Visibility of New Yellow Center Stripes as a Function of Obliteration

HELMUT T. ZWAHLEN, TORU HAGIWARA, AND THOMAS SCHNELL

Temporary center stripe pavement markings in newly resurfaced zones were selected to study driver visibility as a function of the degree of pavement marking obliteration. The Manual on Uniform Traffic Control Devices (MUTCD) specifies 0.1-m-wide retroreflective single dashed yellow stripes with a gap/stripe ratio of 10.98/1.22 m as minimum temporary center stripes in resurfaced zones. The study also investigated the begin and end detection distances of double-dashed (10.98/1.22m) 0.05-m-wide yellow retroreflective center stripes. Such thin double stripes could be used (same amount of material) to actually indicate to a driver whether the traveled section of the newly resurfaced road is a passing or no-passing section by using the double-dashed pattern as a coding mechanism. The center stripe pavement marking treatments were randomly obliterated by removing 0, 50, and 75 percent of the retroreflective material from the stripes. Overall, it is possible to conclude that severe obliteration reduces the begin and end detection distance to a considerable degree. However, using four times less material and the shortest specified stripe length (10.98/1.22 m) reduces, for example, the 85th percentile begin and end detection distances from about 53 to 30 m. Therefore, from a begin or end detection distance point of view, if the nonobliterated center-line pavement marking treatment provides barely adequate visibility performance it may not be possible to tolerate much obliteration at all (more than 5 to 10 percent before the visibility performance of the overall system (driver-vehicle-center stripe system) falls below the acceptable minimum safety level.

Several investigators (*1,2*) investigated the effects of roadway delineation visibility on driver steering performance in terms of lateral lane position standard deviation. The data for their model were collected in both an interactive driving simulator and an instrumented vehicle on the open highway. The collected experimental data were evaluated using a regression analysis to determine the functional relationship between a driver's steering performance and a number of delineation visibility factors including road-marking size and spacing, contrast with respect to the road surface, atmospheric scattering characteristics as a result of fog, snow, and ice, and the visibility range caused by headlight characteristics. The model uses Blackwell's threshold contrast data to evaluate the visibility of the markings. Allen also investigated the effects of delineation contrast on a driver's lateral lane position maintenance performance.

Harkey et al. (*3*) investigated the effect of various pavement-marking configurations on driver performance in work zones. The researchers used the following 0.1-m-wide white pavement-marking pattern types:

1. 0.6-m stripes with 11.58-m gaps,
2. 1.22-m stripes with 10.98-m gaps, and
3. 3-m stripes with 9.14-m gaps, including edge lines.

H. T. Zwahlen and T. Schnell, Human Factors and Ergonomics Laboratory, Department of Industrial and Systems Engineering, Ohio University, Athens, Ohio 45701-2979. T. Hagiwara, Traffic Engineering Laboratory, Department of Civil Engineering, Hokkaido University, Sapporo, Japan.

The first two configurations are commonly used for temporary pavement markings in work zones. These two configurations usually do not include edge lines when applied in pavement resurfacing work zones. The third configuration is the standard dashed pattern as specified in the Manual on Uniform Traffic Control Devices (MUTCD) (*4*). Because it is a permanent center line configuration, edge lines are present most of the time. It is highly questionable to introduce edge lines in a study dealing with nonpermanent markings, especially because the right edge line is considerably more conspicuous and therefore likely to mask the effect of the dashed center line because of the vehicle headlamp geometry (hot spot is 2 degrees to the right and 2 degrees down). The following performance measures were used as independent variables: lateral placement of the vehicle in the roadway; average vehicle speed within the test segment; average number of edge line and lane line encroachments per run; and number of erratic maneuvers. Harkey et al. (*3*) selected a 6.4-km-long experimental site with relatively mild horizontal and vertical curvature. Three sections with the previously described pavement-marking patterns were installed in the newly paved test site. It seems to be a questionable approach to investigate the effect of different pavement-marking patterns by installing them in subsequent sections of a highway. The observed effects might be influenced by the different road geometry and other environmental structures in the three sections. Harkey et al. (*3*) found that there were significant differences in the average running speeds between the Type 1 and the Type 3 patterns. In general, the speeds decreased as the marking length decreased. There was no significant difference between the two temporary pavement markings Types 1 and 2 with respect to lateral placement of the vehicle. There was a significant difference with respect to lateral placement of the vehicle between the two temporary markings (Types 1 and 2) and the full markings (Type 3). In their paper, Harkey et al. present a number of bar graphs that show graphically fairly large effects among the three patterns. However, the scale of the speed graph, the lateral position graph, and the lateral position variance graph is misleading because it does not start at 0. Primarily on the basis of the number of encroachments, the researchers conclude that it would be favorable to install the full (Type 3) pattern rather than the temporary Type 1 or Type 2 pattern in a temporary work zone. However, it appears that the observed average number of encroachments of 0.689 per 36 observed vehicles for the full pattern (Type 3) is hardly sufficient for a sound statistical analysis.

King and Graham (*5*) conducted a field experiment and a laboratory experiment to assess the retroreflectivity requirements of pavement markings. The field experiments consisted of objective retroreflectivity and luminance measurements (for one geometry only) to which the subjective responses of 59 observers were related. In the laboratory experiment only the luminances were measured and related to the subject responses. The field experiment

was conducted on an observation route of approximately 32 km, which included 20 test locations. For safety reasons the researchers decided to take the luminance and retroreflectivity measurements from the road shoulder. A small study, conducted in a dark parking lot, was used to relate the field data to the correct geometric conditions that would exist if the measurements were taken from the center of the lane. Conducting retroreflectivity measurements (for a selected geometry only) from the road shoulder seems to be a questionable approach. The subjects were to judge the adequacy of the presented pavement markings as follows:

- Less than adequate,
- Adequate, and
- More than adequate.

From the field study, King and Graham (*5*) found that all pavement markings having a coefficient of retroreflection greater than 93 mcd/m^2/lx (at a selected single geometry) were judged as being adequate or more than adequate by over 90 percent of the observers. A regression analysis of the average subjective ratings revealed a logarithmic relationship with the measured coefficient of retroreflection. The subsequent laboratory experiment was used to evaluate simulated roadway markings of varied luminance. The experimental setup included a dark tunnel constructed of heavy cloth and a platform 0.91 by 1.82 m installed 0.76 m above the floor. The pavement markings were installed on the platform. Gray and black background colors were used to simulate Portland cement and asphalt road surfaces. A booth with a viewport was used to observe pavement-marking samples 1.82 m long and 2.54 cm wide (3M 5730 white and 3M 5731 yellow). King and Graham found that pavement-marking samples with a luminance greater than 0.38 cd/m^2 were judged as being adequate or more than adequate by over 90 percent of the observers. A logarithmic relationship between subject ratings and luminance, similar to the one found in the field experiment, was obtained.

Zwahlen and Schnell (*6*) investigated the visibility of new pavement markings at night under low-beam illumination in terms of pavement marking begin and end detection distance. Three independent experiments were conducted as part of this study. The objective of Study 1 was to obtain exploratory pavement marking visibility field data for detecting the begin and end of continuous pavement marking lines as a function of line width, retroreflective material, and lateral position of the line. The results of Study 1 indicate that the width of the lines does not appear to significantly increase the average detection distance. It was further found that the average begin and end detection distance for a white continuous pavement marking tape line was slightly but statistically not significantly longer (at $\alpha = 0.05$) than the average begin and end detection distance for a continuous white painted pavement marking line. The average begin and end detection distances for pavement marking lines located to the right of the car are slightly but statistically not significantly longer (at $\alpha = 0.05$) than the average begin and end detection distances for pavement marking lines located to the left of the car. Study 2 was conducted with the objective of obtaining some exploratory pavement marking nighttime visibility data under low-beam conditions in terms of detection distances of the onset of a left or right curve. Regular white continuous edge lines 0.05, 0.1, and 0.2 m wide were used as a stimulus. The results of Study 2 indicate that the width of the edge lines appears to slightly increase the average detection distance. Further, right curves were much more easily detected than left curves. Study 3 had the objective of obtaining the nighttime average detection distances under low-beam illumination conditions for the begin and the end of different new yellow taped center-stripe configurations having different widths (0.05, 0.1 and 0.2 m). The center stripe configurations were as follows:

- Double solid,
- Single solid with dashed line having a gap/stripe ratio of 9.15/3 m,
- Dashed line having a gap/stripe ratio of 9.15/3 m, and
- Dashed line having a gap/stripe ratio of 10.98/1.22 m.

The results of Study 3 indicate that the width of the lines appears to increase the detection distances only slightly.

Except for the data provided by Zwahlen and Schnell (6) there appears to be little pavement marking visibility data available in terms of begin and end detection distances. Further, the literature does not seem to provide any information about the effect of pavement marking obliteration on visibility. Such data, however, would be particularly important to quantify the effect of obliteration on the visibility of pavement markings. Further, having begin and end detection distance data available might provide a basis for specifying a minimum distance, below which no temporary pavement markings need to be applied during the period after the permanent pavement markings of a short section of a road have been totally covered or removed by some maintenance activity until permanent markings are installed again.

OBJECTIVES

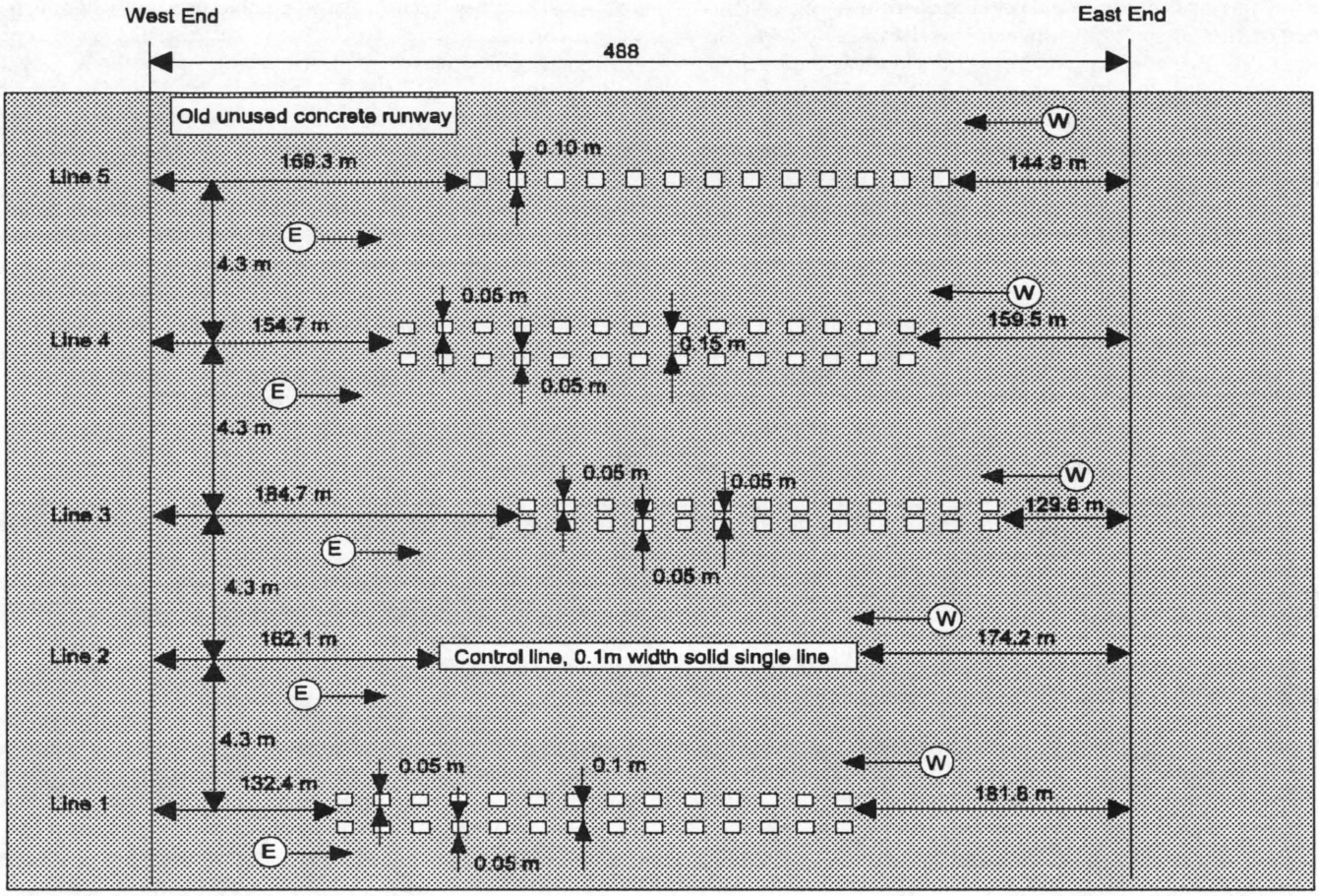
On the basis of previously mentioned needs to quantify the effect of obliteration on the visibility of new yellow center stripes, the objectives of this study were as follows:

- To determine the visibility distances under automobile low-beam illumination at night for new yellow temporary center stripes of finite length as a function of the degree of obliteration (0, 50, and 175 percent of the retroreflective material randomly removed from the new yellow center stripes) in terms of detecting the begin and end of the center stripes;
- To provide these visibility distances in terms of psychometric curves in addition to the average and standard deviation values; and
- As a secondary objective, to investigate the obliteration effect on visibility not only for 0.1-m-wide yellow center stripes with a gap/stripe ratio of 10.98/1.22 m but also for 0.05-m-wide double dashed (coded) center stripes with a gap/stripe ratio of 10.98/1.22 m. If such double dashed 0.05-m-wide coded center-stripe pavement markings would provide the same or better robustness to obliteration and the same or better begin and end detection distances as the single dashed 0.1-m-wide center-stripe pavement markings, it would seem that for the same area of retroreflective material, the coded center stripes could also convey passing/no-passing information in temporary resurfacing zones.

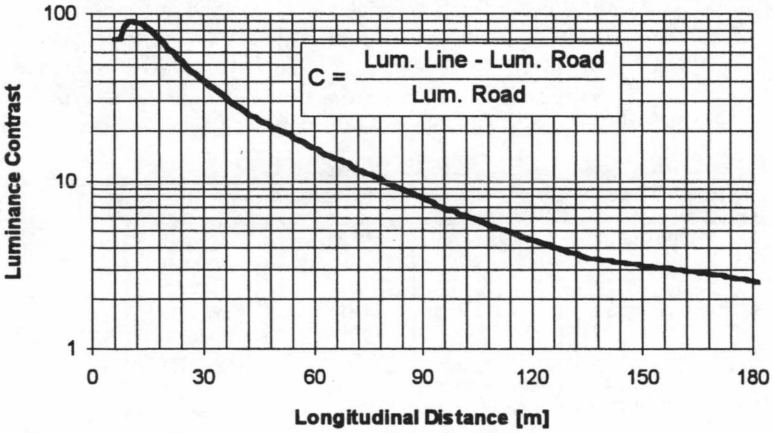
METHOD

Experimental Site

The experiment was conducted on old unused Ohio University airport runway (see Figure 1*a*), which is about 23 m wide and 500 m



a).



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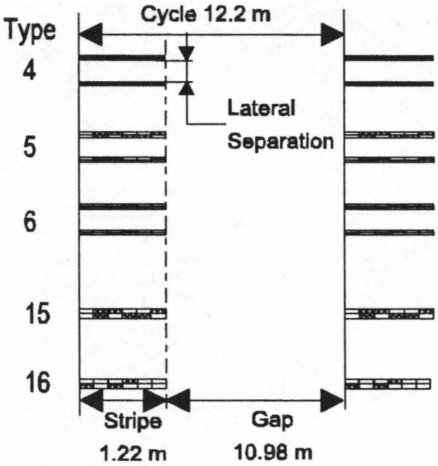


c).

FIGURE 1 Detection of the begin and end of new yellow center stripes having 0, 50, and 75 percent obliteration: (a) experimental treatment layout; (b) approximate computed luminance contrast between centerline and concrete runway as a function of distance ahead of the car; (c) centerline types.

long, running east to west, located on the outskirts of the city of Athens, Ohio. A two-lane state highway with moderate traffic runs parallel about 61 m away from the edge of the runway. The concrete runway was relatively white and provided under low-beam illumination the following approximate luminance values as a function of distance to the front of the car: 0.03 cd/m^2 at 6 m, 0.05 cd/m^2 at 20 m, and 0.027 cd/m^2 at 40 m. Beyond 40 m, the runway luminance asymptotically approached 0.01 cd/m^2 (as a result of ambient illumination). Figure 1*b* shows the luminance contrast between the center line treatments and the concrete runway. During the course of the experiment, the experimental car was driven in both the eastbound and westbound directions. The eastbound direction provided a somewhat darker night horizon background with only a few luminaries in the left part of the driver's visual field, whereas the westbound direction provided a relatively bright night horizon background with a number of luminaries from a nearby shopping mall parking area directly ahead of the driver. The layout of the center stripe treatments on the old Ohio University airport runway is illustrated in Figure 1*a*. The vehicles were driven at about 8 to 16 kph in the lane assigned by the experimental design protocol such that the current center-stripe treatment was always located about 1.8 m to the left of the longitudinal car axis. All center stripes were 3M 5161 yellow pavement marking tape.

Subjects

A total of nine young healthy women college students with an average age of 21.77 years and 27 young healthy men college students with an average age of 21.24 years participated in the experiment. The 36 subjects were distributed over three groups (see also experimental order in Table 1) as follows:

- Group 1 (average age 21.6 years) contained two subjects who were women (average age 23 years) and ten subjects who were men (average age 21.44 years),
- Group 2 (average age 20.8 years) contained four subjects who were women (average age 21 years) and eight subjects who were men (average age 20.75 years); and
- Group 3 (average age 21.5 years) contained three subjects who were women (average age 21.33 years) and nine subjects who were men (average age 21.55 years).

The subjects had an average driving experience of 4.52 years and all of them possessed a valid U.S. driver's license. All subjects were tested on a Bausch and Lomb vision tester and showed visual acuities ranging from 20/17 to 20/22 (average 20/19.6). Out of the 36 subjects 2 wore corrective contact lenses and 12 wore corrective glasses. The contrast sensitivity of all subjects was tested using the Vistec contrast sensitivity chart, Type C. All subjects showed a normal contrast sensitivity.

Experimental Vehicles

Group 1 used a 1994 Ford Probe with a line-of-sight windshield transmission of about 0.7, Group 2 used a 1979 Chevrolet Chevette with H6054 headlamps and a line-of-sight windshield transmission of about 0.7, and Group 3 used a 1990 Eagle Summit DL with a line-of-sight windshield transmission of about 0.7 as experimental vehicle. The average eye height of the drivers in group 1 was 1.07 m; in Group 2, 1.08 m; and in Group 3, 1.08 m.

Experimental Design

A randomized block design was used for the experiment. The dependent variables in this study were the average detection distances of the begin and end of the center stripe treatments. The major independent variables were the degree of obliteration and the approach direction (east/west). The following center stripe types were installed:

- Type 4, a double-dashed, 0.05-m-wide line with 0 percent obliteration,
- Type 5 , a double-dashed, 0.05-m-wide line with 50 percent obliteration,
- Type 6, a double-dashed, 0.05-m-wide line with 75 percent obliteration,
- Type 15, a single-dashed, 0.1-m-wide line with 50 percent obliteration, and
- Type 16, a single-dashed, 0.1-m-wide line with 75 percent obliteration, (see Figure 1*c*).

Table 1 lists the various line types and line numbers that were used in the experimental design. The line type determined what degree of obliteration was present, whereas the line number determined whether a center stripe treatment consisted of a single dashed pattern or a double dashed pattern with a defined lateral separation

TABLE 1 Experimental Configuration and Results: Experimental Order and Center Stripe Configuration

	Line Number					
Group Number	Line 5	Line 4	Line 3	Line 2	Line 1	Order of Group Subjected to Experiment
1	Type 4 LS=0.2m	Type 4 LS=0.15m	Type 4 LS=0.05m	Single solid control line 0.1m wide	Type 4 LS=0.1m	3
2	Type 15	Type 5 LS=0.15m	Type 5 LS=0.05m	Single solid control line 0.1m wide	Type 5 LS=0.1m	2
3	Type 16	Type 6 LS=0.15m	Type 6 LS=0.05m	Single solid control line 0.1m wide	Type 6 LS=0.1m	1

(LS = Lateral Separation between Double Lines)

distance between the center stripes of finite length. It should be noted further that a new 0.1-m-wide single solid center line of finite length was used as baseline comparison between the groups. Although it would have been desirable to use a worn single solid control line with a coefficient of retroreflection of about 100 mcd/m^2 to approximate typical visibility conditions for the control measurements, there was no feasible method available to degrade the new control line material to some specified "used" condition.

The experimental order was determined on the basis of the degree of obliteration. From Figure 1*c* it can be seen that varying obliteration was obtained by randomly adding retroreflective material in a 2 by 6 matrix within each stripe. For the 75 percent obliteration situation, 3 out of the 12 matrix cells were equipped with retroreflective material; for the 50 percent obliteration situation, 6 out of the 12 matrix cells were equipped with retroreflective material; and all cells were equipped for the 0 percent obliteration situation. This method of representing various degrees of obliteration imposed the experimental order 75 percent obliteration, 50 percent obliteration, and 0 percent obliteration.

Each subject was tested under only one obliteration condition and under the conditions shown in Table 2 using three replications. The presentation order within each group was completely randomized by approach direction (east/west) and by line number (Line 1 to Line 5). Therefore, the total number of observations within each group was 360 (12 subjects with 3 replications each, 5 line numbers, east/west approach, begin/end) each for the begin detection distances and for the end detection distances.

Experimental Procedure

First the subject was given the proper instructions and then asked to adjust the driver's seat, mirror, and so on. After performing a number of familiarization runs, the subjects started the first run. For each run, the subject was instructed to line up the experimental vehicle in the one driving lane (visible black joints of concrete plates) that was assigned by the experimental design. The subject was then told to accelerate the experimental vehicle to about 8 to 16 kph and to hold this speed as well as the lateral position as constant as possible. As soon as the subject reported seeing the begin of the corresponding center-stripe treatment a sand bag was dropped onto the runway by the experimenter in the passenger seat. A number of assistant experimenters recorded the distance of the sandbag relative to the beginning of the center stripe. The same method was applied for the detection of the end of the finite-length center-stripe treatment. The distances were measured to the nearest 2.54 cm by the assistant experimenters. As soon as the run was completed, the subject was instructed to drive the car to the next starting position, which was given by the experimental design protocol. Each subject performed three replications. One subject always performed ten runs (five eastbound, five westbound) within which the line number was completely randomized. The detection distances were not adjusted for the experimenter's reaction time to drop the sandbag, or for the drop time; therefore, all the actual detection distances may be about 10 ft longer.

RESULTS

Some subjects could sometimes detect the begin, especially of the 0.1-m-wide single solid control line, already from the starting position, because the runway did not provide enough approach run length for these conditions. This experimental artifact may have artificially reduced the begin detection distances for some conditions to some degree. However, because the artificial reduction is likely to be relatively small as a result of the small retroreflective area of the selected treatments, and to provide a complete account of the experimental results, the begin distances are presented nevertheless.

An analysis of variance (ANOVA) was conducted, and it was found that the factor line type (degree of obliteration) and the factor

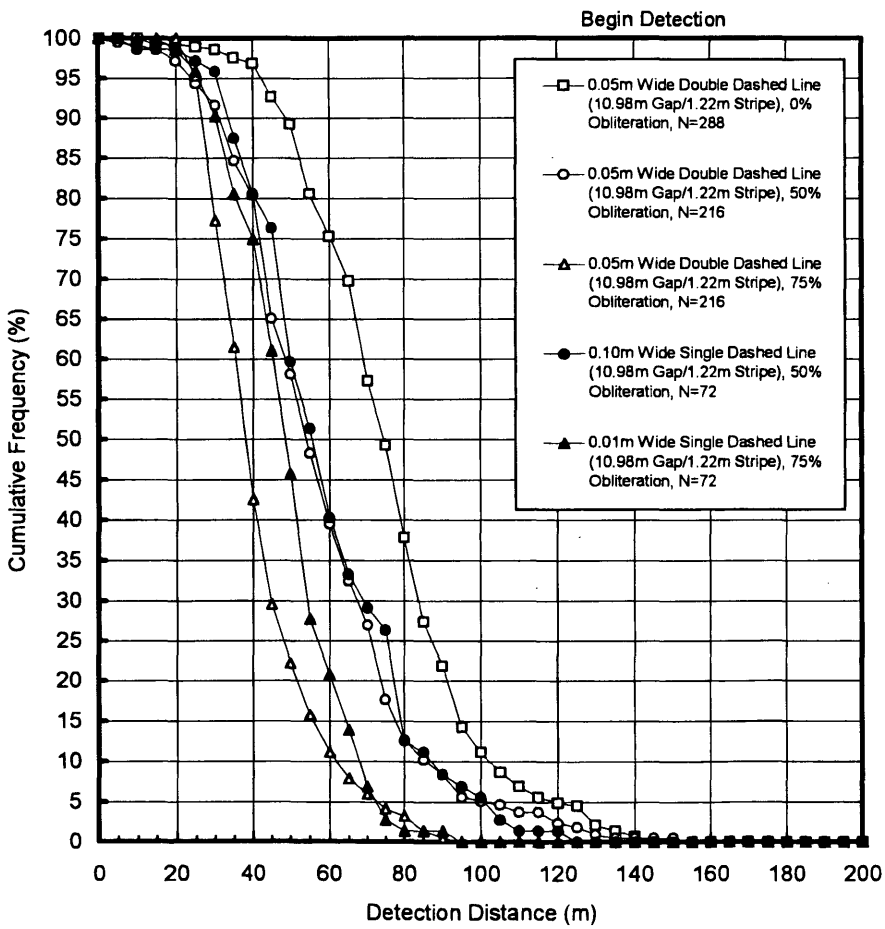
TABLE 2 Begin and End Detection Distances as a Function of Obliteration, Approach Direction, Center Stripe Type, and Gap space

Type of line \ Lat separ.		0%, Obliteration			50%, Oblieration			75%, Obliteration		
		Avg.	SD.	N	Avg.	SD.	N	Avg.	SD.	N
0.05m Lateral Separation, 0.05 m width, Double Dashed Line(10.98/1.22)										
Begin	East	89.0	15.2	36	71.8	31.4	36	46.7	15.8	36
	West	62.7	14.3	36	50.4	16.2	36	45.0	11.7	36
End	East	94.6	18.8	36	74.7	29.3	36	60.9	22.3	36
	West	79.2	26.3	36	66.8	34.3	36	51.7	19.9	36
0.10m Lateral Separation, 0.05 m width, Double Dashed Line(10.98/1.22)										
Begin	East	73.9	13.6	36	61.2	14.1	36	37.6	6.3	36
	West	103.5	26.5	36	79.1	22.6	36	66.7	13.1	36
End	East	78.4	19.0	36	70.8	32.2	36	50.3	26.0	36
	West	86.4	20.1	36	78.2	32.2	36	80.2	27.9	36
0.15m Lateral Separation, 0.05m width, Double Dashed Line(10.98/1.22)										
Begin	East	70.7	24.7	36	56.2	23.9	36	42.4	8.6	36
	West	69.3	18.5	36	51.7	22.2	36	39.5	6.4	36
End	East	79.6	19.1	36	77.2	30.8	36	61.9	28.7	36
	West	82.6	16.7	36	73.0	43.7	36	61.3	25.0	36
0.10m width, Single Dashed Line(10.98/1.22)										
Begin	East	Data not Measured			67.7	24.2	12	55.2	15.4	12
	West				59.8	18.3	12	52.3	13.3	12
End	East				63.3	31.3	12	63.0	33.6	12
	West				62.3	29.1	12	54.1	19.8	12

(All Average and Standard Deviation Detection Distance Values in Meters)

begin and end detection distance were statistically significant. By comparing Figures 2 and 3 it can be seen that the begin of the center stripes was detected very slightly farther than the end of the center stripes. However, the begin detection distances may have been somewhat reduced because of limited available approach run length. The ANOVA further indicated that the approach direction was insignificant, despite the somewhat different background conditions. The interaction effect between the factor line type (degree of obliteration) and the factor begin and end was found to be statistically highly significant. The interaction effect between the factor line type (degree of obliteration) and the factor approach direction was found to be statistically significant, probably because of the high significance of the factor line type. A Scheffe post hoc test generally indicated that the higher the degree of obliteration the shorter the detection distances. Note that the single solid 0.1-m-wide control line data for the begin detection distance was omitted in Figure 3 because of the limited available approach run length.

Figure 2 shows cumulative frequency as a function of the begin detection distance for the experimental center-stripe treatments on a concrete road surface under low-beam illumination conditions at night. The two center-stripe treatments with the highest degree of obliteration of 75 percent (Type 6 and Type 16), clearly provide the shortest begin detection distances. The double-dashed center stripes (Type 6, curve marked with empty triangles) and the single dashed (Type 16, curve marked with filled triangles) show almost the same begin detection distance for a probability of detection greater than 95 percent and smaller than 5 percent. However, in the intermediate probability range it seems that the double dashed 0.05-m-wide center-stripe treatment (Type 6, curve marked with empty triangles) provides somewhat shorter (statistically not significant at $\alpha = 0.05$) begin detection distances than the single dashed 0.1-m-wide center-stripe treatment (Type 16, curve marked with filled triangles). The two center-stripe treatments with 50 percent obliteration (Type 5 and Type 15), provide somewhat longer begin detection distances than



Note: Begin detection distance values may be too short due to limited available approach distance. Both Line type 4 (0.05m wide double solid, 0% obliteration) and the 0.1 m wide single solid control line were omitted in the above figure, because some subjects could detect the begin of those treatments already from the starting position, due to limited available approach run length.

FIGURE 2 Psychometric curves for begin detection distance on a concrete road surface under low-beam illumination at night.

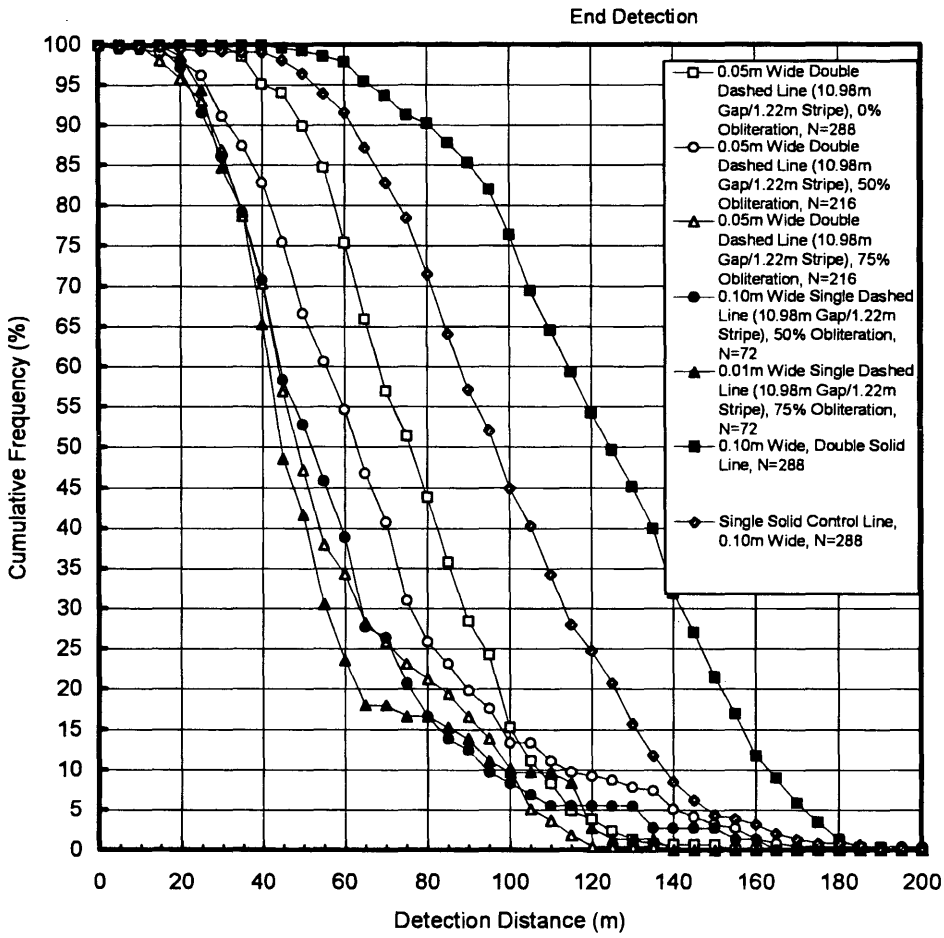


FIGURE 3 Psychometric curves for end detection distance on a concrete road surface under low-beam illumination conditions at night.

the center stripes with 75 percent obliteration. It can be seen from Figure 2 that the double dashed center stripes (Type 5, curve marked with empty disc) and the single dashed center stripes (Type 15, curve marked with filled disc) provide almost identical begin detection distances. The double dashed center stripe with 0 percent obliteration (Type 4, curve marked with empty square) provides, as expected, the longest begin detection distance. On the basis of Figure 2, it seems that obliteration has an effect on begin detection distance in terms of reducing visibility for increased obliteration. It seems that there is no statistically significant difference between the obliterated double dashed, coded center stripes (Types 5 and 6) and their single dashed counterparts (Types 15 and 16) with equivalent area.

Figure 3 shows the psychometric curves as a function of the end detection distance for the experimental center stripe treatments on a concrete road surface under low-beam illumination conditions at night. Strictly for comparison purposes, this figure also includes the end detection distance curve for the 0.1-m-wide yellow single solid control line and the end detection distance curve for a 0.1-m-wide, yellow double solid standard center line. The two center stripe treatments with the highest degree of obliteration of 75 percent (Type 6 and Type 16), clearly provide the shortest end detection distances. The double-dashed center stripes (Type 6, curve marked with empty triangles) and the single dashed (Type 16, curve marked with filled triangles) show almost the same end-detection distance for a probability of detection greater than 65 percent and smaller than 3 percent. However, in the probability range between 3 and 65 percent, it seems that the double-dashed coded 0.05-m-wide center stripe treatment (Type 6, curve marked with empty triangles) provides somewhat longer (statistically not significant at $\alpha = 0.05$) end detection distances than the single dashed 0.1-m-wide center stripe treatment (Type 16, curve marked with filled triangles). The two center stripe treatments with 50 percent obliteration (Types 5 and 15) provide somewhat longer end detection distances than the center stripes with 75 percent obliteration. It can be seen from Figure 3 that the double-dashed coded center stripes (Type 5, curve marked with empty disc) provides longer end detection distances than the single dashed center stripes (Type 15, curve marked with filled disc). The double dashed center stripe with 0 percent obliteration (Type 4, curve marked with empty square) provides, as expected, the longest end-detection distance among the temporary center stripes. On the basis of Figure 3, it seems that obliteration has an effect on end detection distance in terms of reducing visibility for increased obliteration. There does not seem to be any significant difference between the obliterated double dashed, coded center stripes (Types 5 and 6) and their single dashed counterparts (Types 15 and 16). Therefore, one may conclude that for the same area of retroreflective material, the coded center stripes provide comparable robustness to obliteration and comparable begin and end detection

distances. Thus, the coded center stripes might be beneficial in temporary resurfacing zones because they could also convey passing/no-passing information in temporary resurfacing zones.

Figure 2 indicates that at the 85th percentile point the 75 percent obliteration treatment provides a begin detection distance of about 28 m, whereas the 0 percent obliteration treatment provides a begin detection distance of about 56 m (twice the distance for four times more material). Similarly, from Figure 3, it can be seen that at the 85th percentile point, the end detection distances are about 30 m for the treatment with 75 percent obliteration and about 56 m for the treatment with 0 percent obliteration. The end detection distance values are close to the begin detection distance values.

Figure 4 indicates a comparison of the average begin/end, east/west detection distances as a function of obliteration for 0.05-m-wide double dashed center stripes with 0.05-, 0.1-, and 0.15-m lateral separation as well as for the single dashed 0.1-m-wide center stripes. From the figure, it can again be seen that the detection distances generally decrease for increasing obliteration.

Figure 5*a* shows the effect of the retroreflective area for each 12.22-m-long segment of pavement marking on the 85th percentile detection distance, for center stripe Types 4, 5, 6, 15, and 16. Some subjects have detected some of the lines already at the starting position, which has artificially reduced the begin detection distances to some degree for some conditions. As expected and demonstrated by the ANOVA and the Scheffe post hoc tests, which indicated that line type was highly significant, it was found that a more retroreflective area per 12.22-m-long segment generally results in somewhat longer detection distances for both detection of the begin and the end. Figure 5*b* shows the effect of retroreflective area for each 12.22-m-long segment of pavement marking on the 50th percentile detection distance for center stripe Types 4, 5, 6, 15, and 16. The 50th percentile begin and end detection distances are on the average about 37 percent longer than the corresponding 85th percentile begin and end detection distances. For the data shown in Figure 5*a* and *b*, it can be stated that even though there appears to be an almost linear relationship between the begin/end detection distances and the retroreflective area per 12.22-m segment in the investigated range of 0.0301 m^2 to 0.123m^2, there has been enough evidence in related studies (*6,7*) that further increasing the retroreflective area would not necessarily improve visibility in a linear fashion. In fact, calculations indicated that an increase in the retroreflective area from 0.122 to 2.44 m^2 for each 12.2-m-long center line segment (20-fold increase) was

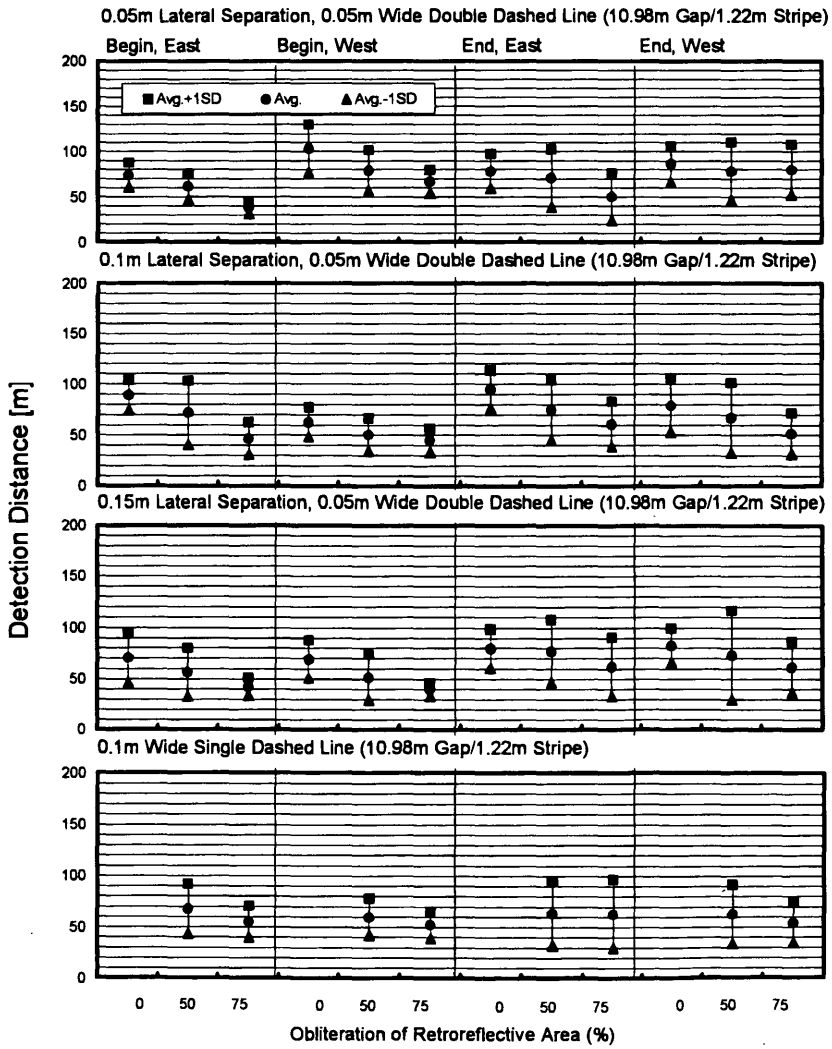
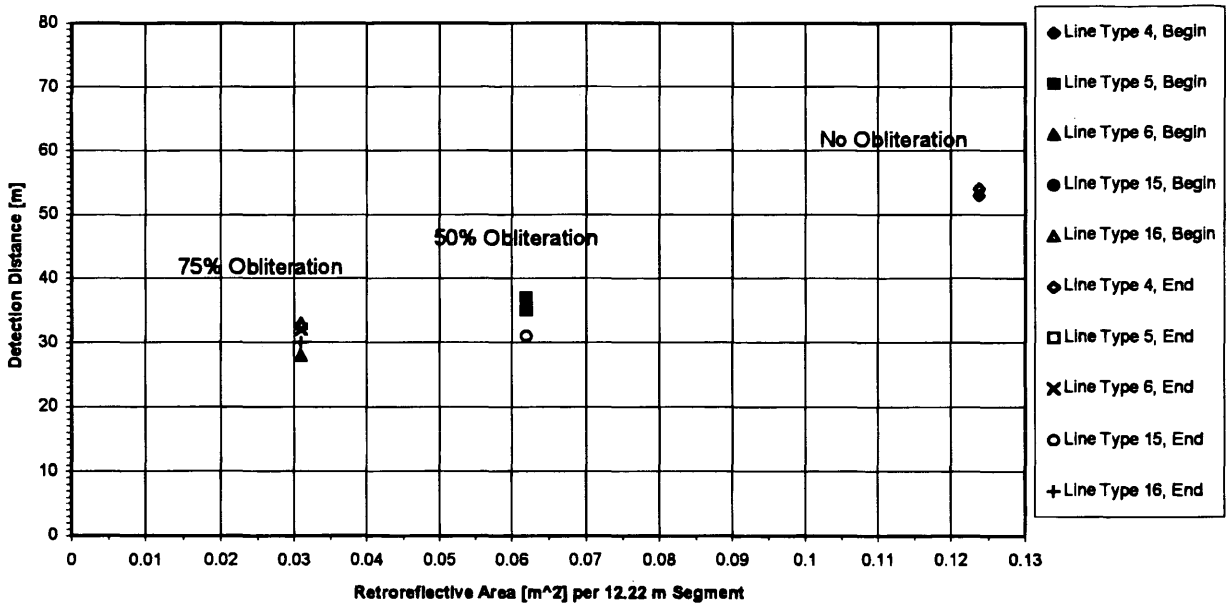
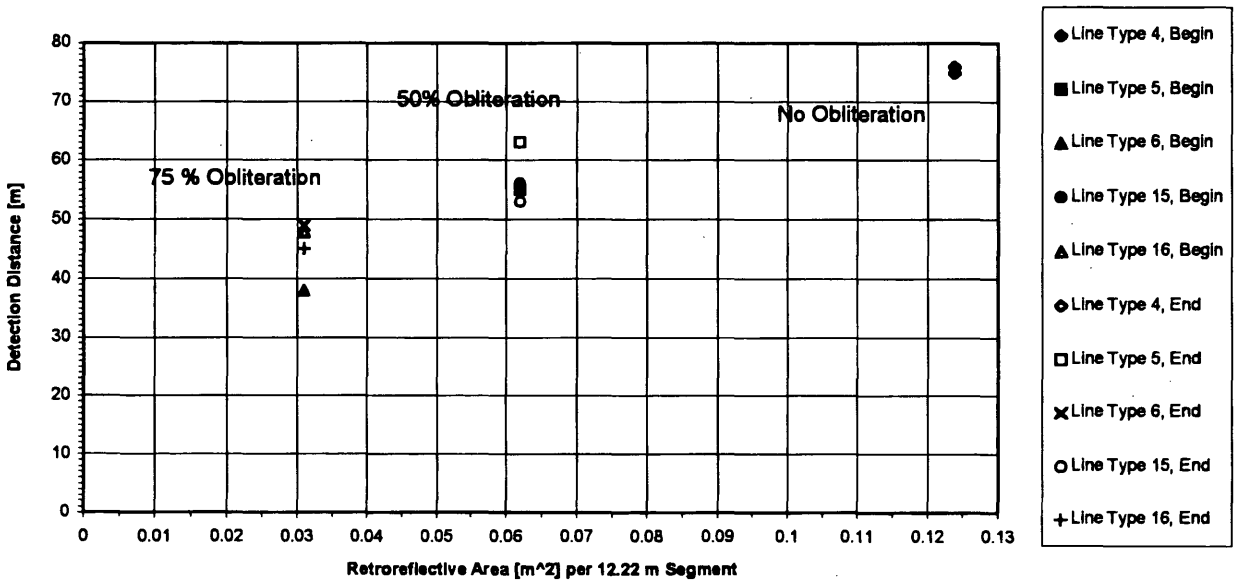


FIGURE 4 Comparison of average begin and end, east/west detection distances as a function of obliteration. Begin detection distance values may be too short because of a limited available approach distance.



a)



b)

FIGURE 5 Detection distances for begin and end on a concrete road surface under low-beam illumination conditions at night as a function of the area of retroreflective material (*a*) 85th percentile detection distance data; (*b*) 50th percentile detection distance data. Begin detection distance values may be too short because of a limited available approach distance.

required to increase the average end detection distance from 55 to 90 m, which amounts only to a gain of 65 percent. Therefore, the positive visibility effects of using more retroreflective material may be gradually outdone by the increased cost for the additional material.

DISCUSSION AND CONCLUSIONS

A review of the technical literature about the visibility of center stripes has indicated that, with the exception of the data provided by Zwahlen and Schnell (*6*), few pavement marking visibility data are available in terms of begin and end detection distances. Further, the literature does not seem to provide any quantitative information about the effect of pavement marking obliteration on visibility. The study was conducted to overcome this lack of information, which is required to quantify the visibility of obliterated or less-than-full pavement marking treatments. New pavement markings were used in this obliteration study because no feasible method was available to degrade new pavement markings in a uniform manner to some specified "used" condition. The use of the minimum specified dimension center stripes (0.05 m wide) was intended to somewhat counteract the newness of the used pavement marking tapes. This

research also may have some value for the cost-effective installation of enhanced "coded" temporary center stripes in newly resurfaced zones. The current Ohio standard given in the Ohio Manual of Uniform Traffic Control Devices (OMUTCD) (*8*) and the federal standard given in MUTCD (*4*) specify 0.1-m-wide single dashed stripes with a gap/stripe ratio of 10.98/1.22 m as temporary center stripes in resurfaced zones, regardless of whether the resurfaced zone happens to be in a no-passing zone. The double dashed 0.05-m-wide "coded" temporary center stripes, which were used in this experiment, have been shown to provide equivalent detection distance performance as the standard OMUTCD/MUTCD single dashed temporary center stripes. However, a driver in a newly resurfaced no-passing zone may be more adequately informed about the passing situation with the double dashed "coded" temporary center stripes using the same amount of retroreflective material. Considering the fact that the thinner double-dashed center stripes can provide additional passing or no-passing information to a motorist in a temporary resurfacing zone without any significant difference in the begin and end detection distances, it may be concluded that the use of temporary double dashed center stripes in resurfaced no-passing zones could improve motorist safety while requiring the exact same amount of material as the presently used single dashed temporary center stripes require. Overall, on the basis of results of this study it is concluded that severe obliteration does reduce the begin and end detection distances to a considerable degree. However, using four times less material and the shortest specified stripe length (10.98/1.22 m) reduces, for example, the 85th percentile begin and end detection distances from about 53 to 30 m (see Figure 5*a*). Therefore, from a begin and end detection distance point of view, it seems that if the nonobliterated center line pavement marking treatment already provides barely adequate visibility performance, it is not possible to tolerate much obliteration at all (possibly no more than 5 to 10 percent before the visibility performance of the overall system (driver-vehicle-center line system) falls below the acceptable minimum safety level.

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Publication of this paper sponsored by Committee on Visibility.