost (dollars)	20 Year Cost (dollars)	Cost Per Year (dollars)
Plain Painted Line	120[1]	1070	53[2]
Grooved Line	720	1670	83[2,3]
Raised Markers	950	1900	95[3]

[1]Cost of initial striping includes alignment and two coats of paint.

[2]Costs based on one restriping per year.

[3]The life of a grooved stripe is estimated at 20 years. The life of the raised marker system is estimated at 10 years.

(1) California has been developing and evaluating various types of raised pavement markers since 1953. A report by Shelly, Rooney and Beede (1971) summarizes their experience:

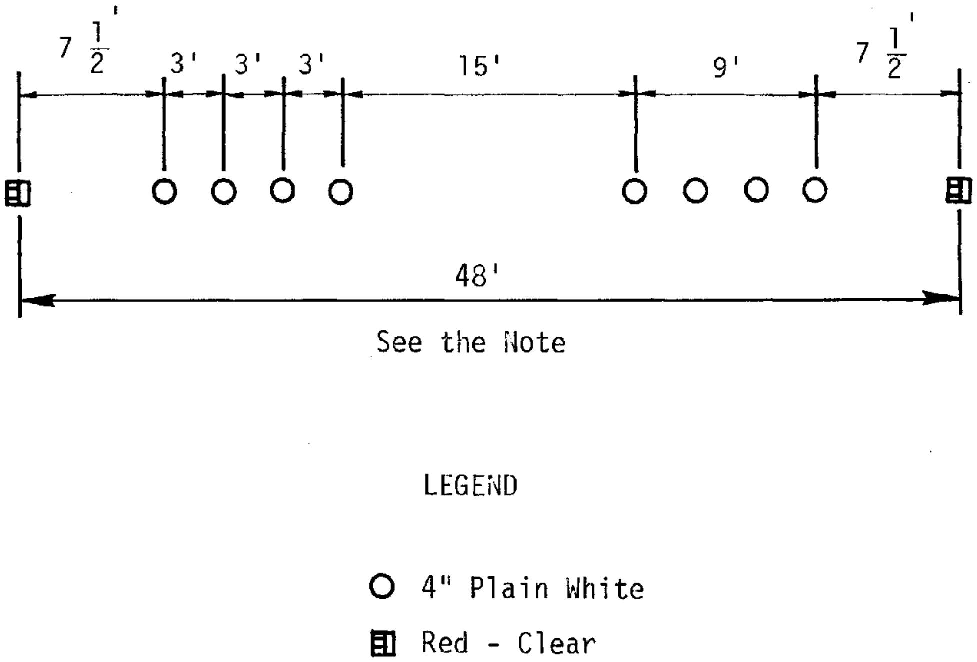
(a) The standard spacing pattern for raised pavement markers as lane lines on California freeways is shown in Figure 8. The white markers are ceramic; the red-clear markers are reflective.

(b) The reflectance of cube-corner reflective markers is reduced to about 1/20 to 1/50 of the original value within a few months due to surface abrasion. This reflectance, however, is adequate and remains relatively constant except when covered with tire stain. When the weather has been dry, and the markers are badly stained by traffic, they may not be as effective at night as a good beaded paint line. During wet weather, however, when the markers are clean and covered with a film of moisture, visibility is excellent, often approaching 1/4 to 1/3 the reflective value when new. Thus, the system is at its best when it is needed most.

(c) Under the most severe conditions service life for reflective markers is estimated at 1-1/2 years. For most freeway locations life expectancy varies from three to eight years and to over ten years for rural roads with low traffic volumes.

(d) The ceramic markers give good daytime visibility when clean, and supplement the cube-corner reflective markers at night when wet. They provide little nighttime delineation in dry weather, as they become pitted and badly stained from traffic. The ceramic markers are expected to last in excess of ten years.

(e) Raised markers are especially susceptible to an accumulation of dark tire stain during periods of hot



<u>NOTE:</u>

Place Reflective Markers at 48' Intervals on Tangents and on Curves of 1000' Radius or Greater, and at 24' Intervals on Curves with Less Than 1000' Radius, Unless Otherwise Shown.

Figure 8. California Freeway Marking Pattern (Shelly, Rooney and Beede, 1971).

dry weather. To overcome this problem, California has developed a traffic marker washer. Effective cleaning has been obtained at speeds up to 45 mph.

(f) Field tests of cast-in-place epoxy markers with glass beads, developed by Southwest Research Institute, showed that after three years of service, the beads were cracked or etched by traffic to such an extent that the markers were barely visible at night. Daytime visibility was poor due to tire stains on the epoxy surface.

(g) The Stimsonite "99" snowplowable markers can withstand normal snowplow operations--i.e., they will not be torn from the pavement. However, they will not withstand the type of plow action encountered when trying to remove packed ice on high elevation California mountain passes. In this situation the markers will be damaged, and also damage to the grader blade will be excessive.

(2) Battelle Columbus Laboratories recently developed a low-profile molded marker, intended to serve as a lane delineator on wet nights. Each marker segment is 3-1/2 inches wide, 1-7/8 inches long, and 1/8 inches thick. Normally, 20 markers are assembled on a strapping tape, which provides a 4 inch wide, 37-1/2 inch long marker. Field tests of both recessed and unrecessed markers indicate that they are effective as lane delineators during wet night conditions. Recessed markers appear to be unaffected by snowplowing with steel-tipped blades; unrecessed markers are less resistant--up to 25 percent were missing after one winter season (Grieser, Epstein and King, 1973).

The Federal Highway Administration is currently evaluating these markers in ten states. Preliminary results show that the markers are effective when covered by water. As these markers are intended to provide guidance only on wet nights, they are placed between regular painted delineation lines. The markers are subject to cracking by impact of vehicles, stones, etc., however.

(3) Two extensive investigations of the physical characteristics of raised pavement markers (reflectivity, durability, bonding) have been carried out in Louisiana. In the first, four brands of raised reflective markers were evaluated on a four-lane urban highway. Two brands were ABS Plastic, one acrylic, and one ceramic (Calhoun, 1970). Important results of this study are:

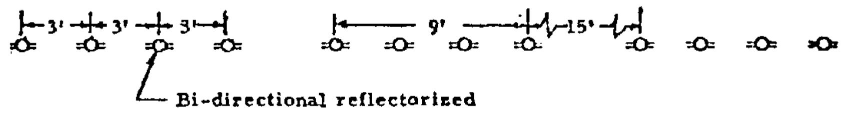
(a) The reflectivity of the markers quickly drops from the new condition to an average of about 50 percent of new, as determined through measurements with a Luckiesh-Taylor Brightness Meter. After this initial wear-in, the reflectivity is primarily a function of cleanliness. The most serious loss is due to road grime covering the reflective surface; the large high markers are least affected, while the low markers with small reflectors suffer the most loss.

(b) The durability of all the plastic markers was excellent; no significant failures occurred. The ceramic markers lost their reflective elements due to an adhesive failure; the body of the ceramic markers did not fail.

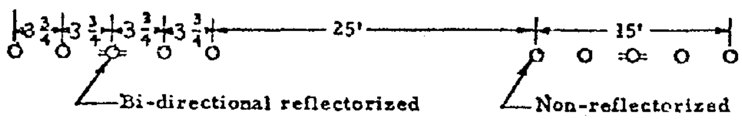
(c) Attachment of the marker to the roadway with a contact adhesive rubber was unsatisfactory. However, an epoxy adhesive system worked very well; no failures of bond occurred with the plastic markers. Those that were lost were due to a failure of the asphalt roadway. A few of the ceramic markers were lost due to failure between the marker and the adhesive.

In an appendix to the Calhoun (1970) report, marker patterns for different situations, as illustrated in Figure 9, are proposed. It appears the recommendations are the result of subjective visual observations by the research team. The marker pattern shown in Figure 9a has a 9 foot stripe (consisting of 4 white bi-directional, low-intensity reflectorized markers on 3 foot centers) and a 15-foot gap. This pattern was judged "impressive," even under considerable ambient light due to luminaires, signs, etc. In the absence of ambient light, it is felt that the marker pattern shown in Figure 9b is adequate. The pattern in Figure 9c is suggested for urban areas with high ambient lighting levels where a 15-foot stripe is desired. For lower levels of ambient light, only the two end markers need be reflectorized. The marker pattern shown in Figure 9d is for a center divider made up of a double line of yellow markers, each with bi-directional amber reflectors. In low ambient light areas, only every other pair of markers need to be reflectorized--i.e., reflectorized markers on 10 foot centers.

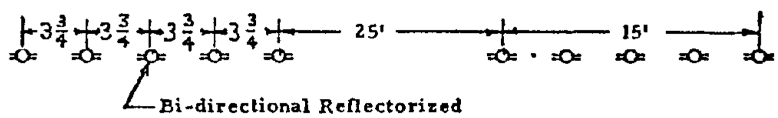
In the second investigation, Rushing, Burt, and LeBlanc (1971) evaluated the effectiveness of four types of raised pavement markers as supplements to painted lines in rural areas. Based on field and laboratory studies, it was concluded that supplementing painted lines with raised pavement markers placed at 40-foot centers is very effective and practical. As a result of their investigations, the Louisiana Department of Highways rewrote their specifications, and categorized the various markers to four classes according to function and/or reflective ability:



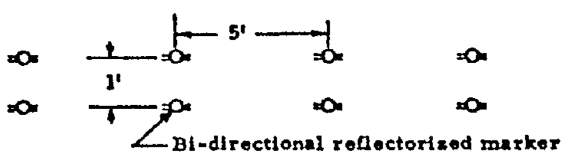
a. Marker Pattern With 9-15 Foot Spacing
With All Four Stripe Markers Reflectorized



b. Marker Pattern With 15-25 Foot Spacing
With Middle Marker of the Stripe Reflectorized



c. Marker Pattern Using 15-25 Foot Spacing
With All Five Stripe Markers Reflectorized



d. Marker Pattern Showing Design of
No Passing Center Divider of Reflectorized Markers

Figure 9. Recommended Marker Patterns (Calhoun, 1970).

- Class I Markers--shall be nonreflectorized and shall be used primarily for traffic rumble strips.
- Class II Markers--shall be highly reflectorized and shall have both daytime and nighttime visibility. Class II markers shall be used only for replacing a painted line.
- Class III Markers--shall be highly reflectorized and shall have both daytime and nighttime visibility. Class III markers shall be used for replacing or supplementing a painted line.
- Class IV Markers--shall conform to all requirements of Class II markers with the exception that daytime visibility shall not be required. Class IV markers shall be used for supplementing painted lines only.

Maintenance

In the report by Lanz (1973) on the evaluation of raised pavement markers in Mississippi, it is stated that 95 percent of the reflective-type markers and 80 percent of the ceramic-type markers remained in place after two years. Another problem cited is that raised pavement markers on asphaltic concrete pavements tend to tear away portions of the pavement when they are dislodged.

Cost

According to a 1972 report (Shelly, Rooney and Chatto, 1972), the cost of the standard pattern of ceramic markers and reflective markers was about $950 per lane mile in California at that time. They estimate the life of the raised marker system at ten years (review Table 4).

In the study of the use of raised pavement markers at lane drop situations, Pigman and Agent (1974) report an average cost of $150 per test installation--including the cost of markers, epoxy, and labor. The cost varies, of course, depending upon the type and spacing of markers used, but they feel this figure can be used for planning purposes.

The City of Memphis, Tennessee, has installed approximately 50,000 Stimsonite "88" raised pavement markers on their street system. Most of these were installed under private contracts. In 1974, the contract prices for installed markers were $3.71 each for yellow markers, and $3.61 each for white markers (Ficklin, 1975). Table 5 is extracted from a report by Lanz (1973) indicating the approximate costs for various lane markings in Mississippi. He states that in terms of direct costs over a ten-year period, thermoplastic stripes are the least expensive, and raised pavement markers the most expensive.

Effect of Snowplows

New Jersey has been testing different versions of the Stimsonite "99" snowplowable raised reflective markers since 1967 (Roberts, 1973). It is stated that the castings and reflectors in the latest marker versions (Series "h" and "k"; see Figure 10) are not damaged by either the tungsten carbide or carbon steel snowplow blades. However, the tungsten carbide insert snowplow blade was damaged by the castings, though no damage was detected in the carbon steel snowplow blades. The reflectivity of the markers has decreased with the model changes as durability has increased. However, while visual observations indicate that the markers are no more effective than painted lines on dry nights, their visual effectiveness is found to increase with a worsening of wet night driving conditions (when the painted lines are no longer visible).

Colored Pavements

In NCHRP Report 130, it was reported that colored pavements were found to be only marginally effective as delineation treatments, and that their use would be justified under only very exceptional conditions and in unique applications due to the relatively high cost. More recent information, confirming these conclusions, has been provided by a study in Ohio (Foody and Hubbell, 1974). Orange colored pavement was evaluated as a delineation treatment on the median storage area of at-grade intersections of a four-lane divided highway with two-lane highways. Field studies at six sites showed that neither the operational safety nor the operational efficiency was improved by the treatment. Also, it was found

Table 5. Summary of Materials Studied (Lanz, 1973)

ITEM	TRAFFIC PAINT 15 Mils 2/6#/gal.	THERMOPLASTIC 75-130 mils w/Dressing Beads	RAISED NONREFLECTIVE MARKERS Ceramic	RAISED REFLECTIVE MARKERS Plastic
Equipment Cost	Min. - $1,000 hand. Production - $35,000 (auto.)	Min. - $8,000 hand. Production - $25-60,000 (auto.)	Min. - $5,000 est. Production - Est. $20,000-$50,000 (auto.)	
Type Application	Atomizing Spray (60 PSI) or Airless Spray (1500 PSI)	Extrusion (Screed) or Atomizing Spray (60 PSI)	Two component epoxy with hand placement (sand blast required on PCCP)	
Service Life	Ave. - 1 Year Min. - 4 Months Max. - 2 Years	Ave. - More than 10 yrs. Min. - 5-7 Years Max. - Not known	Service life not known for our conditions	
Cost (est.) (Skip-line per mile)	$65 State Forces $120 Contract	$300-500 State Forces $500-560 Contract	$640 Contract	$220 Contract
Effectiveness	Day: Good-Excellent Night Wet: Very Poor Dry: Good-Excellent	Day: Good-Excellent Night Wet: Poor Dry: Good-Excellent	Night: Poor(Non-Refl) Day: Good(Non-Refl)	Day: Poor Night Wet: Excellent (Refl.) Dry: Excellent (Refl.)
Cost/mile for 10 years - No interest included	Ave. - $700 Annual Min. - $335 Biannual Max. - $1235 Semi-Annual Average cost of edge stripe $335	Ave. - $550 Min. - $500 Max. - $1200 Average cost for 125 mil edge line $1335	Ave. 2-7 percent lost/year Max. 5-10 percent lost/year Use limited to Max. conditions at present. Est. Avg. cost $1100	Ave. 1-3 percent lost/year Max. 2-6 percent lost/year Use limited to Max. conditions at present. Est. Avg. cost $400

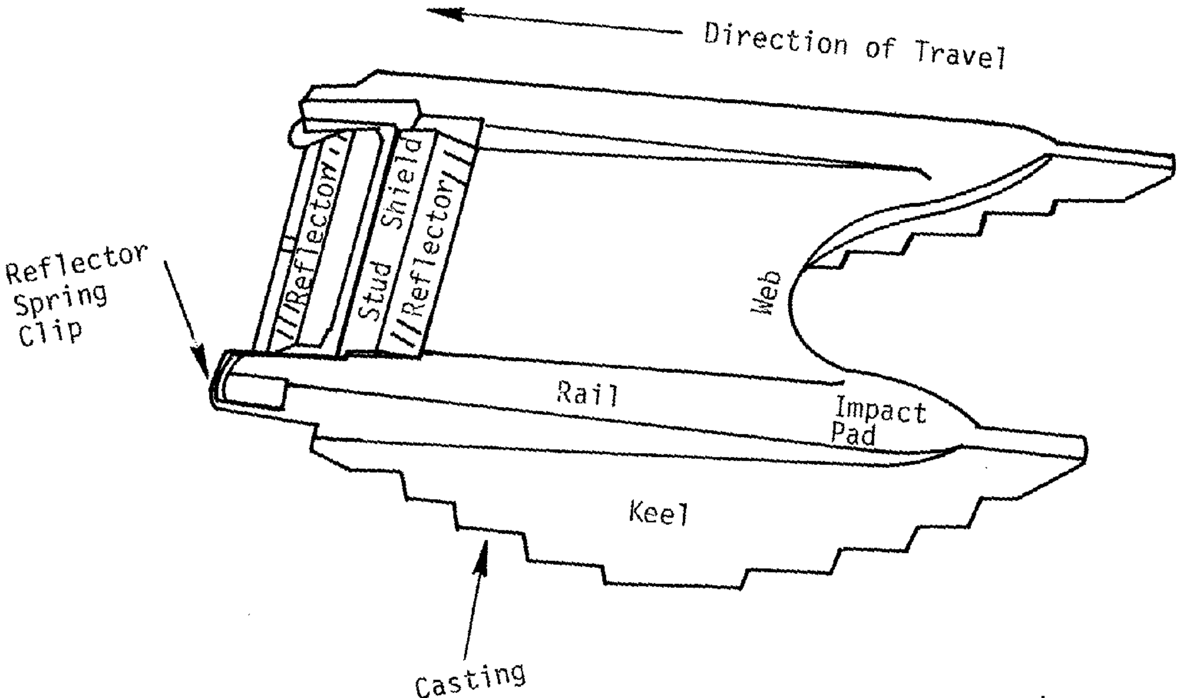


Figure 10. Marker Details (Roberts, 1973).

that the color faded and was also discolored by tire marks. Glass beads were rolled into the pavement in an attempt to increase nighttime visibility--the experiment was not successful, though it is not clear whether the beads or the installation procedure were at fault. (Considerably higher reflectance readings were obtained in the laboratory for these samples incorporating glass beads--see Figure 11.)

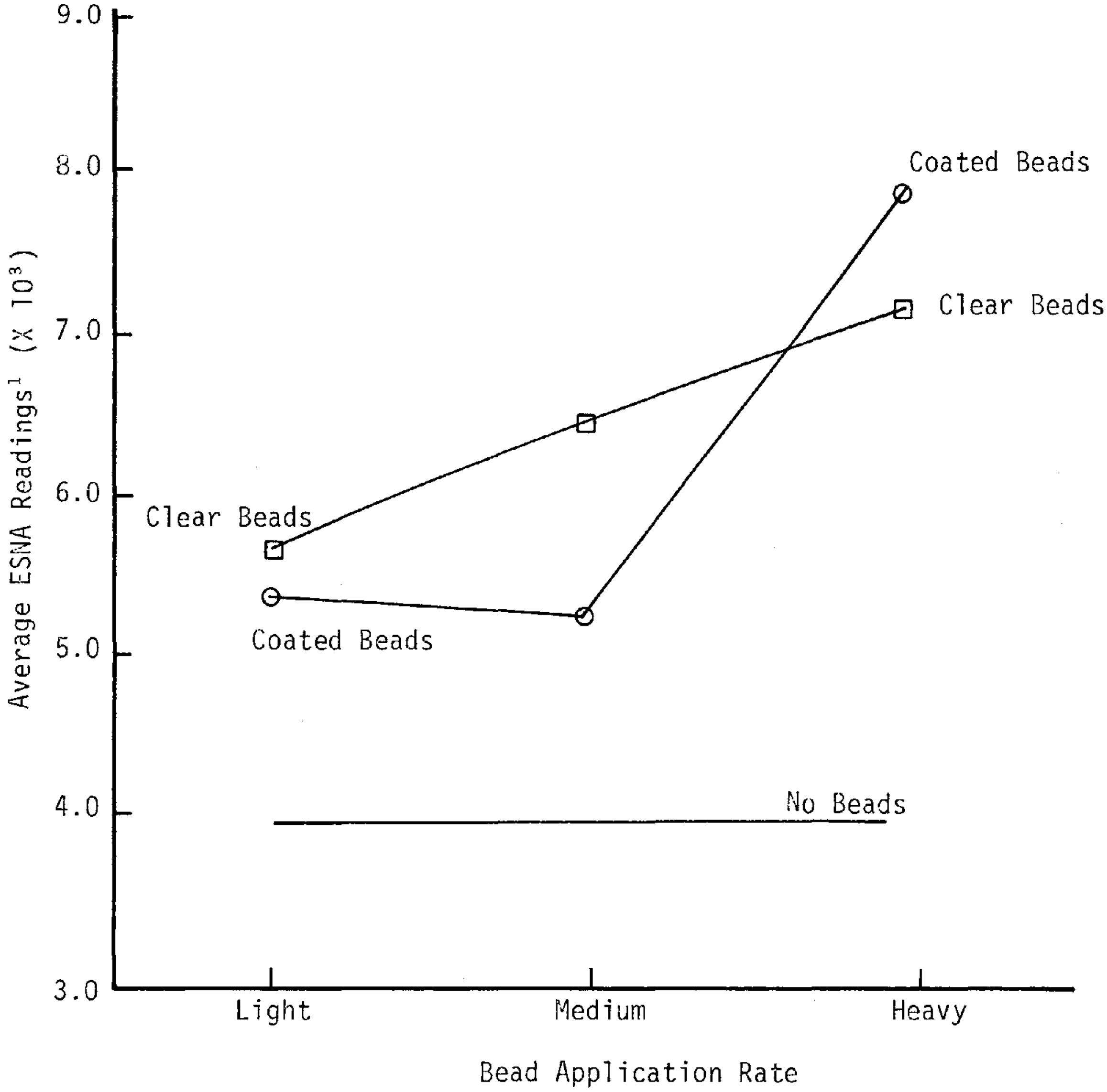
Curbs

In NCHRP Report 130, it was reported that engineers in California had serious doubts regarding the safety aspects of curbs on high-speed freeways. The findings of a subsequent NCHRP-sponsored study by Texas Transportation Institute also suggest that curbs of the configurations tested (those in general use) have no redirection capabilities to enhance safety in a high-speed travel environment, and some may even reduce safety, especially when a curb-guardrail combination exists, by causing vehicle ramping (Olson, et al., 1974).

Since curbs are installed primarily for reasons other than delineation, their absence should not significantly detract from the delineation environment. They will, however, still find application in urban areas and for edging channelization islands.

Synthesis and Evaluation

Since 1970, considerable attention has been given to the development and testing of delineation materials. State and local agencies are continually seeking new cost-effective marking materials and techniques--especially since more and more miles of highway are being brought up to higher marking standards and delineation costs have escalated so rapidly in the past few years. (Norris (1975) reports there has been a 60 percent increase in paint striping material costs over the 1973-75 period.) The quest for an all-purpose, all-weather raised pavement marker suitable for snow as well as dry areas has resulted in the development of a few new types of markers as well as modifications of some of the older types. Evaluation continues, but it appears that high retention rates under severe snowplowing operations are feasible. Decisions on cost versus



[1]Reflectance Data as Obtained by Using a ESNA Reflex Photometer.

Figure 11. Effect of Bead Application Rate on Pavement Reflectance (Foody and Hubbell, 1973).

operational and safety effectiveness must still be made by individual agencies.

Particularly relevant developments of delineation materials and treatments since the publication of NCHRP Report 130 include:

(1) Thermoplastic marking materials are gaining wider acceptance with time--they are reported to be more cost-effective than standard paint lines when the longer service lives and reduced interference from maintenance operations (repainting) are considered. In some instances they are even recommended for rural areas where traffic volumes are high.

(2) The number of reports of studies evaluating raised pavement markers indicates that this method of delineation is being utilized in increasing numbers--at least in states where snow removal is not a problem. For snow areas, at least one type of commercial marker has been installed in significant numbers; others are under development and/or are being field tested.

(3) The desirability of periodic cleaning of post delineators and raised pavement markers is evidenced by studies which have shown that visibility is substantially reduced by dirt film or tire stain.

(4) The problems associated with utilizing colored pavement as a delineation treatment have not been overcome. The costs are high, and nighttime and wet weather visibility are still low and fading also persists. An attempt by the Ohio Department of Highways to increase nighttime visibility through the use of colored beads was not successful.

(5) Curbing on high-speed highways was shown to be unsafe for vehicles that impacted, and its use as a delineation device on these highways is not recommended.

PART II

RECOMMENDATIONS

SUBJECT TO ONGOING RESEARCH

DELINEATION TREATMENTS

Part I was a review of studies reported since the publication of NCHRP Report 130. Essentially, updates have been provided of Appendix A of NCHRP Report 130 where driver information requirements and delineation applications under various geometric situations are of concern, and Appendix C, dealing with the physical characteristics of the various delineation treatments.

In Part II, recommendations and general guidelines for the effective application of delineation treatments and/or systems on the nation's roadways are presented. Therefore, these recommendations are interim and in some cases based on limited data. For completeness and the convenience of the reader, those original recommendations of NCHRP Report 130 which have remained unchanged are repeated here. At the end of this Part, information dealing with specific treatments from the standpoints of materials, costs, maintenance, durability, and environmental effects is presented. For conciseness, the material in this Part has been presented without referring to the specific studies. Further detail can be obtained from Part I of this report or NCHRP Report 130.

Tangent and General Situations

Pavement Markings

1. The gap-to-mark ratio for center lines should be increased from the present standards. A suggested pattern is a 6-foot mark with a 34-foot gap; this will retain the 40-foot module.
   - A savings in paint material costs will result.
   - England has used a 3-foot mark with a 24-foot gap for several years (see Figure 12). 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.

Figure 12. Broken Center Line Pattern, England (3 Foot Mark; 24 Foot Gap).

Figure 13. Test Broken Center Line Pattern (5 Foot Mark; 35 Foot Gap).

- A study reported in Appendix O of NCHRP Report 130, using a 5-foot mark with a 35-foot gap (retaining the basic 40-foot module), with and without edge lines, indicated no meaningful changes in vehicle speeds or lateral placements (see Figure 13).

- Pennsylvania has recently reduced the "strength" of the lane line marking on some divided highways. The old mark (6 inches by 15 feet) and the new mark (4 inches by 10 feet) are visible in Figure 14. Both are applied in a 40-foot module. There have been no complaints (or remarks of any kind) by the public.

- From a human factors standpoint, the number of mark "ends" observed is of relatively greater 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.

- The adoption of a "weaker" broken-line pattern in areas where it serves only to mark the center line of the road will permit the use of "stronger" broken lines in areas where special caution may be required but crossing the line is still permitted (see Figure 15). This concept has been used extensively and successfully in England and some other European countries.

2. Continuous edge lines should be placed on all roads over 22 feet in width, where traffic volumes justify the expenditure. They are 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 not 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.

Figure 14. Old and New (Reduced) Lane Line Patterns in Pennsylvania (1975).

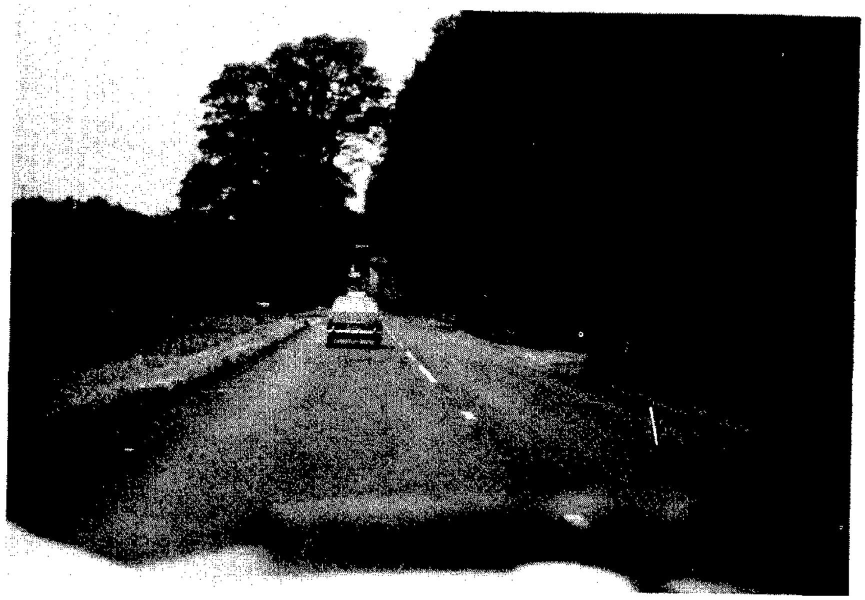


Figure 15. Change in Strength of Broken Center Line Pattern, England.

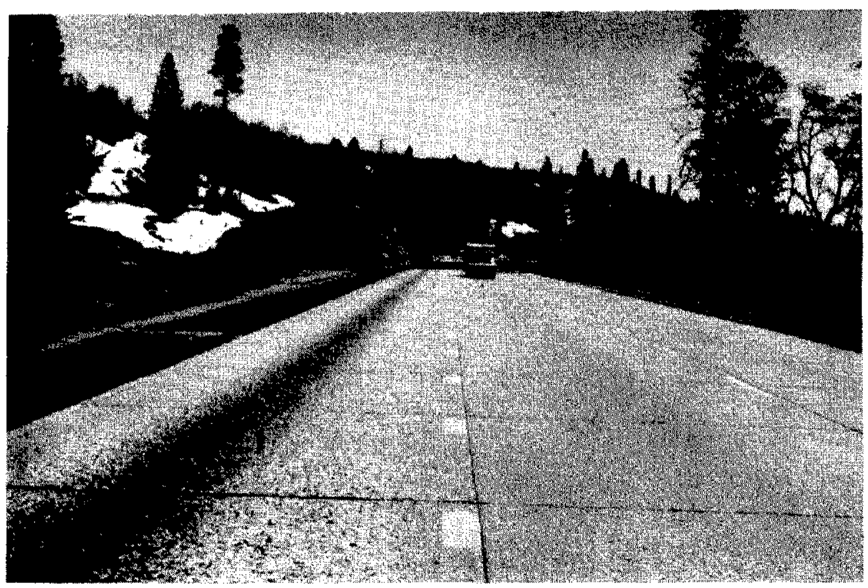


Figure 16. Use of 8-in. Broken Line for Climbing Lane Situation.

- Research on the effectiveness of edge lines on 16 foot wide roads with no center lines is recommended.

3. A 4 inch width should be used for center lines and edge lines in the general case.

   - Various widths of lines were installed in a study in England--they concluded that 2 inch 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 inch lines just provided "more of the same" when compared to the 4 inch lines, and the additional paint costs do not seem justified--compare appearances of these two line widths in Figure 14.
   - The possibility of reducing the line width to 3 inches should be explored.

4. Eight-inch broken lines could be used for special applications where crossing is permitted, but the driver should be made aware that he is entering a nonstandard zone--e.g., climbing lanes (see Figure 16), approaches to lane-drop exit ramps, etc. A pattern of 7-feet mark, 13-feet gap is recommended. Where special purpose travel ways parallel through lanes and crossing is not permitted, a solid 8-inch line can be used.

5. Thermoplastic marking materials should 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.

   - One of the strongest arguments for thermoplastics is that they are available for a larger percentage of the time than painted lines, and hence traffic need not be interrupted as frequently for restriping as with paint lines.

6. Drivers prefer a two-line delineation system (i.e., center line with edge line) 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.

Contrasting Shoulders

The use of visually contrasting materials can be a very effective delineation treatment, as shown in Figure 17. However, the contrast tends to decrease with time.

Post Delineators

1. Post delineators should be installed along the right side of two-lane rural roads. A spacing of 400 feet is adequate on tangents 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.

2. Crystal, or white, delineators should be used on the right side of tangent sections.

3. The standard retroreflective delineators, usually amber, should be removed from culvert markers ("negative" delineation) when the crystal delineators are used for "positive" delineation, as recommended above.

4. The tops of the posts should be painted with reflectorized paint. This will make the posts visible to maintenance crews, but, because of the low intensity, they will not detract from the positive delineation pattern for the average driver.

5. The "negative" delineators should not be removed where the positive delineation pattern is not implemented. Even though not standard in application, they do give the driver some indication of the roadway alignment ahead.

Figure 17. Contrasting Shoulder Treatment as Delineation.

6. 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.

7. The "paddles" used in some states for daytime delineation (see Figure 18) are of limited usefulness, and should not be installed as a standard treatment. In daylight these serve little purpose, as there are usually enough other natural cues to inform the driver of the roadway alignment. However, black and white striped post delineators used in Virginia and some other states (see Figure 19) may be useful in providing both the daytime and nighttime delineation.

8. **Increased emphasis should be placed on the use of post delineators on rural two-lane roads. Sudden changes of alignment and uncertainty of the roadway path are more prevalent on the two-lane roads.**

<u>Raised Pavement Markers</u>

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

   - Ceramic markers are the most effective during the day.
   - A spacing of 3 or 4 feet will simulate a solid line (or the solid part of a broken line) (see Figure 20).

2. 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 feet for reflectorized raised pavement markers is sufficient; this can be reduced to 40 feet in "warning" areas where crossing is permitted, but discouraged.

Figure 18. Paddles for Daytime Delineation
(Use is Discouraged).

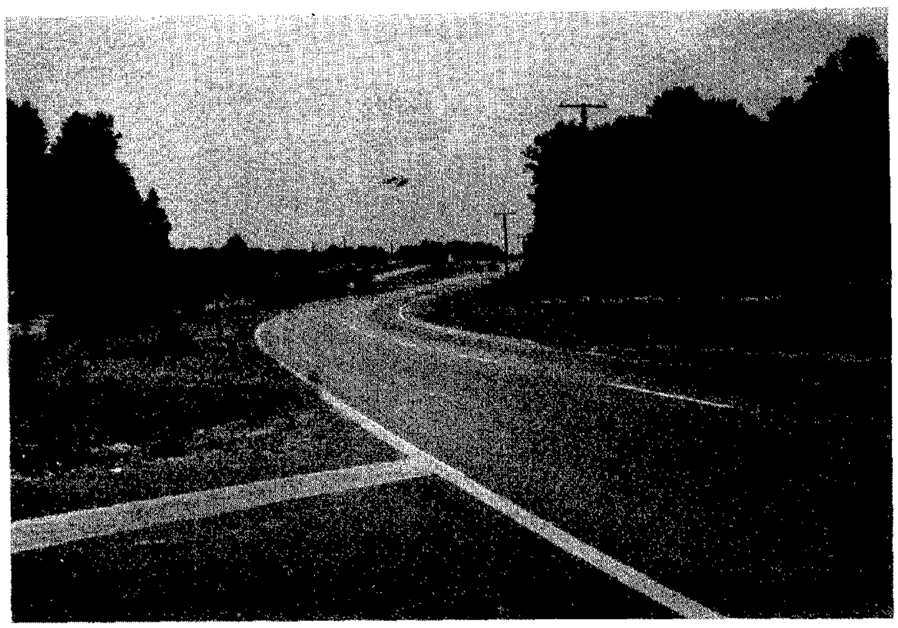


Figure 19. Striped Post Delineators Used in Virginia
and North Carolina.

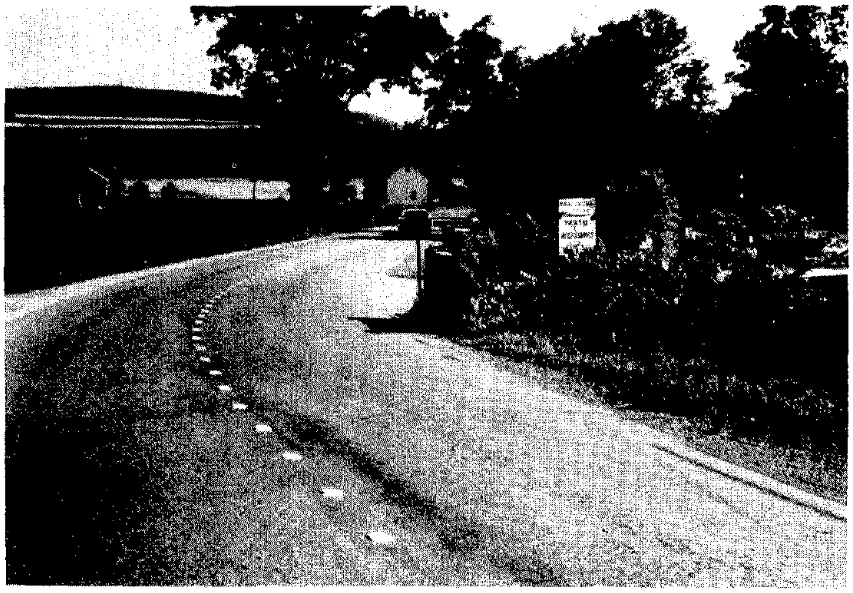


Figure 20. Simulation of Solid Line with Raised Pavement Markers.

Figure 21. Non-Reflectorized Raised Pavement Markers Spaced at 4-Feet, with High-Intensity Markers Spaced at 24-Feet.

- High-intensity markers (e.g., Stimsonite "88") spaced at 24 feet will give the appearance of a solid line at night (see Figure 21); a spacing of about 6 feet is required if low-intensity markers are used. The first type derive their strength from brightness; the latter type from density.

3. No acceptable pattern of raised pavement markers for right edge lines has yet been reported in the literature.

4. 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, costs are relatively high, and effective service lives are still of some concern. They do provide wet night visibility, however, and 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. On the other hand, one of the principal advantages of post delineators is that they are visible for longer distances, particularly at crest vertical curves.

Horizontal Curves

Pavement Markings

1. 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 curves where passing is permitted but discouraged, and on approaches to no-passing areas on more severe curves.

2. If pavement width is sufficient, the addition of edge lines (on roads where they are not being used on the tangents) will improve lateral placement characteristics, with possible reduction in accident experience. For example edge lines were added to the horizontal curve in Figure 22. Note this curve is on the approach to a STOP sign.

3. Pavement markings are good "near" delineation devices, but supplemental treatments with longer visibility distances are required to supply anticipatory information.

4. 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.

5. Transverse stripes of thermoplastic marking material may be used as a visual warning device at particularly hazardous horizontal curves, though it is not felt they should be used as a general treatment. (Rumble strips, which provide tactile as well as visual stimuli, are discussed later.) More research is needed to determine the most appropriate longitudinal patterns for these stripes.

Post Delineators

1. The most effective pattern, from the visual standpoint, is the use of post delineators on the outside of curves only. (See Figure 23).

   - 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 will learn this color code with time, and recognition of the direction of the curve will increase their anticipatory informtion. Continued use of amber delineators at culverts, etc., on both sides of the roadway weakens the code considerably.

Figure 22. Addition of Edge Lines at a Horizontal Curve.

Figure 23. Post Delineators at a Horizontal Curve to the Left--Outside Only.

2. A post delineator spacing on curves as recommended in the MUTCD is adequate. (Spacing in Figure 23 is consistent with MUTCD recommendations.)

3. Maintaining maximum delineator brightness is probably not critical in terms of accident-reduction -- the necessary driver actions can usually be taken after the delineation becomes visible if nominal brightness is still available. However, clean delineators will increase the anticipatory information available and ease the driving task. (It is not implied that cleaning is unimportant, as heavy dirt films can reduce the brightness below an acceptable value.)

4. Consistent application is desirable -- post delineators should be used at all curves over 5° of curvature having a central angle exceeding 20°.

Raised Pavement Markers

1. No change in the patterns of raised pavement markers used on tangent sections is necessary for similar applications at curves, other than the use of solid lines in no-passing areas. Again, a stronger line (derived through closer spacing) than on the tangent could be used at gentle curves where passing may be permitted, and at approaches to no-passing zones.

2. Raised pavement markers can be a very effective supplemental treatment at curves on two-lane roads where the expense may not be justified for continuous application on tangent sections. (See Figures 24 and 25.)

    - They serve as "far" delineation, with good visibility distance and correspondence to the roadway path.

    - They are excellent "near" delineation treatments and usually result in significant improvements in vehicle lateral placement patterns, particularly when used with edge lines as in Figure 26. A comparison of the photographs in Figures 24 and 26, both taken at the same curve, illustrates the im-

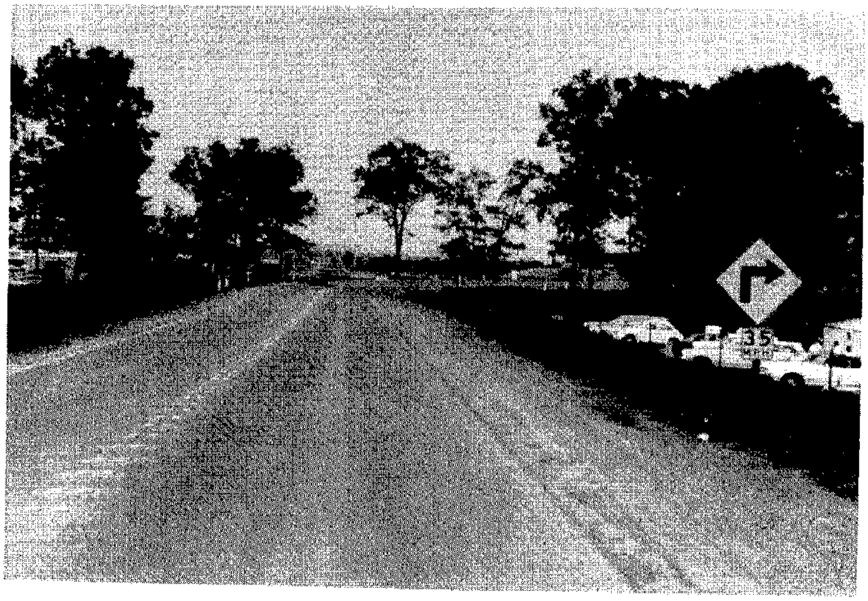


Figure 24. Raised Pavement Markers at a Horizontal Curve (Day).

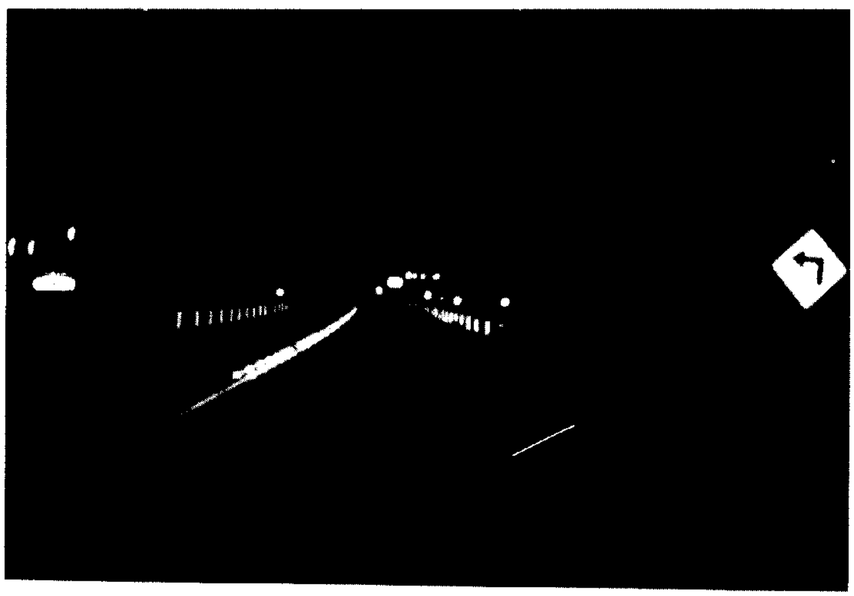


Figure 25. Raised Pavement Markers at a Horizontal Curve (Night).

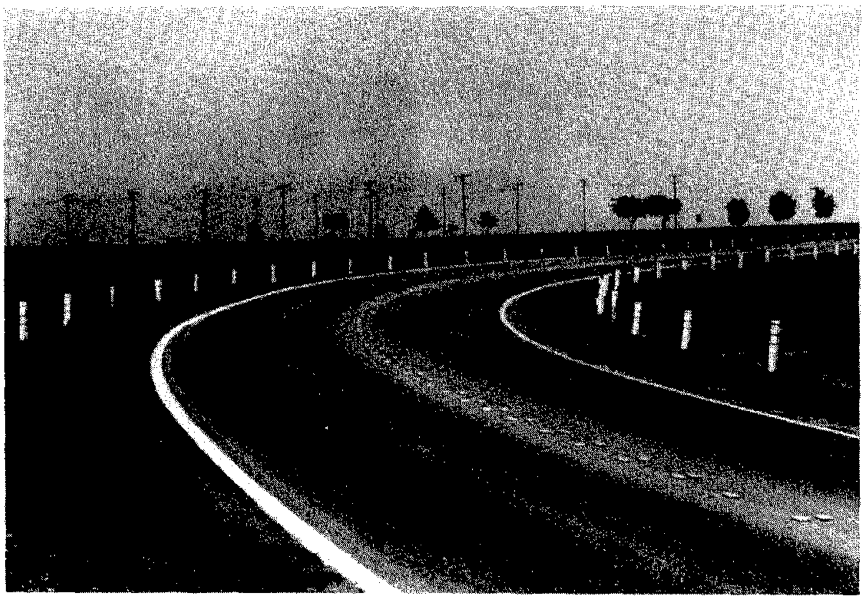


Figure 26. Raised Pavement Markers at Horizontal Curve (Day, with Edge Lines).

Figure 27. Rumble Strips at a Horizontal Curve.

provement in pathway definition obtained through the addition of edge lines.

3. The color of the raised pavement markers should be the same as the pavement markings they are supplementing.

4. 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.

- Patches consisting of a series of transverse spray thermoplastic strips, 6-inch wide with 6-inch spacings, as in Figure 27, are effective and do not give rise to objectionable vibrations or noise (to drivers or neighbors).
- Thermoplastic 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. (The concept is illustrated in Figure 15.)

Raised Pavement Markers

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

Pavement Width Reductions

Pavement Markings

1. Painted or thermoplastic arrows indicating traffic should leave the lane being dropped are recommended where traffic volume justifies.

2. Edge lines should be continued, or added if non-existent on the approach.

3. The use of heavy lines (8 inches wide, with 7-foot mark and 13-foot gap) will be helpful on approaches to the lane-drop ramp situation. (See Figure 28 for concept; dimensions are not those cited here.)

Post Delineators

1. Shortening of the spacing between post delineators in the area of the pavement width reduction will emphasize a feeling of constriction on the part of the driver.

2. Use of post delineators on both sides of the road will further emphasize constriction, and promote slower and more attentive approaches.

3. Modified post delineators with daytime visibility, while generally discouraged for aesthetic reasons (such as shown in Figure 18), may be beneficial in this instance as roadway and topographic cues are often missing. Striped "bridge end panels" on posts, such as those shown in Figures 19 and 29 are suggested -- particularly where accident experience indicates a problem exists during daytime hours.

Rumble Strips

1. Transverse rumble strips can be used to outline the taper area where a reduction in pavement width occurs -- i.e., a rumble will be felt if drivers leave the proper path.

2. The rumble strip treatment should be used primarily as a supplement, where a problem persists after other treatments have been installed.

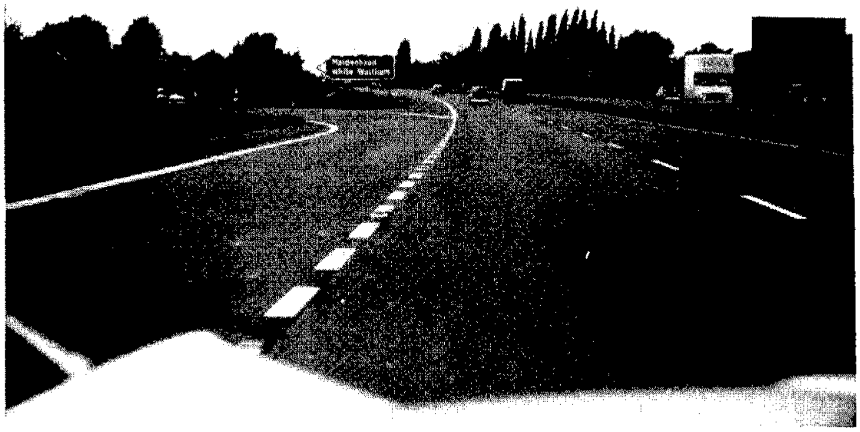


Figure 28. Pavement Markings at Lane-Drop Exit Ramp, England.

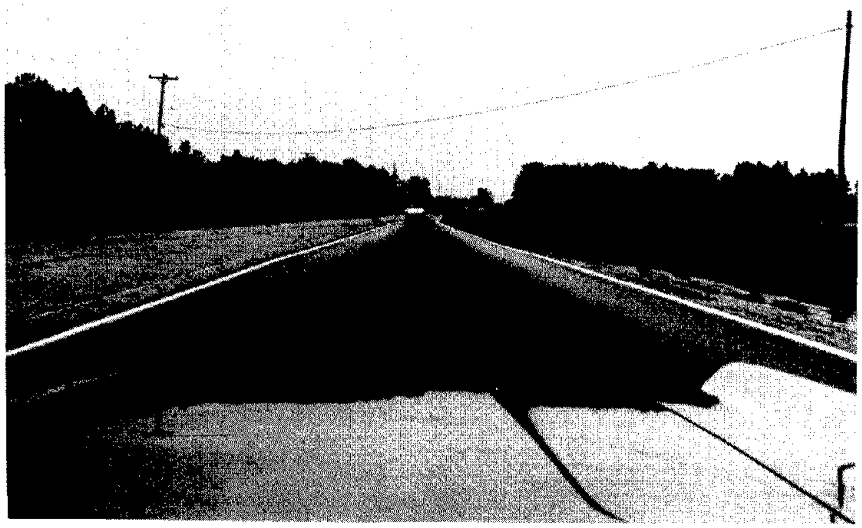


Figure 29. Daytime Delineation at a Lane Drop.

Merge and Diverge Areas

Pavement Markings

1. Discontinuous lanes (such as acceleration and deceleration lanes) should be separated from the through lanes with a special pavement marking pattern. For example, at a parallel type deceleration lane, a dotted line (perhaps 3 foot mark to 10 foot gap) could be used from the beginning of the taper until the full width of the deceleration lane is developed; then the pattern could change to a fairly heavy dashed line (10 foot mark; 10 foot gap) to a point about 200 feet before the physical exit gore, at which point a solid line could continue on to the gore markings. A reverse of this pattern would be used at acceleration lanes. A width of 8 inches for all such lines is recommended. (The general concepts are illustrated in Figures 30 and 31 -- the dimensions of the marking pattern, are not the same as recommended here, however. Also note the suggested "dotted line" was not used in the taper area of the acceleration lane.)

   - Through-drivers are provided a continuous "reading" on the limits of their lane.
   - Exiting (or entering) drivers will recognize that "change of state" is required and, with experience, will enter the deceleration lane through the dotted line pattern.
   - These markings are particularly appropriate where ramps enter or leave curved sections of highway.
   - Thermoplastic markings should be used in this application, as heavy wear will be encountered.

2. Painted gore markings at exit ramps should be heavier than standard lines -- 8 or 12-inch lines are suggested. There is considerable doubt that the zebra stripes or diagonal lines sometimes used within the diverging gore lines are cost-effective. (Figures 32 and 33 depict two exit gore areas without the zebra stripes.)

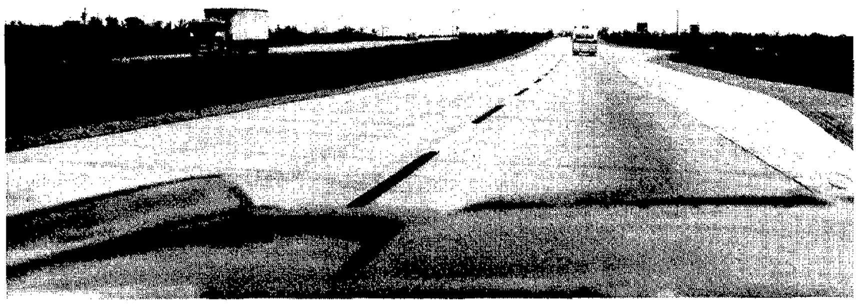


Figure 30. Pavement Markings Separating Deceleration Lane from Through Lanes.

Figure 31. Pavement Markings Separating Acceleration Lane from Through Lanes.

Figure 32. Wide Painted Gore Markings.

Figure 33. Raised Pavement Markers; Diverge Gore Area.

Post Delineators

1. Delineators on ramps should have a different color, shape and/or pattern 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; the blue delineators and markers are not permitted under the current MUTCD, however.

2. Through-way delineation should be strengthened in exit ramp areas -- i.e., the spacing between left-side delineators should be reduced where they are being used, or post delineators should be 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.

3. Once the diverge area has been clearly established, it is desirable to discontinue the use of post delineators on the inside edge of ramp curves (the right edge for standard exit ramps). This is not necessary where different color delineators are used for the two sides of the ramp.

4. An important cue in exit ramp situations is the color change at the point of the gore.

5. Similarly, a change in pattern or 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

1. Where they can be used, raised pavement markers are an excellent treatment for diverge gore areas. (See Figure 33.)

2. Raised pavement markers should be supplemented with post delineators on vertical crest sections, which occur rather frequently in merge/diverge situations.

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

1. 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. (Concept illustrated in Figure 15.)

2. The previously described heavy broken line (i.e., 8-inch wide; 7-foot mark to 13 foot gap) should be used to separate discontinuous lanes from through lanes -- e.g., between a left-turn slot and the through lanes. (Pavement markings separating turn slots from the through lanes are shown in Figure 34; the pattern is considerably lighter than recommended herein, however.)

3. 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 feet for the last 500 feet 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).

Figure 34. Pavement Markings Separating Turn Slots From the Through Lanes (Heavier Markings are Recommended).

Raised Pavement Markers

1. Spacing between raised pavement markers should be reduced in line with the recommendation for strengthening painted lines on the approach to intersections.

2. 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 is desirable to omit the raised pavement markers for the first 100 feet of the left turn slot to permit traffic to get into the slot without crossing the markers themselves.

Stop Approaches

Pavement Markings

1. 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.

2. 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.

3. Transverse stripes, usually painted across the approach lane(s) at gradually decreasing spacings, are effective in reducing approach speeds -- both in absolute magnitude and in variability. While not proposed as a general treatment, these stripes can be applied where the required STOP is unexpected, or where past accident experience indicates the need for special measures.

   - Thermoplastic materials should be used as painted lines will wear away quickly in this situation.

   - The bars should be 24 inches wide. More research is needed before an optimum spacing pattern and longitudinal length of installation can be recommended -- it appears a maximum spacing of about 40 feet, closing to 10 or 15 feet near the STOP bar would be satisfactory; an overall pattern length of 500 feet should be sufficient for rural highways. (It is likely these specifications should change with variations in approach speeds.)

Post Delineators

1. Post delineators at progressively shorter spacings (from 200 feet or more down to 10 feet) on the approach to STOP signs have been found to be effective in reducing approach speeds.

2. Crystal post delineators were found to be at least as effective as red delineators as a stop approach treatment. Hence, crystal is recommended.

3. Post delineators, at progressively shorter spacings, may be added to the left side of the roadway to strengthen this treatment message.

Raised Pavement Markers

1. A progressively shorter spacing of raised pavement markers, where they are in use, is recommended on approaches to STOP signs.

2. 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.

3. 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.

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.

DELINEATION TREATMENTS

Some of the more important physical characteristics and features of pavement lines, raised pavement markers and post delineators are reviewed in this section. There are certain characteristics which are desirable in any delineation treatment. These include:

1. Good visibility during day and night, especially under adverse weather conditions.
2. Ease of installation and maintenance; minimum delay to traffic.
3. Durability and long life.
4. Economical.
5. Resistant to dirt and grime; ease of cleaning.
6. Good adhesive and retentive characteristics.

Pavement Markings

Pavement markings are classified into two broad categories: (a) paints (reflectorized and nonreflectorized), and (b) plastic compounds (cold applied and thermoplastics).

Paints

1. There are a variety of paints available on the market today. These can be classified by the type of base, such as alkyd, rubber vinyl, epoxy, water base and high polymer. Apparently there is no one paint which is suited for every color and for every situation. Specifications for various kinds of paints can be found in "Traffic Control Devices Handbook -- An Operating Guide; Part II -- Pavement Markings" (1974).
2. Drying time of paints varies according to the type of paint, coating thickness, and atmospheric and roadway conditions. Drying times of 10 to 60 minutes are typical. However, some hot applied paints take as little as 20 seconds to dry.
3. Reflectorized paint for nighttime visibility is obtained by dropping glass beads onto the wet painted binder. The refractive index

of the glass commonly used for beads varies between 1.50 and 1.60. Bead size varies according to the type of application: standard drop-on type, U.S. mesh 200 to 20 (74 to 840 micron); floating type beads, U.S. mesh 80 to 40 (117 to 420 microns); and premix beads, U.S. mesh 230 to 60 (62 to 250 microns).

4. A typical cost for beaded painted lines is $0.022 per lineal foot.

5. Traffic paint is generally applied at a rate of approximately one gallon for 100 to 110 square feet, or 300 lineal feet of a 4 inch wide continuous stripe. This corresponds to a wet film thickness of about 15 mils (0.015 inches).

6. Service lives of painted lines are shortened by wear and abrasion from snowplowing and sanding operations. It is not unusual for a painted line to wear out during the course of one winter season with moderate snow. The average life of a painted line is between six and twelve months. (The effect of tire wear on painted lines can be seen in Figure 35 -- traffic swings right at this location to prepare for a sharp curve to the left. The end of the right-side edge line is still clearly visible, indicating the line was repainted recently.)

7. Painted lines have good daytime visibility and provide adequate "near" delineation under dry conditions. Reflectorized paint lines also have good nighttime visibility under dry conditions. Neither type of painted line is effective under wet pavement conditions when the lines are covered with a water film.

Plastic Materials

Plastic marking materials are divided into two basic types according to the method of application: (a) cold applied, and (b) hot applied.

Cold Applied

1. These are generally manufactured into preformed shapes, such as lines and letters. Most are also provided with an adhesive backing

Figure 35. Evidence of Wear of Painted Edge Line.

for application. The markings are either applied directly or with a solvent to activate the adhesive.

2. Cold applied markings are used primarily for high volume urban situations. Typical uses are in marking crosswalks and laying down messages.

3. The lifetime of cold applied markings is estimated to be three to four years. Resistance to wear, especially with regard to studded tires, is considered good.

4. Daytime visibility is good. The visibility at night is variable and depends upon the composition of the material. Beaded plastics have good nighttime visibility.

5. Because of their rather polished surface, they have relatively low skid resistance. However, the overall effect may not be overly hazardous because of the small area covered by these markings.

Hot Applied (Thermoplastics)

1. Thermoplastics are generally used in urban areas where traffic volumes are high. They are not widely used in regions where snow conditions are severe because of their higher cost (compared to paint) and inability to withstand repeated snowplowings.

2. Thermoplastics are of two general types; extruded hot plastic and spray-on. Both are intended for long-life installations and require special application equipment. Because of their longer life, adequate care should be taken to ensure that sites will not be undergoing major changes in the near future. Typical life of thermoplastic markings is estimated to be eight years.

3. Thermoplastics are more durable on bituminous pavements than on Portland Cement Concrete pavements. Under hot weather conditions, thermoplastics have a tendency to creep.

4. Hot spray plastics dry immediately, permitting traffic to cross within as little as five seconds after application.

5. Thermoplastics are approximately 15 times more expensive to install than ordinary paint lines. The average cost of hot extruded thermoplastic lines is on the order of $0.33 per linear foot.

6. Because thermoplastic markings are thicker than paint, they are more visible in moderate rain. The thickness of thermoplastic lines varies between 60 and 90 mils (0.060 to 0.090 inches).

Post Delineators

1. Post delineators consist of a post and a reflective unit mounted on the post. Post delineators are used extensively to provide "far" delineation and delineation in snowfall areas where the snow may completely cover the pavement markings.

2. Posts are typically channel iron posts, although round pipe is sometimes used. Two types of reflective units are commonly used. The first, which is an image forming type, employs small glass beads bound to a rigid backing plate -- i.e., reflective sheeting. The second type consists of multiple triple-mirror arrangements within a reflector housing -- i.e., corner-cube reflectors.

3. Post delineators have a long life expectancy provided they are kept clean and are not damaged by encroaching vehicles.

4. Initial cost of installing post delineators is estimated to vary between $74 and $145 per mile, depending on the type of post and reflective unit and the spacing of the delineators.

5. During the day, post delineators are of little use as delineation. At night, they provide anticipatory information to the driver regarding the general alignment of the road, hazard location, etc. Post delineators are not recommended for use on sections with fixed roadway illumination; they are not effective in areas with moderate to high ambient light levels.

Raised Pavement Markers

1. Raised pavement markers are devices used to supplement or replace painted lines employed for guidance within the travelled way.

2. There are various kinds of markers available on the market today. They can be classified according to material and visibility. Ceramic markers are extensively used as daytime markers. An acrylic cube-corner reflective unit encased in a plastic shell is a popular nighttime marker. Southwest Research Institute has developed formed-in-place markers, but their performance has been largely unsatisfactory. Stimsonite "99" snowplowable markers have a retroreflective unit encased in a steel housing.

3. Advantages of raised pavement markers are:

- They provide delineation even under wet pavement conditions.
- They can provide both "far" and "near" delineation. (Their ability to provide "far" delineation may be restricted by the geometry and alignment of the roadway, however.).
- Vibration and auditions produced by the vehicle crossing the markers provide tactile and audio feedback to the driver.
- Raised pavement markers can be color coded for special purpose situations.

4. Disadvantages of raised pavement markers are:

- The common types are unsuitable for regions with excessive snowfall. They are susceptible to damage or removal from snowplow operations.
- Initial cost is relatively high.
- Ceramic markers become covered with dirt, grime and tire stains during extended periods of hot dry weather. Therefore, periodic cleaning of these markers may be required. There is also some indication that the ceramic markers may present a skidding hazard.

5. Based on a California report, the cost of the standard pattern of ceramic markers and reflective markers (four ceramic markers 3-feet apart simulating a 9-foot line with a 15-foot gap, a reflectorized marker at every other gap -- refer to Figure 8) is about

$950 per lane mile. Hence, raised pavement markers are 10 to 15 times more expensive to install than a painted line.

6. Typical life of raised pavement markers is estimated to be ten years or more on rural roads in areas where snow removal is not required. However, under the most severe conditions, their life can be reduced to as short as 1-1/2 years.

BIBLIOGRAPHY

DELINEATION APPLICATIONS

1. Adams, Gerald H., "Highway Markings (A Bibliography with Abstracts)," Accession No. NTIS/PS-75/122, National Technical Information Service, Springfield, Virginia (January 1975).

This is an annotated bibliography of 64 articles pertaining to highway markings, covering the period 1964 to September 1974. The topics covered within these articles include highway paints and paintings, zone markings, beaded stripes, retroreflectors, road stripes, pavement stripings, geometric bar patterns, high heat paints, traffic lane markings and roadway edge markings.

2. Bolt, Baranek and Newman, Inc., "Investigation of New Traffic Signs, Markings, and Signals," Vol. 1, Laboratory Experiments and Road Tests; Vol. 2, Driver Questionnaire (December 1972).

Traffic signs, markings and signals recommended for the 1971 Manual on Uniform Traffic Control Devices were evaluated both in the Laboratory and on the road to measure the recognizability of both standard and experimental signs. Visual presentation was chosen as the independent variable. An important conclusion was that the research on traffic control devices can use road testing and laboratory testing to complement one another. A questionnaire was designed to provide information about population stereotypes as to the meaning of the traffic control device as a symbol, the implication of this meaning for action, and the preference for one control device over another.

The strong preference of people tested was for signs that carry both symbols and letters. The intended meanings of the form of road markings were correctly interpreted although people dichotomize their judgments into permitted or prohibited. Standarization in traffic control devices was considered as a primary objective in the improvement of devices.

3. Calhoun, J. D., "Raised Reflective Lane Markers for Urban Roadways," Louisiana Tech University (November 1970).

Four representative brands of Raised Reflective Roadway Markers were evaluated for one year. Reflectivity of the markers from illumination of automobile headlamps was measured periodically using a Luckiesh-Taylor Brightness Meter. The reflectivity of all brands dropped quickly with use to a mean of about 50 percent of the new reflectivity, then varied above and below this value depending on weather and fouling.

The loss of markers from the roadway was evaluated. The epoxy adhesives were satisfactory for the plastic markers; all losses were due to failure of the asphalt roadbed under the markers. The ceramic markers were lost due to failure of the epoxy on the roadway marker interface. The use of a rubber pad adhesive was a failure under the conditions of this test.

Failure of the plastic markers was negligible. The ceramic markers suffered drastic loss of the reflective elements. This report also contains a preliminary report "Highway Lane Marking with Reflective Materials."

4. Capelli, John T., "Audible Roadway Delineators," New York State Department of Transportation, Albany, NTIS Report No. PB-221-743, National Technical Information Service, Springfield, Virginia (1973).

The objective of this study was to evaluate audible roadway delineators with respect to their design and effectiveness. Based on a literature search and on site evaluation of some of the installations in New York State, the author recommends their usage in situations known to be hazardous and where the normal traffic control devices are inadequate. On the travelled lanes, (a) intermittent patterns beginning well in advance of a hazardous situation and (b) overlays with exposed 3/4 to 1 inch aggregate provide an objectionably severe stimulus. They are recommended for use only off the travelled lanes such as medians, shoulders, etc. Exposed aggregate surfacing and corrugated portland cement concrete were also found satisfactory for use outside the travelled lane.

5. Denton, G. G., "Influence of Visual Pattern on Perceived Speed at Newbridge M8 Midlothian," Transport and Road Research Laboratory Report LR351, Crowthorne, England (1973).

A Contributory factor in accidents at junctions, particularly at junctions with high-speed roads, is that drivers do not reduce speeds sufficiently to allow them to negotiate the junctions safely. A special road marking has been developed employing a geometric bar pattern that affects driver's judgments of speed, causing them to slow down.

Markings of this type were laid in October 1971 on the approaches to the Newbridge roundabout on the M8 motorway. Measurements during the following month showed considerable and consistent reductions in speed.

6. Duff, J. T., "Focus on Road Markings and Materials," Traffic Engineering and Control, Vol. 11, No. 11, pp. 537-549 (1970).

This article includes five papers from Europe and the United States which illustrate the interest in choosing the most effective and economical materials for road marking. The paper from Germany gives a comparison of costs, life, and reflectivities of paints and plastics. The Dutch paper gives a detailed comparison over an 18-month period of various materials. In another paper, three different devices for marking the edge of a median are compared with conventional paint. Another paper discusses recent experiences in marking materials in the U.S. The final paper reviews costs and present practices in the field of road markings in Great Britain.

7. Enusten, Nejad, "Three Experiments with Transverse Pavement Stripes and Rumble Bars," Final Report TSD-RD-216-72, Michigan Department of State Highways (October 1972).

A study was initiated for the purpose of testing a traffic device that might cause visual sensation for drivers and induce them to reduce speed at a highway construction area, and to measure the effectiveness of transverse plastic pavement stripes with gradually decreased spacing. An ABS plastic rumble bar was tested in conjunction with yellow painted stripes at a rural sharp curve section and at a temporary urban freeway ending. In addition, an experiment was conducted using polyvinyl chloride rumble bars. Speed change was used as the measure of effectiveness.

The effect of yellow transverse pavement striping for inducing speed reduction was marginal, mainly because of familiarity by local drivers. The plastic sheet material failed in durability. Speed reduction obtained by all devices diminished with lapse of time because of driver familiarity.

8. Foody, Thomas J. and Hubbell, J. Stephen, "Night Reflectivity of Colored Pavements," Ohio DOT-06-76, Ohio Department of Transportation (May 1974).

This study was conducted to determine the effect of delineating the median storage area of the intersection of a four-lane highway with a two-lane highway. Operational safety of that intersection was investigated. Colored pavement was used to provide a color contrast between the median storage area and the through lanes of travel, thus delineating the median storage area for a motorist on the two-lane highway. A secondary objective of the study was to develop a method of providing better night-time visibility to the colored pavement. The three-phase study included a laboratory study to determine size and quantity of glass beads to maximize the quantity of light reflected from the pavement surface by incident light from vehicle headlamps; a field study to determine the effect of colored pavement on median usage; and an office study to determine the effect on accident experience.

9. Hassan, Zuhair Y., "Effect of Edge Markings on Narrow Rural Roads," Consortium of Universities, Washington, D.C. (June 1971).

This research was undertaken to evaluate the effectiveness of edge marking on narrow rural roads. At two one-mile sections of rural roads, one 18 feet wide and the other 24 feet wide, spot speeds and lateral placement data were collected and compared on a "Before and after" basis. Edge markings were found to have an effect on vehicle placement at night.

10. Hopkins, T. A. and Marshall, B. R., "Feasibility Study of Luminescent Pavement Markers--A Study of Seven Luminescent Systems for Wet-Night Visibility," Report No. FHWA-RD-74-26, National Aeronautics and Space Administration (June 1974).

This study was undertaken to evaluate the feasibility of adapting a bio- or chemiluminescent system for use in a highway marker for wet-night lane delineation. The study involved a literature survey, theoretical evaluation of systems reported in the literature, and limited laboratory verification and investigation of the visibility problem. Recommendations for further research and development are presented, based on this preliminary work.

The chemiluminescent reaction of siloxene derivatives is recommended because it is expected that this system can be placed in a solid matrix and activated in rainy weather by diffusion of water through a bed of solid oxidizer. The siloxene system is cheaper and more readily adaptable to use in a highway marker. Several other bio- or chemiluminescent systems are evaluated.

11. Hulbert, S. and Beers, J., "Wrong Way IV--Highway Reflectors," UCLA, School of Engineering, Institute of Transportation and Traffic Engineering Report (July 1970).

Drivers' verbal responses and involuntary decelerations to 11 different red highway reflector configurations were investigated. The reflector configurations, presented in 16 mm animated films in the UCLA Driving Simulation Laboratory, indicated an urgent need for a continuing educational program via mass media so that the public is made aware of the existence of the red reflectors and their intended meaning. The regular pattern now being used throughout the State of California was found to be the least effective to unknowledgeable drivers; and that an irregular configuration which is not continuously repeated elicits the most responses from unknowledgeable drivers. The latter configuration would also affect a cost reduction for the State.

12. Olson, R. M., Weaver, G. D., Ross, H. E., and Post, E. R., "Effect of Curb Geometry and Location on Vehicle Behavior," NCHRP Report 150, Transportation Research Board (1974).

The commonly used curb types, two 6 inches and one 4 inches high, and a special configuration 13 inches high were investigated through the use of the Highway Vehicle Object Simulation Model (HYOSM). The applicability of the model was evaluated by 18 full scale tests on the two 6 inch high curbs. A series of nine tests at vehicle speeds of 30, 40, and 60 mph, and approach angles of 5, 12.5, and 20 degrees, were conducted on each curb type. Such vehicle responses as redirection, trajectory, path, roll and pitch, and acceleration were observed and evaluated. The model results were found to correlate well with the full-scale results, and its applicability as a tool for evaluating vehicle response to a wide range of curb configurations appears to have been validated. The findings of the study suggest that curbs of the configurations tested have no redirection capabilities to enhance safety in a high-speed travel environment, and some may even reduce safety by causing vehicle ramping, especially when a curb-guardrail combination exists.

13. Organisation for Economic Co-operation and Development, "Road Marking and Delineation," Road Research Programme, Paris, France (1975).

This report contains a comprehensive assessment of the state-of-the-art of roadway markings and delineation systems drawing on experiences and practices of several countries. Included are specifications and standard acceptance methods, as well as the scientific literature regarding the various products available, their effectiveness and qualities, their application usage and behavior. The report deals with horizontal road markings, raised pavement markers (studs) and lateral delineators and evaluates their main characteristics. Various factors and criteria to be taken into account in treatment selection are considered. The economic aspects involved are discussed and guidelines for the selection of the most suitable marking techniques are proposed. Finally, present trends with regard to new developments and priority areas for further research are highlighted.

14. Pigman, J. G. and Agent, K. R., "Raised Pavement Markers as a Traffic Control Measure at Lane Drops," Research Report 384, Kentucky Bureau of Highways, Division of Research (February 1974).

The purpose of this research was to evaluate the effectiveness of raised pavement markers as a traffic control measure at lane-drop sites. Studies were conducted at five lane-drop locations, each representing one of three classes of lane-drops--lane exits, lane splits, and lane terminations. Conflict surveys (consisting of erratic movement and brakelight application counts) and lane volume counts were conducted at each of the lane-drop locations. A different type of raised pavement marker was used at each of the five lane-drops. Raised pavement markers were found to be an effective means of reducing erratic movements at lane-drop locations, particularly under nighttime driving conditions. The cost of raised pavement markers and their installation was nominal ($150 per location).

15. Ritter, James R., "A Unique Approach to Evaluate Road Stripe Material on Two-lane Rural Roads," Highway Research Record No. 447, pp. 1-7 (1973).

Comparisons between two yellow lines were made by putting them side by side as a double no-passing line on rural two-lane roads. One line was a reference line of 0.015 inch wet paint film with 6 pounds per gallon of conventional glass spheres applied by the drop-on method. The experimental line either was unbeaded or had various amounts of several types and sizes of glass beads. Evaluation, through visual observation, was made under night driving conditions at normal speed on dry and wet pavement. This approach for evaluating lines was found to have many advantages and is recommended for continued use.

16. Roth, Walter J., "Color Coding Study for Freeway Markings, Median Delineation Phase," Final Report TSD-231-73, Michigan Department of State Highways and Transportation (February 1974).

A "before and after" study approach was utilized to evaluate the effectiveness of edgelining the median and right hand side of the pavement. Four inch white edgelines were used with post delineation at four curve sections. Spot speed measurements were made at two points at each of the four locations during night periods only. Also, lane volumes and lane usage were manually recorded.

This study found that speeds were significantly reduced at curves where edge lines were added. Also, center line straddling was substantially reduced.

17. Rushing, H. B., Burt, J. O., and LeBlanc, E. J., "Evaluation of Raised Pavement Markers," Research Report 60, Louisiana Department of Highways (November 1971).

Four representative types of raised pavement markers were evaluated for reflectivity and durability qualities. Traffic wear and breakdown properties of these markers were observed, as well as the effectiveness of various layout patterns in the roadway. Attempts were made in the laboratory to duplicate the types of wear and abuse encountered on these roadway installations. It was determined that supplementing painted lines by the use of raised pavement markers placed at 40-foot centers is very effective and practical. An efficient reflectivity measurement system was developed as a result of this study.

18. Saville, Keith M., "Experimental Installation of Rumble Strips in Indiana," 55th Annual Purdue University Road School Proceedings, pp. 62-78 (1969).

A "before and after" accident analysis was made of rumble strip treatment applied at five locations, including two intersection approaches, two pavement width transitions, and one curve section. The rumble strip treatment consisted of a series of nine rumble strip areas located at different spacings. Each area consisted of 11 strips spaced 8 inches apart. The stripes were 8 inches wide and 1/4 inches to 3/8 inches thick. Each installation costs \$350-\$500.

19. Taylor, James I., "A Study of Roadway Delineation Systems," Highway Research Board Special Report 107, pp. 81-88 (1970).

This paper is a partial summary of NCHRP Report 130, Roadway Delineation Systems.

20. Taylor, James I. and McGee, Hugh W., "Improving Traffic Operations and Safety at Exit Gore Areas," NCHRP Report 145, Highway Research Board (1973).

This project was established to develop recommendations leading to early improvement of traffic operations and safety at exit gore areas, by relating erratic maneuvers to their causes and by devising remedial measures. Included in the study is a summary of past and current research and a report on field investigation of driver behavior. At nine study sites, detailed observations were made to determine the causes and characteristics of erratic maneuvers. Interviews were conducted with drivers whose actions at gore areas were indicative of route choice difficulties. A supplemental study specifically dealing with gore delineation was carried out to measure the effects of presence of gore area delineation on driver exiting performance at night. Four delineation treatments--(1) worn painted diagonal gore markings and edge lines; (2) post delineation; (3) raised pavement markers; and (4) combination of 2 and 3 were evaluated.

21. Taylor, J. I., McGee, H. W., Seguin, E. L., and Hostetter, R. S., "Roadway Delineation Systems," NCHRP Report 130, Highway Research Board (1972).

A comprehensive state-of-the-art summary is provided as the result of an extensive review of current practices and the literature. Reported applications of delineation treatments at various geometrical situations are synthesized and evaluated; materials used, with their cost and maintenance problems, are discussed; relevant visibility, information processing, and cost-effectiveness studies are reviewed; and a summary of practices in other countries is provided to further illustrate the wide variety of delineation systems in current use.

Information requirements for the "classical" geometric situations are presented in flow charts developed from a task analysis of the required maneuvers. The task analysis consisted of defining the desirable driver actions, then working backward to the required information on which driver decisions could be based. The first of a three-part Guideline Form is provided to integrate the results of the task analysis with accident experience to more specifically define information requirements at a given location.

The second part of the Guideline Form provides a structure for rationally evaluating the effectiveness of alternative delineation treatments. A combination of objective and subjective judgment is required. The laboratory and field studies provide some objective data for these evaluations, and considerable background concepts and experimental data for the subjective judgements.

Results of several studies involving installation of alternative treatments at specific sites are included in the appendices. These studies include variations in color and patterns of post delineators at horizontal curves, the use of raised pavement markers with and without edge lines at horizontal curves, variations in color and spacing of post delineators at stop approaches, and the preliminary evaluation of a less-costly center line pattern on rural two-lane roadways.

The complete Guideline Form provides a structure for a well-reasoned selection of delineation treatments. The remainder of the material in the report was developed to assist the decision-marker in the effective use of this Guideline Form. Further, recommendations are included for the application of the various delineation treatments and systems in each of the "classical" geometric situations.

The research indicates that wear- and skid-resistance properties of colored pavements are superior to those of standard asphaltic overlays. Widespread application is not foreseen, however, due to the relatively high cost of these treatments and problems associated with nighttime visibility.

The report also contains suggestions for several potentially fruitful research areas that have become evident as a result of this study. It indicates that more research is needed in correlating various intermediate measures of effectiveness with actual accident experience. Inasmuch as subjective judgments will remain a primary basis for selection and specification of delineation treatments and systems, attention should be directed toward optimizing the effectiveness of these procedures.

22. "Traffic Control Devices Handbook - An Operating Guide, Part II - Pavement Markings," (Draft), prepared by the National Advisory Committee on Uniform Traffic Control Devices, U.S. Department of Transportation, Federal Highway Administration (1974).

The handbook covers the material which are currently in use in marking pavements. Information contained is on paint drying time, the application of beads, thermoplastics and materials for temporary markings. Equipment utilized for applying the markings, guidance on workman safety, record keeping and procedures for laying down no-passing zones are also discussed. Finally, other means of markings such as raised pavement markers and post delineators are discussed.

23. Yu, Jason C., "Driver Performance Related to Median Visibility," Accident Analysis and Prevention, Vol. 1, No. 2, pp. 143-151 (1969).

Drivers on divided highways may not be able to maintain a normal driving pattern with low median visibility, particularly during the nighttime hours. This study was designed to identify and evaluate changes in driver performance resulting from altered median visibility on a divided highway. At a 2000-foot section in West Virginia, post mounted delineators were placed near the median edge. Vehicle speed and placement were simultaneously observed on each sample vehicle at a single point for both the "before" and "after" conditions.

The results of the study indicated that there was no significant effect of the median delineation treatment on vehicle speeds under the study conditions. However, the vehicle lateral placement value shifted a significant distance toward the median under the delineation condition when compared with those observed under the nondelineated condition.

24. Yu, Jason C. and Arnn, Alvah C., "Roadside Delineation Concepts: A National Study," Highway Research Record 440, pp. 57-67 (1973).

In this study an extensive literature review and a national survey of all state highway departments were conducted to form a state-of-the-art summary of roadside delineation concepts. In attempting to formulate a uniform selection process for roadside delineation treatments, evaluation criteria were discussed and a suggested selection program was presented.

Results of this study show post mounted delineators as the most popular technique for roadside delineation. Factors listed in priority for selecting delineation techniques are: (1) type of roadway, (2) traffic conditions, (3) physical conditions, (4) economic consideration, (5) ambient conditions, and (6) high accident locations.

25. "Annotated Bibliography (on Pavement Marking Materials)," Highway Research Board Bulletin, No. 57, pp. 99-128 (1952).

26. Babkov, V. F., Lobanov, Y. M., Silyanov, V. V. and Sitnikov, Y. M., "Efficiency of Various Edge Treatments," paper presented at 12th International Study Week, Traffic Engineering and Safety, Theme IV: Cost-Effectiveness of Carriageway Edge Treatment, Belgrade (1974).

27. Beer, J. and Hulbert, S., "Judgment of Vehicle Speeds and Traffic Patterns," Report No. UCLA-ENG-7281, Institute of Transportation and Traffic Engineering (June 1972).

28. Bernhard, M., "Contributions of Edge Markings to Safety and Traffic Flow," paper presented at 12th International Study Week, Traffic Engineering and Safety, Theme IV: Cost-Effectiveness of Carriageway Edge Treatment, Belgrade (1974).

29. "'Buttoning' the Streets Protects Chicago's Downtown Pedestrians," The Highway Magazine, Vol. XVIII, No. 9, p. 247 (September 1927).

30. "Colored Lane Speeds Traffic on Mountain Highways," Concrete, Vol. 49, p. 4 (January 1941).

31. Edamura, E. T., "Optimum Design of a Central Median Based on the Principle of Benefit Maximization," paper presented at 12th International Study Week, Traffic Engineering and Safety, Theme IV: Cost-Effectiveness of Carriageway Edge Treatment, Belgrade (1974).

32. "Edward N. Hines, Father of the Center Traffic Line," Roads and Streets, Vol. 79, p. 52 (1936).

33. Ficklin, N. C., "Raised Reflective Markers Improve Roadway Safety," The American City, pp. 23-24 (July 1975).

34. Goodwin, D. N., "Investigation of Freeway Lane Drops," Final Report to Transportation Research Board, NCHRP Project 3-16 (October 1973).

35. Krell, K., "Cost-Effectiveness of Carriageway Edge Treatment," paper presented at 12th International Study Week, Traffic Engineering and Safety, Theme IV: Cost-Effectiveness of Carriageway Edge Treatment, Belgrade (1974).

36. Norris, George, "Line Painting for Safer Driving," Better Roads, Vol. 45, No. 12, pp. 14-15 (December 1975).

37. Sumner, R. L. and Shippey, J., "The Effects of Rumble Strips at the Dartford Tunnel," Transport and Road Research Laboratory Report 169UC, Crowthorne, England (1975).

38. Taylor, J. I., "Cost and Effectiveness Assessments for Highway Edge Delineation Treatments," paper presented at 12th International Study Week, Traffic Engineering and Safety, Theme IV: Cost-Effectiveness of Carriageway Edge Treatment, Belgrade (1974)

39. Taylor, J. I. and Hostetter, R. S., "Roadway Delineation Systems," Research Results Digest No. 36, National Cooperative Highway Research Program (March 1972).

40. U.S. Department of Transportation, Federal Highway Administration, "Manual on Uniform Traffic Control Devices for Streets and Highways" (1971).

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41. Cabrera, J. G. and O'Flaherty, C. A., "Durability of Reflectorized Road Markings," Highway Engineer (Great Britain), Vol. 20, No. 4, pp. 21-24 (April 1973).

This paper has a two-fold purpose. First, it puts forward a simple yet basic explanation as to how the initiation of "chipping" failure in a reflectorized road-marking material is associated with the presence of the glass beads in the composite system. Secondly, it suggests that there may be an optimum bead content and gradation from the point of view of the durability of a road marking, and that this optimum could possibly be different from the optimum for reflectivity. Photographic evidence obtained with the scanning electron microscope is presented in support of the above main thesis. Suggestions are made regarding further research needs in this area.

42. Colorado Department of Highways, "Reflective Traffic Road Study," Final Report, Colorado Department of Highways (May 1970).

Evaluation of a new floating type of traffic bead by the Colorado Department of Highways shows that these small uniformly-graded beads are superior in both brightness and durability to the coarser traffic beads that the State had been using. The tests were performed on center line stripes placed on both asphalt and concrete surfaces. During the three year test period, the brightness of 78 test sections was evaluated by human evaluation teams and by a photometer developed during the project. Plans for the construction of these photometers are included in the report as an aid to others who may want to evaluate bead performance.

It was concluded that floating type beads have performed better than nonfloating beads in visibility and retroreflection.

43. Flanakin, H. A., "Traffic Markings--A Procedure for Putting to Use Research Findings," District of Columbia Department of Highways (March 1975).

A procedure for making and maintaining an inventory of traffic markings is presented. A method for setting up accounting ledgers for assuring adequate markings on a continuing basis is offered.

44. Greiser, D. R., Epstein, M. M., and King, R. W., "Development of a New Low-Profile Highway Striping for Wet Night Visibility, Phase 1: Feasibility," Report No. FHWA-RD-72-13, Battelle Columbus Laboratories (September 1973).

A program undertaken to demonstrate the feasibility of using a low-profile corner-cube retroflector marker to solve the problem of visibility on rainy nights in northern states is reported. Molded pieces having a smooth upper surface and capable of being mounted flush with the road surface, or protruding no higher than 1/8 inch above the surface, were fabricated. These pieces were subjected to laboratory evaluation and outdoor road-use experiments to assess their durability and optical performance under wet night conditions and their resistance to traffic and snowplowing.

45. Greiser, D. R., Epstein, M. M., and Preston, J., "Development of a New Low-Profile Highway Striping for Wet-Night Visibility, Phase 2: Road Test," Report No. FHWA-RD-73-78, Battelle Columbus Laboratories (September 1973).

The current phase of this program was undertaken to demonstrate the optical effectiveness and mechanical durability of low-profile molded markers as highway lane delineators on wet nights.

Road tests of 1/8-inch thick, molded, corner-cube retroreflector stripes were conducted on local high-speed, high-density thruways. The molded stripes were installed in the skip zones between the paint stripes. Evaluations were performed using visual, photographic, and photometric inspection techniques.

These tests show that the low-profile markers endure steel-bladed snowplowing, as well as traffic over a winter season, and remain effective for lane delineation on rainy nights. They also show that imbedding the markers in the road surface improves their survival rate compared to installing them on top of the road surface.

46. Hills, B. L., "Measurements of the Night-Time Visibility of Signs and Delineators on an Australian Rural Road," Australian Road Research, Vol. 5, No. 10, pp. 38-57 (December 1972).

The visibilities of in-service signs and delineators were measured under practical driving conditions on a four-lane divided highway. The nighttime experiments were conducted using American-British dipped beams. It was found that the nighttime legibility distances of reflective signs were on average half those obtained during the daytime. Aging and dirt accumulation were shown to reduce sign legibility distances by 30 percent or more at night. These same factors were found to reduce the reflectivity of delineators on guide posts set back ten feet from the pavement by as much as 18 times. The corresponding reduction in visibility was from 1,000 feet to less than 100 feet. Heavy rain was found to have little effect on the performance of enclosed lens reflective sheeting, although other evidence suggests that drizzle can reduce its visibility considerably.

47. Hiss, J. G. Fred Jr., Capelli, John T., and Brewster, David R., "Pavement Marking Paints: Two Studies," Research Report 69-1, New York Department of Transportation (June 1970).

The first study involved establishing the performance of both modified alkyd and modified alkyd-chlorinated rubber yellow traffic marking paints, utilizing normal-lead-silico-chromate in lieu of or in combination with the more commonly used medium chrome yellow in their pigment formulation. Field and laboratory tests were conducted on paint samples in 1964, 1965, and 1967. Straight substitution of normal-lead-silico-chromate for medium chrome yellow in the New York State standard yellow paint was found to be unsatisfactory because of a resulting lemon coloration. However, a formulation that made the substitution and omitted titanium dioxide was comparable to the standard yellow in both color and durability, as was another formulation that employed a combination of all three materials. Their use could result in reduced paint cost. The modified alkyd-chlorinated rubber paints were also considered equal to the standard in color and durability but unsatisfactory in that they cost about $2 per gallon. The state's standard costs about $1.50 per gallon.

The second study concerns emulsion or waterbase paints field tested in 1964 and 1967 to evaluate their performance as pavement markings. Also investigated were the effects on durability of heating these emulsions before applying them in stripes. Emulsion paint would not be a suitable replacement for New York State's standard modified-alkyd paint. The useful life of the emulsions did not exceed three months on bituminous surfaces or four months on portland cement concrete surfaces. The emulsion paints placed at ambient temperature appeared to perform better than those that were heated, but rapid deterioration of the paint stripes prevented comparison of the effects of heating on durability.

48. Holman, F. L., "Glass Beads for Traffic Marking Paint," HPR Report No. 55, Alabama Highway Department (July 1971).

This study was initiated in conjunction with the national experimental and evaluation program for traffic marking beads. Its prime purpose was to evaluate the performance and economy of a traffic marking paint with "drop-on" beads compared to conventional striping methods. The results of this study indicate that "drop-on" beads generally give a better nighttime visibility but are lower in durability over a long period of time when compared with reflectorized paint. However, the best performance was obtained with reflectorized paint and approximately 2 lbs. of "drop-on" beads.

49. Lanz, Larry J., "Road Marking Materials, Interim Report No. 1," MSHD-RD-72-052-1, Mississippi State Highway Department, Research and Development Division (July 1972).

This report is updated by the 2nd Interim Report, July 1973.

50. Lanz, Larry J., "Road Marking Materials, Interim Report No. 2," MSHD-RD-73-052-1, Mississippi State Highway Department, Research and Development Division (July 1973).

This report of Road Marking Materials is an interim report on a State Study. Traffic paint, thermoplastic and raised markers are discussed and merits and shortcomings noted in evaluations are listed. Results of paint and bead studies were published in a previous report for this study but are included for comparisons. Thermoplastic sections have been in service eleven years in the state and all but two sections are still in service. Results show the state can plan on ten years service for thermoplastic installations. Raised ceramic and reflective markers have been in place on Mississippi roadways for over three years and experience with these markers is limited. Estimated annual loss rate is two to five percent of reflective markers and five to ten percent of ceramic markers. Many of these markers failed because of poor bond. Traffic is detrimental to ceramic markers in curves and in areas with much lane crossing. Replacement of ceramic markers is necessary in several locations where up to 50 percent are missing in one-half mile stretches.

Raised reflective markers are recommended to supplement paint or thermoplastic stripes to provide lane delineation during inclement weather. Reflective markers must be used with ceramic markers to provide nighttime delineation.

51. Lanz, L. J. and Davis, J. H., Jr., "An Evaluation of Road Marking Materials," Study No. 52, Mississippi State Highway Department (March 1971).

Seventeen commercial traffic paint formulations were evaluated on three types of roadway surfaces with present Mississippi State specifications as a control. Emphasis was placed on characteristics such as ease of application and drying time. A study of glass marking beads indicates better reflection is obtained with glass spheres having a high index of refraction. Six pounds of beads per gallon and 15 mils wet film thickness provided the most durable stripe.

52. Missouri State Highway Department, "Investigation of Paints and Glass Beads Used in Traffic Delineation Markings, Phase 2," Report 71-4, Division of Materials and Research and Division of Maintenance and Traffic (January 1972), with Addendum (December 1972).

A Missouri dispersion resin-varnish paint and a Missouri chlorinated rubber-alkyd paint were used as a guide to determine the relative wear resistance qualities of several proprietary high heat paints. The ratings were based on field evaluations of the wear resistance of transversely placed paint stripes. The results indicated a wide range of life expectancies for the various proprietary paints. One high heat paint, type "G", was equal to or better than the Missouri paints and the other high heat paints evaluated. The general appearance rating system was used to visually evaluate the transverse stripes. This rating system was used in a previous paint study and was found to correlate best with actual stripe life for pavements in the State of Missouri. Visual evaluation of abrasion and chipping, as described in ASTM, was also used.

53. NCHRP Synthesis of Highway Practice No. 17, "Pavement Traffic Marking, Materials and Application Affecting Serviceability," Highway Research Board (1973).

The increased operation demands on the highway network have led highway engineers to consider thermoplastic materials, raised markers, and rapid-drying traffic paint for achieving minimal interruption of traffic flow. Other considerations include wet-weather and night visibility, climatic resistance, and costs of application and maintenance. The Highway Research Board has attempted in this project to set down those traffic marking practices found to be most effective. The report discusses these practices from the standpoint of serviceability as it is achieved by the appropriate combination of materials, equipment, and application procedures.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from many highway departments and agencies responsible for highway planning, design, construction, operations, and maintenance. A topic advisory panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

54. Rahal, A. S. and Hughes, R. D., "Final Performance Report on Experimental Use of Thermoplastic Pavement Striping Materials," Report No. 5, KYHPR-64-18, Kentucky Department of Highways (February 1970).

This study was undertaken in order to: (1) evaluate the performance of thermoplastic striping materials, (2) compare their performance on both portland cement concrete and bituminous concrete pavements to that of conventional traffic paints, and (3) to evaluate the economics of thermoplastics in terms of cost per mile per day of useful life. The performance of two brands of thermoplastic striping materials and conventional traffic paints applied at nine test sites in both rural and urban areas is reported herein. Application procedures, site locations, repair histories, and materials specifications are included. Accumulative costs for each material at all sites for a seven-year period are summarized.

The performance of thermoplastics placed on bituminous concrete was superior to that placed on portland cement concrete pavements. Epoxy primers were of aid in providing adherence of thermoplastics to portland cement concrete pavements; however, the epoxies were not capable of penetrating surface laitance. Visibility of the thermoplastic stripes decreased with age due to accumulation of road scum.

55. Rizenbergs, R. L., "Development of Specifications for Reflex-Reflective Materials," Research Report HYHPR-65-37, HPR-1(6) Part II, Kentucky Department of Highways, 64 pages (October 1970).

This study was primarily concerned with geometric relationships between the driver, headlamps and traffic signs; investigation of reflectivity, color, durability and other properties of available reflective materials; adoption of testing apparatus to measure material properties; and development of test procedures.

56. Roberts, A. W., "Raised Reflective Pavement Markers," HPR Study No. 7708, Interim Report, Bureau of Operations Research, New Jersey Department of Transportation (November 1973).

This interim report describes a study to evaluate the endurance, visual effectiveness, cost, and spacing of raised reflective markers that are designed to resist hard-blade snowplow blades. Several versions of a "Stimsonite 99" snowplowable, raised, reflective pavement marker were installed and tested for their ability to resist the action of snowplowing by tungsten carbide and carbon steel blades.

57. Shelly, T. L., Rooney, H. A., and Beede, B. K., "Development and Evaluation of Raised Traffic Lane Markers, 1968 to 1971," Research Report No. 635152, Interim Report, State of California, Department of Public Works, Division of Highways, Materials and Research Department (October 1971).

The State of California has continued evaluation of the raised pavement marker system adopted in December 1965. The reflective markers drop considerably in reflectance under traffic but are good at night, especially in the rain when they are needed most. The ceramic markers are good when clean but during hot dry weather darken considerably. Many new markers have been evaluated but none have been found which are superior to the ceramic and reflective markers being specified. Current research includes evaluation of a 1.90 index of refraction beaded white portland cement-limestone-titanium dioxide marker will be given a one-year field trial.

58. Shelly, T. L., Rooney, H. A., and Chatto, D. R., "Evaluation of Grooved Traffic Stripes on Portland Cement Concrete Highways," California Division of Highways, Materials and Research Department (September 1972).

Sections of grooved and painted traffic stripes were evaluated for visibility under various conditions at three locations: in a mountainous area elevation at about 6,000 feet where heavy snow is prevalent in winter; in a foothill area where no snow is expected; and in the valley also where no snow is expected and where the terrain is very flat. In the mountainous area, all paint was removed after the first snowfalls due to chain action, snowplowing, and sanding operations. In the foothill and valley areas, under wet nighttime conditions, the grooved stripes were generally superior to the regular stripes though not as good as raised marker lines. While the initial cost of a grooved and painted stripe is about six times that of a regular painted stripe, the annual cost of a grooved stripe over a 20-year period would be about 60 percent greater than a plain stripe.

It was concluded that a grooved stripe is not a satisfactory solution to the problem of lane line delineation in snowplow areas, and where no snow is expected, the raised marker type line is best.

59. Tooke, W. R., Jr. and Hurst, D. R., "Wet Night Visibility Study," Interim Report, GDOT Research Project No. 6701, Engineering Experiment Station, Georgia Institute of Technology (November 1973).

Apparatus and methods developed for characterization of roadway delineation systems are described, and laboratory and field tests are reported for a selection of eleven retroreflective systems. Plain and textured beaded stripes and four types of retroreflective buttons are included in a full factorial field study covering about fifteen miles on Interstate 85 north of Atlanta. Independent photometric methods yielded good correlation in laboratory and field, wet and dry; and the results were in agreement with visual evaluation. Nominal levels of photometric and physical performance of various systems are indicated, and general recommendations for present practices and for additional needed testing procedures are made. Further fundamental and applied research needs are specified.

The study found that wet night visibility characteristics of the best button delineators are superior to the best continuous line systems. No continuous line system can be considered fully adequate for safe wet night delineation of interstate system roadways. The desired level of intensity of a button reflector is presently attainable only in prismatic or lens-type retroreflectors.

60. Van Vechten, C. T., "Selecting Pavement Marking Materials Based on Service Life," Report No. HPR-PR-1-650, District of Columbia Department of Highways (September 1974).

The main report and Appendix A are concerned with behavior of conventional traffic paint. Samples were tested for purposes of selecting a supplier. A method for selecting successful candidate samples was developed and adopted by Central Procurement for awarding contracts. Research into properties and behavior of three generic marking materials (paint, wetout setting powder and thermoplastic) is reported in Appendices B and C. Resistance to wear due to traffic is measured in the wheel paths. Cost-effectiveness study shows thermoplastic is least expensive on a long-term basis.

61. Graves, R. G., "Traffic Stripes and Formed-In-Place Delineators," Report 500-921 Materials and Tests Division, Utah State Highway Department, 114 pages (June 1973).

62. Mattimore, H. S., "Highway Traffic Line (Zone) Paint," Proceedings, Highway Research Board, Vol. 5, Part I, pp. 177-184 (1925).

63. Sawyer, C. L., "White Brick Form Permanent Centerline in Ohio County Road," Engineering News-Record, Vol. 93, p. 965 (1924).