Effects of Lateral Separation Between Double Center-Stripe Pavement Markings on Visibility Under Nighttime Driving Conditions

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Pavement markings on public roads provide driver guidance, convey advisory or warning information to the driver, or both, and are often used as a supplement to other traffic control devices without redirecting the focus of attention from the road. Adequate visibility of pavement markings at night is an important element of driver safety, especially in the absence of public lighting. Increased lateral separation between double center stripes could increase the detection distance because the human visual system would spatially integrate over the lateral space between the parallel lines to form a more visible target that subtends a greater visual angle. Most of the technical literature has shown that there seems to be no available pavement marking visibility data on begin-and-end detection distances. Also, no data are available on the effects of lateral separation between double solid center stripes and the interaction between lateral separation and line width. The current study was conducted to provide a scientific basis for quantifying the effects of lateral separation between double solid center stripes. It is current standard practice in Ohio to implement double solid yellow center stripes (0.1 m wide) with a lateral separation of 0.1 m. On the basis of a field experiment involving 48 subjects, average begin-and-end detection distances were established and psychometric curves were plotted. An ANOVA and Scheffe post hoc test failed to find any significant systematic effect caused by lateral separation between the center lines. On the basis of the findings of this study it is possible to tentatively conclude that an increase in the lateral separation (from 0.05 to 0.2 m) between the double center stripes does not appear to be a useful method to increase driver visibility. In addition, as expected, the amount of retroreflective material (0.05, 0.1, 0.15, or 0.2 m width, double solid versus dashed, gap/stripe ratio of 9.15/3.05 m versus 10.98/1.22 m) has a fairly small effect on the 85th percentile end detection distances, thus indicating a relatively small marginal gain in visibility with a substantially increased retroreflective area. In fact, calculations indicate that an increase in area from 0.122 to 2.44 m^2 for each 12.2-m-long center line segment (20-fold increase) is required to increase the average end detection distance from 82 to 128 m, which is only an increase of 56 percent.

Except for data provided by Zwahlen and Schnell (*1*) There seems to be no available pavement marking visibility data on begin-and-end detection distances. Dudek et al. (*2*) conducted a field study to investigate the effect of temporary pavement markings in newly paved work zones under dry nighttime driving conditions. As independent variables Dudek et al. used the following center stripe types:

- 0.304-m stripes with 11.88-m gaps,
- 0.61-m stripes with 11.58 m gaps, and
- 1.2261-m stripes with 10.97-m gaps.

The dependent variables were

- Vehicle speed,
- Lateral distance of the vehicle from the centerline,
- Lane straddling, and
- Number of erratic maneuvers.

The study was conducted at seven pavement overlay sites in the states of Texas (four sites), Arkansas, Colorado, and Oklahoma (one site each). All newly paved sites had 3.65-m-wide lanes with paved shoulders. No edge lines were installed. A tangent section and one curve were present in each site. A random scheme was used to assign one of the three patterns to one of the three nights during which the traffic was observed. Dudek et al. tested each pattern at exactly the same location at the test site. This approach eliminated effects caused by road geometry differences. In addition to this unobtrusive driver study, Dudek et al. used an in-vehicle response survey to evaluate the three pavement marking patterns. The survey involved 27 paid driver subjects. Dudek et al. found that there were no statistically significant differences between Types 1, 2, and 3 patterns with respect to vehicle speed. Further, there were no statistically significant differences between Types 1, 2, and 3 patterns with regard to lateral vehicle position. No consistent effect was found for the centerline encroachments. The very infrequently observed encroachments were related to passing maneuvers rather than pavement marking effects. Virtually no erratic maneuvers were observed. The in-vehicle observers reported a slight subjective improvement when longer markings were used. At one site the observers even judged the Type 1 pattern to be the most effective. Dudek et al. concluded that the Type 1 and the Type 2 patterns performed as well as the Type 3 pattern that is currently recommended by the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) (*4*) under the tested conditions. The findings of Dudek et al. (*2*) were based on fresh black pavement and newly installed retroreflective pavement markings under dry nighttime driving conditions. The researchers pointed out that their results should not be generalized to situations in which the pavement and the markings would not provide as much contrast or to situations involving adverse weather conditions.

Cotrell (*5*) investigated the effect of wide edge lines on the reduction of run-off-the-road (ROR) accidents. The experiment was set

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up on three rural road sections with a total length of 60.7 mi. The experiment consisted of a before-and-after study. Accident data for the before-and-after study were collected over 3 and 2 years, respectively. Cotrell concluded that there is no evidence that wide edge lines significantly affect the incidence of ROR accidents.

Very little can be found in the literature with respect to theoretical pavement marking models that would provide detection distances as a function of factors such as (but not limited to) observer/headlamp/pavement marking geometry, retroreflective material characteristics, human visual performance, headlamp candlepower output, and environmental conditions. There currently exists no pavement marking visibility model to evaluate different pavement marking materials under selected geometrical and environmental conditions within the driving context. The visibility model proposed in CIE Publication 73 (*6*) has a number of shortcomings. For straight sections, the model proposes a conservative preview time of 5 sec. The threshold contrast function is inaccurate, does not consider driver age, does not consider glare caused by oncoming vehicles, does not consider the contrast sensitivity in the visual periphery, does not consider the probability of detection, does not account for target recognition (accounts for detection only), and most likely uses an inadequate background luminance. In addition, the model considers the farthest visible point of a pavement marking line only. It does not account for the pavement markings visible between this farthest visible point and the point closest to a driver from which the hood of the car obstructs any closer view to the pavement. The pavement marking piece (located at the farthest visible point) is approximated by a rectangle rather than by a trapezoid as it would be seen from the perspective of a driver. The lateral location (edge line, centerline, etc.) of the pavement markings is not considered. The model does not specify how to obtain the candlepower of the headlamps for the given pavement marking location and also does not specify how to obtain the coefficient of retroreflection for the pavement marking material at the given location. The model does not account for the optical characteristics of the various road surfaces. On the basis of these drawbacks, it seems that additional research about pavement marking visibility is essential.

Saito and Garber (*7*) investigated the effect two different pavement marking patterns have on driver behavior. As the independent variables in their field study they used the following pavement markings:

- Mountain pavement marking (MPM): this type of pavement marking consists of a single broken line (no information about the marking length and color was given in the paper) and two edge lines; and
- MUTCD passing and no passing lines: this included a double solid line, a single solid line with a left broken line, and a single solid line with a right broken line, and always edge lines.

The following dependent variables were considered:

- Traffic volume,
- Vehicle speeds,
- Distance to the leading vehicle (headway maintenance),
- Traffic queues (a platoon of at least two cars with a maximum headway time of 6 sec was considered a queue).

The data were collected with a Leupold and Stevens traffic data recorder. Garber and Saito believed that these dependent variables were justified because the short period of their research did not allow for a meaningful statistical accident analysis. The researchers conducted the study in a before-and-after manner. The before study investigated the effect of the MPM on the dependent variables. Data for the MUTCD markings were collected in the after study. Garber and Saito found that there was no significant change in the vehicle speed between the before and the after study with the exception of two sites, where the speeds were reduced by 2.57 kph and 3.05 kph respectively. Despite the statistical significance, practically, this change does not indicate a strong speed reduction effect of the MUTCD markings. The speed variance during the after phase was smaller than during the before phase, supporting the hypothesis that the MUTCD markings tend to enhance a smooth flow of traffic. There was no significant change in the queue characteristics with respect to queue speed and queue frequency. The headway distributions did not significantly change. The researchers concluded that on the basis of a lack of difference in driver behavior, the MUTCD pavement-marking pattern should be preferred over any other type of pattern.

Zwahlen and Schnell (*1*) 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 markings visibility field data for detecting the beginning and the end of continuous pavement marking lines of finite length 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 (from 0.1 to 0.2 m) does not appear to increase the average detection distance.

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), located approximately 1.8 m to the right of the car, 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 beginning and for the end of different new yellow-taped center-stripe configurations having different widths (0.05, 0.1, 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 (1) there appears to be no 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 lateral separation between double center-stripe pavement markings on visibility.

OBJECTIVES

On the basis of previously mentioned needs to quantify the effect of lateral separation between new yellow double solid and double dashed center stripes on driver visibility, the objectives of this study were as follows:

- To determine the visibility distances under automobile low-beam illumination at night for new yellow double solid center stripes as a function of the lateral separation between the double stripes (0.05, 0.1, 0.15, and 0.2 m);
- To provide visibility distances in terms of psychometric curves in addition to the average and standard deviation values;
- A secondary objective was to investigate the effect of retroreflective material area (0.05 versus 0.1 m width of the double center stripes, solid versus gap/stripe ratio 9.15/3.05 m and 10.98/1.22 m) on begin-and-end detection distances.

METHOD

Experimental Site

The experiment was conducted on an old unused Ohio University airport runway (see Figure 1), which is about 23 m wide and 500 m long, running east to west, and is 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, 0.027 cd/m^2 at 40 m. Beyond 40 m, the runway luminance asymptotically approached 0.01 cd/m^2 (because of ambient illumination). Figure 2*b* shows the luminance contrast between the centerline 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 luminaires 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 luminaires 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. 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 10 young healthy women college students with an average age of 26.77 years and 38 young healthy men college students with an average age of 23.1 years participated in the experiment. The 48 subjects were distributed over four groups (see experimental design) as follows:

- Group 1 (average age 26.1 years) contained five women as subjects (average age 30 years) and seven men as subjects (average age 23 years);
- Group 2 (average age 23.6 years) contained two women as subjects (average age 24 years) and ten men as subjects (average age 23.5 years);
- Group 3 (average age 23.9 years) contained one woman as subject (age 20 years) and eleven men as subjects (average age 24.27 years); and
- Group 4 (average age 21.6 years) contained two women as subjects (average age 23 years) and ten men as subjects (average age 21.44 years).

The subjects had an average driving experience of 5.52 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 20/29 (average 20/20.27). Out of the 48 subjects 2 wore corrective contact lenses and 18 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

Groups 1 through 3 used a 1981 Volkswagen Rabbit with H6054 headlamps with a line-of-sight windshield transmission of 0.77. Group 4 used a 1994 Ford Probe with a line-of-sight windshield transmission of about 0.7. The average eye height was 1.07 m for the drivers in Group 1, 1.08 m for the drivers in Group 2, 1.08 m for the drivers in Group 3, and 1.07 m for the drivers in Group 4.

Experimental Design

A randomized block design was used for the experiment. The dependent variables in this study were the average detection distances of the beginning and the end of the center-stripe treatments. The major independent variables were the lateral separation between the double center stripes and the approach direction (east/west). The following center-stripe types were installed using 0.05, 0.1, 0.15, and 0.2 m of lateral separation between the lines:

- Type 1, a double solid line that is 0.1 m wide;
- Type 2, a double solid line that is 0.05 m wide;
- Type 3, a double dashed line that is 0.05 m wide and has a gap/stripe ratio of 9.15/3.05 m; and
- Type 4 a double dashed line that is 0.05 m wide and has a gap/stripe ratio of 10.98/1.22 m. (see Figure 1, bottom).

Table 1 lists the different line types and line numbers that were used in the experimental design. The line number determined what lateral separation between the lines was present while the line type determined whether a center stripe consisted of a dashed pattern or a solid line of finite length.

A new 0.1-m-wide single solid center line of finite length was used as base line 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. Each subject was tested under only one line type (Type 1, double solid 0.1-m-wide lines; type 2; double solid 0.05-m-wide lines; Type 3; double-dashed 0.05-m-wide lines with a gap/stripe ratio of 9.15/3.05 m; and Type 4, double-dashed 0.05-m-wide lines with a gap/stripe ratio of 10.98/1.22 m) and under the conditions shown in Table 1 using

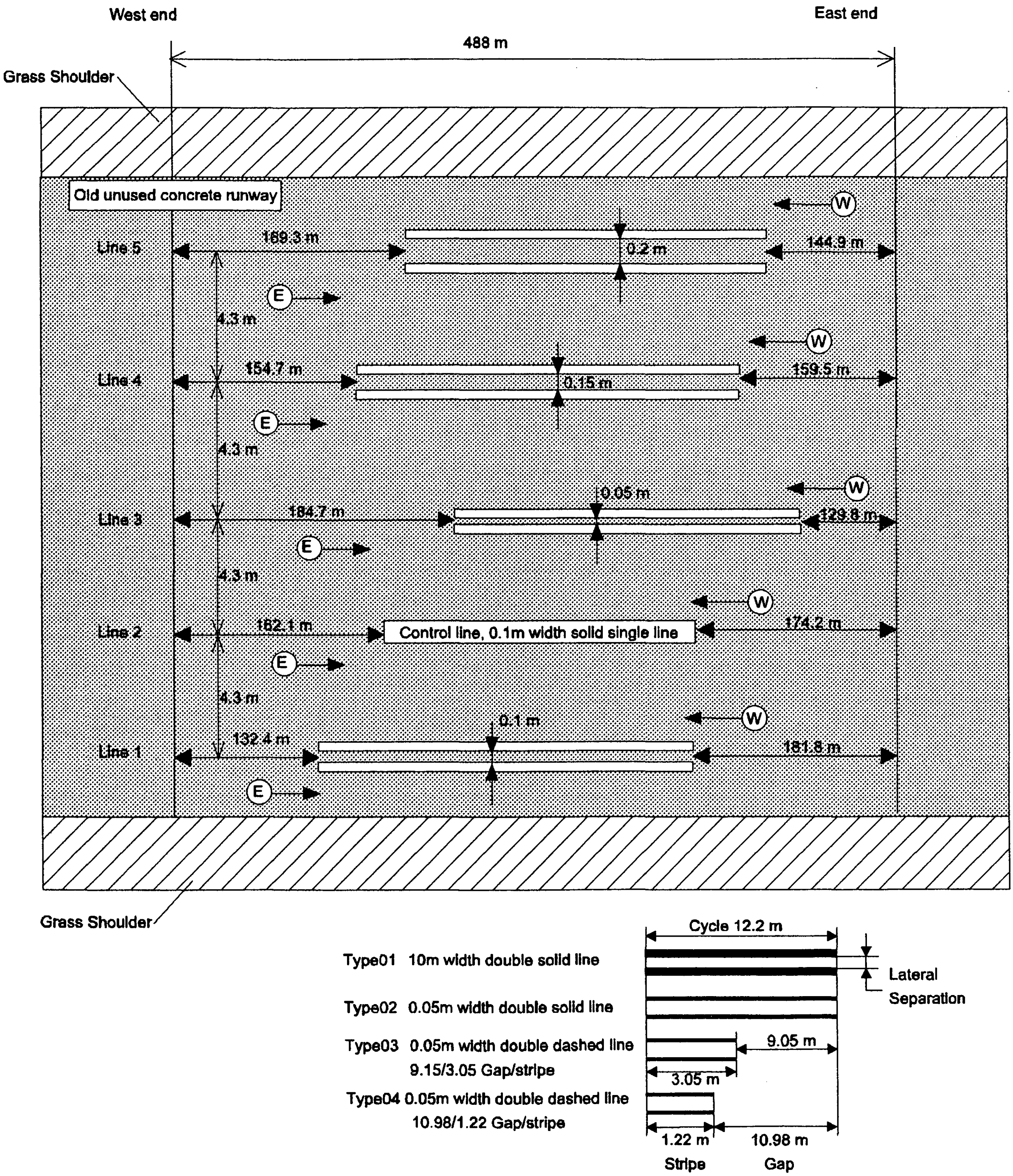
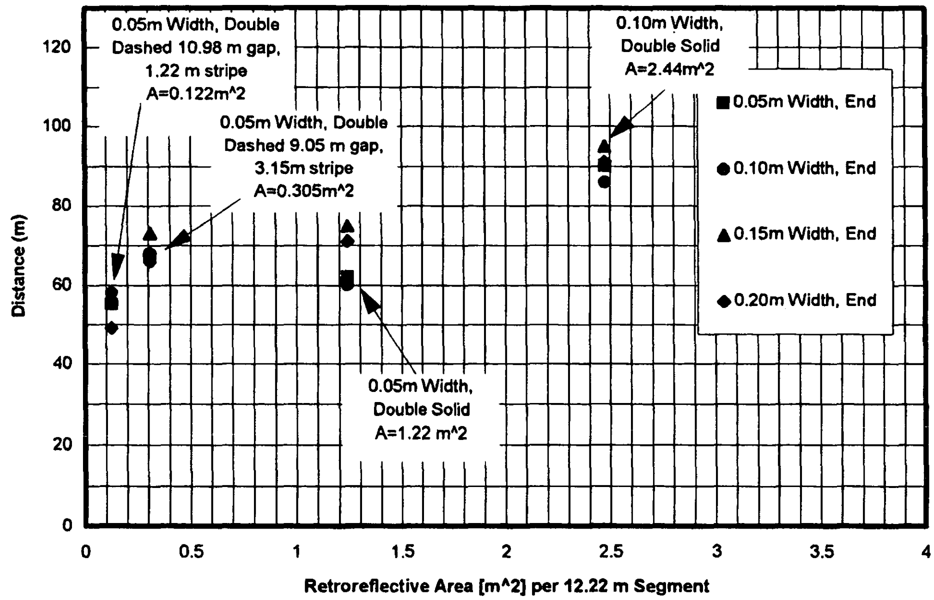
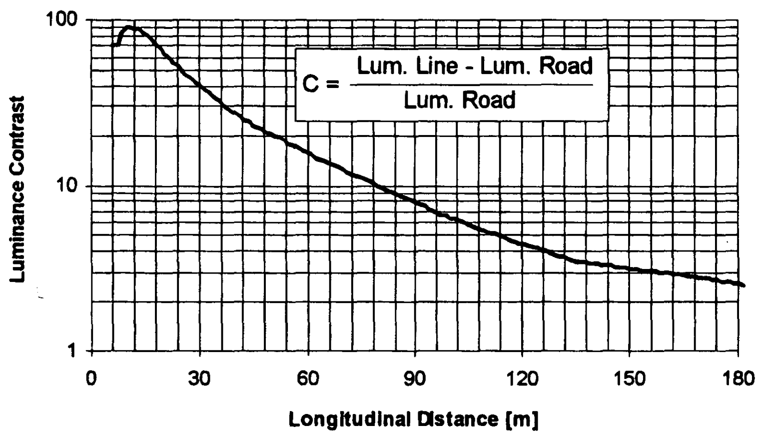


FIGURE 1 Layout for detection of begin and end of new yellow double solid center stripes having 0.05, 0.1, and 0.2 m lateral separation between lines.



a) 85th Percentile Detection Distance for the End of New Yellow Double Solid and Double Dashed Stripes on a Concrete Road Surface under Low Beam Illumination Conditions at Night as A Function of the Area of Retroreflective Material.



b) Approximate Computed Luminance Contrast Between the Center Line Treatments (3M 5161 Yellow, Measured and Extrapolated Ra Matrix) and the Concrete Runway Surface (Ra Matrix measured and Extrapolated) as Function of Distance ahead of the car.

FIGURE 2 Effect of area of retroreflective material on visibility under low-beam illumination and approximate computed luminance contrast ahead of car.

three replications. The presentation order within each group was completely randomized by approach direction (east/west) and by line number (Lines 1 to 5). Therefore, the total number of observations within each group was 360 (12 subjects with three replications each, five 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 such items as the driver seat and mirror. 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 beginning 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

TABLE 1 Experimental Order and Center Stripe Configuration

	Line Number					
Grp No.	Line 5	Line 4	Line 3	Line 2	Line 1	Order of Group Subjected to Experiment
1	Type 2, Double Solid, 0.05m wide, 0.2m separation	Type 2, Double Solid, 0.05m wide, 0.15m separation	Type 2, Double Solid, 0.05m wide, 0.05m separation	Single solid control line 0.1m wide	Type 2, Double Solid, 0.05m wide, 0.1m separation	3
2	Type 1, Double Solid, 0.1m wide, 0.2m separation	Type 1, Double Solid, 0.1m wide, 0.15m separation	Type 1, Double Solid, 0.1m wide, 0.05m separation	Single solid control line 0.1m wide	Type 1, Double Solid, 0.1m wide, 0.1m separation	4
3	Type 3, Double dashed, 0.05m wide, 0.2m separation, 9.15/3.05m gap/stripe	Type 3, Double dashed, 0.05m wide, 0.15m separation 9.15/3.05m gap/stripe	Type 3, Double dashed, 0.05m wide, 0.05m separation 9.15/3.05m gap/stripe	Single solid control line 0.1m wide	Type 3, Double dashed, 0.05m wide, 0.1m separation 9.15/3.05m gap/stripe	2
4	Type 4, Double dashed, 0.05m wide, 0.2m separation, 10.98/1.22m gap/stripe	Type 4, Double dashed, 0.05m wide, 0.15m separation 10.98/1.22m gap/stripe	Type 4, Double dashed, 0.05m wide, 0.05m separation 10.98/1.22m gap/stripe	Single solid control line 0.1m wide	Type 4, Double dashed, 0.05m wide, 0.1m separation 10.98/1.22m gap/stripe	1

treatment. The distances were measured to the nearest 2.54 cm by the assistant experiments. 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 experiment'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 beginning, especially of Type 1 double solid, 0.1 m wide and of the single solid control line 0.1 m wide, already from the starting position, because the runway did not provide enough approach run length for these conditions. This experimental artifact has artificially reduced the begin-detection distances for these conditions to some degree. However, to provide a complete account of the experimental results, the begin distances are displayed nevertheless. It is likely that the begin-and-end detection distances would be closer together for a longer approach length. Figure 3 shows the group 1 psychometric curves for new yellow double solid center stripes 0.05 m wide with the lateral separations 0.05, 0.1, 0.15, and 0.2 m, as a function of the begin-and-end detection distance. It can be seen from the figure that the end-detection distances are somewhat longer than the begin-detection distances. Within the begin-detection distances there is an obvious lack of an effect caused by lateral center stripe separation (Line 3 with 0.05 m of lateral separation, Line 1 with 0.1 m lateral separation, Line 4 with 0.15 m lateral separation, and Line 5 with 0.2 m lateral separation). Within the end-detection distance cluster for the Group 1 data indicated in Figure 3 one can observe a slight tendency for the larger lateral separations to provide slightly longer detection distances. Line 5 with the 0.2-m lateral separation seems to provide the longest end-detection distances followed by Line 4 with 0.15 m of lateral separation. Line 3 with the 0.05-m lateral separation seems to provide the shortest end-detection distances for Group 1. The ANOVA, which was conducted for Group 1, confirmed the observations that were made on the basis of Figure 3 because the line number is slightly significant. A Scheffe post hoc test, which was conducted for Group 2, identified, as expected, a significant difference between Line 1 (0.1 m of lateral separation), Line 3 (0.05 m of lateral separation), and Line 4 (0.15 m of lateral separation) and Line 5 (0.2 m lateral separation).

Figure 4 shows the Group 2 psychometric curves for new yellow 0.1-m-wide double solid center stripes with the lateral separations 0.05, 0.1, 0.15, and 0.2 m as a function of the begin-and-end detection distance. The figure indicates that the end-detection distances are

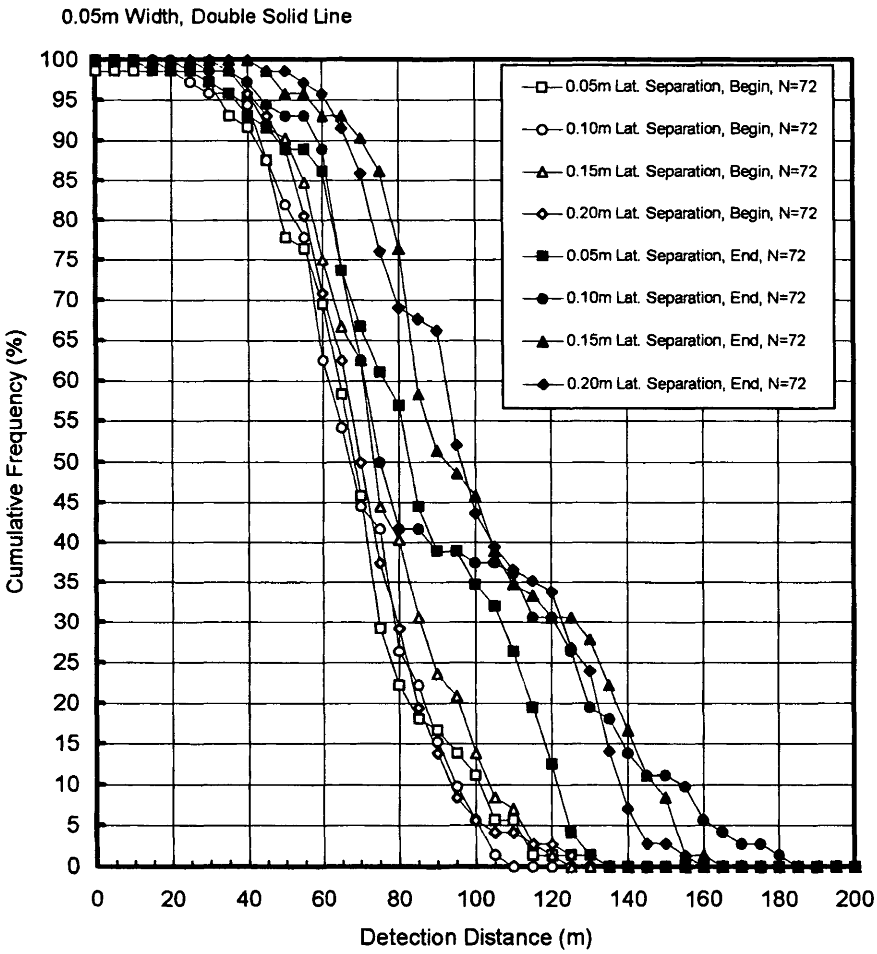


FIGURE 3 Group 1 psychometric curves showing cumulative frequency (percent) for begin and end detection distance of new yellow 0.05-m-wide solid center stripes with lateral separations of 0.05, 0.1, 0.15, and 0.2 m on concrete road surface under low-beam illumination at night as function of detection distance (in meters). Begin detection distance values may be too short because of limited available approach distance.

considerably longer than the begin-detection distances. The analysis of variance (ANOVA) that was conducted for Group 2, confirmed a highly significant difference between the begin-and-end detection distances. Within both the begin-detection distance cluster and the end-detection distance cluster, there is an obvious lack of an effect caused by lateral center stripe separation. The Group 2 ANOVA further indicated that line type (Types 1 to 4) is insignificant, that is, lateral separation does not have a significant effect. A Scheffe post hoc test that was conducted for Group 2, as expected, did not indicate any statistical significance caused by the lateral separation.

Figure 5 shows the Group 3 psychometric curves for new yellow 0.05-m-wide double-dashed center stripes with lateral separations 0.05, 0.1, 0.15, and 0.2 m and a gap/stripe ratio of 9.15/3.05 m as a function of the detection distance. Observations similar to the ones made for Group 2 can be made. However, it can be seen that the difference between begin-and-end detection distance is considerably smaller, probably because of the dashed line treatments. Again, within both the begin-and-end detection distance cluster there is no significant effect because of lateral separation. The ANOVA, which was conducted for Group 3 indicated that the factor line type (Types 1 through 4) was significant. However, a close investigation of the Group 3 data with a Scheffe post hoc test, revealed that the significance was always against Line 2, which is the single solid control line. Therefore, no statistical significance caused by the lateral separation between the double center stripe pavement markings was indicated by the post hoc test.

Figure 6 shows the Group 3 psychometric curves for new yellow 0.05-m-wide double-dashed center stripes with lateral separations 0.05, 0.1, 0.15, and 0.2 m and a gap/stripe ratio of 10.98/1.22 m as a function of the detection distance. The difference between begin-and-end detection distance is even smaller for this group. It seems that the gap/stripe ratio has an effect on the difference between begin-and-end detection distance. Within both the begin-and-end detection distance cluster there is only a small statistical significance in terms of lateral separation between Lines 4 and 1 (as indicated by the Group 4 Scheffe post hoc test). The ANOVA, which

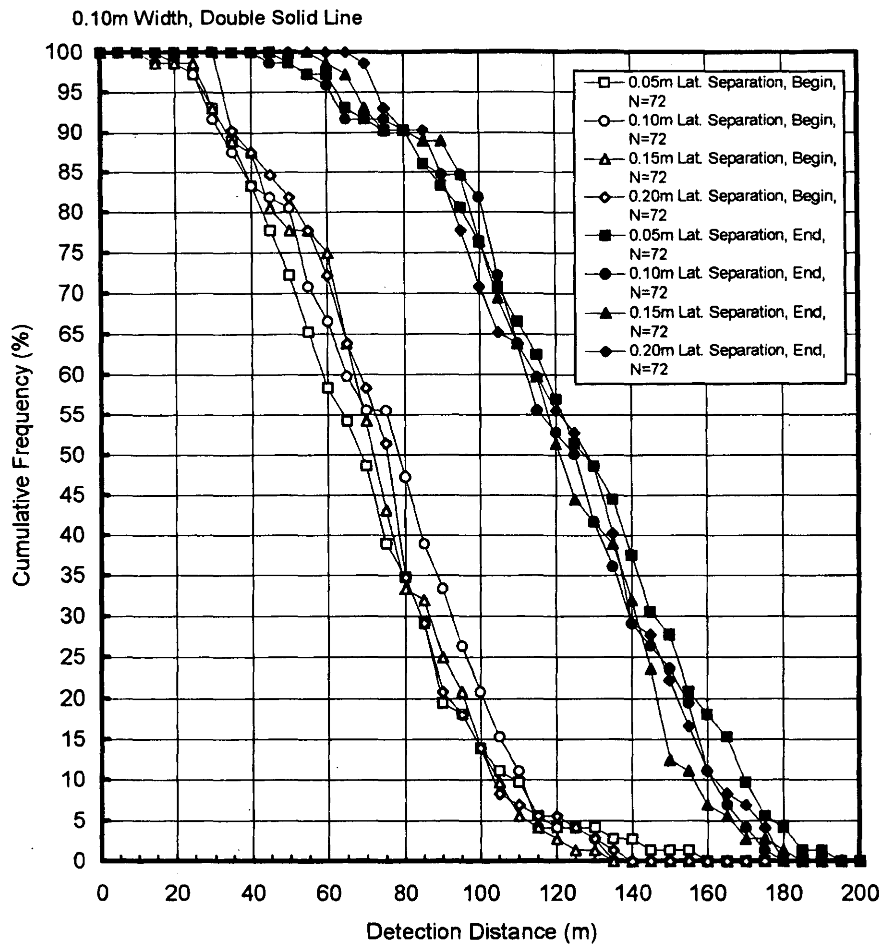


FIGURE 4 Group 2 psychometric curves showing cumulative frequency (percent) for begin and end detection distance of new yellow 0.1-m-wide double solid center stripes with lateral separations of 0.05, 0.1, 0.15, and 0.2 m on concrete road surface under low-beam illumination at night as function of detection distance (in meters). Begin detection distance values most likely are too short because of limited available approach distance.

was conducted for Group 4, indicated that the factor line type (Types 1 through 4) was significant. However, a close investigation of the Group 4 data with a Scheffe post hoc test again revealed that the significance was against Line 2 (with the exception of a very slight difference between Lines 1 and 4), which is the single solid control line. Overall from the psychometric curves, from the ANOVA and the Scheffe post hoc tests, there appears to be no significant systematic effect caused by the lateral separation between center lines. Figure 7 shows a comparison of the average begin/end, east/west detection distances as a function of lateral separation (0.05, 0.1, 0.15, 0.2 m) for 0.05 and 0.1-m-wide double solid center stripes. The figure again demonstrates that there is no effect caused by lateral separation because the detection distances within one line width and approach direction are almost the same for the 0.05, 0.1, 0.15, and 0.2-m lateral separation. Figure 8 shows a comparison of the average begin/end, east/west detection distances as a function of lateral separation (0.05, 0.1, 0.15, and 0.2m) for 0.05-m-wide double-dashed center stripes with a gap/stripe ratio of 9.15/3.05 m and 10.98/1.22 m. No systematic effect caused by lateral separation can be found. Both Figures 7 and 8 generally show somewhat longer begin-and-end detection distances in the eastbound direction. This observation was confirmed by the ANOVAs that were conducted on data from Groups 1 through 4. The slightly longer east-bound begin-and-end detection distances may be attributed to the darker night horizon background, which was present in the eastbound direction.

Figure 2*a* shows the effect of available retroreflective area on the 85th percentile detection distance for center stripe Types 1 through 4. The begin-detection distances are not shown in this graph because some subjects have detected some of the lines already at the starting position. This has artificially reduced the begin-detection distances to some degree for some conditions. A more retroreflective area (wider lines or solid rather than dashed lines, or all of these) generally results in somewhat longer detection distances for detection of the end. However, it can be clearly seen from Figure 2(*a*) that there appear to be severe limitations in terms of increasing the detection distances by increasing the amount of retroreflective material used. The positive effects of using more retroreflective material may be

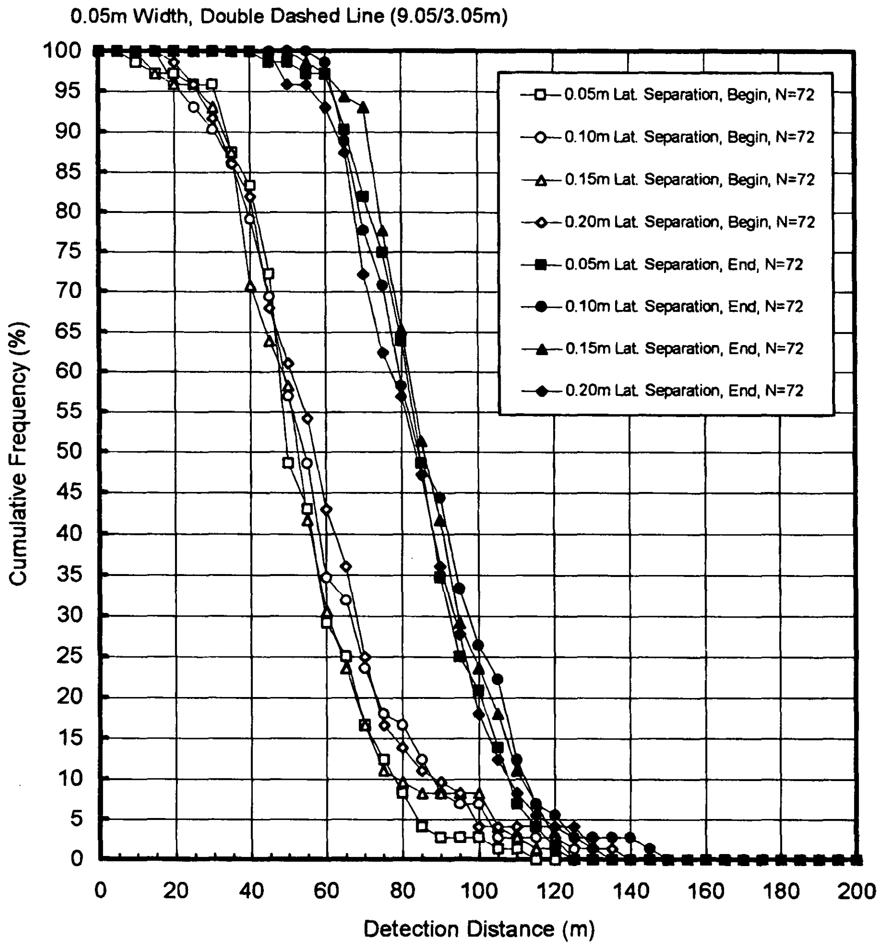


FIGURE 5 Group 3 psychometric curves showing cumulative frequency (percent) for begin and end detection distance of new yellow 0.05-m-wide double-dashed center stripes with lateral separations of 0.05, 0.1, 0.15, and 0.2 m and gap/stripe ratio of 9.15/3.05 m on concrete road surface under low-beam illumination at night as function of detection distance (in meters). Begin detection distance values may be too short because of limited available approach distance.

gradually outdone by the increased cost for the additional material. Further, Figure 2*a* indicates that the gain in the 85th percentile end-detection distance as a function of retroreflective material area seems to asymptotically approach a maximum of about 85 m. The reason for this asymptotic detection distance curve shape may be found in the limited reach of the low-beam headlamps (80 to 100 m) and the shallow entrance and observation angles that are present at such distances, which generally reduces the photometric effectiveness of the retroreflective material. The amount of retroreflective material (0.05, 0.1, 0.15, or 0.2 m width, double solid versus dashed, 9.15/3.05 m versus 10.98/1.22 m gap/stripe ratio) has a fairly small effect on the 85th percentile end-detection distances, thus indicating a relatively small marginal gain in visibility with a substantially increased retroreflective area. In fact, calculations indicate that an increase in area from 0.122 to 2.44m^2 for each 12.2-m-long center line segment (20-fold increase, see Table 2) is required to increase the average end-detection distance from about 82 to 128 m, which is an increase of only 56 percent. However, because of logistic constraints, it was necessary to use two experimental vehicles. Some additional variability caused by differences in headlamps and windshield transmission was likely being introduced.

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 (*1*) there seems to be no availability of pavement marking visibility data in terms of begin-and-end detection distances. Further, the literature does not seem to provide any information about the effect of lateral separation between double center-stripe pavement markings on visibility. This study was conducted to overcome this apparent lack of information. New pavement markings were used in this lateral separation study because no feasible method was available to degrade new pavement markings uniformly 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

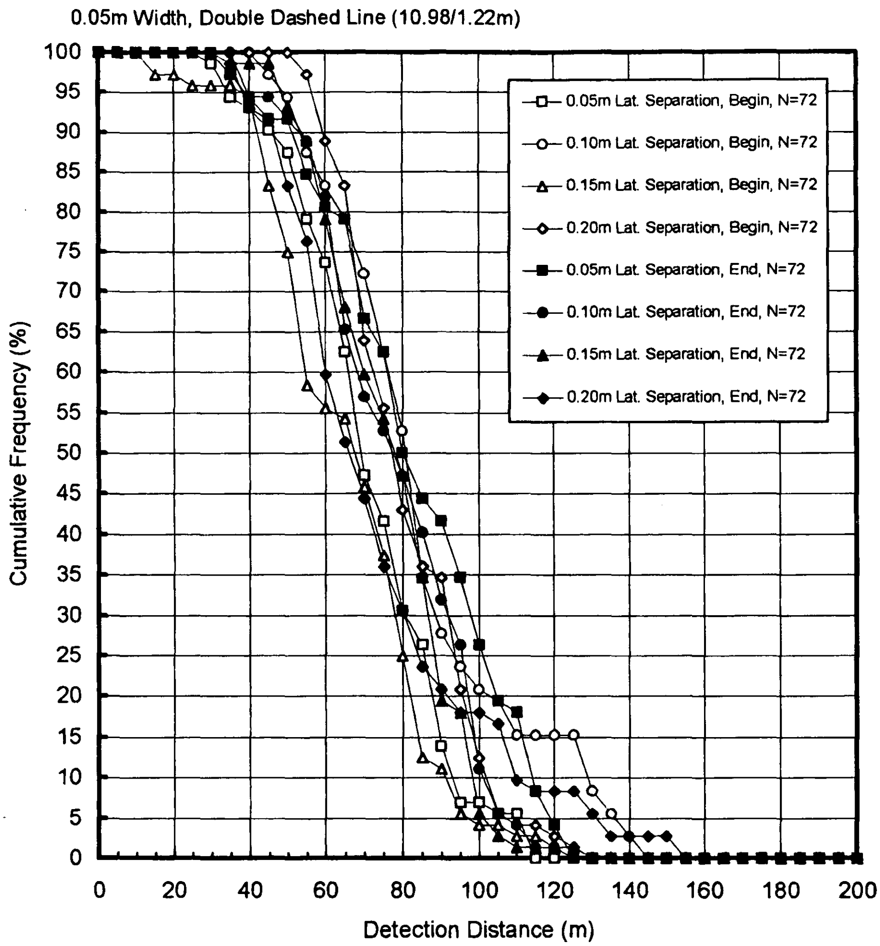


FIGURE 6 Group 4 psychometric curves showing cumulative frequency (percent) for begin and end detection distance of new yellow 0.05-m-wide double-dashed center stripes with lateral separations of 0.05, 0.1, 0.15, and 0.2 m and a gap/stripe ratio of 10.90/1.22 m on concrete road surface under low-beam illumination at night as function of detection distance (in meters).

TABLE 2 Begin and End Detection Distances as Function of Lateral Separation, Approach Direction, Center Stripe Type, and Gap Space

Separation / Type of line		5 cm			10 cm			15 cm			20cm		
		Avg.	SD.	N	Avg.	SD.	N	Avg.	SD.	N	Avg.	SD.	N
0.1 m Double Solid Line													
Begin	East	88.9	30.5	36	73.1	27.6	36	75.4	29.9	36	83.5	28.2	36
	West	60.1	19.6	36	85.6	28.9	36	77.9	21.1	36	73.3	20.7	36
End	East	146.6	31.3	36	121.1	30.4	36	131.5	29.1	36	136.7	31.7	36
	West	114.6	30.4	36	132.7	32.0	36	121.1	27.3	36	120.5	27.5	36
0.05 m Double Solid Line													
Begin	East	79.6	24.8	36	69.3	18.2	36	81.9	24.1	36	81.5	21.9	36
	West	67.0	18.9	36	76.6	20.7	36	78.6	17.6	36	70.1	13.3	36
End	East	84.1	31.1	36	89.1	36.3	36	101.9	30.2	36	100.5	32.9	36
	West	96.1	22.5	36	106.9	38.4	36	112.1	30.7	36	108.0	28.5	36
0.05 m Double Dashed Line(9.15/3.05)													
Begin	East	63.4	18.5	36	55.8	20.1	36	60.2	23.7	36	67.5	27.4	36
	West	54.5	16.8	36	68.9	25.1	36	58.4	21.2	36	60.2	18.8	36
End	East	99.3	11.8	36	83.6	14.8	36	92.4	15.2	36	97.4	18.3	36
	West	81.6	14.8	36	102.1	19.9	36	94.1	16.4	36	80.6	15.2	36
0.05 m Double Dashed Line(10.98/1.22)													
Begin	East	89.0	15.2	36	73.9	13.6	36	70.7	24.7	36	87.9	18.2	36
	West	62.7	14.3	36	103.5	26.5	36	69.3	18.5	36	82.6	15.4	36
End	East	94.6	18.8	36	78.4	19.0	36	79.6	19.1	36	84.4	32.6	36
	West	79.2	26.3	36	86.4	20.1	36	82.6	16.7	36	71.2	18.8	36

Note: Begin Detection Distance values maybe too short due to limited available approach distance

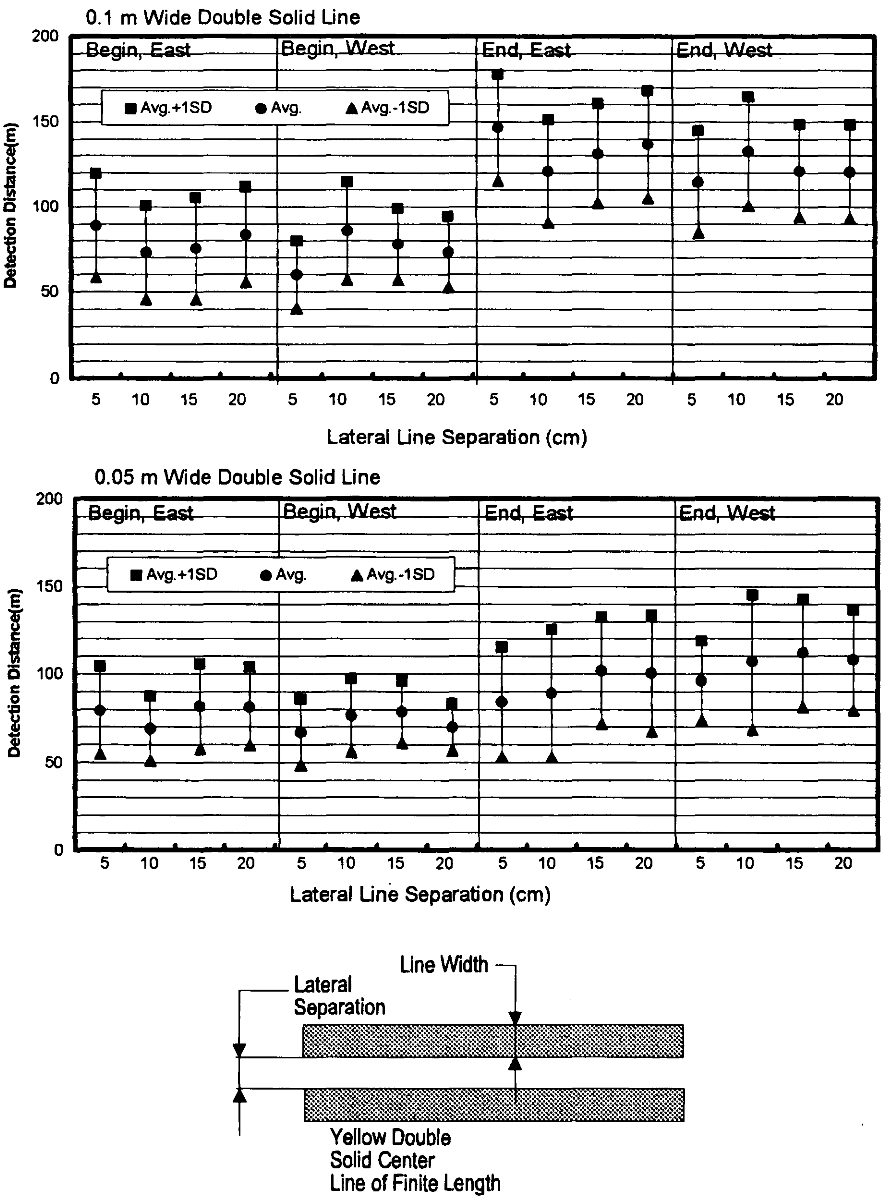


FIGURE 7 Comparison of average begin and end, east/west detection distances as function of lateral separation (0.05, 0.1, 0.15, and 0.2 m) for 0.05- and 0.1-m-wide double solid center stripes. Begin detection distance values for 0.1-m-wide double solid line is most likely too short; begin detection distance values for 0.05-m-wide double solid line may be too short because of limited available distance.

tapes. This research may also have some value for the cost-effective installation of enhanced "coded" temporary center stripes in newly resurfaced zones. It was initially hypothesized that increased lateral separation between double center stripes may increase the detection distance because the human visual system would spatially integrate over the space between the lines to form a more visible target that subtends a greater visual angle. This study investigated the effect of various lateral separations (0.05, 0.1, 0.15, and 0.2 m) for double solid and for double-dashed center stripes with a gap/stripe ratio of 9.15/3.05 m and 10.98/1.22 m. Average begin-and-end detection distances were established and psychometric curves were plotted. An ANOVA and Scheffe post hoc test failed to find any consistent statistically significant systematic effect caused by lateral separation. On the basis of the findings of this study one may tentatively conclude that the lateral separation between the center stripes (from 0.05 to 0.2 m) under the investigated conditions does not appear to be a useful method to increase driver visibility in a practically significant manner. However, if on the other hand one would want to increase the lateral separation between double center stripes to possibly increase the lateral separation between opposing vehicles on two-lane roads, there appear to be no significant difficulties in terms of driver visibility.

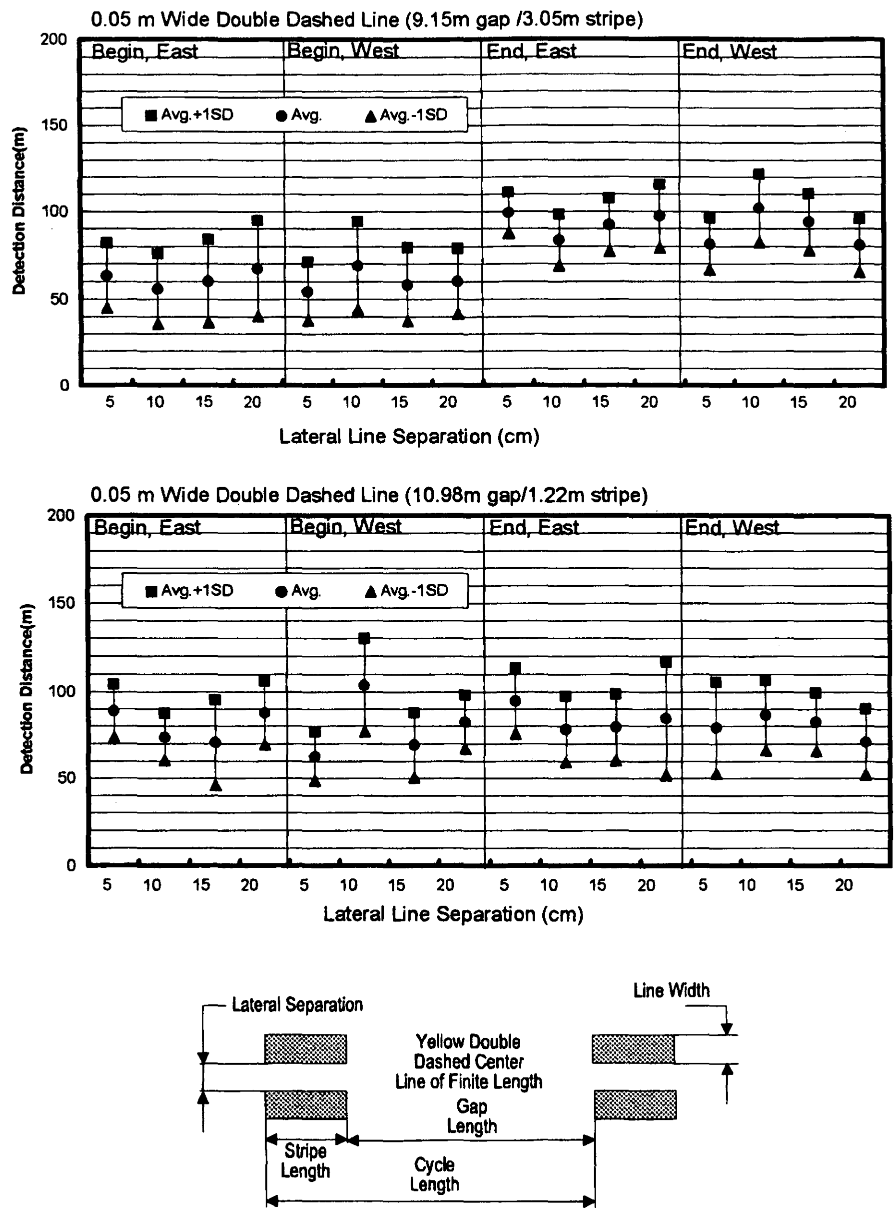


FIGURE 8 Comparison of average begin and end, east/west detection distances as function of lateral separation (0.05, 0.1, 0.15, and 0.2 m) for 0.05-m-wide double-dashed center stripes with gap/stripe ratio of 9.15/3.05 m and 10.98/1.22 m. Begin detection distance values may be too short because of limited available approach distance.

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