Evaluation of Pavement Marking To Designate Direction of Travel and Degree of Safety

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This study was designed to investigate the effectiveness of pavement marking as related to three items—driver perception, driver understanding, and driver performance. Three marking systems were studied using white, yellow, broken and solid lines, singly and in combination.

Since there appeared to be no single measure that fully described the effectiveness of pavement marking, five phases of study were developed. Each phase was directed toward a different measure of effectiveness. The analysis of the results of these phases provided sufficient data from which conclusions were drawn regarding the effectiveness of various marking types. Significant results were found in many of the studies which indicated that pavement marking systems could be devised to convey meaningful information to the driver. However, this would require some period of education and adjustment on the driver's part. Also, the use of color appears to have greater potential in the long run than the use of line shape.

•A TRUE evaluation of the effectiveness of a traffic control device is dependent on a determination of three factors—driver perception, driver understanding, and driver performance. A traffic control device may be ineffective as a result of a deficiency in any of these three factors. Thus, any attempt to establish or alter standards for traffic control devices must consider each item. In many cases, the functions cannot be separated and studied exclusively, but must be studied in combination.

Pavement marking, in conjunction with the appropriate signing, is one such traffic control device. This project was designed to study the effectiveness of pavement marking as related to each of the three factors. The project consisted of five separate studies, each designed to evaluate these factors either singly or in combination.

Under the driver perception factor, tests were conducted to determine the driver's ability to discriminate between line pattern and color. These elements were used to form a two-factor analysis. The color difference was limited to white and yellow, and the line was either continuous or broken.

The driver understanding item was divided into three separate elements: (a) the definition of a corridor within which the driver should maintain his position; (b) a supplement to signing in informing the driver that the sight distance is inadequate to complete a passing maneuver; and (c) the designation of conditions existing beyond the defined corridor. Specifically, the marking should indicate whether the space immediately adjacent to this corridor is reserved for vehicles traveling in the same direction, in the opposite direction, or is not designated as a corridor for moving vehicles.

Driver performance was separated into three basic elements. Each element is a combination of driver visibility and driver understanding, as well as driver acceptance. These elements are roughly defined as ability to maintain lateral position, observance of passing restrictions, and lane utilization.

Paper sponsored by Committee on Characteristics of Traffic Flow and presented at the 47th Annual Meeting.

The study consisted of five phases, each directed toward a different measure of effectiveness, yet each a measure of one of the three factors listed previously. This approach was selected because there did not appear to be any single measure that fully described the effectiveness of a pavement marking system. The analysis of the results of these five phases provided information on which decisions can be made regarding the effectiveness of various pavement marking systems.

Phase I consisted of a slide presentation, depicting various pavement markings and pavement marking systems, which was presented to various groups of drivers. Each subject was questioned regarding his interpretation of the meaning conveyed by the markings. The two elements of driver understanding involved information transfer regarding the direction of travel and passing safety. Results were used to measure driver understanding on these two questions. This test was also used to evaluate the ability of the observer to adapt to selected pavement marking systems. This was accomplished by questioning the subject with the slides arranged in random order, and then repeating the test with the slides systematized.

Phase II was conducted as a direct measure of driver performances under various markings. The unit of measure was the ability of the driver to maintain lateral position while negotiating a series of curves. This phase was designed to provide further insight into driver perception. The purpose of the pavement marking system was corridor definition, because driver understanding was not a variable in this phase.

Phase III, directed toward driver understanding and acceptability, was conducted to determine whether pavement marking is successful in deterring the driver from crossing the centerline to initiate a passing maneuver. The unit of measure was the number of drivers passing a slow-moving vehicle introduced into the traffic stream. Comparing these numbers provided information concerning the relative value of the markings as a deterrent to the passing maneuver. These data provided additional information on the driver's understanding as well as his performance.

Phase IV also dealt with driver performance as a function of driver understanding. Various pavement markings were placed on a section of highway including a transition from 2-lane to 4-lane highway, and lane utilization observances were made. The objective was the determination of differences in lane usage occasioned by pavement marking. This test provided information on which judgments were made regarding the deterrent effect of pavement marking in a situation where lane changing is appropriate. This differed from the preceding phase where the deterrent effect was measured in a section where lane changing was not allowed.

The final phase of the project was designed primarily to measure driver perception. A questionnaire was designed to test driver perception of pavement marking on a section of highway over which he had just driven. The questions concerned: (a) what the driver had seen; (b) his interpretation of the marking; and (c) his opinion of the marking. In this way, results could be used to evaluate understanding and acceptance as well as perception. However, these two measurements could only be obtained from those drivers who had correctly identified the markings. The pavement marking question depicted a transition from a 4- to 2-lane highway. This particular type of pavement marking accents differences between the various proposed marking systems. The results of all five phases of the study were used to form conclusions regarding the factors which defined effectiveness. Recommendations regarding pavement marking are based on a composite of all five phases.

PROCEDURE AND RESULTS

Phase I

Procedure—A series of slides illustrating two vehicles on a simulated highway was prepared. The vehicles were placed in a car-following position in the right-hand lane in each case, and the pavement markings were varied. These markings included all combinations of white, yellow, dashed and solid lines, singly and in combination.

The first eight slides depicted pavement markings as described by the present Manual on Uniform Traffic Control Devices. The only two lines defined in this system are the dashed white and the solid yellow.

The next 16 slides depicted pavement markings that are described by an alternate pavement marking system proposed by the subcommittee on pavement marking of the National Joint Committee on Uniform Traffic Control Devices. This marking system is designed on the principle of using color to define direction of travel and line shape to define degree of safety. A yellow line is used to separate traffic flowing in opposite directions, whereas a white line separates two traffic streams flowing in the same direction. A solid line is used to designate areas where no passing or lane changing is permitted, with a broken line used at all other locations.

The remaining 12 slides depicted pavement markings as they would appear in a second alternate system proposed by the committee. Line shape is used to designate direction of travel, and color to designate degree of safety. A solid line separates traffic streams moving in opposite directions; a dashed line separates traffic streams moving in the same direction. A yellow line designates locations where it is unsafe to pass or change lanes.

In both alternate systems, a meaning is defined for four possible lines: solid or broken white, solid or broken yellow. All these markings were illustrated on the 36 slides that comprised the problem set for Phase I. The slides were presented first in random order and with very little explanation. The subjects were asked to identify with the car following in each slide and to answer the following two questions:

1. Is the lane immediately to your left for vehicles moving in the same direction? (yes or no)
2. Is passing permitted at this location? (yes or no)

The purpose was to obtain data from which conclusions regarding driver understanding and interpretation of line pattern and color could be drawn.

The subjects were then told the purpose of the interview and the rationale for each of the three marking systems. Principal differences among the three systems were emphasized and all questions from the subjects were answered.

Finally, slides were grouped with respect to system (8 slides for the present marking system, 16 for alternative 1, and 12 for alternative 2), and each group was presented sequentially after a short review of the rationale. For each system presentation the subject was required to answer the preceding pair of questions, but in the context of the system being presented.

Analysis and Results—The analysis was conducted to answer the following questions:

1. How does the driver presently interpret each pavement marking configuration?
2. Can the driver easily understand a marking system?
3. Which elements of the marking system are most easily understood?
4. Are these answers influenced by the subject's geographical location (state), sex, or driving experience?

The answer to the first question was derived from the random presentation. There is only one of the four possible combinations of line and color that is uniquely defined in the present manual. This element is a solid yellow line. The dashed white line is used in the present system, but it carries two meanings. The results of the response are given in Table 1.

It is apparent that the line type closest to conveying a universal message is the solid yellow. Ninety percent of the subjects interpret this line as a separation between opposite direction flows, and 88 percent feel that it indicates no passing. The broken white line is also interpreted the same by nearly all interviewees on the question of passing. Ninety-one percent of the responses indicated that this line could be crossed to execute a passing maneuver. However, this line does not convey a unique message regarding the direction of travel because approximately two-thirds of the subjects interpreted the line to mean same direction and one-third to mean opposite direction flow.

Color alone does not convey a consistent message. Only 77 percent interpreted the broken yellow as separating opposite direction flow, and 63 percent indicated they felt it was safe to cross this line type when passing. The solid white line was more often considered a barrier to passing (66 percent) and to indicate opposite direction of flow (79 percent). This might suggest that the shape of the line is the more critical of the two parameters.

TABLE 1

LINE INTERPRETATION FROM RANDOM PRESENTATION

Response	Type of Line			
	Solid Yellow	Broken Yellow	Solid White	Broken White
Indicates opposite direction (%)	90	77	79	34
Indicates unsafe to pass (%)	88	37	66	9

The analysis of the ability of drivers to understand and respond correctly to different marking systems was based on the results of the systematized presentation. Each of the three systems was analyzed and the percentage of correct responses was recorded. The present system rated highest, with 96 percent correctly identifying the direction of travel and 97 percent the degree of safety. This is due to the fact that there are only two line types involved, and one of these has two correct responses. Thus, the only errors involved would be either in response to the solid yellow line or in the passing response to the dashed white.

Alternate 2 was the most easily understood of the two alternatives, perhaps because this system is more closely related to the present system. Both systems use all four line types to describe the direction of travel and degree of safety; thus, they are somewhat more complex than the present system. However, 92 percent of the subjects correctly identified the direction of travel and the same number identified the degree of safety following the discussion.

Alternate 1 showed a greater number of errors. Both the question concerning the direction of travel and that concerning passing had a lower percentage of correct answers (89 and 89 %). This system is the most different from the present marking system.

Table 2 gives the number of incorrect responses given in the random order presentation that were corrected when the slides were systematized and the system rationale explained. These figures give some indication of the ease with which each of the systems could be learned, and the ability of the driver to adapt to new systems.

Over the past 25 years there has been no change in the present marking system, and it should be readily identifiable to the subjects answering the questionnaire. In other words, the percent correct for the present system given in random order presentation should be an indication of the ease with which this system could be learned. However, since alternate systems 1 and 2 are new to the driver, an explanation of these systems is necessary to arrive at a comparable measure of learning and adaptation.

Using the present system, 87 percent correctly identified the direction of travel and 89 percent the degree of safety. The total corrected percentage using alternates 1 and 2 combined was 90 percent for correctly identifying the direction of travel and the same for the degree of safety. This indicates that the driver could learn and adapt to a new system as easily as to the present system.

An analysis was next made of the responses to line type to isolate the elements of the various systems that proved to be most difficult to the driver. It may be assumed that a "difficult" marking element is less readily learned after the system rationale has

TABLE 2

LINE INTERPRETATION FROM SYSTEM PRESENTATION

System	Sample Size	Random (no. correct)	Percent Correct	Random (no. incorrect)	System (no. corrected in presentation)	Percent Corrected	Total Corrected (%)
(a) Identification of Direction of Travel							
Present	3376	2957	87	419	298	72	96
Alt. No. 1	9035	6019	67	3016	1988	66	89
Alt. No. 2	6822	5562	81	1260	701	56	92
(b) Identification of Passing Safety							
Present	3376	2991	89	385	270	70	97
Alt. No. 1	9035	6327	70	2708	1727	64	89
Alt. No. 2	6822	5755	84	1067	506	47	92

TABLE 3

LINE INTERPRETATION BY LINE TYPE

Line Type	Sample Size	Random (no. correct)	Percent Correct	Random (no. correct)	System (no. corrected in presentation)	Percent Corrected	Total Corrected (%)
(a) Identification of Direction of Travel							
Broken white	6244	4638	74	1606	1117	70	92
Solid white	4538	2644	58	1894	1227	61	85
Broken yellow	2232	1718	77	514	312	65	91
Solid yellow	6219	5538	89	681	411	63	96
(a) Identification of Passing Safety							
Broken white	6244	5662	91	582	384	74	97
Solid white	4538	2487	55	2051	1123	56	80
Broken yellow	2232	1491	67	741	468	65	88
Solid yellow	6219	5433	87	786	528	69	96

been explained than an "easy" one. If the responses from the random presentation are scored right or wrong in the context of the system represented by each slide, the subject's improvement in the systematized presentation can be computed as the portion of incorrect responses that were corrected after the rationale for the system was explained. This improvement is indicated in Table 3.

The results were consistent with the analysis of the random presentation. The solid yellow line was most often correctly defined on both questions (96 and 96 %). The type of line next most often correctly identified was the broken white, particularly when the slides were arranged by system and an explanation given for each system. The question of a dual meaning was removed in this context, and the responses reflect this simplification.

The meaning of color is apparently easier to convey than that of line shape. The percent of responses correctly identifying the meaning of the dashed yellow line was greater than that for the solid white. Of the responses to the broken yellow line, 91 percent correctly identified the direction; the respective percent for the solid white was 85 percent. The question of safety was correctly identified 88 and 80 percent, respectively.

It is apparent from Table 3 that the type of line that comes closest to conveying a universal message is the solid yellow. As in Table 1, 90 percent of the subjects interpret this line as a separation between opposite direction flows, and 88 percent feel that it indicates no passing. The broken white line was also interpreted the same by nearly all interviewees on the question of passing. Ninety-one percent of the responses indicated that this line could be crossed to execute a passing maneuver. However, this line does not convey information regarding the direction of travel because approximately two-thirds of the subjects interpreted the line to mean same direction and one-third to mean opposite direction flow.

Color alone does not convey a consistent message. Only 77 percent of the subjects interpreted the broken yellow as separating opposite direction flow, and 63 percent

TABLE 4

PERCENT OF CORRECT RESPONSES

Marking System	Years of Driving Experience										
	Drivers Ed.	<1	1-3	3-5	5-10	10-15	15-20	20-25	25-30	30-35	>35
Present (without explanation)	88	80	93	89	86	90	88	90	86	88	85
Present (with explanation)	96	92	99	99	98	98	96	98	95	94	96
Alternate 1 (with explanation)	89	80	94	86	92	93	89	90	87	86	86
Alternate 2 (with explanation)	92	84	94	91	92	94	92	94	90	90	90

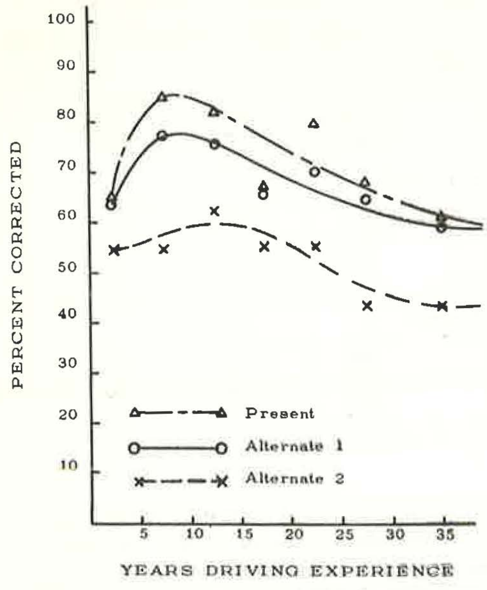

Figure 1. Effect of driving experience on learning power.

indicated they felt it was safe to cross this line type when passing. The solid white line was more often considered a barrier to passing (66 %) and to indicate opposite direction of flow (79 %). This might suggest that the shape of the line is the more critical of the two parameters.

The final question analyzed was the influence of location, sex, and driver experience on the results. Questionnaire results were received from 7 states, and the results showed that there were no significant differences in the responses. None of these states differ markedly with respect to its use of pavement markings.

The subjects were classified by sex, and an analysis was made to determine if this had any effect on the responses to the questions. The male group had a slightly higher percent of total corrected for each system than the female group. However, there was found to be no significant difference between the groups.

Next an analysis was made to determine the influence driver experience had on the results (Table 4). The 1 to 3-year group ranked highest in percent of correct responses for all systems. The next highest ranking for all systems was the 25 to 30-year group, and beyond this the percentages dropped. For all groups, the present system with an explanation given ranked highest, with alternate 2 second and alternate 1 last. However, it should be reemphasized that alternate 2 is the more closely related to the present system; the only variation being the solid white line.

Therefore, an analysis was made of those subjects who incorrectly answered a question in random order presentation, and correctly answered the same question after an explanation of each system. It is evident (Fig. 1) that alternate 1 could be learned easier than alternate 2 for all driving experience groups.

Phase II

Procedure—The second phase was an analysis of the lateral position of vehicles on curves. The effect of various markings on the positioning and the variance in this positioning provide information on the adequacy of these lines in the definition of a corridor. The specific aims of the lateral placement research phase were (a) to relate lateral placement to variations in pavement markings (solid or broken lines and edge lines) and illumination (day vs night); and (b) to determine if the changes caused by the various markings are different for various locations on a curve.

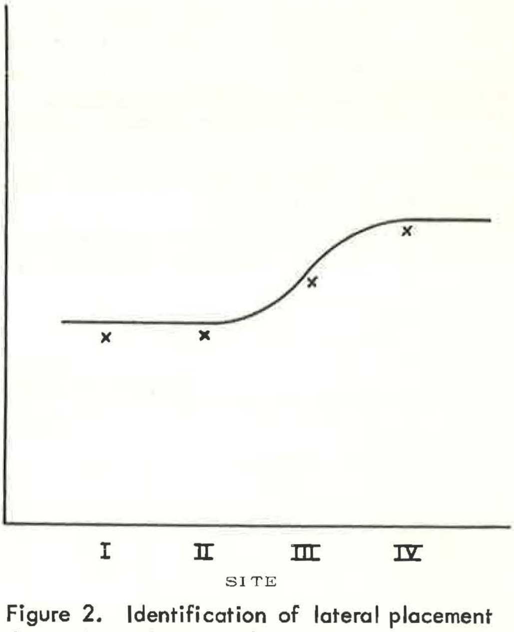

Figure 2. Identification of lateral placement data points relative to the curve.

The research was done at two Ohio locations—on State Route 16 about 16 miles east of Newark, and on State Route 62 about 10 miles south of Washington Court House.

The first location was a section of newly paved roadway that was unmarked at the start of the program. Four data collection sites were chosen at an S-curve within a total road distance of one-third mile. Site 1 was along the straight portion of the highway about 150 yd before the start of a left curve. Site 2 was about 30 yd beyond the start of the curve. Site 3 was in the middle of the curve (approximately 150 yd beyond site 2). Site 4 was at the end of the left curve where the reverse curve began (it was more than 200 yd beyond site 3). The second location studied was set up similarly, but it was a more gentle curve.

The lateral placement of vehicles was measured as the distance between the right rear tire and the edge of the highway. This was determined by photographs. The location of the data collection points in relation to the curve is shown in Figure 2.

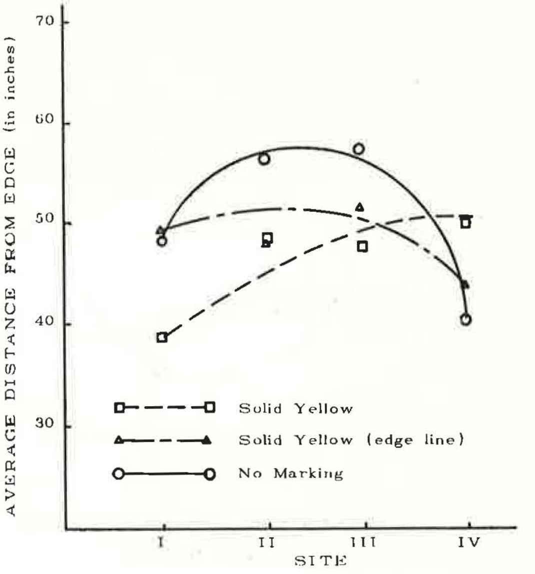

Figure 3. Distance from outside rear tire to edge of road.

Since the Ohio Department of Highways did not have the photographic capabilities required for data collection, a contract for collection and reduction of data was awarded to H. R. B. Singer, Inc., of State College, Pa.

A motor-driven camera, triggered by an infrared detector unit, was used to photograph the vehicles at the specific point where measurements were to be made. The camera was mounted on a sign stake driven into the ground at the same distance from the road edge as a normal route sign. One stake was driven at each data collection site and left in place until the entire data collection program was completed. The camera and film magazine were slender enough to be almost concealed by the stake. Since both the camera and magazine were painted flat black, they could not be seen until the vehicle was within one or two car lengths of the camera, and at night, normally they were not visible.

The infrared triggering unit was concealed in the weeds and grass by the road edge. When a vehicle drove through the detector's field of view, the difference in infrared radiation between the vehicle and the background was detected. The circuitry was designed so that the camera trigger pulse was generated when the detected signal returned to background level. This occurred as the rear of the vehicle passed the detector so that the rear tire was photographed.

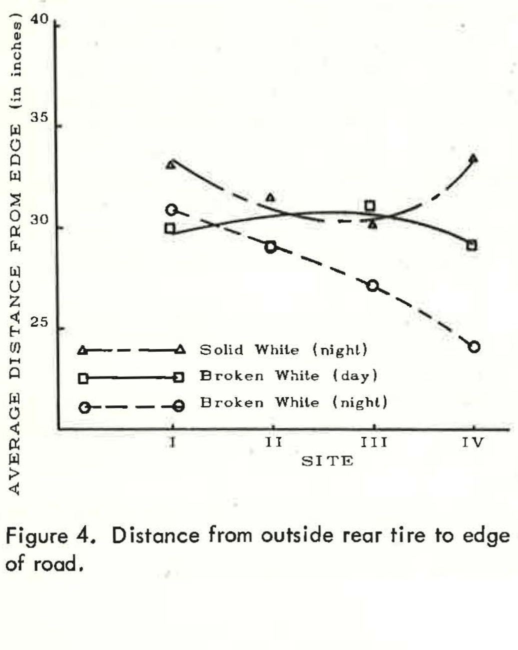

Figure 4. Distance from outside rear tire to edge of road.

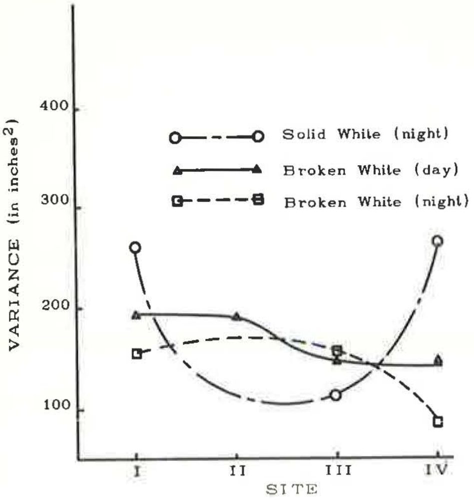

Figure 5. Variance of mean distance from the edge of the road to outside rear tire.

Photographs were obtained at night by using a standard electronic flashgun to illuminate the scene. However, to keep the data recording unobtrusive, it was necessary to mask out all visible light from the flash. This was accomplished by placing a Wratten type 87 filter over the flashgun and using a high-speed infrared film. With this technique, the light flash could be seen by looking directly into the flash gun; however, the light was not visible to the driver of the vehicle because the unit was below and behind him when it flashed.

At each site, marker stripes were laid on the road for one or two photographs to provide reference marks for later data reduction. These strips were then removed so they would not interfere with the vehicle placement while data were being taken.

To obtain distance measurements, the developed films were projected on the screen of a film reader. The marker stripe positions were scribed on the screen, and the pictures were projected in register with the scribe marks. The marks were used to obtain the spacing between the right rear tire and the road edge. The uncertainty in these measurements was <3 in. even when the exact point of contact between tire and road was masked by shadows.

At the first location five different markings were tested: (a) small, reflectorized buttons in the center of the roadway; (b) double solid yellow line in the center of the roadway; (c) double solid yellow line in the center, with solid white edge line; (d) broken yellow line in the center of the roadway; and (e) broken yellow line in the center, with solid white edge line.

The second location tested two other markings—solid and broken white centerlines, with solid white edge lines in both cases.

Analysis and Results—The mean distance from the edge of the road and the variance around the mean were recorded for each sample. Data were taken on each marking system at the four locations. The results of this study are given in Figures 3, 4, 5, and 6.

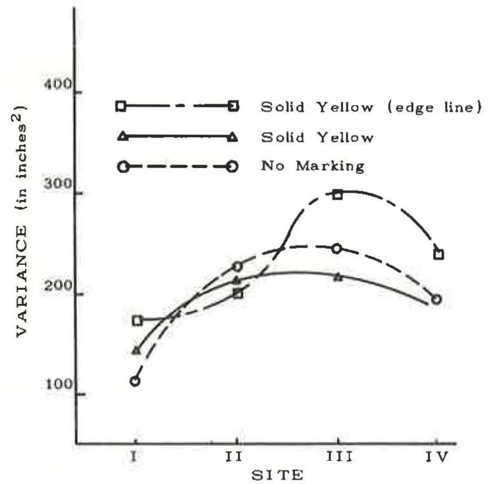

Figure 6. Variance of mean distance from the edge of the road to outside rear tire.

An analysis of variance was conducted on the mean value of the distance from tire to road edge with respect to data collection site. The results indicate that vehicles negotiating the sharper curve (first location) exhibited a significant change in position, whereas those at the gentle curve (second location) did not. For this reason, the analyses of differences by site were limited to the data collected at the first location.

The relative ability to define a corridor, as measured by the mean and variance, is most pronounced between the highway with no marking and the one with solid yellow centerlines plus edge lines. These are the extremes among the schemes of delineation considered here.

Edge delineation was the only element that proved significant in all cases. The addition of an edge line invariably produced a change

TABLE 5

RESULTS OF SIGNIFICANCE TESTS ON LATERAL DISTANCE AND VARIANCE

Item	Element Being Tested	Mean Value	Variance	Difference in Mean	Difference in Variance
Day	Solid yellow vs no marking	45.4 50.6	227 198	S.[a]	N. S.[b]
	Solid yellow vs broken yellow	45.4 44.3	227 171	N. S.	S.[c]
	Solid white vs broken white	28.1 29.8	213 175	N. S.	N. S.
Night	Solid yellow vs broken yellow	47.8 46.0	257 117	N. S.	S.[c]
	Solid white vs broken white	32.8 27.4	225 131	S.	S.[c]
Edge line	Day:				
	Solid yellow vs (with) Solid yellow (without)	48.0 45.4	187 227	S.	N. S.
	Night:				
	Solid yellow vs (with) Solid yellow (without)	54.1 47.8	240 257	S.	S.[c]
	Broken yellow (with) vs Broken yellow (without)	36.5 44.3	234 171	S.	S.[c]
Day Night	(D) Solid white (N)	27.9 32.8	213 225	S.	N. S.
	(D) Broken white (N)	30.0 27.4	175 131	N. S.	N. S.
	(D) Solid yellow (N)	44.4 47.8	227 257	S.	S.[c]
	(D) Broken yellow (N)	42.4 46.0	171 117	S.	S.[c]

[a]Significant.
[b]Not significant.
[c]Significant at one or more locations.

in the mean value of the lateral position. Changes in the color or configuration of the centerline had a less pronounced effect on the lateral placement.

In two of the five comparisons of solid vs dashed lines, the mean distance between the vehicle and the edge of the highway was, by an analysis of variance test, significantly different. In each case, the distance was greater with the solid line. The other three cases exhibited no significant difference. A ratio test of variances of 18 sites showed that the solid line produced a wider dispersion of means in five cases and a narrower dispersion in one. The remaining 12 sites showed no significant difference.

An analysis of variance of means for day data showed no significant difference between markings (solid vs broken white lines) with respect to the distance from the road edge. A ratio comparison of the variances also showed no significant differences. Thus, there is no measurable difference between their ability to define a corridor in daylight. The night data showed a significant difference. The broken white line produced a corridor closer to the road edge. Table 5 gives the results of the significance tests for all the data.

Phase III

Procedure—The third phase of this project was conducted on State Route 98 in Marion County, Ohio. Its purpose was to determine the merit of various markings as a deterrent to passing. Variations in the effectiveness were obtained for two geometric conditions and for day and night.

Data records indicated the percentage of drivers who crossed the various markings to pass another vehicle. To assure the comparability of data, the same experimental setup was used for all line types. The experiment involved the introduction of a constant velocity vehicle into the traffic flow and the recording of the number of drivers that passed the test vehicle.

The test-car velocity was 40 mph, although the speed limit is 60 mph in daytime and 50 mph at night. The driver of the test vehicle was stationed along the road approximately one-fourth mile from the test section. As a vehicle approached, the test car

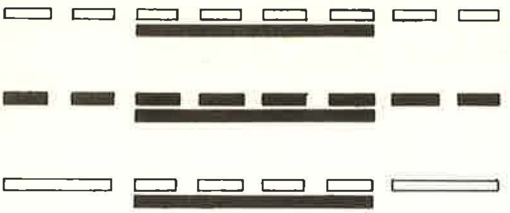

Figure 7. Various pavement markings tested.

entered the highway and paced himself so that the observed vehicle was immediately behind him as he entered the test section. The test vehicle then maintained a velocity of 40 mph and the driver noted the action of the following vehicle. The experimental section was 1 mi long, and the observations were noted as "pass" or "no pass." We did not attempt to record the location within this 1-mi section where a passing maneuver took place.

No data were recorded for the situation where oncoming vehicles prevented a passing maneuver. In all cases, the data indicated the driver's willingness to cross the line to pass when there is no apparent reason to follow the slow-moving vehicle.

Analysis and Results—Two 1-mi long sections of highway were selected. The first was a very straight, level section of road with no sight restrictions of any kind. The second site was also a straight section of road, but it was in rolling terrain. There were no severe sight restrictions, but this would not be obvious to the driver. The undulations were severe enough to obscure sections of the road ahead. Thus, the depth of the dips between the rises could not be determined by a driver unfamiliar with the road.

A complete set of data was obtained for these two sections immediately following a repaving contract before the standard marking had been replaced. The purpose was to establish base data against which valid comparisons could be made. The results showed that 100 percent of the subject drivers passed in the flat section and 95 percent passed in the hilly section. All of the seven no-passing observations occurred at night.

A solid yellow line was then placed in the test sections and the centerline marking was changed according to the various systems. First, a broken white line was used approaching the test section and continuing adjacent to the solid yellow. Next, a broken yellow line replaced the broken white line. Finally, a solid white line was used for the centerline approach, and a broken white line used adjacent to the solid yellow (Fig. 7).

The data for each of these three markings were similar; χ-square tests indicated that the shape or color of the approach line did not change the percentage of the observed passes significantly. This could be expected because the predominant line in all cases was the solid yellow line adjacent to a broken line.

Significant differences were noted when the percentage of the observed daytime passes was compared with nighttime passes. Table 6 summarizes the data for the three centerline types used with the solid yellow line. It is apparent that there is no difference between the flat and hilly sections either during the day or at night.

The solid yellow line was replaced by a solid white line to mark the flat test section. A dashed white line was placed on the approach to the solid white, but no markings were used adjacent to the solid white. This marking was found to be much less a deterrent than the solid yellow. In fact, the percentage of drivers crossing this line to pass increased from 46 to 93 percent during the day and from 26 to 87 percent at night. It is obvious that a solid line does not deter many drivers from executing a passing maneuver.

The white line was then removed and a series of reflective markers placed on the test highway. White reflectors were used as the centerline, and yellow reflectors were used through the two test sites. This afforded an opportunity to test the effect of a broken yellow line (simulated by the yellow reflectors) on the number of drivers who pass. As with the solid white line, this proved to have little deterrent effect on the drivers. During the day, 87 percent of the vehicles crossed the broken yellow line and 46 percent crossed the solid yellow line. At night, the percentages were 70 and 26 percent, respectively.

TABLE 6

VEHICLES CROSSING YELLOW LINE TO PASS

Site	Percent of Vehicles Passing		
	Day	Night	Total
Flat	46	28	36
Hilly	47	27	37
Total	46	27	36

The yellow line, even when broken, was a slightly greater deterrent than the solid white line. This difference was more pronounced at night (70 to 87 percent) than during the day (87 to 93 percent). This may be partially due to the increased visibility of the markers at night.

TABLE 7

CHI-SQUARE TEST—ALL MARKING SYSTEMS

Classification	Pass		No-Pass		Total
Local	215	(220)	196	(187)	407
Nonlocal	265	(256)	208	(217)	473
Total	476		404		880

$\chi^2 = 1.49$.
Not significant at 0.05 level.

It was recognized that the deterrent effect the solid yellow, broken yellow, or solid white line had on the driver could be biased towards those familiar with the test section. Therefore, the license plate of the following vehicle was recorded enabling local vs nonlocal classification of vehicles. χ-square tests indicated driver knowledge of the section did not significantly affect the percent of vehicles passing on each of these marking systems (Table 7).

Phase IV

Procedure—This phase was conducted to determine the driver's interpretation of pavement marking. In Phase III we tested driver perception and interpretation in a relatively critical situation. That is, the driver was subjected to a decision involving his safety; his reaction to the various centerlines was recorded. In Phase IV we were interested in the driver's interpretation under conditions involving no particular stress. The test site selected included a 2-lane to 4-lane transition. In this phase, the data were collected on drivers going to the 4-lane from the 2-lane section. The test site was on Hamilton Road in Columbus.

The measure of the effect of the various pavement markings was the relative amount of use of the two southbound lanes of the 4-lane roadway. Here the 4-lane pavement reached its full width and also began the lane-dividing lines in the southbound lanes. Beginning at this point and continuing at 100-ft intervals, the number of vehicles in each lane was recorded until the relative number of vehicles in the two lanes reached a constant value.

Analysis and Results—Three types of pavement markings were studied: broken white, solid white, and broken yellow. For all marking types, the number of vehicles in each lane reached a relatively constant value between 300 and 700 ft from the initial data collection point. Thus, the number of vehicles was recorded at 0, 100, 200, 300, and 700 ft. The sample size for each data point consisted of 400 vehicles. Figure 8 sketches the study site.

Beyond the last data point was an approach ramp to West Fifth Avenue. The number of vehicles using this ramp remained constant for all marking types. This indicated the desire to cross into or remain in the outer lane was the same for this turning maneuver. This proved to be an aid in measuring the deterrent effect of the different markings as a desire to cross into the outer lane was exhibited. Also, in the 2-lane section, the single southbound lane fed directly into the inner lane of the 4-lane section. Any influence the line type would have in restricting the driver's desire to cross into the outer lane could be measured. Table 8 gives the percent vehicles in both lanes for each marking type.

It is apparent that for the existing broken white lane line use remained relatively constant for each lane. χ-square tests indicated there were no significant differences between any two data points for the inside lane.

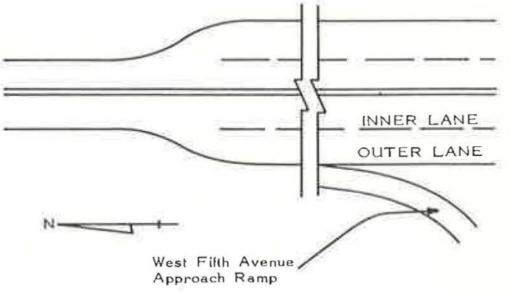

Figure 8. Phase IV test section.

TABLE 8

LANE USAGE OF VEHICLES

Lane	Percent Vehicles at Each Data Point				
	0 Ft	100 Ft	200 Ft	300 Ft	700 Ft
Inside:					
Present	42	39	42	44	41
Solid white	53	50	42	38	38
Broken yellow	62	50	44	42	42
Outside:					
Present	58	61	58	56	59
Solid white	47	50	58	62	62
Broken yellow	38	50	56	58	58

The marking was changed to a solid white line and a second data set was collected. This alteration significantly increased driver reaction for the first two data points. For this data set, 53 percent of the vehicles remained in the inside lane, whereas 42 percent remained in this lane for the broken white line at the initial data point. Fifty percent stayed in this lane for the solid white line as compared to 39 percent for the broken white line at the second data point. Beyond the 200-ft point the percent of vehicles in the inner lane reached a constant value for both markings. This would indicate that the solid white line influenced the driver's immediate desire. In other words, there was an initial hesitancy on the part of the driver to cross the solid white line.

The marking was next changed to a broken yellow line and a third data set collected. The broken yellow line significantly increased driver performance for the first two data points. Sixty-two percent of the drivers did not cross this line, whereas 42 percent did not cross the broken white line at the first data point. The data at the 100-ft point and thereafter were similar to the solid white line.

This indicates that the broken yellow line had an initial deterrent effect on driver desires. This line type had an even more deterrent effect than the other two types for the initial data point. For this point, 62 percent of the vehicles stayed in the inside lane, whereas 53 percent for the solid white and 42 percent for the broken white remained in this lane. However, after the initial data point, the solid white and broken yellow resulted in a similar percent of lane use.

The broken white showed a constant lane use throughout the study area. The broken yellow and solid white resulted in cars merging into the outer lane for the first 100 to 200 ft. After this point, lane use became constant and the number of vehicles in each of the lanes did not vary significantly from the broken white.

Phase V

Procedure—The previous two phases of the project tested driver perception and interpretation under under stress and driver interpretation under a "no-stress" condition. Phase V was conducted to determine the driver perception and interpretation under this "no-stress" condition.

Again, the test site selected included a transition from a 4-lane to a 2-lane highway. The site was located at Olentangy River Road in Columbus. The pavement marking was changed on the 2-lane section of highway, and driver interviews were conducted. The interview took place approximately one-half mile beyond the point of transition.

The interview consisted of an explanation of the purpose of the interview, followed by a series of questions. The wording of the interview was as follows:

> Good morning, sir. We are from the Ohio Department of Highways and are conducting a survey on pavement marking. Accordingly, we would like to ask you a few questions.
>
> 1. Would you please describe the pavement marking on the 4-lane section?
>
>   For example: Was it yellow or white? Solid or broken?
>
> 2. Would you please describe the pavement marking on the 2-lane section?
>
>   For example: Was it yellow or white? Solid or broken?

If the subject driver accurately described the pavement marking, the interview proceeded to the third question:

3. What is the major difference in the meaning of these two markings you described?

4. Do you feel that this type of marking is helpful and should be standard treatment?

Thank you for your cooperation.

Analysis and Results—The first set of interviews was conducted with the existing pavement marking, consisting of a broken white lane line on the 4-lane section and a broken white centerline on the 2-lane section. The transition area was marked with a double yellow line. However, if the subject described this transition section, the interviewer indicated that we were interested in the 2-lane highway beyond the point of transition. In this particular case, questions 3 and 4 were not applicable since the correct answer to questions 1 and 2 would be identical.

The results of the first interview indicated that drivers were not consciously aware of the pavement marking. In fact, only 16 percent of the 94 drivers interviewed could properly identify the pavement marking on both the 2-lane and the 4-lane sections. Twenty-two percent of the drivers offered no description of the pavement marking in either section.

The number of drivers who properly described the pavement marking for the 4-lane section was higher than for the 2-lane section. Exactly 50 percent of the drivers correctly identified the broken white line on the 4-lane section, but only 19 percent could identify the broken white on the 2-lane section. Seventeen percent of them erroneously described both the 4-lane and the 2-lane sections.

The pavement marking was then changed to a solid white line on the 2-lane section. The broken white line remained on the 4-lane section. A second set of interview data was then obtained. In this case, questions 3 and 4 were applicalbe and were summarized.

The alteration of the pavement marking did not increase driver awareness by a significant amount. For this set of interviews, 21 percent of the drivers correctly identified the dashed white lane line and the solid white centerline. Twelve percent of the drivers erroneously identified both sections.

The changed section, the solid white centerline, increased driver perception somewhat. The number of drivers correctly identifying the centerline increased from 19 to 28 percent. The percentage of drivers correctly identifying the lane line dropped from 50 to 44 percent. The number of drivers offering no description increased from 22 to 28 percent.

The marking tape used to produce the solid white line was brighter than the existing painted lines. The existing lines had not been repainted since the previous summer. We felt that this might influence the results by calling special attention to these lines. Consequently, alternate sections of the solid white line were removed leaving a broken line which matched the painted line. Another set of data was obtained which duplicated the first set.

The results of the third set of interviews indicated that the brightness of the line does have an effect on driver perception. The percentage of drivers correctly identifying both sections was 22 percent. The percentage correctly identifying the 4-lane section dropped from 50 to 42 percent, whereas the percentage identifying the 2-lane section increased from 19 to 30 percent.

The remainder of the interviews were conducted on locations with new tape for the markings. All further comparisons are based on the results of this second set of interviews on the present system.

TABLE 9

DRIVER AWARENESS—BY LINE TYPE

Marking Type on 2-Lane	Percent Corrected			No Opinion (%)
	2-Lane	4-Lane	Both Sections	2-Lane
Broken white	30	42	22	31
Solid white	28	44	21	33
Broken yellow	34	41	15	16

The pavement marking was next changed to a broken yellow centerline on the 2-lane section. This alteration did not significantly affect driver awareness. Of the 91 drivers interviewed, only 15 percent correctly identified the dashed white lane line and broken yellow centerline. Twenty-one percent could not correctly identify the 2-lane and 4-lane sections.

The broken yellow centerline was correctly described by 34 percent of the drivers. The dashed white lane line was correctly identified by 41 percent. Fourteen percent of drivers interviewed could not recall the pavement marking in either section and offered no description.

Table 9 summarizes these percentages for all markings. It appears that the broken yellow has a greater influence on driver perception than the other markings. χ-square tests indicated there was no significant difference. Also, it should be emphasized that the broken yellow is completely new to the driver. Thus, the driver would be more aware of this alteration than the other marking types. This is evident from the last column.

SUMMARY AND CONCLUSIONS

The study was conducted to determine some facts about the effectiveness of various pavement markings in terms of driver perception, understanding, and performance. The results are discussed separately for all but the perception factor, which could not be isolated. However, perception may be considered basic to both understanding and performance.

Driver Perception and Understanding

Measures of driver perception and understanding were tested in 4 of the 5 phases. In two cases, slide presentation and passing study, the solid yellow line proved to be the best understood line type. In the lane use and driver interview phases, the solid yellow line was not used.

The slide presentation results showed that 96 percent of the subjects correctly identified the meaning of the line both in relation to direction of travel and degree of safety. The broken white line proved to be nearly as effective, with 92 percent correctly identifying the direction of travel and 98 percent the degree of safety. The solid white and broken yellow lines were less often identified correctly.

When categorized by sex and driver experience, the results are the same. The 5 to 10-year driver experience group has the best perception and understanding for each type of line. The same is true in correctly identifying the direction of travel and degree of safety. For all line types, males had a higher but not significant total corrected than females in identification of direction of travel and degree of safety.

In the passing phase, the solid yellow line also proved to be more uniformly understood. Only 46 percent of the drivers crossed this line during the day and 26 percent at night. When this marking was replaced with a solid white line, the percentage of drivers passing increased to 93 and 87 percent, respectively. The broken yellow line produced nearly the same effect as a solid white line with 87 and 70 percent, respectively.

The driver interview phase indicated no significant difference in driver perception of the different line types. However, 34 percent correctly identified the broken yellow line, 30 percent the broken white, and 28 percent the solid white.

A solid yellow line was not used in the lane use phase. Drivers appeared to be more aware of the broken yellow line, and there was a higher percentage of vehicles that were deterred by this line type. The solid white was less of a deterrent while the broken white line had little or no deterrent effect.

It is apparent that driver interpretation is conditioned to the present marking system. The use of a solid yellow line as a barrier has come to be generally used and accepted. It is also apparent that neither color nor solid line (alone) conveys this message. The solid white line did not prove to be an acceptable substitute; neither did the broken yellow. Any proposed revision of the pavement marking that uses line type and line color to convey separate meanings would involve a driver education period.

Driver Performance

Three phases of the project involve measures of driver performance associated with different types of lines. The lateral placement studies were intended to illustrate differences in driver dependence on the line to convey the corridor description. The passing study was conducted to determine the driver's willingness to cross different lines in a critical situation, and the lane use study was for this determination in a "no-stress" condition.

The lateral placement study indicated that drivers interpret various line types differently when negotiating a curve. When lateral positions of vehicles are compared for the conditions with no lines and with the solid yellow, the driver tends to move away from the center of the road. When an edge line is added, the driver tends to move back toward the center. It can be hypothesized that the driver is shifting his reference guide from the edge of the road when there is no marking, to the center of the road when a solid yellow line is supplied, and back again to the edge of the road when an edge line is added. The use of a solid white line appears to influence the driver in much the same manner as a broken white line. It does not cause the driver to avoid the centerline as much as the solid yellow line.

The results of the passing study illustrate driver performance in regard to crossing various type lines. Again, the solid yellow line is the only line to which drivers react. The results of the lane use study give an indication of the deterrent effect of line types. The broken yellow line had more influence on driver performance in this respect.

In summary, it appears that the results of these tests were influenced by driver conditioning. However, significant differences were found in many of the tests that indicate that systems could be devised to convey meaningful information to the driver following some period of education and adjustment. The use of color appears to have a greater potential than the use of line shape. No observations can be made of the long-range effects because of the limited duration of the study.

Discussion

R. J. ISRAEL, California Division of Highways—I congratulate the authors on their ingenious approach methods to a problem that is very difficult to research. Particularly, I would like to cite the slide presentation study, duplicates of which were forwarded to engineers throughout the nation for comparable tests in their specific areas; therefore, this phase represents subjects from many geographical areas, substantially increasing the validity of this part of the study.

The authors state that the establishment of a new system of longitudinal markings would require a period of education and adjustment on the driver's part. I agree that there would be some such period because there are some segments of the driving population that react slowly to new signs or markings. However, the establishment of a new system would be heavily publicized and I believe the changeover would not be a major problem as evidenced by the far greater changeover, from driving on the left to driving on the right, recently accomplished in Sweden. Hopeful evidence in this regard is given by Phase I. With only a few minutes' explanation and a more orderly arrangement of the slides, from 56 percent to 72 percent of the subjects were able to correct previous errors concerning the direction of travel.

The problem of confusion with a single marking to indicate both two-way and one-way travel has been one of long standing. The problem is being intensified by the building of Interstate and other freeways and multi-lane divided highways. Serious accidents due to this confusion are on the increase, particularly in areas where a high percentage of travel is on freeways.

It is fortunate that this research indicates color as being the more effective. The dashed yellow centerline has the greater possibility as a line for two-directional roads. It presents the greatest contrast to the lane line on one-directional roads and should not be confused with other current uses. The solid white line is being used in other concepts such as a channelizing line through tunnels and interchanges to discourage unnecessary lane changes. The dashed yellow line on the great mileage of two-lane roads can also be attained at considerably less cost. The dashed line requiring only 40 percent of the paint will be far more acceptable than a solid line by most states and particularly by counties and other local jurisdictions.

This research gives firm backing to the recent actions of the National Joint Committee, which has voted to establish the yellow dashed line on two-directional roads as a basic change in their forthcoming revised manual. I personally believe that the elimination of the present duplication will provide a substantial contribution to traffic safety on a national basis.

JAMES L. FOLEY, JR., Commissioner, Department of Transit and Traffic, City of Baltimore—The research conducted by Taylor and Hubbell was greatly needed. For several years the markings subcommittee of NJCUTCD has been struggling to eliminate the conflicts in the existing manual. These conflicts are of two kinds: (a) differing meanings for the same marking, and (b) differing markings for the same meaning.

Examples of (a) are: dashed white line (urban) means lane line, and dashed white line (rural) means centerline or lane line. Examples of (b) are: dashed white line (rural) means centerline, and solid white line (urban) means centerline. The problem becomes more acute when we add solid white edge lines, solid white reversible lane lines, dashed white lane lines in rural areas, and many others.

Fortunately for the subcommittee, a draft of this report became available in July 1967. The data and interpretations proved valuable in developing the basic concepts on which to base improvements to this part of the Manual. The public understanding of markings, as indicated by the random slide presentation, shows the effect of the conflicts noted previously. Those markings that have had consistent meanings rated high in general understanding. The best example is that solid yellow indicated traffic from the opposite direction, and that passing was unsafe. Another, dashed white indicated that passing was allowed.

On the other hand, those markings with multiple meanings in the present system resulted in confused interpretations when new systems were presented. For example, two-thirds of those tested felt a solid white line indicated no passing zone. Some of this may be due to older drivers remembering 15 to 20 years ago when that was its meaning. Another example, two-thirds do not expect opposing traffic on the other side of a broken white line.

The only obvious rationale is the likelihood that a significant number of the viewers were city oriented, where this symbol is used for lane lines. It is an unfortunate interpretation because literally hundreds of thousands of miles of rural highways use this symbol as the centerline of two-way, 2-lane roads. It seems that the broken yellow marking—not used in present system—indicates to most viewers that opposing traffic will be in other lane, but that sight distances are not restrictive.

Table 10 compares the meanings of the present system and the two alternates with the interpretations from the random slide presentation.

Of significance in the Committee effort to revise and improve the pavement marking system are the problems related to the transition period. During the changeover, the conflicting or alternative meanings for any given marking should not differ drastically from the present meaning; potential misinterpretations should be "fail safe."

Also important is a high probability of rapid comprehension of the new system. The "percent corrected" column of Table 2 suggests that alternate 1 is more readily "learned" than alternate 2. The values being 66 vs 56 percent and 64 vs 47 percent, respectively, for "Identification of Direction of Travel" and "Identification of Passing Safety."

It is quite likely that in the present system, the percent corrected is more likely the result of a memory jogger when the system rationale is explained. Figure 1 seems to corroborate the greater "learnability" of alternate 1 over all ranges of driving experience.

TABLE 10

Based on System Response Should Be	Type of Line			
	Solid Yellow	Broken Yellow	Solid White	Broken White
Indicates opposite direction:				
Present rural	Yes	—*	No	Yes & No
Present urban	Yes	—*	Yes	No
Alternate 1	Yes	Yes	No	No
Alternate 2	Yes	No	Yes	No
Random response	90%	77%	79%	34%
Indicates unsafe to pass:				
Present rural	Yes	—*	Yes	No
Present urban	Yes	—*	Yes	No
Alternate 1	Yes	No	Yes	No
Alternate 2	Yes	Yes	No	No
Random response	88%	37%	66%	9%

*No meaning assigned.

It appears from the field tests conducted in Phase III that two lines in combination are required to form a barrier line or no passing zone. It is probable that the low response to single solid white centerline as a barrier is due to the use of this marking as a centerline in urban areas where crossing is permitted. The greater deterrent value of the broken yellow over solid white is probably the combination of a new or novel technique with the carryover effect from present use of yellow only at no passing zones.

Table 8 indicates that both solid white and broken yellow lane lines tend to discourage crossing initially, but with passage of time (distance traveled) this reluctance is overcome. The similarity of the solid white and edge lines could account for this action by drivers. The novelty or caution meaning of the broken yellow line probably accounts for the initial hesitancy to cross this marking. The novelty characteristic of the broken yellow seems to be borne out by the interviews in Phase V.

The studies, especially the slide tests and the passing tests, indicate an undesirable amount of misunderstanding in the present markings system. However, the authors point out that understanding of any new systems is conditioned by driver experience with the present system. Thus, any proposed system must be deeply rooted in the existing system of markings. The system of marking being proposed by the NJCUTCD endeavors to eliminate the existing conflicts while retaining the most firmly rooted elements of the present system.

Essentially the proposed system is alternate No. 1, modified to use double lines to form the barrier or no passing line. Thus the solid yellow barrier line element of the two-line no passing marking is retained. The new symbol—broken yellow line—is used in the context most often understood (Table 1). The basic concepts on which the system is based are: (a) yellow lines delineate the separation of traffic flows in opposing directions; (b) white lines delineate the separation of traffic flows in the same direction; (c) broken lines are permissive in character; (d) solid lines are restrictive in character; and (e) width of line indicates the degree of restriction—a narrow line indicates less, and a wide line indicates greater restriction than a single normal width line.

ALAN T. GONSETH, Supervisor, Test and Applications, Port of New York Authority—Although safety and efficiency of highway operation depend to a considerable degree on the geometric design of the highway, the physical layout must also be supplemented by effective lane markings as a means of informing, warning, and controlling drivers. As with signs, respect for lane markings grows mainly from proper use because of the natural tendency for lane markings to guide the road user along whatever path the striping outlines.

This report truly investigates the effectiveness of various combinations of line striping as related to three items: driver perception, driver understanding, and driver performance. The five-phase study fully evaluated various combinations of white, yellow, broken, and solid lines, and the conclusions of the authors are well founded and supported with substantial research data.

Since the findings are well documented and conservatively stated, I took the liberty of trying to find other relationships in their presentation that may lack solid back-up, but which might be indicative of some particular trend.

Although the authors never lose sight of their goal of determining which pavement marking is better for designating direction of travel and degree of safety, I feel an underlying point is suggested; that is, drivers who are properly taught can learn any striping system, but in practice will only consciously follow the "rules" if the rules really affect their personal safety or perhaps fit their convenience.

To illustrate, in the authors' random slide presentation people were basically unsure of meaning, but when the various striping systems were described and the slides presented orderly then all subjects "scored" much better. There was a slight edge for relearning the existing system rather than learning, for the first time, the two alternate schemes. In essence, Phase I indicates that people either do not remember the meanings of various pavement markings or unconsciously elect to disregard them and thereby use their own judgment rather than rely on markings.

The lane placement study indicates that people will tend to follow a clearly identified corridor and will position themselves with the most obvious striping, regardless of the striping's meaning or intent.

Similarly, the passing study showed that people used their own judgment in passing when the striping indicated it was unsafe. Did they consciously consider the no-crossing lines, or rather, did they just drive as they felt safe? This latter attitude appears particularly true on the level test section.

The 2- to 4-lane transition study again shows that people may temporarily react to lane striping, but tend to disregard it if they feel it is not applicable to their needs or convenience.

The 4- to 2-lane transition study indicates that only 16 percent of the drivers interviewed could properly identify the pavement marking on both the 2- and 4-lane sections. If you apply the results of Phase I to the 16 percent you find that even less people knew what the pavement marking meant.

My intent is not to be critical of the existing or any proposed alternate pavement marking scheme. I believe the authors have truly shown "... the results of these tests were influenced by driver conditioning" and, "The use of color appears to have a greater potential than the use of line shape." What the study does suggest to me is that we have been lax in promoting the existing uniform standard, and therefore, whatever standard is adopted should not be used properly and consistently throughout the nation as reinforcement to warning or regulatory signs, but most of all an increased public education program on the meaning of the lane markings should be initiated and frequently followed up.