Table 7. Driver use of the red intervals.

City	Intersection	Approach	Length of Amber Interval (s)	Length of ARI (s)	Percentage of Driver Use, P_r
Hartford, CT	Farmington-Sigourney	Farmington eastbound	3.0	0.0	29.7
	Main-Gold	Main northbound	2.6	1.6	31.5
	Ann-Asylum	Asylum westbound	3.0	3.0	42.2
New Haven, CT	College-Elm	Elm eastbound	3.4	0.0	36.7
	Church-George	George eastbound	3.5	2.8	21.9
	Church-Elm	Elm eastbound	3.4	0.0	38.0
	Chapel-Church	Church northbound	3.2	1.8	63.0
Providence, RI	Dorrance-Weybosset	Weybosset eastbound	2.7	0.0	22.0
	Empire-Washington	Washington westbound	3.0	0.0	25.4
Worcester, MA	Main-Pearl-Mechanic	Main southbound	3.4	0.0	19.1

REFERENCES

1. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, 1971.
2. Institute of Transportation Engineers. Transportation and Traffic Engineering Handbook. Prentice-Hall, Englewood Cliffs, NJ, 1976.
3. D. Gazis, R. Herman, and A. Maradudin. The Problem of the Amber Signal Light in Traffic Flow. Operations Research, Vol. 8, No. 1, Jan.-Feb. 1960, pp. 112-132.

Publication of this paper sponsored by Committee on Traffic Control Devices.

Comparison of Signs and Markings for Passing and No-Passing Zones

RICHARD W. LYLES

An experiment was undertaken to examine the relative effectiveness of five pavement marking and signing sequences for informing motorists of passing and no-passing zones on rural two-lane, two-way rural roads. Treatments included (a) standard pavement markings, (b) pavement markings plus standard regulatory signing, (c) pavement markings plus no-passing pennants, and (d) and (e) two combinations of regulatory signs and pennants. Data were collected on overtaking and passing vehicles by two observers in a staged vehicle that traveled over a measured length of roadway. The principal findings were that the addition of any sign sequence to pavement markings resulted in motorists being appreciably more observant of the passing and no-passing zones and spending less time in the passing (opposing) lane. Less conclusive evidence was presented in support of the more emphatic and informative sequences that resulted in progressively more compliance with the marked zones.

Overtaking and passing maneuvers are two of the most common sources of conflict between two or more vehicles on two-lane, two-way rural roads. Numerous possibilities exist for collision, including rear-end, sideswipe, and, most dangerous, head-on. Drivers, in overtaking and passing another vehicle, depend on a number of visual cues to ascertain whether such maneuvers can be completed safely. In addition to checking for oncoming traffic and gauging the speed of both any oncoming vehicles within sight and the vehicle to be overtaken and passed, the driver also uses the information provided by pavement markings and roadside signs to ascertain the advisability of the maneuver--Is he or she in a marked passing zone, how much of the passing zone remains, and so forth. Signs and marking can clearly provide considerable guidance to the motorist in making judgments about the relative safety of passing maneuvers. Despite the presumed importance of the signs and markings for passing and no-passing zones, there appears to be a considerable range in how such devices are, or should be, used in practice [see, for example, Nickerson, (1) and Weaver and others (2)].

In the context described above, the basic objective of the research described herein was to evaluate several alternatives for roadside signing, relative to traditional pavement markings, for indicating passing and no-passing zones.

STUDY METHODOLOGY

Many traffic situations lend themselves to straightforward examination; for example, vehicles approaching a specified intersection or other potentially hazardous situation can be observed or tracked by using sensors on the road surface and appropriate electronic equipment (3) with the acquired data being used to calculate vehicle speeds at certain points on the approach to the hazard. The result is that fairly extensive sets of data can be obtained in a relatively short time, even in low-volume situations. By contrast, overtaking and passing maneuvers are dynamic in nature and, hence, more difficult to document relative to where certain events took place. Alternative methods for documenting such maneuvers include the use of film or videotape, isolation of one specific passing or no-passing zone, or use of some sort of mobile data-collection device.

For a variety of reasons, including equipment availability and the explicit capability to use several different zones, a mobile data-collection device was selected in this instance. The basic approach was to have a staged vehicle (Jeep Wagoneer) traverse a specified section of road while traveling at an explicit (and constant) speed. The driver and observer in that vehicle would make observations on any other vehicle that overtook them and passed, or attempted to pass, as well as on approaching vehicles and certain location information (e.g., Was the staged vehicle in a passing zone?).

A technical description of the data collection is provided by Wyman and Lyles (4) and also by Lanman (3). In general, the system was based on a modified vehicle speed measurement device (i.e., the Traffic Analyzer System manufactured by Leupold and Stevens, Inc.) and allowed specific observed events to be recorded by the observers on a machine-readable cassette tape that, when analyzed, provided both an indication of the event occurrence and its associated time.

The site was an approximately 6-mile segment of US-2 just east of Canaan, Maine. US-2 in this vicinity traverses rolling terrain and is two lane over the entire distance with a maximum grade of approximately 7 percent. Passing zones (which were, for the most part, established by the Maine Department of Transportation (DOT) independent of the experiment) ranged in length from 600 to 3200 ft and no-passing zones ranged from 400 to 9800 ft. The longest no-passing zone occurred on the hill that had the maximum grade, although a passing zone had recently existed in that area. The speed limit over the entire road segment was 50 mph (although it had, at one time, been 60 mph).

Both directions of travel over the segment were used for data collection. The observers in the staged vehicle would begin at one end of the segment, start the data-collection equipment, drive through to the other end of the segment while collecting data on any maneuvers and opposing traffic, and then reset the data-collection device and return to the original starting point over the same segment in the opposite direction.

In order that there be public familiarity (for motorists on whom data were collected) with the signs being tested, whenever the sign condition was changed (three of the five treatments are not typically used in Maine) the new condition was erected (used) not only on the actual test segment but also for about 2 miles in advance of the test segment in each direction. Hence, regardless of direction of travel, the average motorist encountered the first of the test signs about 2 miles prior to the actual test segment.

In general, the procedure during the experiment was to (a) deploy a given treatment on the test segment of road (plus the advance sections), (b) have the staged vehicle operate over the segment for up to two weeks (dependent on the amount of data gathered), and (c) change the treatment condition and collect more data. In addition to the data collected by the two people in the staged vehicle (on overtaking and passing vehicles and opposing traffic), data were also collected on weather conditions, time-of-day, and treatment condition deployed. When the data were coded for the analysis, certain other information (e.g., approximate sight distance at any point) was also calculated and recorded.

The five treatment conditions that were evaluated are shown in Figure 1. They included the standard pavement markings, a regulatory DO NOT PASS sequence, a warning NO PASSING ZONE sequence, and two combinations of the DO NOT PASS and NO PASSING ZONE treatments. The final combination (treatment condition 5) consisted of both the DO NOT PASS sign (on the right-hand side) and the NO PASSING ZONE (on the left-hand side) at the beginning of each no-passing zone; the latter was repeated at intervals throughout the zone. The intervals in condition 5 varied such that a motorist would have either just passed a sign, be able to see one ahead indicating the no-passing zone, or be able to see the PASS WITH CARE sign at the beginning of the next passing zone. Hence, the actual intervals between sequential NO PASSING ZONE signs in the final treatment were variable, depending on topography and sight distance.

The staged vehicle operated at 35 mph throughout the experiment, although a speed of 45 mph was also tried. The latter speed, given prevailing traffic volumes and a normal mean speed of just over 50 mph, resulted in a very low number of overtaking and passings of the staged vehicle and the few data that were obtained were not used.

FINDINGS

The raw data (the events and their associated times of occurrence) that were collected were organized so that a number of variables could be calculated from any overtaking of passing vehicle's time of event record (e.g., the time spent entirely within the passing lane during a passing maneuver). Events recorded by the two observers in the staged vehicle included the following.

The passenger observed

1. Vehicle overtaking staged vehicle,
2. Vehicle making maneuver from queue behind staged vehicle,
3. Left wheels (of overtaking vehicle) over centerline,
4. Right wheels over centerline,
5. Passing vehicle adjacent to staged vehicle,
6. Right wheels recross centerline,
7. Left wheels recross centerline,
8. Pass completed when passing vehicle had Maine license,
9. Pass completed when passing vehicle had non-Maine license,
10. Recreation vehicle,
11. Automobile and trailer,
12. Truck,
13. Abort (an error was made by observer), and
14. East or west (direction of staged vehicle, indicated at start of data run).

The driver observed the following events:

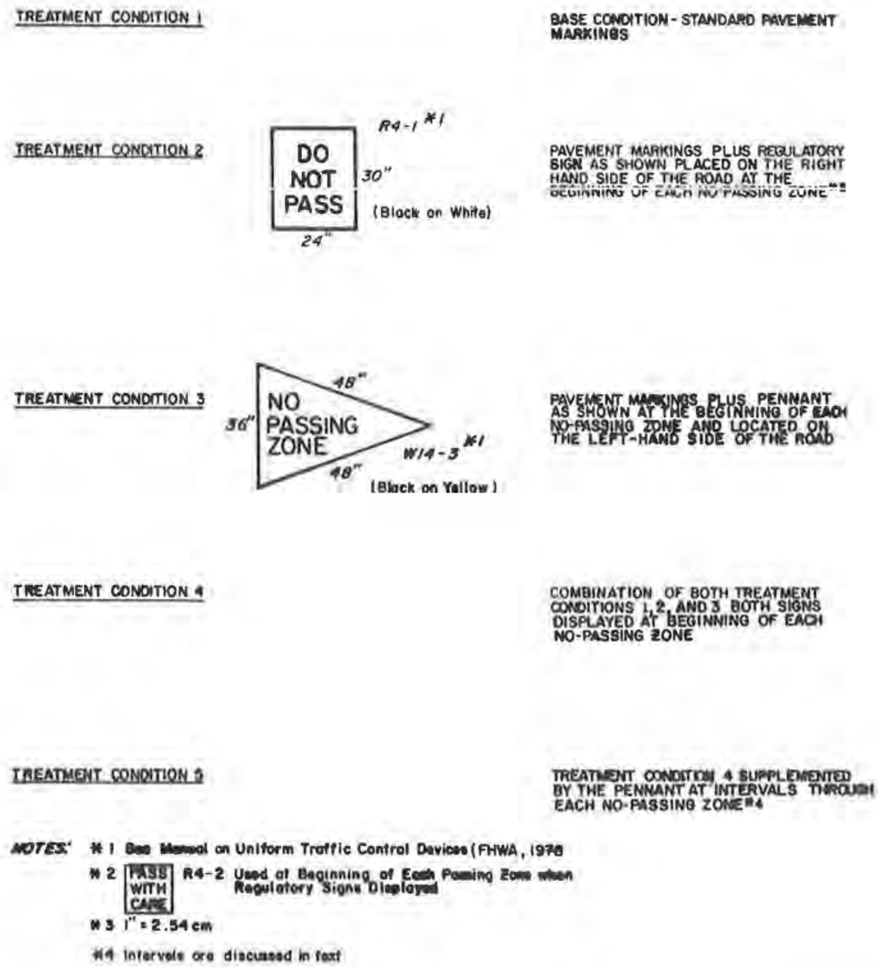
1. Staged vehicle entering no-passing zone,
2. Staged vehicle entering passing zone,
3. Opposing vehicles approaching (would be in sight of passing vehicle),
4. Opposing vehicle adjacent to staged vehicle (repeated if more than one), and
5. No opposition vehicles in sight.

Note that the data record for each overtaking or passing vehicle was a sequence of events with their associated times of occurrence.

Individual vehicles were also classified as to whether a given maneuver was a completed pass with no opposing traffic in view or one of several other categories (e.g., a quick-look where the overtaking vehicle's left wheels crossed the centerline although it pulled back in and did not pass), and whether the vehicle was a repeat (more than one maneuver was made) or not. In most instances, the data were analyzed with others in the same category unless analysis showed that there were no differences between the types being considered.

The data on the various maneuvers were of two basic types: concerning the context of the maneuver (e.g., in which passing or no-passing zone did it

Figure 1. Treatment conditions.



take place) or concerning the characteristics of the execution of the maneuver (e.g., how long was the passing vehicle completely in the opposing lane). Hence, analysis of the data was also of two general types: examination of the distribution of the maneuvers (e.g., the incidence of passes by passing and no-passing zone) and analysis of variance performed on some of the execution characteristics (e.g., time in the opposing lane).

The results reported here are not exhaustive but, rather, representative of the outcome of the overall analysis that was relatively extensive. Although not all aspects of the overtaking and passing maneuver and those independent factors that affect it are discussed, several were dealt with in the study. Some of the factors addressed in the complete report (6) included the impact of differences in topography and other characteristics of individual zones, the differences between familiar and nonfamiliar drivers (the latter were assumed, in the end, to be primarily represented in the data), speed of the vehicle being overtaken, and type of vehicle performing the maneuver. In some instances the factors were dealt with directly (e.g., length of passing zones) and, in others, indirectly (e.g., only automobiles were considered due to a lack of data on other types).

The distribution of the total number of observed maneuvers by type (although the last two types listed actually represent the absence of some action) is given below. Included in the vehicle types is ignored opportunity, which was defined as where the overtaking vehicle was unopposed in a passing zone with adequate sight distance and had an adequate amount of the passing zone remaining (i.e., the vehicle could have passed safely but did not make any maneuver).

Type of Maneuver	No. of Observations
Unopposed pass	485
Opposed pass	58
Partly opposed pass	132
Quick-look, unopposed	195
Quick-look, opposed	96
Lane change--no passing, unopposed	3
Lane change--no passing, opposed	6
Total	975
Never pass, opportunities ignored	71
Ignored opportunities	103
Total	1149

The distribution of maneuvers by vehicle status was as follows:

Vehicle Status	Observations (%)
New vehicles, i.e., those making first maneuver	57
Repeat vehicles, i.e., those that made more than one maneuver	27
Queue vehicles, i.e., those that were relatively close behind staged vehicle when maneuver of	13

Vehicle Status	Observations (%)
preceding was completed	
Pack vehicle, i.e., those that passed from a position other than immediately behind the staged vehicle	3

In general, the results of the experiment were not overwhelming relative to the desirability or effectiveness of one treatment over another, although there was a clear and definite break between the use of signs (of any sort) and the use of only pavement markings. Several positive results are presented below.

Maneuvers (both passes and quick-looks) tended to take longer if only the pavement markings were used (treatment 1) versus use of the pavement markings in conjunction with any type of sign condition (treatments 2-5). It can be hypothesized that this was due to the fact that motorists were more aware that they were in a passing zone and where the next no-passing zone started.

The number of clips (where a motorist was actually in the next no-passing zone before a pass was completed) of the next no-passing zone appeared to be unrelated to the marking or sign condition that was displayed. Approximate sight distances for passing maneuvers were somewhat lower when treatment 1 (pavement markings only) was displayed as opposed to the other four.

When opposing traffic was present, the acceptable time gap (termed passing gap) for the passing maneuver was about 14-16 s, whereas quick-looks were done when passing gaps averaged 10-12 s. However, no differences among the treatments were noted.

Comparison of the observations obtained in this experiment with similar values from other work for several key variables showed that there was basic agreement insofar as the structure of the passing maneuver was concerned. For example, the exposure time (time spent in the opposing lane) was in the same range as earlier reported figures (7,8). This finding lends credibility to both the experimental approach that was taken (i.e., using observers in a staged vehicle traveling at a set speed) as well as to the results obtained.

The most compelling result concerned the incidence of use of passing zones versus no-passing zones for any maneuvers (see Tables 1 and 2). As the treatment conditions became more emphatic and informative, the percentage of maneuvers done in passing zones continued to increase. The compliance statistic increased by 47-57 percent for all maneuvers and by 17-39 percent for unopposed passes between treatment 1 and treatment 5. The best rate of compliance was 92.9 percent for unopposed passes in the eastbound direction whereas the best for the pavement markings only was 72.6 percent.

Based on these results, no-passing signs (DO NOT PASS, NO PASSING ZONE, or some combination) used in conjunction with pavement markings seemed to increase not only compliance with the desired behavior (as indicated by the compliance of maneuvers in marked zones) but also more conservative, and presumably safer, passing behavior (as indicated, for example, by the drivers' requiring longer sight distance). There was also some evidence that more emphatic and informative treatments tended to have incrementally more effect. This last result was not, however, demonstrated conclusively.

These results are not substantially different from what might be expected intuitively, but they do provide an empirical foundation for using roadside signs in conjunction with pavement markings when better compliance with passing and no-passing zones is desirable. Presumably, use of such signs would be even more effective when visibility is somewhat restricted or when the pavement markings are not visible (e.g., when the road is snow covered). The positive increment of compliance could, however, be lessened if the signs were universally used for all passing and no-passing zones due to the potential for motorist disdain of oversigning. Although there is little question of the increased safety to be achieved through use of the signs in some situations, the results fall short of providing strong and conclusive support for selecting one sign treatment over another.

Table 1. Distribution of all maneuvers by passing and no-passing zones.

No.	Treatment Condition	Eastbound (%)		Westbound (%)	
		In Passing Zone	In No-Passing Zone	In Passing Zone	In No-Passing Zone
1	Pavement markings only	52.3	47.7	50.3	49.7
2	Do not pass regulatory signs	69.2	30.8	66.3	33.7
3	No-passing pennants	53.5	46.5	60.3	39.7
4	Regulatory signs and pennants	71.2	28.8	61.4	38.6
5	Treatment 4 plus supplemental pennants	82.0	18.0	73.8	26.2

Notes: A total of 975 observations were made, which does not include never pass and ignored opportunities maneuvers.
In order of emphasis and information, treatment 2 is considered to be more emphatic than treatment 3.

Table 2. Distribution of unopposed pass maneuvers by passing and no-passing zones.

No.	Treatment Condition	Eastbound (%)		Westbound (%)	
		In Passing Zone	In No-Passing Zone	In Passing Zone	In No-Passing Zone
1	Pavement markings only	66.7	33.3	72.6	27.4
2	Do not pass regulatory signs	80.0	20.0	82.0	18.0
3	No-passing pennants	80.0	20.0	82.0	18.0
4	Regulatory signs and pennants	88.9	11.1	75.0	25.0
5	Treatment 4 plus supplemental pennants	92.9	7.1	85.1	14.9

Notes: A total of 485 observations were made.
In order of emphasis and information, treatment 2 is considered to be more emphatic than treatment 3.

ACKNOWLEDGMENT

Considerably more detail on the research reported on herein can be found in the final report, submitted to the Federal Highway Administration (FHWA) (6). The research was funded by FHWA and undertaken at the Maine facility with staffing from FHWA, the Maine DOT, and the Social Science Research Institute of the University of Maine at Orono. The contributions of that staff notwithstanding, the responsibility for the conclusions presented here and in the final reports and any errors therein rest with me and are not necessarily those of FHWA, Maine DOT, or the University of Maine.

REFERENCES

1. M.H. Nickerson. No-Passing Zones State of the Art. Presented at 1979 AASHTO Traffic Committee Meeting at Colorado Springs, CO; Department of Transportation and Public Facilities, Juneau, AK, Nov. 1979.
2. G.D. Weaver, D.L. Woods, A. Huber, and S. Richards. Passing and No-Passing Zones: Signs, Markings, and Warrants. Texas Transportation Institute, College Station, Interim Rept. to FHWA, Nov. 1977.
3. M.H. Lanman, III. The Maine Facility: Capability for Rural Road Research. ITE Journal, Arlington, VA, Dec. 1978.
4. J.H. Wyman and R.W. Lyles. Mobile Traffic Data Collection System. Maine Department of Transportation and Social Science Research Institute, Univ. of Maine, Orono, Final Rept. to Office of Research, FHWA, Sept. 1979.
5. Manual of Uniform Traffic Control Devices. FHWA, 1978.
6. R.W. Lyles. Comparison of Signs and Markings for Passing/No-Passing Zones. Social Science Research Institute, Univ. of Maine, Orono; Maine Department of Transportation, Final Rept. to FHWA Office of Research, Rept. FHWA/RD-81/094 and FHWA/RD-81/095, 1981.
7. G.D. Weaver and J.C. Glennon. Passing Performance Measurements Related to Sight Distance Design. Texas Transportation Institute, College Station, Rept. 134-6, July 1971.
8. A Policy on Geometric Design of Rural Highways. AASHO, Washington, DC, 1965.

Publication of this paper sponsored by Committee on Traffic Control Devices.

Effect of Raised Pavement Markers on Traffic Performance

WILLIAM L. MULLOWNEY

This project measured and documented the effect that snowplowable raised pavement markers (SRPMs) have on the behavior of traffic at certain geometric highway conditions. Two-lane rural curves, highway exits with deceleration lanes, and highway bifurcations were studied. Measures of performance selected to study the effects of the markers included erratic maneuvers such as cutting through painted gores, lane changes or encroachments, center and edgeline encroachments, point of entrance into deceleration lanes, and mean speeds and speed variance at curves. All erratic maneuvers studied were reduced significantly at various sites for traffic volumes per lane of up to 500 vehicles/h. At volumes per lane of between 900 and 1000 vehicles/h the markers had no effect on traffic. Raised markers were not successful in causing motorists to enter deceleration lanes at exits earlier. As far as speeds, the markers seem to have caused a smoother speed profile through the two curves studied, which resulted in less abrupt speed changes. The effect of SRPMs on speed variance was inconclusive. The markers were effective in reducing erratic maneuvers at sites with and without overhead lighting. At one site a significantly higher rate of erratic maneuvers during rain conditions before the markers were placed was not only severely reduced but the wet condition erratic maneuver rate approached the quality of the dry condition rate when markers were present.

This study was undertaken to determine whether snowplowable raised pavement markers (SRPMs) can reduce the variable behavior of traffic with regard to lane placement, choice of exit pathway, and speed to the extent that traffic conflicts and erratic maneuvers are reduced. The general belief is that the delineation provided by SRPMs would increase the driver's view of road and exit geometry and assist him or her in choosing a safe and efficient pathway.

OBJECTIVES

The study was designed to achieve the following objectives:

1. To measure the effect of SRPMs on centerline and edgeline encroachments on both lit and unlit curved sections of highway;
2. To measure the effect of SRPMs on speeds and speed variances on lit and unlit curves;
3. To measure the effect of SRPMs on the incidence of drivers encroaching on painted gores, both at exits and at highway bifurcations; and
4. To see whether SRPMs would cause motorists to enter the deceleration lanes at exits more consistently.

INSTALLATION PROCEDURE

Eight hundred raised pavement markers were installed at 11 sites in central and southern New Jersey. Amerace Corporation was contracted to provide the markers, concrete saw, epoxy dispensing machine and epoxy, and two machine operators. The New Jersey Department of Transportation provided the safety operation, a water truck, and sufficient workers to assist in placing the markers.

STUDY DESIGN

Potential sites were selected on the basis of the following criteria.

1. Existance of higher than normal rates of run-off-the-road accidents for a short section of highway;
2. Existance of a traffic performance problem such as encroachments, variability in exiting path, and weaving;
3. Subjective determination of the problem-