FINAL REPORT

CENTERLINE PAVEMENT MARKING ON TWO-LANE MOUNTAIN HIGHWAYS

VOLUME I

Study Methodology, Regression Pass Model, and Summary of Findings

by

Nicholas J. Garber
Faculty Research Engineer

and

Mitsuru Saito
Graduate Research Assistant

Virginia Highway and Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

September 1983

VHTRC 84-R8

SAFETY RESEARCH ADVISORY COMMITTEE

W. E. DOUGLAS, Chairman, Director, Planning & Programs Development, Division of Motor Vehicles

P. L. ASH, JR., Chief of Police, Staunton, Virginia

V. M. BURGESS, Transportation Safety Administrator, Division of Motor Vehicles

C. F. CLARK, Driver Services Administrator, Division of Motor Vehicles

C. P. HEITZLER, JR., Program Manager, Department of Management Analysis and Systems Development

B. G. JOHNSON, Supervisor, Driver Education, Department of Education

C. S. JOHNSON, JR., Field Supervisor - West, Department of State Police

R. F. MCCARTY, Safety Program Coordinator, FHWA

W. F. MCCORMICK, Assistant District Engineer, VDH&T

R. M. MCDONALD, Project Director, Transportation Safety Training Center, Virginia Commonwealth University

S. D. MCHENRY, Director, Bureau of Emergency Medical Services, Department of Health

F. F. SMALL, Highway Engineering Program Supervisor, VDH&T

J. A. SPENCER, Assistant Attorney General, Office of the Attorney General

C. B. STOKE, Research Scientist, VH&TRC

E. W. TIMMONS, Director of Public Affairs, Tidewatter AAA of Virginia, Norfolk, Virginia

TABLE OF CONTENTS

/ 09

TABLE OF CONTENTS Continued

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES Continued

ABSTRACT

The Virginia Department of Highways and Transportation uses a lane marking designated mountain pavement marking (MPM) on two-lane highways in mountainous areas. This special marking consists of a single broken yellow line supplemented with "PASS WITH CAUTION" signs. The standard Manual of Uniform Traffic Control Devices (MUTCD) passing and no-passing zones are not marked, with the result that passing maneuvers are not prohibited even when sight distances are inadequate for prevailing speeds. This practice has been criticized by the Federal Highway Administration, highway safety officials, and motorists. Consequently, the Research Council undertook a study to evaluate this centerline marking pattern. The evaluation adopted was made in the form of a before and after study. The before study entailed a literature review, a questionnaire survey of motorists and officials of other states, the recording of passing maneuvers at different sites using a movie camera, the collecting of data on traffic characteristics, and an analysis of accident data. The information obtained on passing maneuvers was then used to develop guidelines on minimum lengths of passing zones and minimum sight distances. The after study entailed the collection and analysis of data on passing maneuvers and traffic characteristics at sites marked with the MUTCD marking patterns based on the guidelines developed. It was determined that traffic characteristics do not significantly change when centerline markings are changed from MPM to the standard MUTCD marking and that the minimum passing zones and passing sight distances given in the MUTCD are inadequate for safe passing maneuvers. It was also determined that the minimum sight distances discretionally used in Virginia are too conservative. The data collected on passing maneuvers during the after study showed that the guidelines developed for minimum passing zones and sight distances are adequate for passing maneuvers on two-lane highways in mountainous areas.

FINAL REPORT

CENTERLINE PAVEMENT MARKINGS ON TWO-LANE MOUNTAIN HIGHWAYS

by

Nicholas J. Garber
Faculty Research Engineer

and

Mitsuru Saito
Graduate Research Assistant

INTRODUCTION

Uniform standards for road markings, signs, and signals are used to convey information to drivers and thus improve the safety and operational aspects of highways. National standards for devices that regulate and control traffic are given in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD).(1) While the general provisions of the MUTCD are approved for use on all public highways, conformance with the standards set forth is required only on federal-aid highways.

Section 3B-1 of the MUTCD notes that centerline markings on two-lane highways are used to separate traffic travelling in opposite directions. In order to provide additional information to drivers, marking patterns are used to delineate passing and no-passing zones as follows:

1. A single, broken, yellow line where passing is permitted in both directions.

2. A double line consisting of a broken yellow line and a solid yellow line where passing is permitted in one direction.

3. A double line consisting of two solid yellow lines where passing is prohibited in both directions.

The meanings of these marking patterns are conveyed to Virginia motorists in the driver's manual and through driver education courses.(2) The results of a study by the Federal Highway Administration indicate that the majority of the drivers correctly interpret the meanings of these centerline patterns.(3)

The long-standing policy of the Virginia Department of Highways and Transportation is to use the centerline marking standards outlined in the MUTCD. The Department, however, has been using a special marking on two-lane highways in mountainous areas since the early 1940s.[4] This special marking, designated "mountain pavement marking (MPM)," consists of a single, broken, yellow line supplemented with "PASS WITH CAUTION" signs as shown in Figure 1. Passing maneuvers are not prohibited by the use of the solid yellow line even when sight distances are inadequate for prevailing speeds. The decision to pass is, therefore, left entirely to the judgment of the motorist. The argument in favor of this marking pattern is that motorists can legally pass slow-moving vehicles, which would not be possible for long distances if these roads were marked in compliance with the MUTCD standards because of their circuitous alignment.

FIGURE 1. MOUNTAIN PAVEMENT MARKING AND "PASS WITH CAUTION" SIGN.

This practice of marking two-lane highways in mountainous areas has been criticized by the Federal Highway Administration, highway safety officials, and motorists.[5] In keeping with the national emphasis on providing uniform road marking and the Department's continuing interest in promoting safety and efficiency on the highways of the Commonwealth, the Research Council undertook a study to evaluate the MPM pattern.

The final report of this study consists of two volumes. This first volume documents —

1. the methodology used in carrying out the study;
2. the results from an analysis of data collected;
3. a description of the models developed for minimum passing sight distances and minimum lengths of passing zones;
4. recommended guidelines for establishing passing and no-passing zones; and
5. the expected consequences of implementing the recommendations.

Volume II gives —

1. a detailed statistical analysis of the collected data;
2. the step-by-step development of the kinematic pass model and the multiple linear regression model;
3. the development of the suggested requirements for passing zones and passing sight distance; and
4. an analysis of headway distributions in queues.

PURPOSE AND SCOPE

The purpose of the study was to determine whether the MPM should be replaced with the standard MUTCD marking patterns or some other marking system, and, if so, to recommend guidelines that could be used by the Department of Highways and Transportation to determine the appropriate marking pattern. Emphasis was placed on a comparison of the effects of the MPM and the standard MUTCD markings on the safety and operational aspects of travel such as vehicle speeds, volumes, and passing maneuvers. The objectives of the study were to —

1. examine the public's interpretation of the road marking and signing systems;
2. determine the safe and acceptable passing distances;

3. outline the legal implications of using a non-MUTCD roadway signing system;

4. determine if significant differences exist between the observed operational and safety characteristics for the MPM and the MUTCD marking pattern; and

5. make recommendations that could be used to determine appropriate marking patterns.

The scope of the study included a literature review, a questionnaire survey of marking practices in other states, data collection on selected two-lane highways in mountainous areas, and a motorist opinion survey.

METHODOLOGY

The study methodology entailed the following tasks.

Literature Survey

A literature survey was conducted through the facilities of the University of Virginia and the Virginia Highway and Transportation Research Council. Also, contacts were made and reports were collected through the Texas Transportation Institute and the Federal Highway Administration. Reports on completed studies concerning passing maneuvers were reviewed taking cognizance of the peculiarity of the passing maneuvers undertaken on two-lane, two-way highways in mountainous areas.

Questionnaire Survey of Marking Practices in Other States

A questionnaire survey was designed to obtain information on roadway markings and signing practices used for two-lane highways in mountainous areas in other states. Information was also sought on the types of non-MUTCD sanctioned marking patterns that have been used by other states to determine the associated advantages and disadvantages in using non-MUTCD marking patterns (see Appendix A). Completed questionnaires were returned by the District of Columbia, Puerto Rico, and all states except Nevada and Mississippi.

Inventory of MPM in Virginia

A list of the Virginia roads on which the MPM has been used and the locations of these markings was compiled. The information for this inventory was obtained from the Department's district traffic engineers (see Appendices B, C, and D).

Site Selection

Using the inventory prepared, several visits were made to the counties having roads marked with MPM to identify suitable sites for data collection. The selection of the sites were based on:

1. Traffic volume — each study site should have an average daily traffic greater than 1,000 to facilitate the collection of adequate data on traffic characteristics.

2. Operating speeds — the sites should reflect the range of operating speeds on highways bearing the MPM.

3. Number of passing maneuvers — each site should offer a reasonable chance for an adequate number of passing maneuvers to be recorded during the study.

Using the above criteria, sections of Route 501 in Bedford County (S-1), Route 311 in Roanoke County (S-2), Route 220 in Alleghany County (S-3), Route 130 in Amherst County (S-4), Route 116 in Franklin County (S-5), and Route 39 in Bath County (S-6) were selected as the study sites.

Motorist Opinion Survey

A motorist opinion survey was conducted at the study site on Route 130. The questionnaire was designed to determine if motorists correctly interpret the meaning of the markings and the supplemental signs (see Appendix E). Drivers' opinions of the centerline pattern were also requested.

The survey was conducted by stopping and interviewing a randomly selected number of drivers. Route 130 was selected for the survey as it has geometric characteristics typical of two-lane, two-way roads in mountainous areas and has a long continuous stretch in the Lynchburg District striped with MPM and a similar section in the Staunton District striped with the standard MUTCD markings.

Field Studies

The field studies were the major activity and were conducted to determine the operational effects of the MPM (before study) and the standard MUTCD marking patterns (after study). The before data were collected at the six study sites, and were used in developing the guidelines for establishing passing and no-passing zones.

Two of the sites, S-1 on Route 501 and S-5 on Route 116, and a new site, S-5A on Route 116 near site S-5, were then re-marked in accordance with the MUTCD marking patterns for passing and no-passing zones using the guidelines developed in the study. Data for the after study were then collected after allowing a period of a few weeks for motorists to get acquainted with the new markings.

Data Collection

Data collection consisted of two major tasks: the collection of traffic flow data with an electronic traffic data acquisition system and the filming of passing maneuvers with a 16-mm movie camera.

The traffic data recorder made by Leupold and Stevens, Inc. was used for the first task. Operational data such as traffic volumes, vehicle speeds, headways, traffic queues, and vehicle classifications were collected for at least 24 continuous hours during Tuesday through Thursday.

For the second task, the Canon Scoopic 16 MS 16-mm movie camera was employed. The camera was placed at a point from which the centerline pavement marking was clearly visible. A film speed of 24 frames per second was used with Kodak Ektachrome film 7241EE (ASA 80) on 100-ft. rolls.

Passing maneuvers were photographed with a zoom lens (12.5 mm - 75 mm) that allowed the camera operator to have a full field of view at all sites. The camera positions were selected carefully at each site so that the camera was placed on an extension of the tangent portion of each site. Twenty-five rolls (2,500 feet) of film were used to record passes for the before study and four rolls (400 feet) for the after study.

Data Reduction

To reduce the traffic flow data collected by the TDR, the software package traffic performance measures reporting system developed by Leupold and Stevens, Inc.[6] was used.

The events filmed with the 16-mm camera were examined with a photo-optical data analyzer that could change the speed of the film projection and provide the stop action necessary to extract the distance elements required for the analysis of passing maneuvers.

From the projections on a screen, the completed passes were identified using field notes and reduced traffic flow data. Only the 38 passes with the complete information required for the analysis were selected and the necessary distance elements were measured. Among the 38, two performed by motorcyclists were excluded since passes by motorcyclists, who generally complete a pass in a shorter distance than drivers of other vehicles, might bias the results. Four passes recorded on the downslope of site S-3 were also discarded. The remaining 32 passes were determined to be adequate for a minimum error on the mean passing distance of $\pm$ 6.5 ft. at the 95% confidence level.

Each selected pass was projected back and forth several times to ascertain the correct locations of the important vehicle positions. The measurements of centerline markings taken at the sites were used to obtain the required distance elements.

Development of Pass Models and Guidelines

A statistical and a kinematic pass model were developed. The former was derived by a stepwise multiple linear regression analysis on the data collected at the study sites. The latter was based on the theory of kinematics, although it incorporated statistical elements taken from the field data, and is called the modified kinematic pass model in this report because it was modified from a purely theoretical kinematic model. To expedite the computation of various cases, this kinematic pass model was programmed in FORTRAN IV for the CDC Cyber. It was found to reasonably approximate the actual passing maneuvers.

In order to incorporate the impact of grade upon the passing distance into the kinematic pass model, it was necessary to account for the acceleration capabilities of vehicles on gradients.

It was found that the data given in Acceleration and Passing Ability[7] of the Consumer Aid Series by the National Highway Traffic Safety Administration were adequate for general use, but not sufficient for the objectives of this study. In this reference, the conditions of the passing maneuver are set in advance and do not reflect passing maneuvers on mountainous roads. Therefore, the typical maximum acceleration rates given in the Transportation and Traffic Engineering Handbook were used for developing the kinematic pass model.[8]

The criteria and guidelines were, however, established on the basis of the actual data; i.e., the results of a stepwise multiple linear regression analysis. The reasonableness of the guidelines was double-checked using the data collected during the after study.

Accident Analysis

The safety aspects of MPM were examined through an analysis of reported accidents on several selected routes. The Summary of Accident Data[9] for 1979, 1980, and 1981, and the breakdown of accidents by type were used as the accident analysis data base. Particular emphasis was given to identifying accidents related to passing maneuvers.

Legal Issues

A review of federal and state codes and regulations was conducted to ascertain the legal implications of using a non-MUTCD-sanctioned pavement marking and signing system in mountainous areas. Also, state laws on no-passing zones were examined.[10]

ANALYSIS

The following subsections summarize the results of the analyses conducted on the data collected during the before study. The analytical results of the after study will be discussed later in another section.

Literature Survey

The literature survey undertaken during the study revealed that although there have been studies concerning the requirements for the length and sight distance for passing zones on two-lane, two-way highways, most of them have dealt in general with the passes performed on two-way highways with geometrically favorable conditions,(11,12) or with passes under experimental conditions. These conditions, however, do not prevail on roadways marked with MPM.

The summary presented here, however, particularly relates to the concept used for the MUTCD warrants for passing and no-passing zones and the practices for marking no-passing zones. A detailed literature review is found in reference 13.

The MUTCD Passing/No-Passing Zone Warrants

Section 3B-4 of the MUTCD states that "where the distance between successive no-passing zones is less than 400 ft., the appropriate no-passing marking (one direction or two directions) should connect the zones."(1) This statement can be interpreted as stating that the minimum length of a passing zone is 400 ft. Since the MUTCD does not specify any speed range for this value, the minimum passing zone of 400 ft. can be applied to any range of the 85th percentile operating speeds. The responses to the questionnaire survey of other states conducted in this study indicate that approximately 33% of the states follow this interpretation. Some states use minimum lengths longer than 400 ft., and others use lengths that vary according to the operating speeds as shown in Appendix A. However, studies have shown that the MUTCD sanctioned minimum passing zone substantially underestimates the distance required for a passing maneuver when the 85th percentile speeds are greater than about 50 mph.(11,12) Weaver and Woods, for example, suggest that where the distance between successive no-passing zones is less than 750 ft., the appropriate no-passing zone marking should connect the zones.(12)

Section 3B-5 of the MUTCD states that a no-passing zone at a horizontal or vertical curve is warranted where the sight distance is less than the minimum necessary for safe passing at the prevailing speed of traffic as given in Table 1. It should be noted that this requirement is based on different criteria from those used for the AASHTO passing sight requirements.(14)

TABLE 1

MINIMUM PASSING SIGHT DISTANCE
BY THE MUTCD

85th Percentile Speed (MPH)	Minimum Passing Sight Distance (Feet)
30	500
40	600
50	800
60	1,000
70	1,200

Source: Reference 1.

The forerunner of the MUTCD sight distance requirements is given in Table 2. These suggested minimum sight distances, given in reference 15, served as the basis for developing the MUTCD requirements. Note that the speed difference used in this case is not constant but increases as the assumed design speed of the road increases. Also, the speed of the oncoming vehicle is not the same as that of the passing vehicle, as is assumed in the AASHTO sight distance requirements.

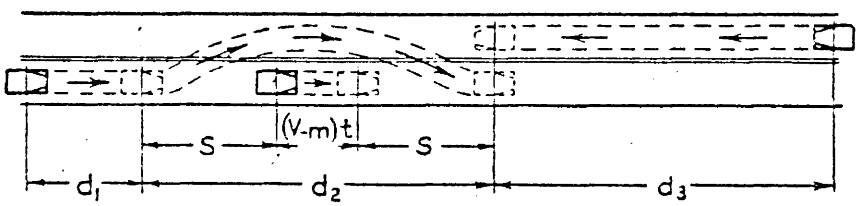
TABLE 2

SUGGESTED MINIMUM PASSING SIGHT DISTANCES
BY THE 1940 POLICY

Assumed Design Speed (V), mph	30	40	50	60	70
Speed Difference (m), mph	10	12.5	15	20	25
Assumed Oncoming Vehicle Speed (V_0), mph	25	32.5	40	47.5	55
Sight Distance for Flying Pass, ft.	440	550	660	660	660
Sight Distance for Delayed Pass, ft.	510	760	1,090	1,380	1,780
Suggested Minimum Sight Distance, ft.	500	600	800	1,000	1,200

Source: Reference 15.

The minimum passing sight distances specified by the MUTCD for striping no-passing zones are equal to the suggested minimum sight distances in Table 2, which are compromises between the minimum sight distances required for "flying" passes and those required for "delayed" passes.(15) Figure 2 also shows sight distance requirements for design purposes based on kinematic theory, as was developed by the AASHTO.(16) A comparison of the corresponding values in Table 2 and Figure 2 indicates that the suggested minimum sight distances given in Table 2 for speeds between 40 mph and 60 mph are approximately equal to the d_3 values given for the appropriate speeds in Figure 2. It should be noted, however, that the d_3 in Figure 2 is the distance travelled by the oncoming vehicle during the time the passing vehicle is on the left lane.(16)



PASSING ONE VEHICLE AT 10 M.P.H. LESS THAN ASSUMED DESIGN SPEED, V. (m = 10)

V	30	40	50	60	70
V-m	20	30	40	50	60
S=V-m+20	40	50	60	70	80
a (table 4)	2.6	2.1	1.7	1.3	1.0
$t=\sqrt{\frac{2.73\,S}{a}}$	6.5	8.1	9.8	12.1	14.8
$d_1=4.4(V-m)$	88	132	176	220	264
$d_2=2S+1.47(V-m)t$	270	455	696	1028	1460
$d_3=1.47\,Vt$	285	473	719	1068	1512
$d=d_1+d_2+d_3$	643	1060	1595	2316	3236
Rounded	600	1100	1600	2300	3200

FIGURE 2. TYPICAL PASSING SIGHT DISTANCE CALCULATIONS. (REPRINTED FROM REFERENCE 16 , P. 9.)

Marking No-Passing Zones

Currently in Virginia, for roadways striped with the MUTCD marking patterns the double solid yellow line is used to stripe a no-passing zone using either the MUTCD requirements (see Table 1) or the sight distance requirements sanctioned by the Department (see Table 3), the latter of which are discretionally used in the districts of the Commonwealth.

TABLE 3

MINIMUM PASSING SIGHT DISTANCES
BY VDH&T

85th Percentile Speed (MPH)	Min. Passing Sight Distance (Feet)
30	1,000
40	1,200
50	1,600
60	2,000
70	2,400

NOTE: These requirements are discretionally used by the districts of Virginia. The MUTCD sanctioned minimum passing sight distances are used also.

Whenever the requirements for passing sight distances are compared and their adequacies or inadequacies discussed, the concept used to derive those requirements should be clearly stated, as passing sight distance requirements are established on either the long-zone or short-zone concept. The current MUTCD minimum passing sight distance requirements for marking a no-passing zone are based on the short-zone concept. Under this concept the passing vehicle must return to the right lane prior to or at the beginning of the double solid yellow line indicating the commencement of a no-passing zone. Consequently, the passing driver must decide either to complete or to abort a pass at a position upstream of traffic where either maneuver can safely bring him back in the right lane when the oncoming vehicle appears in sight. The long-zone concept permits the completion of a passing maneuver beyond the commencement of the marked no-passing zone.[17] It should be noted that under this concept the sight distances available at the start of the no-passing zone are obviously longer than those used for the short-zone concept, thus providing a buffer zone at the upstream end of the no-passing zone.[12]

Weaver and Woods suggest a demarcation system to denote this buffer zone, naming it the "advance dotted treatment."[12] This advance notification concept would provide the passing driver a passing sight distance based on the long-zone concept. At the same time it provides the short-zone concept for enforcement personnel.[12] This demarcation system was tested in pilot field studies,[17] and the final analysis was under way when this report was prepared.

The adoption of the long-zone concept, however, may create problems for enforcement when the buffer zone is striped with the solid yellow line. As far as enforcement personnel are concerned, the short-zone concept is preferred to the long-zone concept, since the former defines a distinct position where a passing driver should return to the right lane. The short-zone concept, therefore, ameliorates the subjectiveness in determining driver violation.[12]

Questionnaire Survey of States

A summary of the responses received from the District of Columbia, Puerto Rico, and forty-eight states which returned completed questionnaires is given on pages A-6 through A-8 of Appendix A. In response to the question relating to the use of MUTCD standard pavement markings, about 76% of those who responded stated that they always specifically adhere to the MUTCD standards, while the remaining 24% stated that they use these standards in most cases. Four states — Arkansas, Hawaii, Massachusetts, and California — use special pavement markings on two-lane highways in mountainous areas.

In cases when operational or safety problems may arise because of the existence of several miles of continuous no-passing zones on two-lane highways, about 71% of the states will carry out some reconstruction to alleviate the problem rather than use special pavement markings as is done in Virginia. The reconstruction may be either the provision of climbing lanes or a realignment of a section of the highway. About 14% of the states will either increase law enforcement to reduce illegal passing maneuvers or erect special signs. However, no specific or special problems were reported by states which have long distances of two-lane highways marked as no-passing zones.

In response to the question on whether passing and no-passing zones are marked in accordance with the minimum passing sight distances given in the MUTCD, 45 of the respondents indicated that the minimum passing sight distance requirements in their states are in accordance with the guidelines given in the MUTCD, while 4 states have standards which vary from the MUTCD, considering additional factors such as grades and high percentages of slow-moving trucks.

The information obtained from the survey of the states clearly indicates that the use of non-MUTCD markings is not a common practice, and that no serious problems have been observed where long distances of no-passing zones have been marked on two-lane, two-way highways because of inadequate sight distances.

Motorist Opinion Survey

Table 4 summarizes the results of the motorist opinion survey conducted on Route 130, which included information on vehicle registration, frequency of travel on the test route, trip purpose, delay as perceived by the drivers, frequency at which drivers pass vehicles moving in the same direction at no-passing zones, and the necessity for marking passing/no-passing zones at the study sites. The summaries given in Table 4 are based on 207 usable completed questionnaires. This represents about 17% of the average daily traffic on Route 130. The maximum error for this sample size is ± 6.8% at the 95% confidence level.

Vehicle Registration

Table 4 (a) shows the states of registration for the vehicles driven by the motorists interviewed. This summary indicates that a high percentage (75.5%) of the vehicles traveling on the study site were registered in Virginia.

Frequency of Travel

Table 4 (b) gives the frequency at which the motorists interviewed travelled on the road. The results indicate that only about 50% of the drivers travelled on this road on a regular basis, and about 15% were using the road for the first time on the day of the interview. This suggests that it is desirable to use standard markings and signs on the road in order to accommodate the significant percentage of drivers who do not regularly use the road.

Trip Purpose

Approximately 53% of the motorists interviewed travelled the study site for business purposes as shown in Table 4 (c). The next major trip purpose was recreation, at about 25%, followed by work trip at about 17%. It should be noted that the percentage of recreational trips was quite substantial despite the fact that the survey was conducted on a weekday. This is because Route 130 goes through the vicinity of Natural Bridge, a popular recreational site.

Perceived Delay

Table 4 (d) summarizes the responses relating to delay. Approximately 17% of the motorists interviewed indicated that they had experienced delay within 2 miles of the study site. About 60% of those who had experienced a delay attributed it specifically to slow-moving vehicles, whereas 40% of them attributed it to curves. Among those who had experienced delay, only about one-third felt that the delay was either excessive or moderate.

The analysis of the responses also showed that only about 18% of the regular users (daily and 2-3 times a week) indicated that they had experienced delay. It can, therefore, be said that delay was not considered to be a serious problem by the majority of motorists.

Frequency of Passing

A summary of the responses obtained from motorists on how often they passed vehicles moving in the same direction is shown in Table 4 (e). This indicates that nearly 40% of the interviewed motorists never passed and only about 11% regularly undertook a passing maneuver. This suggests that although the provision of the MPM makes it legal for one to undertake a passing maneuver on long stretches of this road, very few motorists do so.

TABLE 4

SUMMARY OF THE MOTORIST OPINION SURVEY ON ROUTE 130

(a) Vehicle Registration

State	Percent of Vehicles
Virginia	75.5
North Carolina	4.9
West Virginia	2.5
Tennessee	1.6
Others	8.8
No Response	6.7
	Total 100.0

(b) Frequency of Travel on Test Section

Frequency	Percent of Drivers
Daily	29.4
2 - 3 Times Weekly	18.6
2 - 3 Times Monthly	17.2
Rarely	18.6
First Time	14.7
No Response	1.5
	Total 100.0

(c) Trip Purpose

Purpose	Percent of Drivers
Work	16.6
Business	53.4
Shopping	1.5
Recreation	24.6
Others	3.9
	Total 100.0

TABLE 4 CONTINUED

(d) Causes and Degree of Delay

Delay Characteristics		Percent of Drivers
1. Perception of Delay	a. Perceived delay	17.2
	b. Did not perceive delay	82.8
	Total	100.0
2. Reasons for Delay	a. Slow moving Vehicles	
	o Cars	0.5
	o Trucks	9.8
	b. Curves	6.9
	c. Not applicable	82.8
	Total	100.0
3. Degree of Delay	a. Excessive	0.5
	b. Major	0.5
	c. Moderate	2.0
	d. Minor	2.5
	e. No response	11.7
	f. Not applicable	82.8
	Total	100.0

(e) Frequency of Passes

Frequency	Percent of Drivers
Daily	1.5
Several Time a Week	9.3
Rarely	47.1
None	39.7
No Response	2.4
Total	100.0

Provision of Passing and No-Passing Zones

Motorists were also asked whether they thought it was necessary for passing and no-passing zones to be clearly marked on the highway. An analysis of the responses showed that about 78% of them thought that it was important that the zones be clearly marked, while only 19% indicated that it was not important. The remaining 3% either had no opinion or were not sure. This suggests that the standard MUTCD marking system for the designation of passing and no-passing zones will be welcomed by the majority of motorists using two-lane, two-way highways in mountainous areas.

Field Studies

The field studies were of the before and after type. In the before study, data were collected at the study sites with the MPM, whereas for the after study, two of the sites and a newly selected site were re-marked with the MUTCD marking patterns, using the guidelines developed in the study. In this section, the results of the analysis on the before data will be presented, as they are used to develop the proposed guidelines presented. The results of the analysis on the after data will be given later when a comparison of these two data sets is made.

Description of Study Sites

The locations of the selected study sites are given in Table 5 and descriptive data in Table 6. Figure 3 provides panoramic views.

Site S-1 on Route 501 has a sag-shaped vertical alignment that differentiates it from the rest of the sites. The horizontal curvatures on its approaches are quite mild compared with those of the rest of the sites, except site S-2 on Route 311. Also, it has a relatively longer sight distance, which permits motorists to drive at a higher speed.

Site S-2 has a very steep grade, with mild horizontal curvatures on both approaches. At this site most of the passes were started on the steepest upgrade portion at the entrance of the site and completed just before or after a low crest caused by the succeeding milder grade, which is located approximately in the middle stretch of the site.

TABLE 5

LOCATIONS OF STUDY SITES

Site No.	Route Number	County/District	Location
S-1	Rte. 501	Bedford/Salem	7.1 Mi. North of NCL of Lynchburg
S-2	Rte. 311	Roanoke/Salem	2.0 Mi. East of Catawba
S-3	Rte. 220	Alleghany/Staunton	2.0 Mi. North of the junction with Rte. 687
S-4	Rte. 130	Amherst/Lynchburg	1.7 Mi. West of Snowden
S-5	Rte. 116	Franklin/Salem	At the junction with Rte. 681
S-6	Rte. 39	Bath/Staunton	10.3 Mi. North from the junction with Rte. 220

TABLE 6

GENERAL CHARACTERISTICS OF STUDY SITES

Site No.	Average Daily Traffic[a]	Posted Speed Sign (MPH)	Available Site Distance (Ft.)[b]	Grade (%)	Pavement Width (Ft.)[c]
S-1	1,490	55[d]	1,420	NB = -6.5 ~ + 3.2 SB = -3.2 ~ + 6.5	NB = 10.3 SB = 10.3
S-2	2,695	45[e]	900	WB = +7.8 EB = -7.8	WB = 12.0 EB = 10.8
S-3	1,865	35[e]	800	NB = +5.4 SB = -5.4	NB = 9.6 SB = 9.0
S-4	1,210	35[e]	720	EB = -4.3 WB = +4.3	EB = 9.8 WB = 9.7
S-5	2,840	25[e]	1,060	NB = -7.0 SB = +7.0	NB = 10.3 SB = 10.0
S-6	1,065	30[e]	980	Approx. Level	NB = 9.3 SB = 9.3

[a]These values were taken from Reference 9.

[b]Maximum available sight distance in feet.

[c]Measurements were taken at the switches of the traffic recording device.

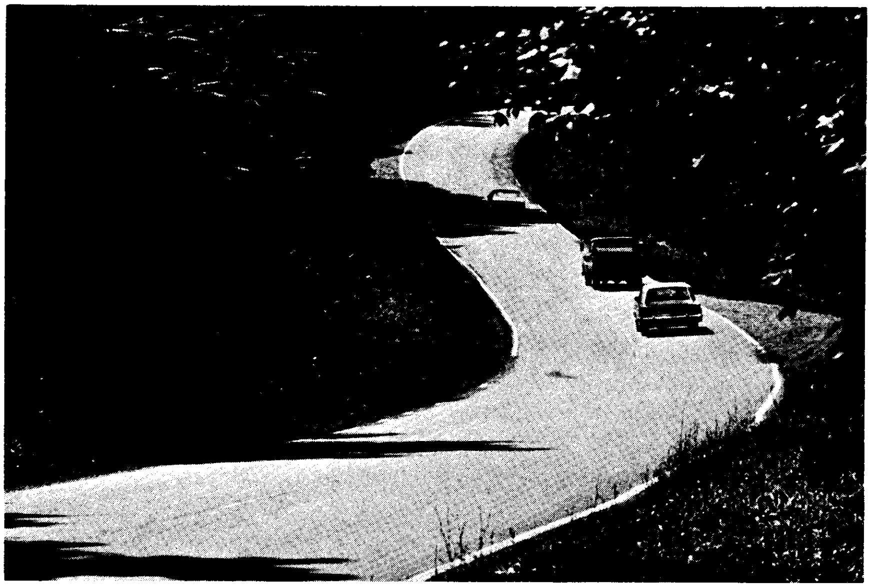
[d]Regulatory sign (black and white).

[e]Warning sign (black and yellow) indicating the maximum safe speed for the curve ahead.

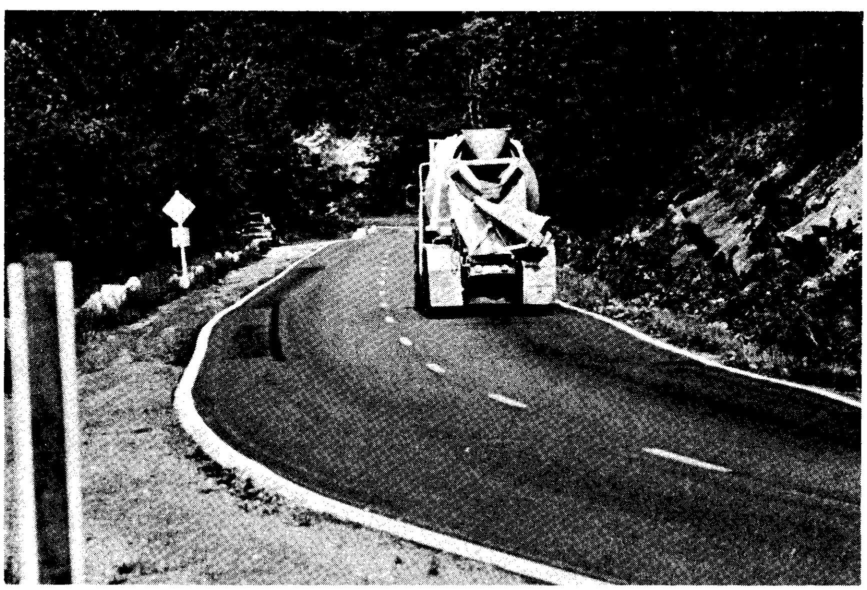
Sites S-3 and S-4 have relatively short sight distances (700 ft. to 800 ft.), flanked by sharp horizontal curves on both approaches.

Site S-5 provides probably the best condition for investigating the passing maneuver on mountainous roads. This site has a moderate sight distance, steep grade, and sharp curves on both approaches.

Site S-6 was eventually excluded from the analysis because of the low traffic volume and the low number of passes recorded during data collection.



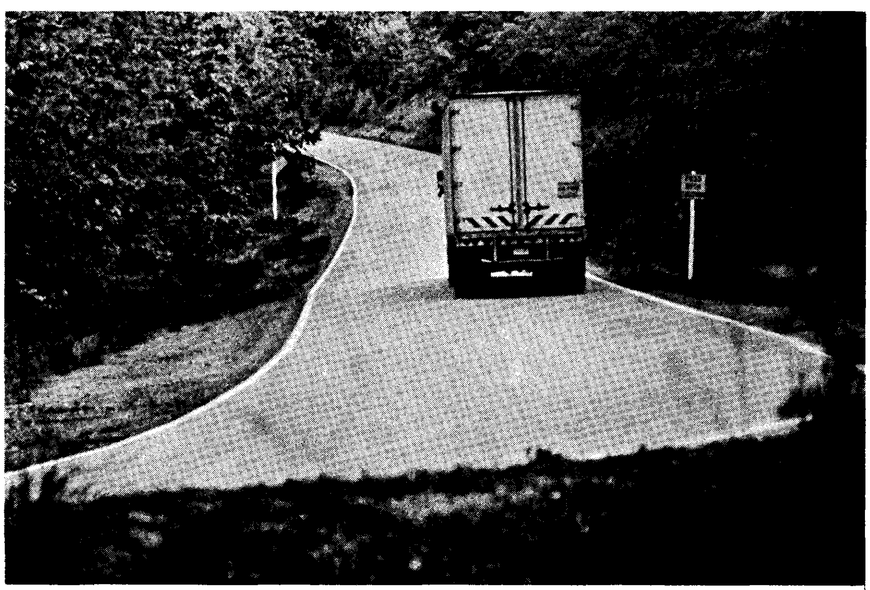
Site — 1 on Route 501.



Site — 2 on Route 311.

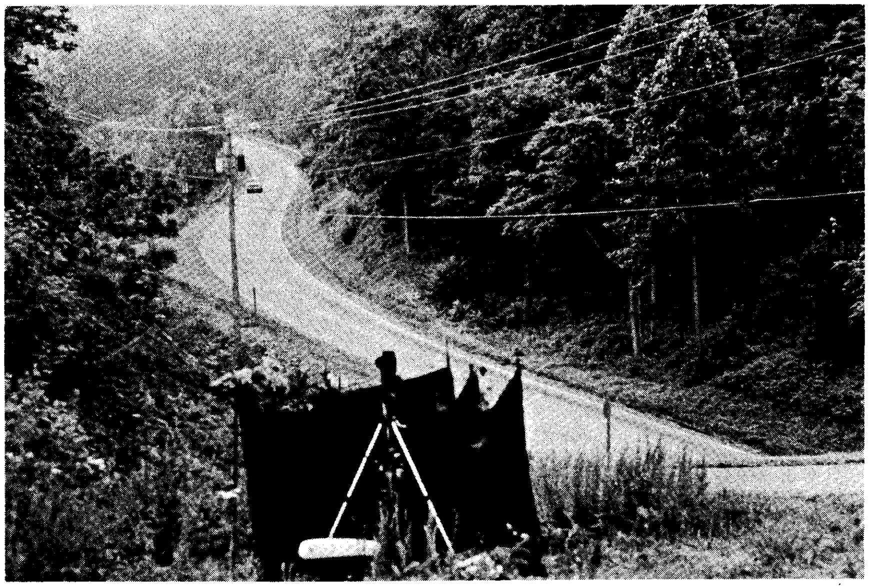
FIGURE 3. PANORAMIC VIEW OF THE STUDY SITES.

Site 3 on Route 220.

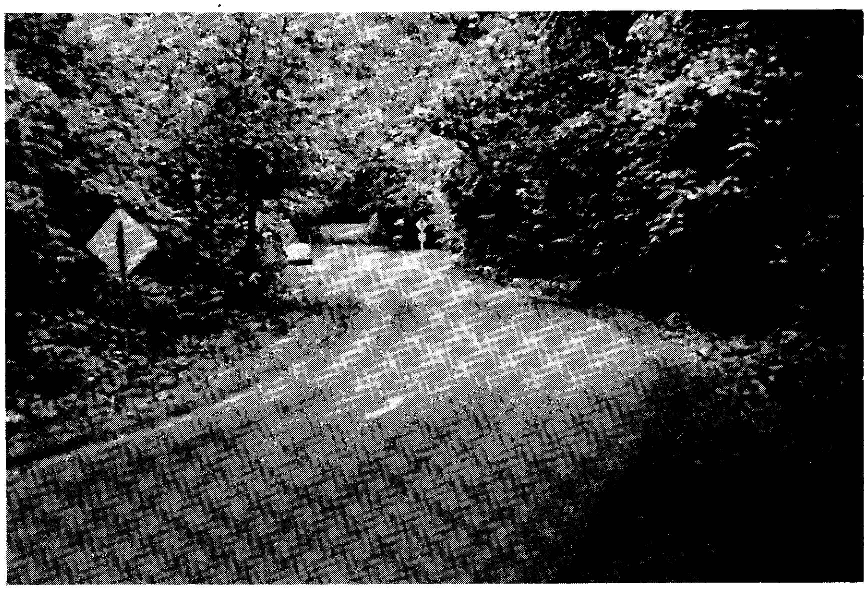


Site 4 on Route 130.

FIGURE 3 CONTINUED.



Site 5 on Route 116.



Site 6 on Route 39.

FIGURE 3 CONTINUED.

Traffic Operating Characteristics

The analysis on traffic operating characteristics was undertaken for the elements listed below. A detailed discussion on these elements is found in Volume II of this final report.

- Traffic volume
- Traffic mix
- Operating speed
- Queueing characteristics
- Speed difference between the opposite lanes
- Speed difference between passing and impeding vehicles
- Speed of passing vehicle and 85th percentile operating speed

Traffic Volume. As shown in Tables 6 and 7, the traffic volumes were quite low on these roadways. The AHT for selected time periods were in most cases less than 100 vehicles per hour. Only sites S-2 and S-5 had distinct peak hour volumes as shown in Table 7. The peak hour traffic consisted mainly of commuters to the cities nearby.

Traffic Mix. Table 8 shows the percentage traffic mix at the study sites. Vehicles with three or more axles, "trucks" and "tractor trailers" together, represented from about 2% on Route 116 to about 20% on Route 130.

Operating Speed. The mean, 85th percentile, and 15th percentile speeds at the study sites are summarized in Table 9. The table shows that apart from S-1, which has a relatively long sight distance, the 85th percentile speeds were approximately between 40 and 50 mph and that the mean speeds were between 35 and 45 mph. The 15th percentile speeds were in the range of 30 and 40 mph. These data suggest that the requirements for passing and no-passing zones on two-lane, two-way highways in mountainous areas should be developed for operating speeds ranging from 30 mph to 50 mph. On the average, the speed difference between the 85th and 15th percentile speeds was 10 mph at the study sites.

TABLE 7

AVERAGE HOURLY TRAFFIC VOLUMES FOR SELECTED TIME PERIODS

Time Period	S - 1[a] on Rte. 501		S - 2[b] on Rte. 311		S - 3[c] on Rte. 220		S - 4[d] on Rte. 130		S - 5[e] on Rte. 166		S - 6[f] on Rte. 39	
	NB	SB	EB	WB	NB	SB	EB	WB	NB	SB	EB	WB
6:00 - 8:00	34	45	219	42	21	18	36	25	191	24	10	67
8:00 - 10:00	33	45	99	75	27	25	35	43	72	38	16	24
10:00 - 14:00	35	29	71	71	44	39	38	36	47	44	16	15
14:00 - 16:00	45	40	102	118	42	48	50	48	52	51	13	13
16:00 - 18:00	59	41	86	196	52	51	46	49	55	167	65	33

Average hourly traffic volumes were computed based on the data collected on:

[a]September 29-30, 1981

[b]June 2-3, 1982

[c]October 14-15, 1981

[d]September 9-10, 1981

[e]June 8-9, 1982

[f]May 25-26, 1982

All days were clear and dry.

TABLE 8

TRAFFIC MIX AT STUDY SITES

Site No.	Route Number	Direction	Cars[a] (%)	Trucks[b] (%)	Tractor Trailer[c] (%)	Total (%)
S - 1	Rte. 501	NB SB	87.6 95.3	9.5 2.7	2.9 2.0	100.0 100.0
S - 2	Rte. 311	EB WB	96.1 94.4	2.9 4.6	1.0 1.0	100.0 100.0
S - 3	Rte. 220	NB SB	94.6 93.9	2.7 2.7	2.7 3.4	100.0 100.0
S - 4	Rte. 130	EB WB	81.7 77.1	6.2 10.7	12.1 12.2	100.0 100.0
S - 5	Rte. 116	NB SB	98.4 95.4	1.2 4.5	0.4 0.1	100.0 100.0
S - 6	Rte. 39		----	omitted ----		

[a] Cars = 2-axle vehicles

[b] Trucks = 3- or 4-axle vehicles

[c] Tractor trailer = 5-axle vehicles

TABLE 9

MEAN, 85th PERCENTILE, AND 15th PERCENTILE SPEEDS AT STUDY SITES.

Site No.	Route Number	Direction	Mean Speed (MPH)	85th Percentile Speed (MPH)	15th Percentile Speed (MPH)
S-1	Rte. 501	NB	47.5	54.0	40.5
		SB	47.0	54.0	39.5
S-2	Rte. 311	EB	43.5	48.5	37.5
		WB	42.0	46.5	34.0
S-3	Rte. 220	NB	41.0	46.0	35.5
		SB	42.5	48.0	36.5
S-4	Rte. 130	EB	39.5	45.0	32.5
		WB	36.5	40.5	30.0
S-5	Rte. 116	NB	44.5	49.5	38.0
		SB	37.5	42.0	32.0
S-6	Rte. 39	EB	47.5[a]	53.0[a]	41.0[a]
		WB	42.5	48.0	35.5

NOTE: Based on the cumulative percentage curves given in Volume II.

[a]These might have been biased by the motorists (construction workers of the nearby hydroelectric dam project) during the evening peak hours, since they had known that the data collection was under way.

Queueing Characteristics. A queue was defined in this study as two or more vehicles traveling in the same direction, with a maximum headway of six seconds between any two consecutive vehicles. Table 10 summarizes the queueing characteristics of the sites. It is obvious that the average number of queues per hour increased along with the increase in traffic volumes. Apart from site S-1, the average queue speeds ranged from about 35 mph to 45 mph. The lowest, recorded for the west lane of Route 130, may have reflected the relatively high percentage of multi-axle vehicles on this upgrade. As would be expected, the average queue speeds on upgrades were lower than those on downgrades. The average number of vehicles per queue was approximately 2.5.

Speed Difference Between Opposite Lanes. The difference in speeds between opposite lanes on most two-lane, two-way highways is not sufficiently great to be considered in the determination of minimum passing sight distances. However, for two-lane, two-way highways in mountainous areas, the speed difference between the upgrade and downgrade may be large enough to warrant consideration.

To determine whether there was a significant difference between the speeds on the opposite lanes, means test for two independent samples with the standard deviations known was used. At the 95% confidence level, the speed difference on the upgrade and downgrade was not significant at sites S-1 and S-4, which have grades of 3.2% and 4.3%, but was significant at sites S-2, S-3, and S-5 with grades of 7.8%, 5.4%, and 7.0%, respectively. The maximum speed difference between the opposite lanes was 7.0 mph.

Speed Difference Between Passing and Impeding Vehicles. The speeds of impeding vehicles varied from 15 mph to 45 mph, whereas those of the passing vehicles ranged from 30 mph to 64 mph. These findings indicate that because of the geometric conditions of the roadway at these sites, motorists will not likely attempt to pass if their desired speed is less than 30 mph.

TABLE 10

QUEUEING CHARACTERISTICS

Site No.	Route Number	Direction	Avg. Number of Queue per Hour	Avg. Number of Vehicles per Queue	Avg. Queue Speed (MPH)
S - 1	Rte. 501	NB SB	5.2 3.6	2.4 2.4	46.0 48.0
S - 2	Rte. 311	EB WB	21.4 19.5	2.6 2.8	44.4 39.5
S - 3	Rte. 220	NB SB	7.3 4.7	2.5 2.4	41.9 39.9
S - 4	Rte. 130	EB WB	3.7 4.4	2.4 2.2	38.4 34.0
S - 5	Rte. 116	NB SB	14.2 13.3	2.5 2.5	44.0 36.8
S - 6	Rte. 39		---- omitted ----		

NOTE: The values shown in the table were obtained from the samples taken from the time groups:

8:30 - 18:30 for sites S - 1, S - 3, and S - 4

6:30 - 18:30 for sites S - 2 and S - 5

Figure 4 shows the cumulative distribution curve of the speed differences between passing and impeding vehicles. As shown in the figure, approximately 62% of the passing vehicles passed the impeding vehicles with a speed difference at or greater than 15 mph. This may indicate that motorists tend to aim at a higher desired passing speed on mountainous roads with limited sight distance than on non-mountainous roads with higher sight distances in order to complete the pass in the shortest possible distance. The AASHTO Blue Book employs a constant 10 mph as the speed difference for computing passing sight distances for any speed range.(14)

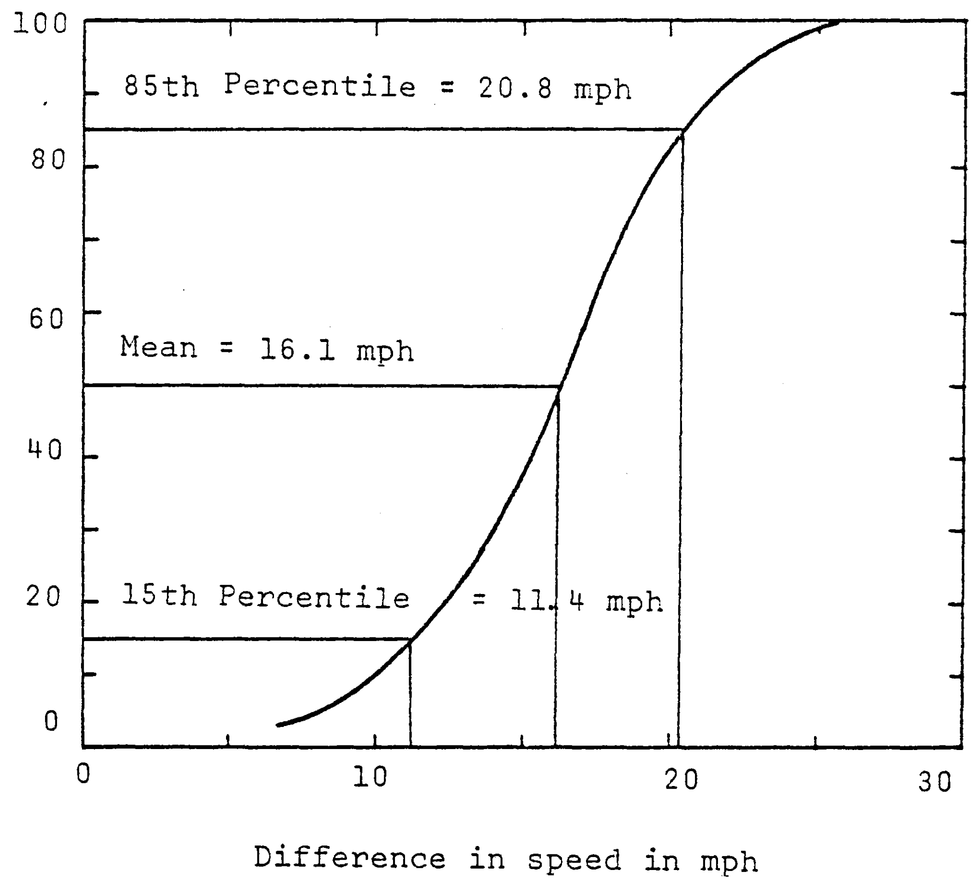


FIGURE 4. CUMULATIVE DISTRIBUTION OF SPEED DIFFERENCE BETWEEN PASSING VEHICLE AND IMPEDING VEHICLE.

Passing Speed vs. Off-Peak 85th Percentile Speed. The MUTCD employs the off-peak 85th percentile speed as a variable to compute minimum passing sight distances.[1] Table 11 shows that this general assumption is also reasonable for two-way highways in mountainous areas.

Table 11

SPEED OF PASSING VEHICLE VS. OFF-PEAK 85TH PERCENTILE SPEED

Site No.	Mean Speed of Passing Vehicles, mph	Off-Peak 85th Percentile Speed, mph
S-1	55.0	54.0
S-2	47.0	48.0
S-3	47.0	47.0
S-4	42.0	43.0
S-5	42.7	45.0

Accident Analysis

It was originally intended to determine whether there were any significant differences between passing related accident rates on sections of roads striped with MPM and similar rates on adjacent sections of the same roads striped with MUTCD markings. This would have facilitated a direct comparison, since the influences of other variables would have been eliminated to a certain extent. It was, however, impossible to undertake this analysis because there were inadequate data on passing related accidents for each site. It was, therefore, decided to compare the passing related accident rate for all sections of roads striped with MPM with that for all sections of road striped with the MUTCD markings within each district. Although this analysis did not lead to definite conclusions on the influence of the type of centerline marking on the occurrence of passing related accidents, as the influence of other factors was not eliminated, it is the opinion of the authors that the results do give broad indications of the influence of the type of centerline marking.

Accident analyses using the student t-test were conducted for the following cases.

- Passing related accidents on sections of road with MPM vs. passing related accidents on sections of road with MUTCD marking. These accidents involved at least one passing maneuver.

- Total accident rates on sections of roads with MPM vs. total accident rates on sections of road with MUTCD marking.

Summaries of the accident analyses are shown in Tables 12 and 13. These results do not indicate that there are any reasons to assume that accident rates are higher on the sections striped with MPM.

TABLE 12

Pass Related Accident Rate : MPM Sections vs. Adjacent MUTCD Sections

District	MPM Sections			MUTCD Sections			Computed t-Scores	Degrees Freedom	Significance Test At α =-0.05[a]
	N_1	X_1[b]	S_1[b]	N_2	X_2[b]	S_2[b]			
Bristol	28	9.73	10.68	28	9.39	13.14	0.104	54	Not Significant
Lynchburg	5	2.62	5.86	7	7.94	6.30	1.355	10	Not Significant
Salem	23	8.75	10.43	20	9.27	17.50	0.117	41	Not Significant
Staunton	13	3.55	10.82	8	8.13	7.85	0.990	19	Not Significant

a The two-tail t-test was performed.

b In accidents per 100 million vehicle miles of travel.

N = Number of samples, $\overline{X}$ = mean, S = standard deviation.

TABLE 13

TOTAL ACCIDENT RATES: MPM SECTIONS VS. ADJACENT MUTCD SECTIONS

(AVERAGE 1979 - 1980)

District	MPM Sections			MUTCD Sections			Computed t-Scores	Degrees Freedom	$T_{.05}$	Significance Test At $\alpha = 0.05$[a]
	N_1	X_1[b]	S_1[b]	N2	X_2[b]	S_2[b]				
Bristol	28	306	179	28	270	213	0.555	54	2.021	Not Significant
Lynchburg	5	355	202	7	238	128	1.116	10	2.228	Not Significant
Salem	23	329	230	20	291	217	0.552	41	2.021	Not Significant
Staunton	13	393	551	8	266	121	0.611	19	2.093	Not Significant

a The two-tailed t-test was performed.

b In accidents per 100 million vehicle miles of travel.
N = Number of samples, $\bar{X}$ = mean, s = standard deviation.

Legal Issues

The purpose of this part of the study was to determine whether Virginia or its employees could incur tort liability because of the Commonwealth's mountain marking policy. The analysis was based on the assumption that a plaintiff could show that the markings at an accident site were not in conformance with the MUTCD standard markings and that confusion created by the nonstandard markings was at least partially responsible for damages. A complete report on this analysis is given in Appendix F. The examination, however, led to the following conclusions.

1. Virginia's policy does not create a tort claim under federal law. Thus, a plaintiff would have to sue under the Virginia Tort Claims Act.

2. Because the Virginia Tort Claims Act has been in effect for a relatively short time, the Virginia courts have not had an opportunity to articulate how they will analyze acts of nonconformance to determine whether they amount to negligence. Virginia courts will choose between two alternatives: either the MUTCD will be viewed as establishing mandatory minimum standards or are such that nonconformance will be viewed as prescribing a desirable but noncompulsory standard such that the jury may consider the MUTCD standards as a yardstick in determining whether the degree of nonconformance amounted to negligence. Although other states have split over these two approaches, pre-VTCA decisions indicate that Virginia will adopt the latter view.

3. In regard to the reasonableness of the mountain marking policy, the state's case is bolstered to the extent that the policy was motivated by empirically established gains in traffic efficiency and safety. On the other hand, the state's case is hindered by the fact that Virginia did not follow MUTCD procedures for proposing and testing the new markings.

DEVELOPMENT OF MODELS

Two models for predicting passing distances were developed. One was based on a statistical analysis of the data collected during the before study. This involved an analysis of variance

(ANOVA) to determine the variables which significantly affect the passing distance and a stepwise multiple linear regression analysis on them. The other model was based on a theoretical kinematic analysis, and eventually was modified to reflect the results of a statistical analysis of the data obtained at the study sites. The proposed guidelines were, however, established from the model based on the stepwise multiple linear regression model because it conforms more accurately to the actual passing maneuvers observed at the study sites.

Factors Affecting Passing Distance

It was first necessary to determine which factors affect the passing distance (PD). The following four factors were examined for this study.

- Passing speed (PS)
- Available sight distance (ASD)
- Speed difference between passing and impeding vehicles (m)
- Grade (g)

The single factor (one-way) ANOVA was used for each variable as the limited spread of the available data did not permit a multifactor analysis. In order to reduce this interdependence of the variables, the study sites and the data were grouped into different treatments, as shown in Table 14, so that the impacts of one factor would prevail. A summary of one-way ANOVA for each factor is given in Table 15. As shown in the table, PS and ASD have a distinctively significant correlation with PD, whereas m and g have a moderately significant correlation with PD. It was, therefore, decided to consider these four factors in developing the pass models. As discussed later, it was found during the development of the pass models that g will not be a major factor as long as PS is lower than 50 mph and g is less than approximately 10%. It was also found that speed is related to ASD, which led to the exclusion of ASD from the model developed.

Analysis of Data on Passing Maneuvers

A major objective of this study was to investigate the passing maneuver performed in the geometrically restricted sections on two-lane, two-way highways in mountainous areas. In this subsection, the results of the analyses conducted on the distance elements of the filmed passing maneuvers and the factors affecting the passing maneuvers are presented.

TABLE 14

GROUPING OF THE DATA FOR ONE-WAY ANOVA

Factor	Treatment				
	1	2	3	4	5
Passing Speed (V)[a]	$V < 40$ mph	$40 \leq V < 45$ mph	$45 \leq V < 50$ mph	$50 \leq V < 55$ mph	55 mph $\leq V$
Available Sight Distance (ASD)[b]	Route 501 ASD = 1,400 ft. (m=avg.14.6 mph)	Route 8[e] ASD = 1,700 ft. (m=avg.16.0 mph)			
Speed Difference (m)[c]	$m < 15$ mph	$15 \leq m < 20$ mph	20 mph $\leq m$		
Grade (g)[d]	Route 130 & 220 g=+4.0~+5.5% (ASD=700~800 ft) (m=avg.17.5 mph)	Route 311 & 116 g=+7.0~+8.0% (ASD=900~1,100 ft) (m=avg.15.2 mph)			

[a] See Appendix B -1, Volume II.

[b] See Appendix B -2, Volume II.

[c] See Appendix B -3, Volume II.

[d] See Appendix B -4, Volume II.

[e] The data for Route 8 were taken from Reference 5.

TABLE 15

SUMMARY OF ONE-WAY ANOVA FOR FACTORS AFFECTING PASSING DISTANCE

Factor	Passing Distance		
	Computed F - Value	F_o - Value at $\alpha = 0.05$	Evaluation
Passing Speed	12.36	2.74	Significant
Available Sight Distance	10.22	4.13	Significant
Speed Difference	3.88	3.33	Significant
Grade	5.88	4.41	Significant

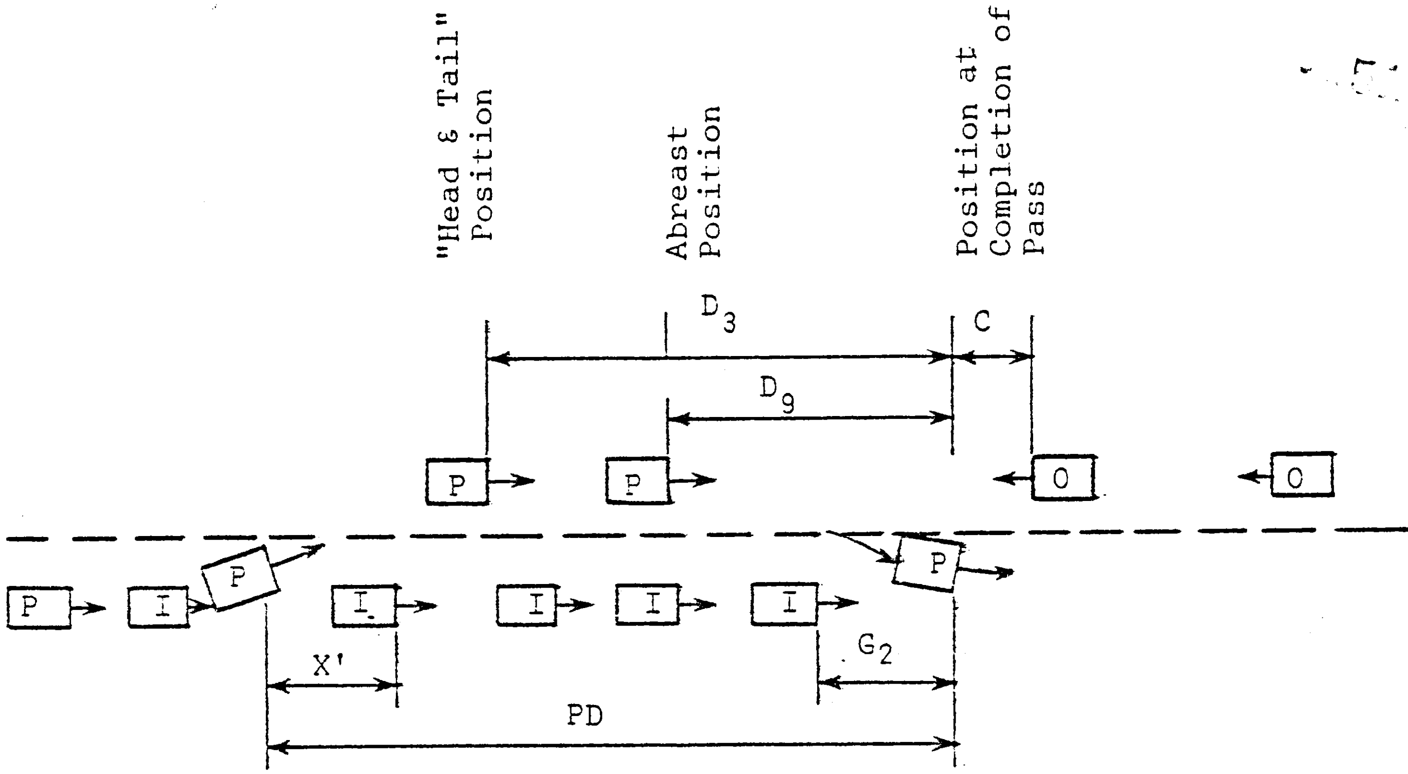
Figure 5 is a schematic presentation of the passing maneuver. Among the distance elements shown in the figure, PD, D_3, D_9, G_2, and X' are extracted from the passes filmed with the 16-mm camera. The definitions of these elements are shown in Figure 5. See Volume II for an in-depth discussion on this subject.

In this study, PD is defined as the distance through which the passing vehicle travels to complete a pass after it has encroached on the left lane; i.e., the distance through which the passing vehicle travels on the left lane with its body partially or completely in the left lane.

D_3 is the distance traveled by the passing vehicle to complete a pass after it has caught up with the impeding vehicle at the latter's rear bumper. The mean percentage of D_3 to the PD was found to be 69%, which is approximately equal to the 67% assumed by AASHTO for the distance traveled while the passing vehicle occupies the left lane.

D_9 is the distance traveled by the passing vehicle to complete a pass after it has become abreast of the impeding vehicle. Weaver and Woods state that this distance is approximately 2/3 PD.[12] In this study on passing maneuvers on two-lane highways in mountainous areas the mean percentage of D_9 to the PD turned out to be 56%, which is approximately 10% lower than the value stated by Weaver and Woods.

The after spacing (G_2) is the space headway that the passing vehicle maintains from the impeding vehicle when it completes a pass, whereas the before spacing (X') is the space headway that the passing vehicle retains just before it encroaches onto the left lane. The ratio of these two space headways was computed for several passing speeds as shown in Table 16. The ratio is directly related to the passing speed. The average ratio was approximately 0.70. Prisk's study reported that X' was approximately 0.65 of G_2.[18] Prisk also reported that the average before spacing was 54 ft. as compared with an 83 ft. after spacing.[18] In this study of mountainous highways an average of 56 ft. was obtained for the before spacing compared with an average of 79 ft. for the after spacing.



P = Passing vehicle

I = Impeding vehicle

O = Oncoming vehicle

PD = Passing distance — the distance traveled by the passing vehicle while it is on the left lane.

D_3 = Distance traveled by the passing vehicle from the "head and tail" position, where the passing vehicle catches up with the impeding vehicle, to completion of the pass.

D_9 = Distance traveled by the passing vehicle from the abreast position to the completion of the pass.

X' = Space headway retained by the passing vehicle just before it encroaches onto the left lane: before spacing.

G_2 = Space headway left for the impeding vehicle by the passing vehicle when it completes the pass: after spacing.

C = Clearance distance between the passing and oncoming vehicles at completion of passing maneuver.

FIGURE 5. DISTANCE ELEMENTS EXTRACTED FROM THE FILMS.

TABLE 16

RATIO OF THE SPACE HEADWAYS: $F_1 = X'/G_2$

Speed of Passing Vehicle (MPH)	$X'^a = F_1 G_2$ (ft)	$G_2{}^b$ (ft)	F_1
30	34	59	0.58
35	44	68	0.65
40	54	77	0.70
45	64	86	0.74
50	74	95	0.78
55	84	104	0.81

Average $F_1 = 0.71$[c]

[a] X' is the space headway that the passing vehicle maintains when it encroaches onto the left lane.

$X' = 1.99\, V - 25.30$
$r = 0.57$
(Correlation significant at $\alpha = 0.05$)

[b] G_2 is the space headway left for the impeding vehicle when the passing vehi completes the pass.

$G_2 = 1.80\, V + 4.96$
$r^2 = 0.50$
(Correlation significant at $\alpha = 0.05$)

[c] Prisk's study reports that X' is about two-thirds of G_2.(Reference 18)

Multiple Linear Regression Model

The results of the analysis of variance (ANOVA) indicated that each of the four variables considered — PS, ASD, g, and m — had some impact on PD. To determine and incorporate the relative importance of each of these variables, a stepwise multiple linear regression analysis was performed using the software package BMDP1R.[19] The analysis showed that PS had the greatest impact on PD, and was followed in order by ASD, m, and g. Further analysis also showed that for speeds less than 50 mph the effect of g on PD was negligible. As can be seen from Figure 6 the analysis also showed that multicolinearity existed amongst the variables, i.e., PS was related to ASD and g. This finding necessitated the exclusion of ASD and g from the model. The regression equation was, therefore, finally developed using the two major variables of PS and m. The equation thus obtained is

$$PD = 266.397 + 9.689 (V) - 12.448m ,$$

where

PD = passing distance in feet,

V = passing speed (off-peak 85th percentile speed) in mph, and

m = speed difference in mph .

Figure 6 shows partial printouts for this model. The coefficient of correlation is 0.77.

Kinematic Pass Model

A theoretical model based purely on kinematic theory was first developed, then modified by incorporating the data obtained on the space headway between the passing and impeding vehicles at the completion of the pass. The first model was developed based on the pass assumptions shown in Figure 7. An initial assumption made for this model was that the acceleration phase (D_1) would be performed entirely in the right lane and that the passing vehicle would encroach onto the left lane after completion of the acceleration phase. As given by this theoretical kinematic pass model,

		SPEED 1	PASSDIS 2	SITEDIS 3	GRADE 4	SPEDIF 5
SPEED	1	1.0000				
PASSDIS	2	.6222	1.0000			
SITEDIS	3	.6227	.7743	1.0000		
GRADE	4	-.1132	.2487	.3322	1.0000	
SPEDIF	5	.2187	-.3004	-.0693	.1463	1.0000

NOTE- PASSDIS(PASSING DISTANCE) IS THE INDEPENDENT VARIABLE

(A) CORRELATION MATRIX FOR SELECTED FOUR FACTORS

MULTIPLE R .7663 STD. ERROR OF EST. 77.1263
MULTIPLE R-SQUARE .5873

ANALYSIS OF VARIANCE

	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO	P(TAIL)
REGRESSION	245437.612	2	122718.806	20.630	.00000
RESIDUAL	172505.357	29	5948.461		

VARIABLE		COEFFICIENT	STD. ERROR	STD. REG COEFF	T	P(2 TAIL)	TOLERANCE
INTERCEPT		266.39701					
SPEED	1	9.68923	1.640	.722	5.909	.000	.952153
SPEDIF	5	-12.44834	3.320	-.458	-3.749	.001	.952153

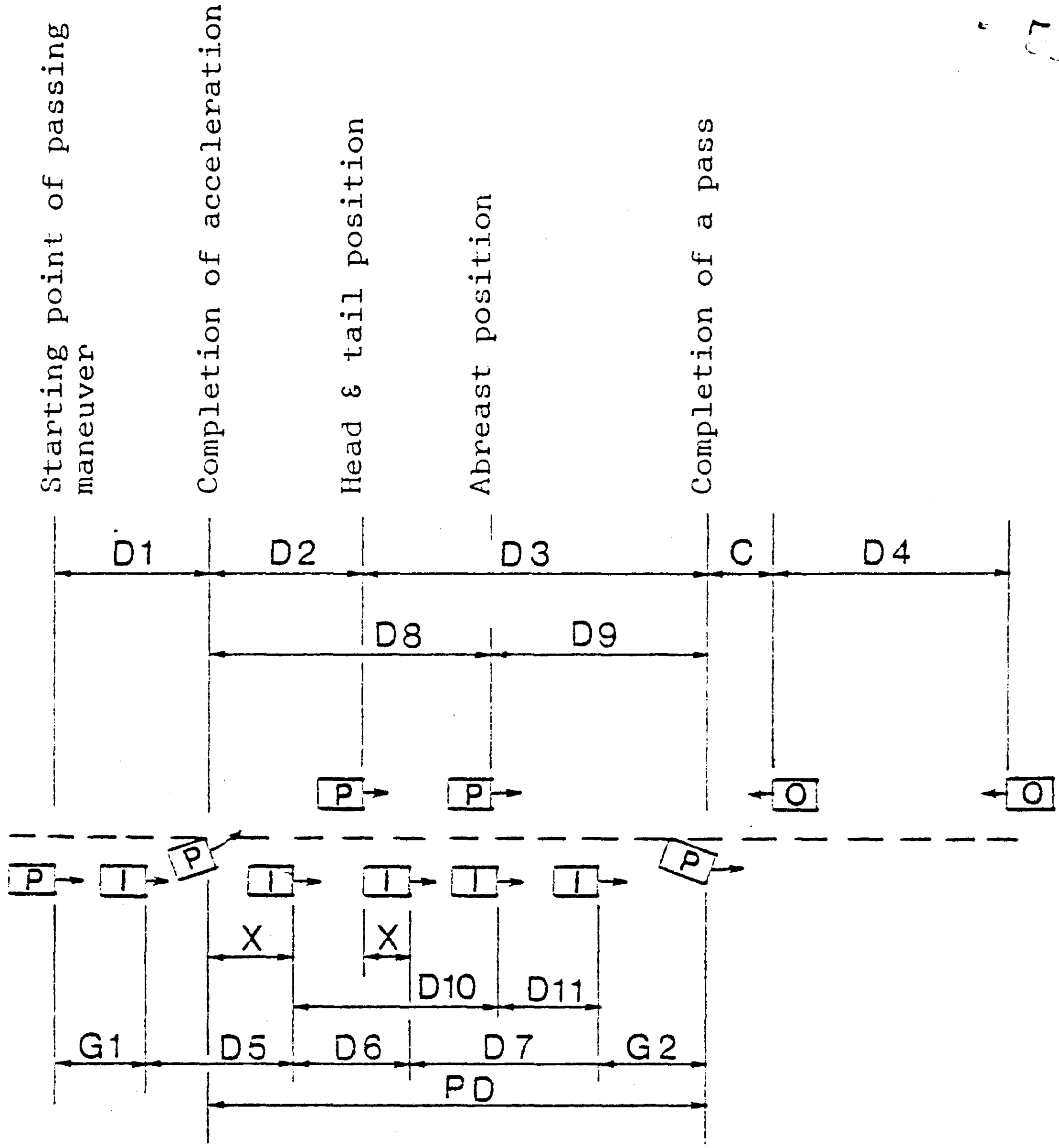
CORRELATION MATRIX OF REGRESSION COEFFICIENTS

		SPEED 1	SPEDIF 5
SPEED	1	1.0000	
SPEDIF	5	-.2187	1.0000

NOTE-
PASSDIS= 266.397 + 9.689 (SPEED) - 12.448 (SPEDIF)
OR PD= 266.397 + 9.689 (V) - 12.448 (M)

(B) REGRESSION MODEL USED TO DEVELOP GUIDELINES

FIGURE 6. RESULTS OF THE MULTIPLE LINEAR REGRESSION ANALYSIS ON PASSING DISTANCE.



P : Passing vehicle

I : Impeding vehicle

O : Oncoming vehicle

Note : The definitions of the distance elements are found in Appendix E, Vol. II.

FIGURE 7. PASS SCENARIO AND DISTANCE ELEMENTS OF THE PASSING MANEUVER.

$$PD = D_2 + D_3$$

(For the derivation of this model see Volume II)

$$= \frac{V}{m} (G_1 - \frac{m^2}{2\alpha} - X) + \frac{V}{m} (X + G_2) \ ,$$

where

- PD = passing distance in feet;
- V = passing speed in ft./sec.;
- m = speed difference in ft./sec. between passing and impeding vehicles when passing vehicle is in the left lane;
- α = acceleration in ft./sec.^{2};
- G_1 = space headway in feet between passing vehicle and impeding vehicle before the passing maneuver commences;
- G_2 = space headway in feet after the completion of a pass; and
- X = length of impeding vehicle in feet.

This model produces negative values for a distance element D_2. (See Volume II.) This suggests that the passing vehicle collides with the impeding vehicle during the acceleration phase, since the former is still traveling in the right lane based on the assumption made.

To alleviate this problem, the ratio (F_1) of the before spacing (X') was incorporated into the after spacing (G_2). The data taken in this study showed that X' was approximately 70% of G_2. The passes in this study were performed mostly by passenger cars. This meant that G_1 and G_2 were similar. Therefore, it was reasonable to say that X' be approximately 70% of G_1. For this reason, the modification was made based upon the following assumption:

$$F_1 = \frac{X'}{G_1} = \frac{X'}{G_2} \ .$$

In other words, the passing vehicle would encroach onto the left lane when the starting space headway (G_1) of the acceleration phase was shortened to approximately 70% of its distance ($0.70\ G_1$). Using this value, the modified kinematic model was developed as:

$$PD = \frac{m}{\alpha}\left(V - \frac{m}{2}\right) + \frac{V}{m}\left(2G_1 - \frac{m^2}{2\alpha}\right) - \left(V - m\right)\left(\sqrt{\frac{0.6G_1}{\alpha}} - 1\right) + 0.3G_1$$

(For the derivation of this model see Volume II.)

This model was programmed in FORTRAN IV and run. Partial outputs are shown in Figure 8.

The PDs computed by the modified kinematic model, listed in the PDA column in Figure 8, show that although steep grades directly affect PD, the difference would be small up to 50 mph compared with those for speeds greater than 50 mph.

Figure 9 shows plots of PD vs. PS for both the kinematic and regression models for an m of 12 mph. As determined earlier, 85% of all passing maneuvers were carried out at an m equal to or greater than 12 mph (see Figure 4). Figure 9 also shows a plot of the regression model for an m of 16 mph, which is the mean of the observed differences. PDs for the kinematic model were computed as the average of volumes for the three values of g, as this model indicates that for speeds less than 50 mph g is not a major factor.

Suggested Minimum Lengths of Passing Zones

A passing zone is analogous to PD in this study. It is the distance travelled by the passing vehicle in the left lane during the course of a passing maneuver. Within this distance the passing vehicle encroaches onto the left lane, takes over and passes the impeding vehicle, and returns to the right lane upon completion of the passing maneuver.

In developing the proposed minimum lengths of passing zones, two factors were taken into consideration. First, the value of m used in the regression model was 12 mph. This assures that the lengths of passing zones suggested will be equal to or greater than the actual PD of 85% of all passing maneuvers. Second, in order to provide for passing maneuvers which do not commence at the beginning of the passing zone, the 95% confidence level (upper limit) of the obtained regression model was used. The relation between this model and the actual data is shown in Figure 9. Table 17 summarizes the suggested minimum lengths of passing zones rounded to the nearest 10 ft. From this table it can be said that the MUTCD sanctioned minimum passing zone requirement (400 ft.) is inadequate on two-lane, two-way mountainous roads even at 30 mph.

**** PASS MODEL *****

NO.	TYPE	SPEED (FT/S)	SPDIF (FT/S)	GRADE (%)	ACCEL (FT/S2)	X (FT)	G1 (FT)	G2 (FT)	ORIGINAL VALUES D1 (FT)	D2 (FT)	D3 (FT)	D8 (FT)	D9 (FT)	TPD (SEC)	PD (FT)	F1	F2	F3	TOTALD (FT)	ADJUSTED VALUES D1A (FT)	D2A (FT)	PCA (FT)	F2A	F3A
7.	1.	44.1	22.1	2.0	6.76	55.	85.	50.	108.	-12.	210.	98.	100.	4.47	197.	.58	1.06	.51	305.	86.	10.	219.	.95	.45
8.	1.	44.1	22.1	6.0	5.44	55.	85.	50.	134.	-30.	210.	80.	100.	4.08	180.	.47	1.17	.55	314.	93.	12.	221.	.95	.45
9.	1.	44.1	22.1	10.0	4.12	55.	85.	50.	177.	-58.	210.	51.	100.	3.43	151.	.30	1.39	.66	328.	103.	16.	225.	.93	.44
16.	1.	51.5	22.1	2.0	6.47	55.	95.	60.	138.	5.	268.	133.	140.	5.31	273.	.60	.98	.51	411.	116.	28.	296.	.91	.47
17.	1.	51.5	22.1	6.0	5.22	55.	95.	60.	171.	16.	268.	112.	140.	4.90	252.	.51	1.06	.55	423.	126.	30.	298.	.90	.47
18.	1.	51.5	22.1	10.0	3.90	55.	95.	60.	229.	-53.	268.	75.	140.	4.18	215.	.34	1.24	.65	444.	141.	36.	304.	.88	.46
25.	1.	58.8	22.1	2.0	6.17	55.	105.	70.	171.	28.	333.	174.	186.	6.13	360.	.62	.92	.52	531.	149.	50.	383.	.87	.49
26.	1.	58.8	22.1	6.0	5.00	55.	105.	70.	211.	3.	333.	149.	186.	5.71	316.	[illegible]	.99	.55	547.	162.	52.	385.	.86	.48
27.	1.	58.8	22.1	10.0	3.68	55.	105.	70.	287.	-44.	333.	103.	186.	4.92	285.	.37	1.15	.64	576.	183.	60.	392.	.85	.47
34.	1.	66.2	22.1	2.0	5.59	55.	115.	80.	218.	49.	404.	214.	240.	6.85	453.	.62	.89	.53	671.	189.	77.	482.	.84	.50
35.	1.	66.2	22.1	6.0	4.34	55.	115.	80.	281.	11.	404.	176.	240.	6.28	416.	.51	.97	.58	696.	210.	82.	486.	.83	.49
36.	1.	66.2	22.1	10.0	3.02	55.	115.	80.	404.	-62.	404.	102.	240.	5.16	342.	.30	1.18	.70	745.	245.	96.	500.	.81	.48
43.	1.	73.5	22.1	2.0	5.00	55.	125.	90.	276.	70.	482.	253.	299.	7.52	553.	.61	.87	.54	829.	237.	110.	592.	.81	.51
44.	1.	73.5	22.1	6.0	3.68	55.	125.	90.	375.	12.	482.	195.	299.	6.73	494.	.47	.98	.61	869.	270.	118.	600.	.80	.50
45.	1.	73.5	22.1	10.0	2.35	55.	125.	90.	587.	-113.	482.	70.	299.	5.03	369.	.17	1.31	.81	957.	328.	147.	629.	.77	.48
97.	1.	80.9	22.1	2.0	4.27	55.	135.	100.	362.	83.	567.	285.	366.	8.05	651.	.58	.87	.56	1012.	297.	146.	716.	.79	.51
98.	1.	80.9	22.1	6.0	2.95	55.	135.	100.	523.	-10.	567.	191.	366.	6.89	557.	.39	1.02	.66	1080.	349.	164.	732.	.78	.50
99.	1.	80.9	22.1	10.0	1.62	55.	135.	100.	953.	-259.	567.	-58.	366.	3.81	308.	-.12	1.84	1.19	1261.	456.	238.	805.	.70	.45

PC vs. WB - 50

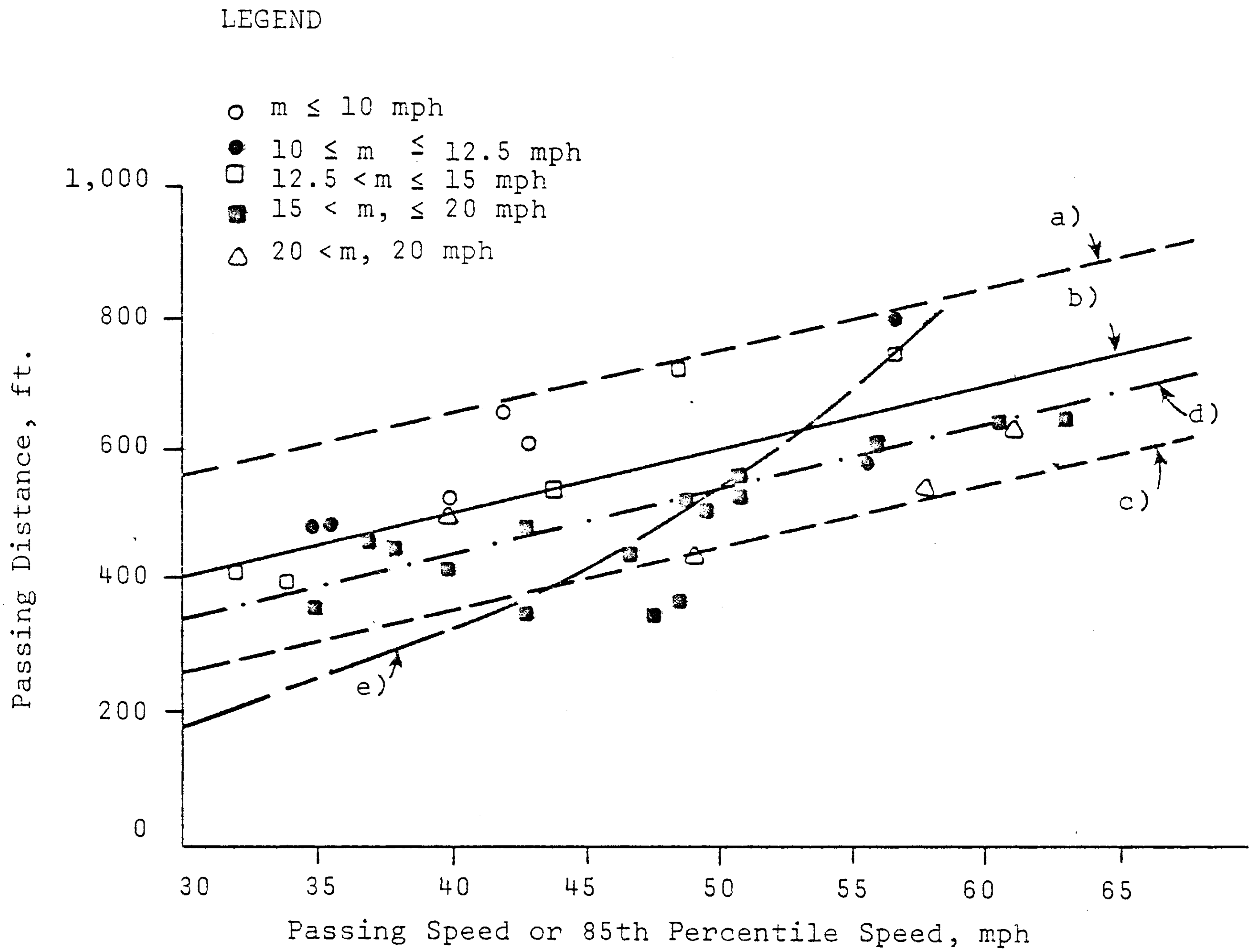
FIGURE 8. PARTIAL COMPUTER PRINTOUT OF KINEMATIC PASS MODEL.

**** PASS MODEL *****

NO.	TYPE	SPEED (FT/S)	SPDIF (FT/S)	GRADE (%)	ACCEL (FT/S2)	X (FT)	G1 (FT)	G2 (FT)	ORIGINAL VALUES D1 (FT)	D2 (FT)	D3 (FT)	D8 (FT)	D9 (FT)	TPD (SEC)	PD (FT)	F1	F2	F3	TOTALD (FT)	ADJUSTED VALUES D1A (FT)	D2A (FT)	PCA (FT)	F2A	F3A
52.	2.	44.1	22.1	2.0	6.76	20.	50.	50.	108.	-12.	140.	28.	100.	2.89	127.	.28	1.10	.78	236.	61.	34.	174.	.80	.57
53.	2.	44.1	22.1	6.0	5.44	20.	50.	50.	134.	-30.	140.	10.	100.	2.49	110.	.10	1.27	.91	244.	67.	38.	178.	.79	.56
54.	2.	44.1	22.1	10.0	4.12	20.	50.	50.	177.	-58.	140.	-19.	100.	1.84	81.	-.19	1.72	1.23	259.	74.	45.	184.	.76	.54
61.	2.	51.5	22.1	2.0	6.47	20.	60.	60.	138.	5.	186.	52.	140.	3.72	192.	.37	.97	.73	330.	87.	56.	242.	.77	.58
62.	2.	51.5	22.1	6.0	5.22	20.	60.	60.	171.	-16.	186.	31.	140.	3.31	171.	.22	1.09	.82	342.	95.	60.	247.	.76	.57
63.	2.	51.5	22.1	10.0	3.90	20.	60.	60.	229.	-53.	186.	-6.	140.	2.60	134.	-.04	1.39	1.05	363.	107.	69.	256.	.73	.55
70.	2.	58.8	22.1	2.0	6.17	20.	70.	70.	171.	28.	239.	81.	186.	4.54	267.	.43	.90	.70	438.	117.	82.	321.	.74	.58
71.	2.	58.8	22.1	6.0	5.00	20.	70.	70.	211.	3.	239.	56.	186.	4.12	243.	.30	.99	.77	454.	127.	87.	326.	.73	.57
72.	2.	58.8	22.1	10.0	3.68	20.	70.	70.	287.	-44.	239.	10.	186.	3.33	196.	.05	1.22	.95	483.	145.	98.	338.	.71	.55
79.	2.	66.2	22.1	2.0	5.59	20.	80.	80.	218.	49.	300.	109.	240.	5.26	348.	.45	.86	.69	566.	153.	114.	413.	.72	.58
80.	2.	66.2	22.1	6.0	4.34	20.	80.	80.	281.	11.	300.	71.	240.	4.69	311.	.30	.96	.77	592.	171.	121.	421.	.71	.57
81.	2.	66.2	22.1	10.0	3.02	20.	80.	80.	404.	-62.	300.	-3.	240.	3.58	237.	-.01	1.26	1.01	641.	200.	141.	441.	.68	.54
88.	2.	73.5	22.1	2.0	5.00	20.	90.	90.	276.	70.	366.	137.	299.	5.93	436.	.46	.84	.69	712.	196.	150.	516.	.71	.58
89.	2.	73.5	22.1	6.0	3.68	20.	90.	90.	375.	12.	366.	79.	299.	5.14	378.	.26	.97	.79	753.	224.	163.	529.	.69	.57
90.	2.	73.5	22.1	10.0	2.35	20.	90.	90.	587.	-113.	366.	-46.	299.	3.44	253.	-.15	1.45	1.18	840.	273.	201.	567.	.65	.53
106.	2.	80.9	22.1	2.0	4.27	20.	100.	100.	362.	83.	439.	157.	366.	6.46	523.	.43	.84	.70	884.	250.	195.	634.	.69	.58
107.	2.	80.9	22.1	6.0	2.95	20.	100.	100.	523.	-10.	439.	63.	366.	5.30	429.	.17	1.02	.85	952.	295.	218.	657.	.67	.56
108.	2.	80.9	22.1	10.0	1.62	20.	100.	100.	953.	-259.	439.	-186.	366.	2.23	180.	-.51	2.44	2.03	1133.	388.	306.	745.	.59	.49

PC vs. PC

Figure 8. CONTINUED.



a) 95% confidence band on regression model with m = 12 mph (upper limit)

b) Regression model with m = 12 mph

c) 95% confidence band on regression model with m = 12 mph (lower limit)

d) Mean regression model with m = 16 mph

e) Kinematic model

FIGURE 9. ACTUAL PASSING DISTANCES VS. PREDICTED PASSING DISTANCES.

TABLE 17

SUGGESTED MINIMUM LENGTHS OF PASSING ZONES

85th Percentile Speed (MPH)	Minimum Lengths of Passing Zones	
	Suggested by this study[a] (FT.)	MUTCD[b] (FT.)
30	560	400
35	610	400
40	660	400
45	710	400
50	750	400
55	800	400

[a]Rounded to the nearest 10 ft. The upper limit of 95% confidence band of the regression model was used to develop the suggested minimum lengths of passing zones.

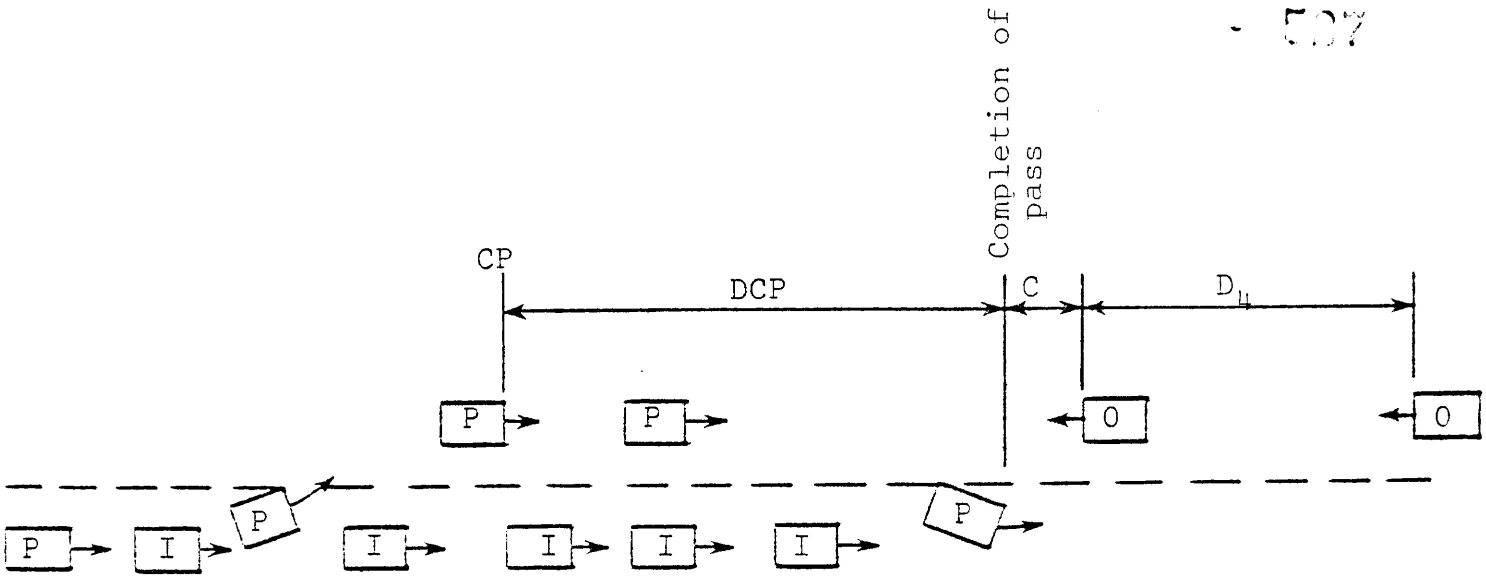
[b]An interpretation of Section 3B-4 of the MUTCD (Reference 1), which states that "where the distance between successive no-passing zones is less than 400 ft., the appropriate no-passing marking (one direction or two directions) should connect the zones."

Suggested Passing Sight Distance Requirements

In this study, passing sight distance (PSD) was defined as the summation of the distance between the critical position (CP) and the position at completion of a pass, the clearance distance between the passing and the oncoming vehicles at completion of a pass (C), and the distance travelled by the oncoming vehicle while the passing vehicle travels from the critical position until the latter completely returns to the right lane (D_4). This relation is shown in Figure 10.

In order to compute the values of PSD for different values of PS, it was first necessary to locate the CP of a passing maneuver. CP was defined by Lieberman as the point where "the decision by the passing vehicle to complete the pass will afford it the same clearance relative to an oncoming vehicle as will the decision to abort the pass."[20] The same concept was used in this study. Lieberman developed a kinematic model which indicated that CP moves depending on the deceleration rate of the passing vehicle and m. The passing motorist must decide earlier to abort as the deceleration rate decreases.

To determine CP in this study, the deceleration rates required for a passing vehicle to abort a pass from different positions were determined. The positions considered were the head and tail (front of passing vehicle in line with back of impeding vehicle), abreast (front of passing vehicle in line with front of impeding vehicle), and a position intermediate between the first two. The data obtained from the field studies showed that the head and tail position was located, on the average, at 0.69 PD from the position at completion of a pass and the abreast position was located, on the average, at 0.56 PD. The intermediate position was located at 2/3 PD, which is a value used by the AASHTO to develop PSD requirements for design purposes. The selection of these positions for testing was based on the assumption that CP will be between the head and tail position and the abreast position. This assumption is logical as it is easier to abort a pass when the passing vehicle is downstream of the head and tail position, while it will be easier to complete the pass when the passing vehicle is upstream of the abreast position. Values of PD were determined from the regression model for an m of 12 mph. This value of m was used for the same reason discussed earlier. The deceleration rates necessary for an abort maneuver starting at a point to have a clearance distance equal to the clearance distance for a pass maneuver starting at the same point (see Figure 11), were calculated for different passing speeds and are shown in Table 18. Details of the calculations are shown in Volume II of this report.



P = Passing vehicle

I = Impeding vehicle

O = Oncoming vehicle

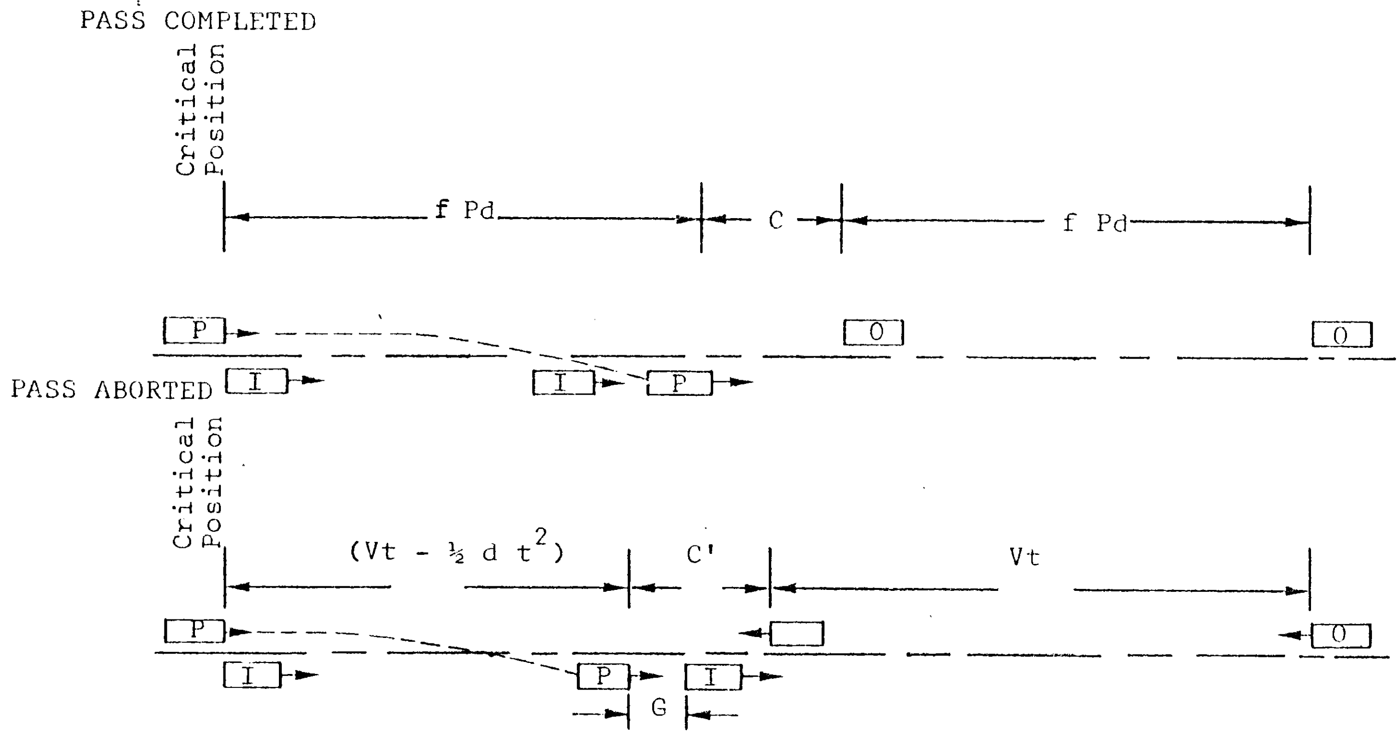
CP = Critical position from which the passing vehicle can still abort a pass and return to the right lane with reasonably comfortable and safe deceleration rates

D_{CP} = Distance travelled by the passing vehicle between the critical position and completion of pass

C = Clearance distance between the passing and oncoming vehicles at completion of pass

D_4 = Distance travelled by the oncoming vehicle while passing vehicle travels from critical position till it completely returns to right lane

FIGURE 10. CRITICAL POSITION AND DISTANCE ELEMENTS NECESSARY TO COMPUTE PASSING SIGHT DISTANCES.



$$(V\hat{t} - \tfrac{1}{2} d \hat{t}^2) + C' + V\hat{t} = 2 f Pd + C$$

$$d = \frac{4 (Vt - f Pd)}{\hat{t}^2}$$

[P] — Passing vehicle

[I] — Impeding vehicle

[O] — Oncoming vehicle

d = Deceleration rate — $ft./s^2$

V = Velocity — ft./s.

Pd = Passing distance, in ft.

f = Constant

C = Clearance distance in ft.

$\hat{t}$ = Time to complete or abort maneuver in sec.

$$\hat{t} = t' + \frac{G}{V - m}$$

$$t' = \frac{f\ Pd}{V}$$

G = Gap between P and I

m = speed difference between P and I

FIGURE 11. LOCATION OF CRITICAL POSITION FOR COMPLETED AND ABORTED PASSES.

TABLE 18

DECELERATION RATES TO ABORT PASSING MANEUVERS FROM ESTIMATED CRITICAL POSITIONS WITHIN GIVEN PASSING DISTANCES

85th Percentile Speed	Location Of Critical Position From The Position Of Completion Of Pass		
MPH	Head & Tail: 0.69 PD Decel. Rate (d) $Ft./Sec.^2$	2/3 PD Decel. Rate (d) $Ft./Sec.^2$	Abreast: 0.56 PD Decel. Rate (d) $Ft./Sec.^2$
30	5.1	5.4	7.0
35	6.0	6.3	8.1
40	7.2	7.5	9.8
45	8.3	8.7	11.3
50	9.1	9.6	12.4
55	10.4	10.9	14.5

Note: The passing vehicle is assumed to start the aborting maneuver from the critical position and return to the right lane with a deceleration rate that results in a clearance distance which is equal to the clearance distance for the passing maneuver.

Passing distances based on regression model with m = 12 M.P.H.

It has been reported by Wilson that average deceleration rates for comfort did not exceed 9 ft./sec.^{2}, and that drivers generally consider decelerations of about 11 ft./sec.^{2} to be undesirable and 14 ft./sec.^{2} to be uncomfortable and possibly alarming.[21]

The deceleration rates computed for the different positions were then compared with the acceptable deceleration rates. It can be seen that while the deceleration rates for 0.69 PD and 2/3 PD are within acceptable limits; those for 0.56 PD are relatively higher and exceed comfortable limits when passing speeds are greater than 40 mph. It was, therefore, decided to select CP as 2/3 PD, which is in conformity with the assumption made by the AASHTO for the distance travelled while the passing vehicle occupies the left lane. This position was, therefore, used to determine the PSD requirements as shown in Table 19. The values given in this table were calculated with the assumption that the oncoming vehicle was travelling at the speed of the passing vehicle. This study has revealed, however, that for grades higher than 5%, there may be significant differences between speeds in opposite lanes, although the maximum speed difference observed was 6 mph. This factor was, therefore, taken into consideration in developing PSD requirements for speed differences up to 5 mph and between 5 mph and 10 mph. The suggested values are shown in Table 20.

TABLE 19

COMPARISON OF MINIMUM PASSING SIGHT DISTANCE REQUIREMENTS

85th Percentile Speed (MPH)	Clearance Distance C[a] (Ft.)	Suggested by This Study (Ft.)	MUTCD[b] (Ft.)	VDH&T[c] (Ft.)
30	100	645	500	1,000
35	125	735	550	1,100
40	150	825	600	1,200
45	175	910	700	1,400
50	200	1000	800	1,600
55	250	1115	900	1,800

Note: The suggested minimum passing sight distances computed using the following equation:

$$PSD = 4/3\ PD + C$$

where PD = Passing distance (ft.) from regression model for m = 12 MPH
C = Clearance distance (ft.) estimated from AASHTO

[a]Obtained by interpolating (Ref.14).

[b]Interpolated.

[c]This requirement is discretionally used. The VDH&T also uses the MUTCD.

TABLE 20

SUGGESTED PASSING DISTANCES FOR TWO-LANE, TWO-WAY HIGHWAYS WITH THE SPEED DIFFERENCES ON UP & DOWNSLOPE GREATER OR LESS THAN 5 MPH

Upslope 85th Percentile Speed (V_l) (MPH)	Passing Sight Distance (Ft.) Downslope 85th Percentile Speed (V_h) Range: $V_l \leq V_h < (V_l + 5.0)$	$(V_l + 5.0) \leq V_h < (V_l + 10.0)$
30	700	800
35	800	870
40	885	950
45	970	1070
50	1095	1190
55	1200	-

$$PSD' = \frac{2}{3} PD_l + C_h + D_h$$

Where

PSD' : adjusted passing sight distance, in ft.
PD_l : passing distance for lower speed, in ft.
C_h : clearance distance for higher speed, in ft.
D_h : distance travelled by oncoming vehicle at higher velocity during time passing vehicle travels from critical lane to completion of pass.

COMPARISON OF BEFORE AND AFTER DATA

The adequacy of the proposed guidelines and their effect on traffic characteristics when used to provide passing zones using the MUTCD standard marking patterns were evaluated. It was originally intended to use all of the test sites for the after study, but this was not possible as the geometric and traffic characteristics at some of these sites did not conform with the guidelines developed for providing passing zones. For example, the 85th percentile speed at site S-2, where several passes were recorded during the before study, is about 58 mph. This requires a minimum PSD of about 1,000 ft. for a safe passing maneuver based on the proposed guidelines. The maximum PSD available at this site, however, is 900 ft. This immediately suggests that the MPM encourages motorists to undertake passing maneuvers at sections of roads with sight distances less than the minimum required for a safe completion of the pass or a comfortable aborting of the pass.

The traffic and geometric characteristics at site S-1 conform with the proposed guidelines, while those of sites S-2, S-3, and S-4 do not, as the ASDs at these latter sites are lower than those of the proposed guidelines (see Table 21). Although the ASD at site S-5 is greater than the minimum proposed for the 85th percentile speed at this site, this distance reduces to a value less than the proposed minimum within 400 ft. from the point of the maximum (see Table 21). It is, therefore, not possible to provide an adequate length of passing zone based on the proposed guidelines. Taking these factors into consideration, it was decided to use the following sites for the after study.

- Site S-1 on Route 501 — To evaluate the adequacy of the passing zone requirements, and the effect of changing from MPM to MUTCD marking of the passing and no-passing zones on traffic characteristics.

- Site S-5 — To evaluate the effect of changing from MPM to MUTCD marking of no-passing zones, and to determine the extent to which motorists comply with the no-passing zone marking.

- Site S-5a, a new study site on Route 116 — To evaluate the adequacy of the proposed guidelines. The 85th percentile speed at this site was determined as 50 mph and the maximum ASD was 1,850 ft.

TABLE 21

COMPARISON OF GEOMETRIC CHARACTERISTICS
AT STUDY SITES WITH PROPOSED GUIDELINES

Study Site	85th Percentile Speed (MPH)	Proposed Guidelines		Available Sight Distance (Ft.)	Max. Passing Zone (Ft.)
		Min. Passing Zone (Ft.) [a]	Min. Sight Distance [b] (Ft.)		
S-1	54.0	795	1105	1420	820
S-2	47.0	725	940	900	-
S-3	47.5	730	945	800	-
S-4	42.0	680	850	720	-
S-5	42.7	685	855	1060	400
S-5a	50.0	750	1000	1850	760

a Calculated from regression model (m = 12 M.P.H.)

b Calculated from 4/3 PD + C

c This is the maximum length at the site within which the ASD is greater than or equal to the proposed minimum sight distance

Conditions for the After Study

Since site S-1 was found to have geometric characteristics which satisfy the minimum requirements for a passing zone as proposed in this study, the site was re-marked using the MUTCD pattern and minimum lengths proposed in this study. A passing zone of 800 ft. was provided in each direction as shown in Figure 12. Site S-5 was re-marked as a no-passing zone using the MUTCD pattern as shown in Figure 13. Site S-5a was re-marked using the MUTCD marking pattern. A passing zone of 750 ft. was provided in each direction as shown in Figure 14. Table 22 also summarizes the alterations made for the after study.

Comparison of Traffic Operating Characteristics

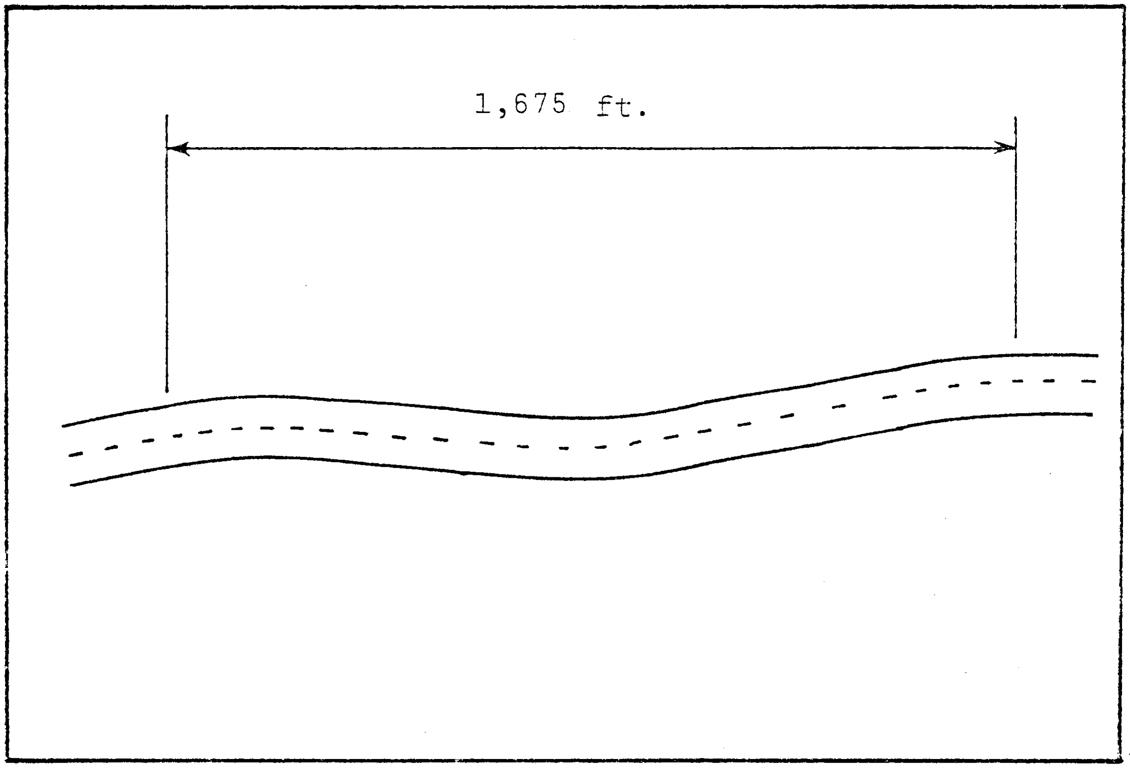
The before and after data were compared for the following traffic operating characteristics at sites S-1 and S-5. Table 23 shows the sample size and limits of tolerable error for each traffic characteristic compared.

Average Hourly Traffic Volume

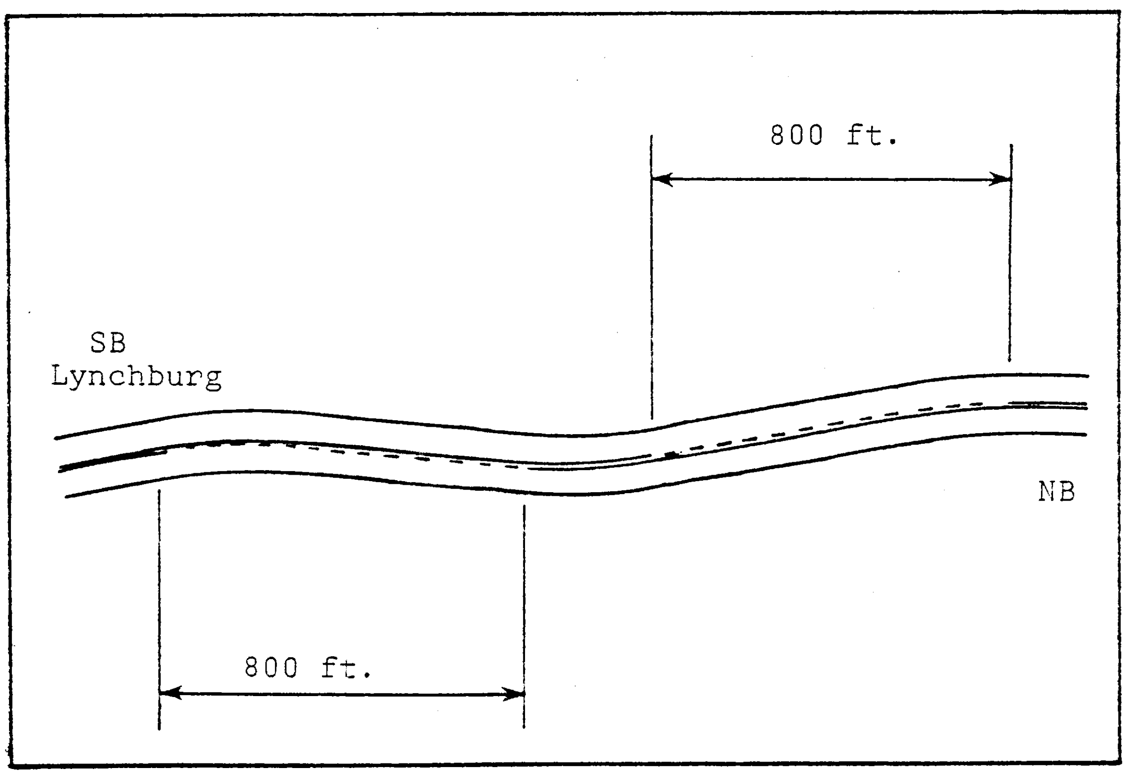
Table 24 shows a comparison of the average hourly traffic volumes for the before and after phases for selected time groups. The means test using the t-distribution showed that the difference in mean average hourly traffic volumes was not significant at a 5% significance level. These similar before and after traffic volumes were helpful in delineating the effects of changing the centerline marking.

Traffic Mix

Table 25 gives a comparison of the traffic mix for the before and after phases. As shown, the difference in traffic mix ratios between the phases was not significant at a 5% significance level.

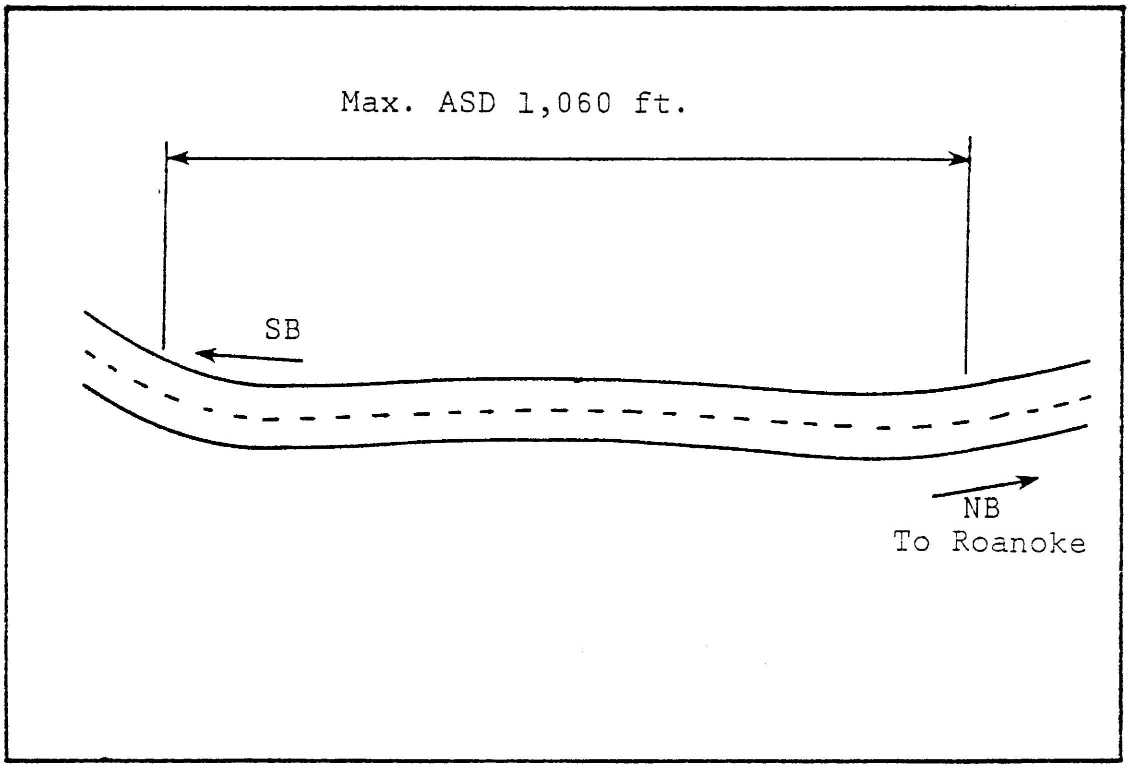


Before — MPM

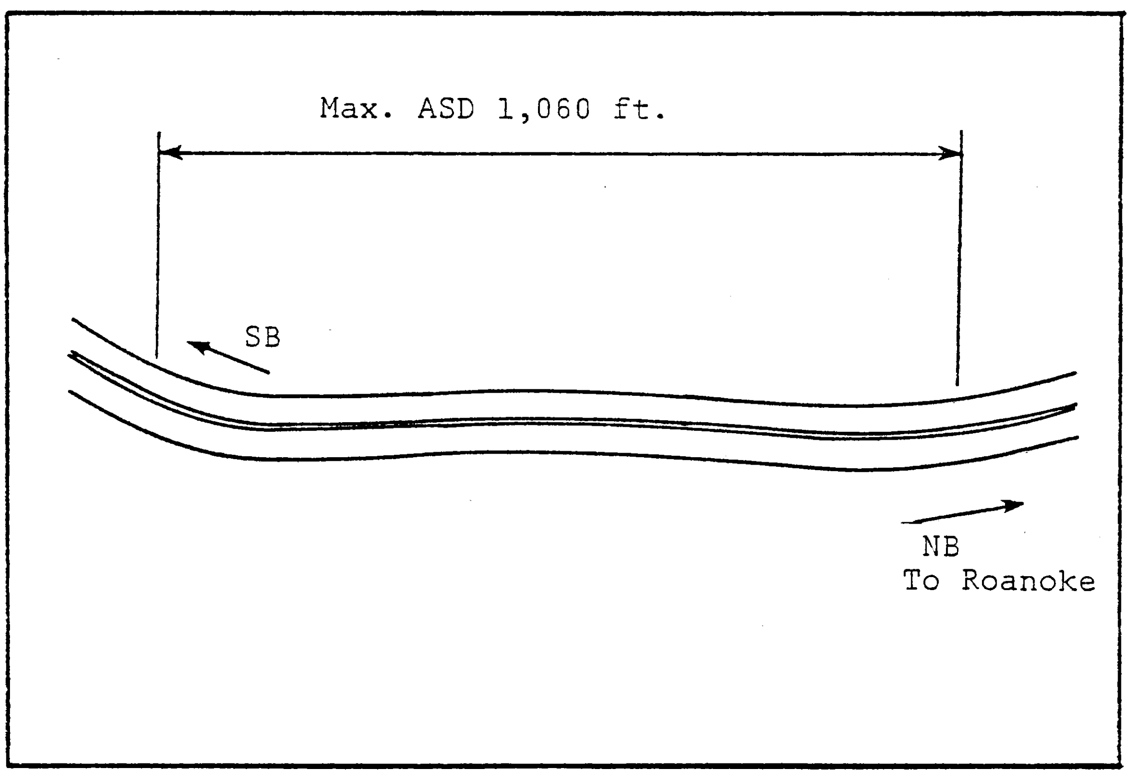


After — MUTCD Passing/No-passing Marking

FIGURE 12. CENTERLINE PAVEMENT MARKING PATTERNS ON SITE S-1, ROUTE 501.

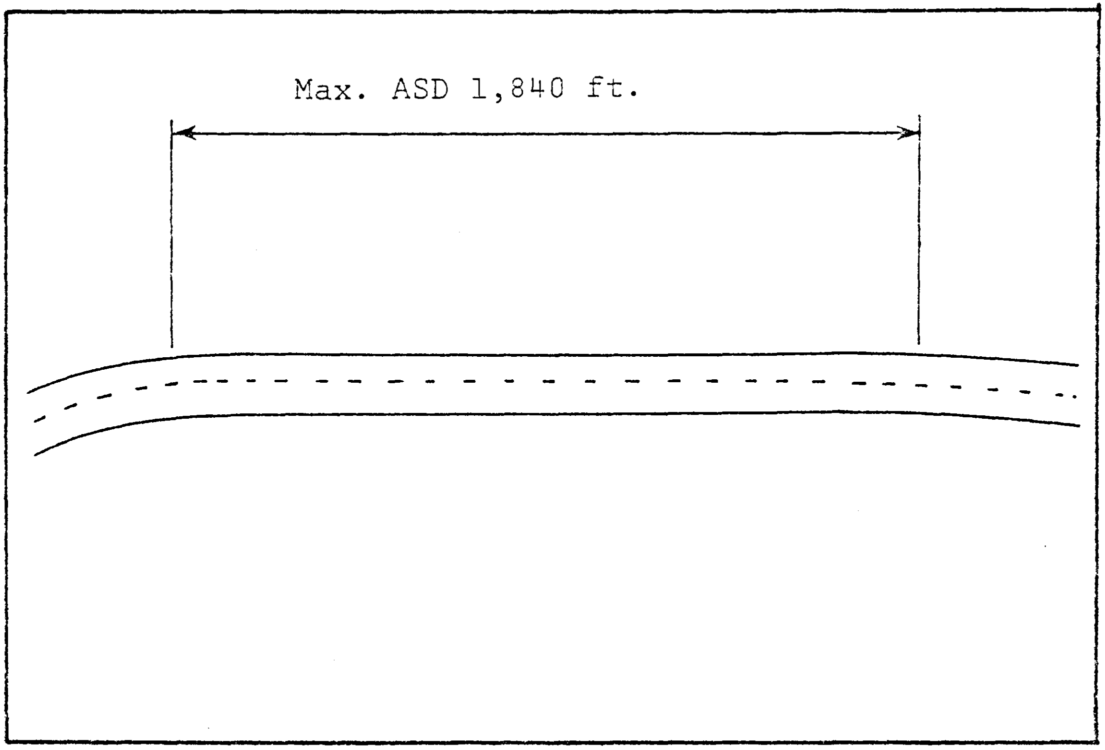


Before — MPM

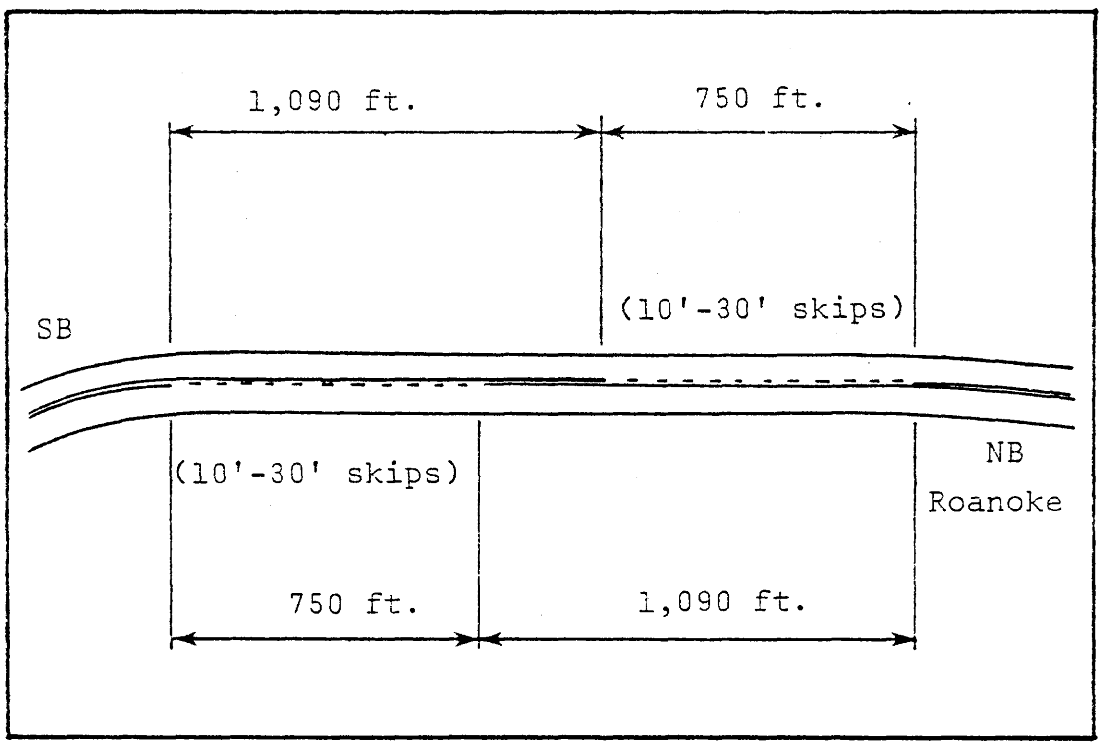


After — MUTCD No-passing Marking

FIGURE 13. CENTERLINE PAVEMENT MARKING PATTERNS ON SITE S-5, ROUTE 116.



Before — MPM



After — MUTCD Passing/No-passing Marking

FIGURE 14. CENTERLINE PAVEMENT MARKING PATTERNS ON SITE S-5A, ROUTE 116.

TABLE 22

CONDITIONS FOR THE AFTER STUDY

Site No.	Route Number	Before	After
S -1	501	MPM	MUTCD passing/no-passing zone marking patterns 800 ft. passing zone[a]
S-5	116	MPM	MUTCD no-passing zone marking, i.e., double solid yellow line, for the entire length of the study site and on the approaches
S-5A[b]	116	MPM	MUTCD passing/no-passing zone marking patterns 750 ft. passing zone

[a]Satisfies proposed minimum length of passing zone for 85th percentile speed.

[b]This new study site is located approximately 2.0 miles south of site S-5, with an ASD of about 1,850 ft.

TABLE 23

SAMPLE SIZE AND LIMITS OF EXPECTED ERRORS FOR TRAFFIC CHARACTERISTICS

Site	Traffic Characteristics	Before Study			After Study		
		n_1	σ	e	n_2	σ	e
S-1	Operating speed (NB)	404	6.95 MPH	± 0.68 MPH	418	7.6 MPH	± 0.73 MPH
	Operating speed (SB)	345	7.09 MPH	± 0.75 MPH	427	6.4 MPH	± 0.61 MPH
	Queue speed (NB)	52	6.7 MPH	± 1.80 MPH	67	7.5 MPH	± 1.80 MPH
	Queue speed (SB)	36	5.5 MPH	± 1.80 MPH	51	6.0 MPH	± 1.65 MPH
	Time headway (WB)	78	1.12 Sec.	± 0.25 Sec.	85	1.28 Sec.	± 0.27 Sec.
	Time headway (SB)	59	1.33 Sec.	± 0.34 Sec.	64	1.34 Sec.	± 0.28 Sec.
S-5	Operating Speed (NB)	541	5.93 MPH	± 0.50 MPH	537	5.24 MPH	± 0.44 MPH
	Operating Speed (SB)	773	5.10 MPH	± 0.36 MPH	754	5.28 MPH	± 0.38 MPH
	Queue speed (NB)	170	6.4 MPH	± 0.96 MPH	175	4.0 MPH	± 0.59 MPH
	Queue Speed (SB)	160	4.8 MPH	± 0.74 MPH	147	4.6 MPH	± 0.74 MPH
	Time headway (NB)	149	1.38 Sec.	± 0.22 Sec.	162	1.40 Sec.	± 0.22 Sec.
	Time headway (SB)	138	1.37 Sec.	± 0.23 Sec.	123	1.35 Sec.	± 0.24 Sec.

TABLE 24

COMPARISON OF AVERAGE HOURLY TRAFFIC VOLUMES BEFORE VS. AFTER

Time Group	S - 1 on Rte. 501				S - 5 on Rte. 116			
	Before[a]		After[b]		Before[c]		After[d]	
	NB	SB	NB	SB	NB	SB	NB	SB
06:30 - 08:30	40	50	39	48	182	26	184	33
08:30 - 10:00	25	38	27	36	66	41	74	29
10:00 - 14:00	35	29	41	34	53	42	48	28
14:00 - 15:30	44	37	42	44	53	58	52	54
15:30 - 16:30	52	52	56	62	65	127	47	142
16:30 - 18:30	55	34	30[e]	33[e]	57	163	55	155
06:30 - 18:30	40	37	41[f]	42[f]	78	69	75	63

The average hourly traffic volumes were computed from the following data:

[a] September 29 - 30, 1981, 06:30 - 18:30

[b] October 26, 1982, 06:30 - 18:30

[c] June 8 & 10, 1982, 06:30 - 18:30

[d] November 9, 1982, 06:30 - 17:00

[e] Volume from 16:30 to 17:00 only

[f] Avg. hourly volume for 06:30 - 17:00

t - test on before and after hourly traffic volumes

Rte. 501 06:30 - 16:30

t_{NB} = 0.72 (Not significant at $\alpha = 0.05$)

t_{SB} = 0.74 (Not significant at $\alpha = 0.05$)

Rte. 116 06:30 - 18:30

t_{NB} = 0.11 (Not significant at $\alpha = 0.05$)

t_{SB} = 0.85 (Not significant at $\alpha = 0.05$)

TABLE 25

COMPARISON OF TRAFFIC MIXES BEFORE VS. AFTER

Site No.	Route Number	Direction	Before				After			
			Cars[a] (%)	Trucks[b] (%)	Tractor Trailers[c] (%)	No. of Samples	Cars[a] (%)	Trucks[b] (%)	Tractor Trailers[c] (%)	No. of Samples
S - 1	Rte. 501	NB	87.6	9.5	2.9	485	86.2	9.6	4.2	429[d]
		SB	95.3	2.7	2.0	446	93.7	2.5	3.8	446[d]
S - 5	Rte. 116	NB	98.4	1.2	0.4	932	98.5	1.3	0.2	905
		SB	95.4	4.5	0.1	822	93.3	6.0	0.7	754

[a] Cars = 2-axle vehicles

[b] Trucks = 3- and 4-axle vehicles

[c] Tractor trailers = 5- or more axle vehicles

[d] Data from 06:30 to 17:00. The rest of the samples are from 06:30 to 18:30.

χ^2-tests on cars, trucks, and tractor trailers (Significance level at $\alpha = 0.05$, $\chi^2_{.05} = 5.99$)

Route 501	NB:	χ^2-value = 1.17	d.f.= 2	Not significant
	SB:	χ^2-value = 2.60	d.f.= 2	Not significant
Route 116	NB:	χ^2-value = 0.84	d.f.= 2	Not significant
	SB:	χ^2-value = 4.60	d.f.= 2	Not significant

Operating Speed

Figure 15 shows the distribution of operating speeds in percentages for the two phases. The difference in mean speeds was not significant at the 5% significance level as shown in Table 26, except for the southbound lane of site S-1, where the average speed increased by 1.6 mph, and the northbound lane of site S-5, where the speed increased by 2.5 mph during the peak period. Notice that the latter increase took place in a no-passing zone striped with a double solid yellow line. At site S-5, however, the overall speed difference was not significant at the 5% significance level, which indicated that there would be only a minimal difference, if any, caused by the replacement of the MPM.

Queueing Characteristics

Table 27 compares the queueing characteristics of the phases. The queue cut-off time used in this study was 6.0 seconds. As shown in the table, there was no significant difference between the two types of marking patterns. The student t-tests showed that the difference in average numbers of queues per hour was not significant at the 5% significance level. The difference in average numbers of vehicles per queue was also not significant. Means tests using a normal distribution were performed on the average queue speeds for the before and after phases and the results are shown in Table 28. Only the difference in mean queue speeds on the northbound lane of site S-5 was found to be significant at a 5% significance level, and this increment was only a 1.5 mph increase. These results indicate that substitution of the MUTCD marking patterns did not significantly alter the formation of queues.

Headway Distribution in Queues

The headway distribution in queues was examined to determine whether the replacement of the MPM with the MUTCD marking pattern had an influence. Figure 16 shows two cases of this analysis. It was found out that the shifted (1.0 second) negative exponential curves would fit the time headway distribution in queues at a 5% significance level. As shown in the figure, although not much difference is identifiable, the accumulation of very short time headways found in the before data were slightly reduced in the after study and the distribution was spread slightly toward the longer headways. This could be an improvement of driving safety in the queue, and may be an indication that the MUTCD marking patterns would provide better driving conditions in the queue than the MPM. Nonetheless, the difference in means of the time headways in the queues was not significant at the 5% significance level, as shown in Table 29. The mean time headway ranged from 2.2 to 2.8 seconds.

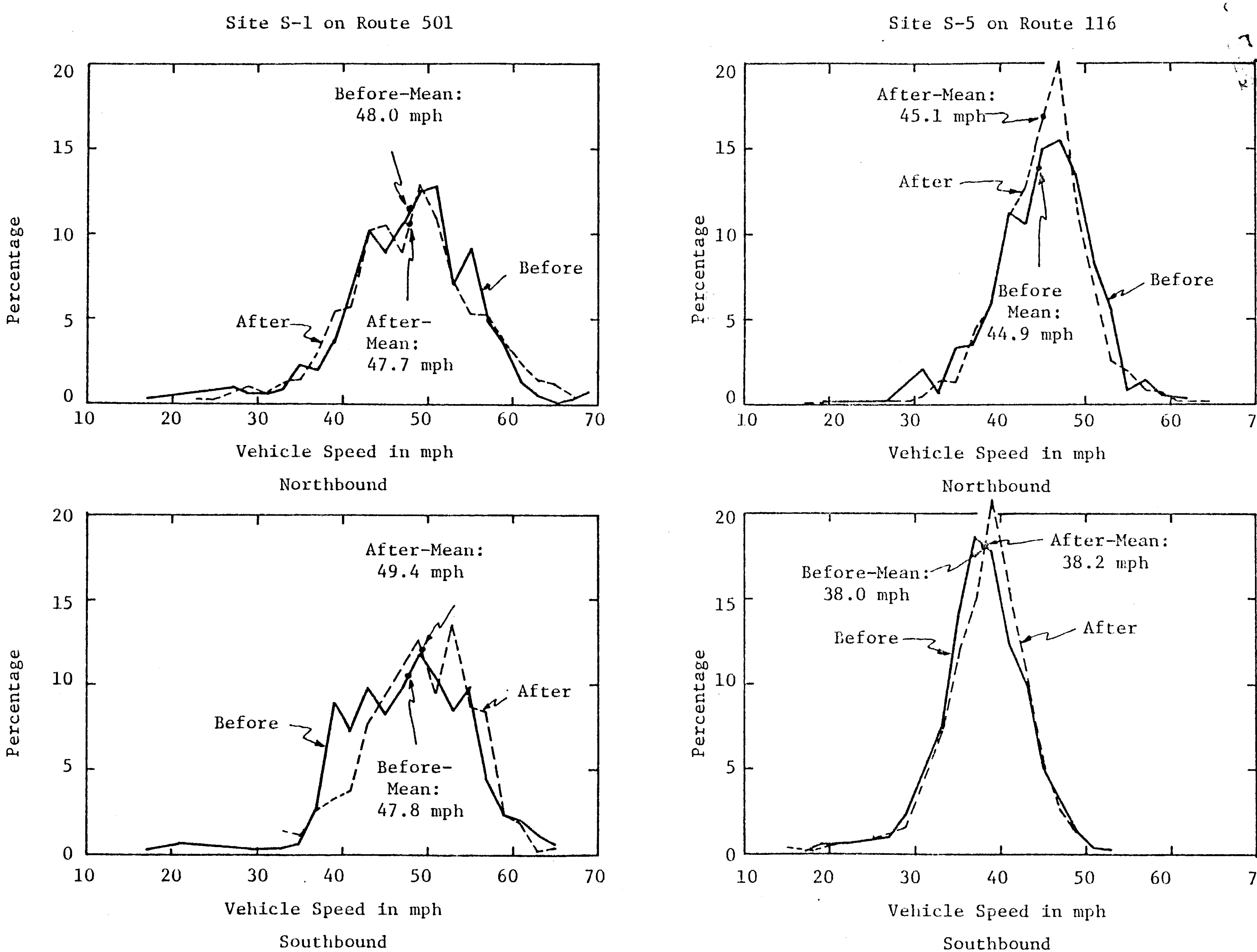


FIGURE 15. COMPARISON OF SPEED DISTRIBUTION IN PERCENTAGES.

TABLE 26

COMPARISON OF OPERATING SPEEDS BEFORE VS. AFTER

Site S - 1 on Route 501

Direction	Before			After			Computed z-Scores	Significance Test at $\alpha = 0.05$ ($z = 1.96$)
	n_1	$\overline{X}_1$(mph)	S_1(mph)	n_2	$\overline{X}_2$(mph)	S_2(mph)		
NB[a]	404	48.0	6.95	418	47.7	7.60	0.59	Not Significant
SB[a]	345	47.8	7.09	427	49.4	6.47	3.24	Significant[b]

Site S - 5 on Route 116

Time Group	Direction	Before			After			Computed z-Scores	Significance Test at $\alpha = 0.05$ ($z = 1.96$)
		n_1	$\overline{X}_2$(mph)	S_1(mph)	n_2	$\overline{X}_2$(mph)	S_2(mph)		
Peak Period	NB[c]	364	44.2	4.60	368	47.1	4.20	8.70	Significant[f]
	SB[c]	324	39.1	4.61	310	38.7	4.63	0.78	Not Significant
Off-Peak Period	NB[d]	250	44.9	6.06	245	44.5	5.31	0.67	Not Significant
	SB[d]	223	37.7	6.15	160	38.4	5.53	1.18	Not Significant
Peak & Off-Peak	NB[e]	541	44.9	5.93	537	45.1	5.24	0.59	Not Significant
	SB[e]	773	38.0	5.10	754	38.2	5.28	0.85	Not Significant

n = Number of samples, $\overline{X}$ = Mean, S = Standard deviation.

[a] Data from 08:30 - 18:30

[b] Only 1.6 mph difference

[c] NB = 06:30 - 08:30, SB = 16:30 - 18:30

[d] NB & SB = 10:00 - 15:00

[e] NB & SB = 08:30 - 18:30

[f] The difference is 2.9 mph

TABLE 27

COMPARISON OF QUEUEING CHARACTERISTICS BEFORE VS. AFTER

Study Site	Direction	Before			After		
		Avg. Number of Queue per Hour	Avg. Number of Vehicles per Queue	Avg. Queue Speed (mph)	Avg. Number of Queue per Hour	Avg. Number of Vehicles per Queue	Avg. Queue Speed (mph)
S - 1 on Rte. 501	NB	5.0	2.4	46.0	6.4	2.3	46.7
	SB	3.5	2.4	48.0	4.8	2.3	48.4
S - 5 on Rte. 116	NB	14.1	2.5	44.0	14.6	2.5	45.5
	SB	13.3	2.6	36.8	12.1	2.5	37.8

NOTE: Samples are from 08:30 - 18:30 for the before data and from 06:30 - 16:30 for the after data at site S - 1. The samples for site S - 5 are from 6:30 - 18:30.

T-tests on the before and after avg. numbers of queues an hour (Significance level at $\alpha = 0.05$)

Route 501

$t_{NB} = 1.50$ d.f. = 18 Not significant

$t_{SB} = 1.31$ d.f. = 18 Not significant

Route 116

$t_{NB} = 0.09$ d.f. = 22 Not significant

$t_{SB} = 0.21$ d.f. = 22 Not significant

Means test by normal distribution on the before and after avg. numbers of vehicles per queue (Significance level at $\alpha = 0.05$)

Route 501

$z_{NB} = 0.63$ Not significant

$z_{SB} = 0.63$ Not significant

Route 116

$z_{NB} = 0.00$ Not significant

$z_{SB} = 0.83$ Not significant

TABLE 28

COMPARISON OF QUEUE SPEEDS BEFORE VS. AFTER

Study Site	Route Number	Direction	Before			After			Computed z-Scores	Significance Test at $\alpha = 0.05$ ($z = 1.96$)
			n_1	$\overline{X}_1$(mph)	S_1(mph)	n_2	$\overline{X}_2$(mph)	S_2(mph)		
S - 1	Rte. 501	NB	52	46.0	6.7	67	46.7	7.5	0.[illegible]4	Not Significant
		SB	36	48.0	5.5	51	48.4	6.0	0.32	Not Significant
S - 5	Rte. 116	NB	170	44.0	6.4	175	45.5	4.0	2.59	Significant[a]
		SB	160	36.8	4.8	147	37.8	4.6	1.85	Not Significant

NOTE: Samples are from 06:30 - 17:00 for S - 1 on Route 501, after study. All others are from 06:30 - 18:30.

n = Number of Samples, $\overline{X}$ = Mean, S = Standard deviation.

[a]Only 1.5 mph difference.

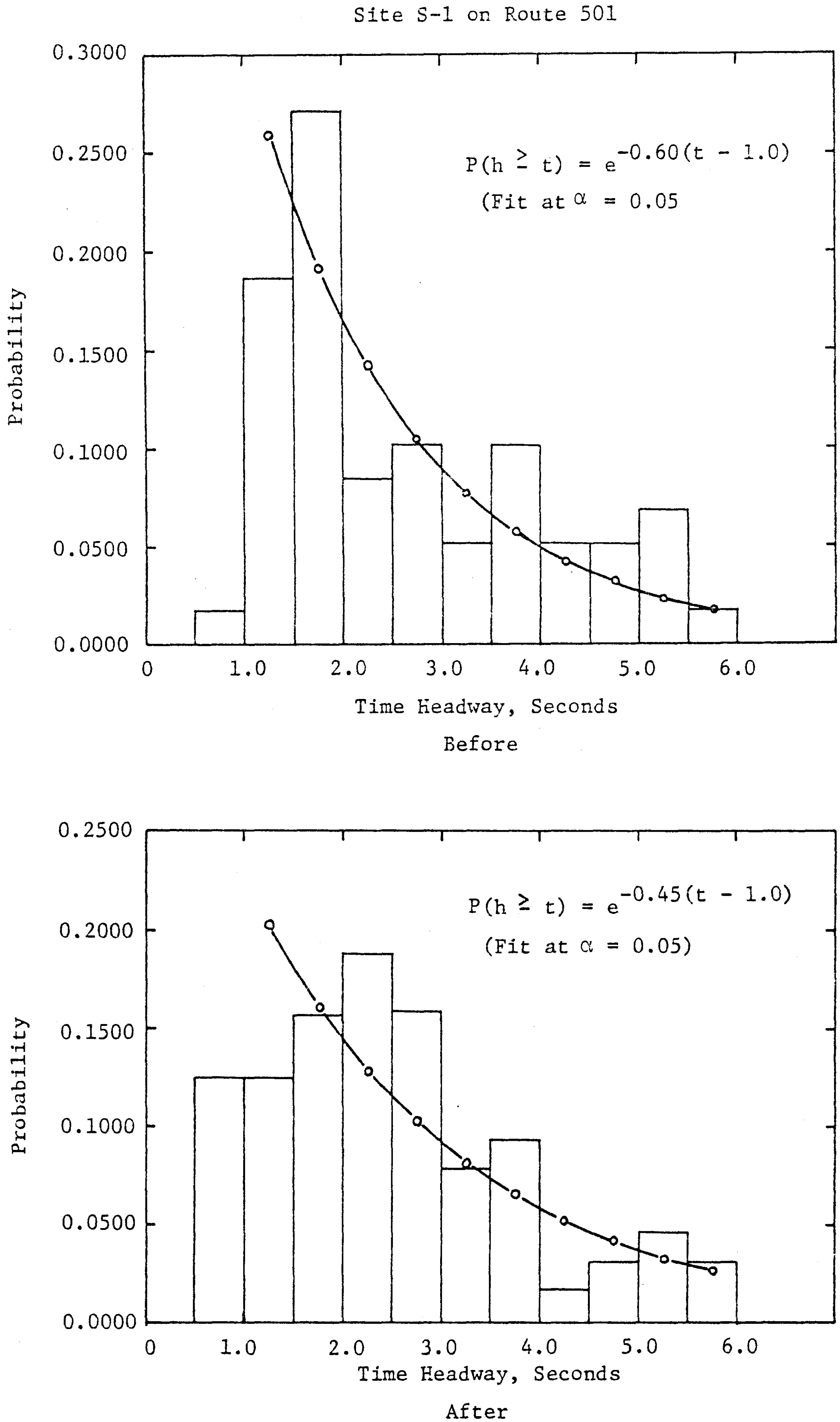
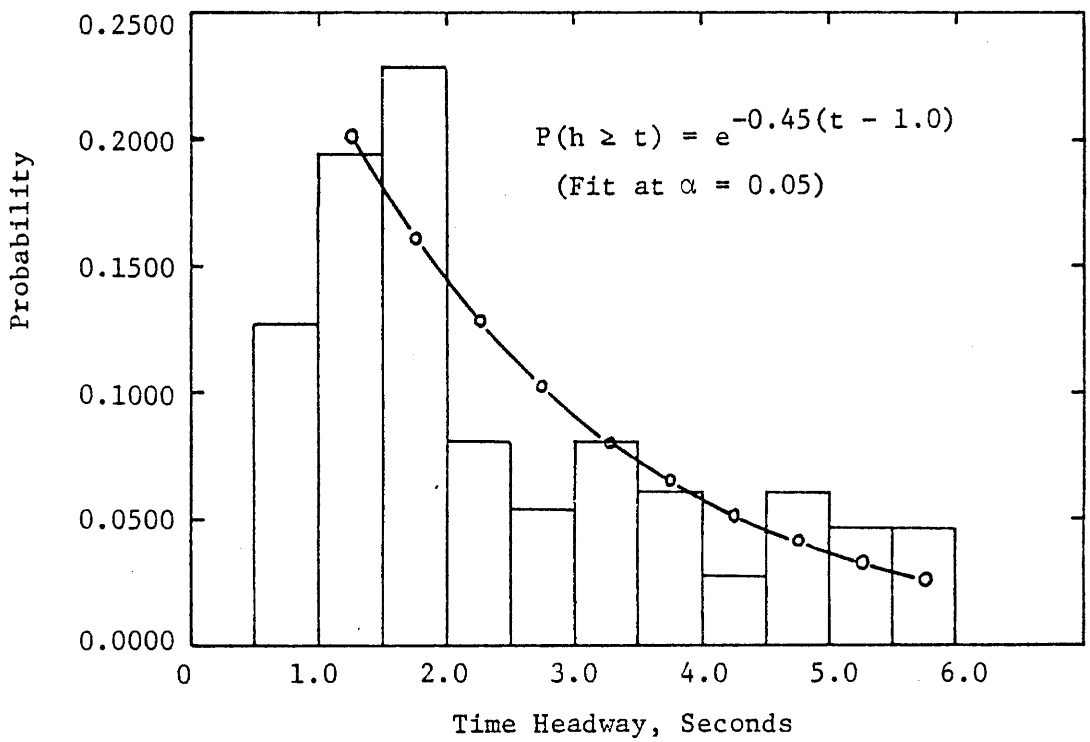
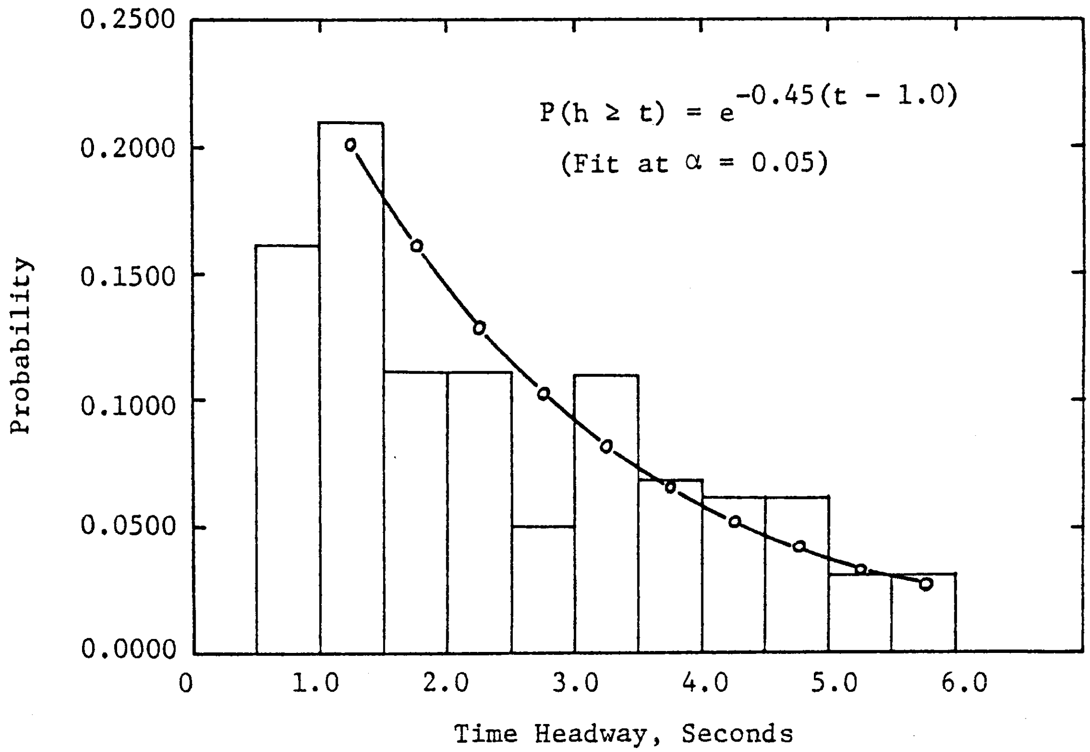


FIGURE 16. COMPARISON OF TIME HEADWAY DISTRIBUTION IN QUEUES.

Site S-5 on Route 116



Before



After

FIGURE 16. CONTINUED.

TABLE 29

COMPARISON OF TIME HEADWAYS IN QUEUE: BEFORE VS. AFTER

S - 1 on Route 501

Lane	Before[a]			After[b]			Computed z-Scores	Significance Test at $\alpha = 0.05$ ($z = 1.96$)
	n_1	$\overline{X}_1$(sec)	S_1(sec)	n_2	$\overline{X}_2$(sec)	S_2(sec)		
NB	78	2.19	1.12	85	2.33	1.28	0.78	Not Significant
SB	59	2.65	1.33	64	2.49	1.34	0.65	Not Significant

S - 5 on Route 116

Time Period	Lane	Before			After			Computed z-Scores	Significance Test at $\alpha = 0.05$ ($z = 1.96$)
		n_1	$\overline{X}_1$(sec)	S_1(sec)	n_2	$\overline{X}_2$(sec)	S_2(sec)		
Peak Period	NB[c]	149	2.47	1.38	162	2.45	1.46	0.12	Not Significant
	SB[d]	138	2.68	1.37	123	2.83	1.35	0.89	Not Significant
Off-Peak Period	NB[e]	99	2.39	1.73	102	2.40	1.58	0.03	Not Significant
	SB[f]	116	2.54	1.27	101	2.57	1.37	0.16	Not Significant

Note: n = Number of samples, $\overline{X}$ = Mean, S = Standard deviation.

[a] Samples from 06:30 - 18:30

[b] Samples from 06.30 - 17.00

[c] Samples from 06:30 - 08:30

[d] Samples from 16:30 - 18:30

[e] Samples from 08:30 - 18:30

[f] Samples from 06:30 - 16:30

Effects on Passing Maneuvers

Passing maneuvers were filmed at sites S-1 and S-5A for the after study. Two types of information were obtained from the filmed passing maneuvers. One of them was the motorists' interpretation of and compliance with the MUTCD marking patterns, and the other was the adequacy of the proposed minimum lengths of passing zones.

Motorists' Interpretation and Compliance

At site S-1 on Route 501, where the available sight distance is approximately 1,400 ft., 87.5% of the passing motorists encroached onto the left lane in the first one-third of the passing zone provided. On the other hand, at site S-5A, where the available sight distance is about 1,850 ft., only 36% of the sampled passing motorists encroached on the left lane in the first one-third of the provided passing zone. Forty percent of them started in the second one-third of the provided passing zone. These findings may indicate that the passing motorists may delay their decision to commence a pass when the perceived safety is enhanced by the long ASD.

About 70% of the passing motorists returned to the right lane without intruding on the passing zone in the opposite lane at both study sites. This indicates that the majority of motorists would correctly interpret the MUTCD passing and no-passing zone marking patterns.

Although passing maneuvers were not filmed at site S-5 where the MPM was replaced with the double solid yellow line for the no-passing zone, it was found from data taken by the electronic data acquisition system that hardly any passing maneuvers occurred at this site. This indicates that motorists would correctly interpret the marking and also comply with it.

Evaluation of the Proposed Passing Zone Lengths

A total of 24 passing maneuvers were filmed at site S-1 and 25 at site S-5a. At site S-1, 92% of the passes were completed within the proposed minimum length of passing zone for the 85th percentile speed. At site S-5A, about 88% of the passes were completed within the proposed minimum length for the 85th percentile speed. These figures suggest that the proposed minimum lengths of passing zones are adequate.

Summary of Before and After Findings

The comparisons of the before and after data produced several significant results as summarized below.

- The replacement of the MPM with the standard MUTCD passing and no-passing zone marking patterns did not produce substantial changes in the traffic operating characteristics.

- Although some passing zones designated by the MPM would be changed into no-passing zones, the queuing characteristics were not significantly altered; therefore, the increase in delay would be minimal, if any.

- The standard MUTCD marking patterns not only provided better indications of sections of roads suitable for passing maneuvers, but also encouraged motorists to refrain from improper driving maneuvers, as shown by a reduction in the percentage of very short headways.

- The proposed minimum lengths for passing zones developed in this study proved to be adequate and provided some distance for the delayed passes if motorists chose to do so based on their perception of safety in performing a passing maneuver.

CONSEQUENCES OF IMPLEMENTING PROPOSED GUIDELINES

The major consequences of implementing the proposed passing zone and passing sight distance requirements are probably anticipated losses in passing opportunities and an increase or decrease in accident rates. These are discussed below.

Pass Opportunity

The immediate concern would be the loss of passing zones that theoretically exist on all sections of the MPM roads. To estimate the reduction of such passing zones, several routes were randomly sampled. Each sampled MPM road was divided into 1-mile segments and numbered. Then, four segments were randomly chosen from each MPM road, and the ASDs were measured at each quarter of the selected 1-mile segment. Along with the available ASD, vehicle speeds were sampled by a radar gun to estimate the 85th percentile speed for the sampled MPM road or section of road.

Table 30 summarizes the results of this survey. It is estimated that approximately 30% of the MPM roads would remain open as passing zones and the rest would be designated as no-passing zone. It should be noted, however, that several sections of the MPM roads are not suitable for undertaking passing maneuvers and that, in general, motorists would not pass at these sections. Therefore, the implementation of the proposed guidelines using the MUTCD sanctioned marking patterns would not impose serious restrictions upon motorists.

Accident Rates

As discussed in the section on accident analysis, the data on passing related accidents are inadequate for any definite conclusion to be made. It can, however, be said that there is no evidence that will support an assumption that passing related accident rates on sections of roads striped with MPM are higher than the rates on sections of roads striped with standard MUTCD markings.

TABLE 30

ESTIMATED PERCENTAGES OF PASSING/NO-PASSING ZONES
ON THE MPM ROADS BY THE SUGGESTED STANDARDS

District	Route	Number of Randomly Selected Segments	Number of Sites for Possible Passing Zone	Expected Passing Zones (%)	Expected No-Passing Zones (%)
Bristol	Rte. 58	12	3	25	75
	Rte. 63	20	5	25	75
	Rte. 70	8	2	25	75
	Rte. 72	4	1	25	75
	Rte. 72	8	3	38	62
	Rte. 83	20	6	30	70
	Rte. 83	20	7	35	65
			Average	29.0	71.0
Lynchburg	Rte. 56	16	4	25	75
Salem	Rte. 40	16	6	38	62
	Rte. 42	16	3	19	81
	Rte. 61	16	2	13	87
	Rte. 311	16	4	25	75
			Average	23.8	76.2
Staunton	Rte. 39	20	4	20	80
	Rte. 60	8	4	50	50
	Rte. 220	12	5	42	58
	Rte. 250	12	2	17	83
			Average	32.3	67.7
			Grand Average	28.8	71.7
			Confidence Interval (95 % Confidence Level)	22.8 - 33.8	66.2 - 77.2

SUMMARY OF FINDINGS

The major findings from the study are summarized below.

Summary of Survey of States

1. A large majority of the states (approximately 76%) always adhere to the MUTCD standards, while the remaining 24% use the standards in most cases.

2. A large majority of the states (approximately 71%) carry out some reconstruction to alleviate the problem of inadequate sight distances on two-lane, two-way roads rather than use special pavement markings as is done in Virginia.

3. Approximately 14% of the states increase law enforcement or erect special signs to reduce illegal passing maneuvers.

4. No special problems have been observed in states which have long distances of two-lane highways marked as no-passing zones.

5. The use of non-MUTCD markings is not a common practice.

Summary of Motorists' Opinion Survey

6. Approximately 17% of the interviewed motorists indicated that they had experienced some delay. Among those who had experienced delay, only about one-third actually believed that the delay was either excessive or moderate. Delay was, therefore, not a serious problem for the majority of motorists interviewed.

7. Approximately 78% of the interviewed motorists favored clearly marked passing and no-passing zones, which indicates that the majority of motorists will welcome the standard MUTCD marking system for the designation of passing and no-passing zones.

Field Studies

8. More passes were observed on upgrade lanes than on downgrade lanes. This demonstrates higher demands for passing zones on upgrade lanes.

9. The speed difference between the opposite lanes for the 85th percentile operating speed for the peak and off-peak hours combined ranged from zero to 7 mph. If the difference is large (say more than 5 mph), it would be safer to use different 85th percentile operating speeds for downgrades and upgrades to compute passing sight distances.

10. On mountainous highways, where the available sight distance was limited, motorists tended to pass with differences in speed greater than the 10 mph cited in the AASHTO Blue Book. Slightly more than 60% of the sampled passing vehicles traveled with a 15 mph difference in speed. The 15th percentile speed difference was 11.4 mph. These findings may imply that the passing drivers are more pressed to complete the pass in a shorter length on mountainous highways than on ordinary, less restrictive two-lane, two-way highways.

11. The lowest speed of the passing vehicles was approximately 30 mph. This may indicate that motorists would not attempt a pass if their desired speed is less than 30 mph due to the restrictive geometries.

12. The mean speed of the passing vehicles sampled was found to be approximately equal to the off-peak 85th percentile speeds at the study sites. The use of the prevailing off-peak 85th percentile speed for the determination of passing sight distance requirements on two-way highways in mountainous areas is, therefore, reasonable.

13. The distance traveled by the passing vehicle between the head and tail position and the position at completion of the pass (see Figure 7) was on the average approximately 69% of the passing distance, whereas the distance traveled by the passing vehicle between the abreast position and the position at completion of pass was on the average about 56% of the passing distance.

14. The ratio of the before spacing to the after spacing was found to be approximately 0.70 on the average. The average before spacing was 56 ft. after spacing 79 ft. These findings imply that if the passing and impeding vehicles are of similar type, say passenger cars, the passing vehicle would encroach on the left

lane after it has reduced the starting spacing by approximately 30%. Thus, the starting space headway and the after space headway could be considered equal for a pass performed by similar vehicles.

15. On two-lane, two-way highways in mountainous areas, although speed is a major factor affecting the passing distance, the difference in speed between the passing and impeding vehicles and grade, in that order, have significant effects on the passing distance. Grade is, however, not a major factor if the passing speed is less than 50 mph.

Kinematic Pass Model

16. The modified kinematic pass model developed in the study approximates the actual passing maneuver reasonably. This indicates that passing maneuvers could be simulated by this type of kinematic model.

Results of Analyses

17. The MUTCD requirements for marking no-passing zones are not adequate to ensure safe passing maneuvers on mountainous highways. The minimum length of 400 ft. for a passing zone specified by the MUTCD may not be adequate for passing vehicles to safely complete a pass even at a 30 mph passing speed.

18. The Virginia Department of Highways and Transportation sanctioned requirements for marking no-passing zones, which are used discretionally in Virginia, are extremely conservative. Such excessively conservative requirements may eliminate many possible passing zones, not only on mountainous highways but also on two-lane, two-way highways with more favorable geometries.

19. The minimum passing sight distance requirements developed in this study using the long-zone concept are longer than the MUTCD requirements. The proposed requirements are long enough to provide safe deceleration rates and clearance distances.

20. In the before and after study, the replacement of the MPM with the MUTCD markings did not create significant differences between the traffic flow characteristics noted for the two marking systems.

Legal Issues

21. A study of the tort liability issues indicated that it cannot be concluded that Virginia or its employees incur tort liability because of the Commonwealth's mountain marking policy, as the decision will be based mainly on how the courts analyze specific acts of nonconformance to determine whether they amount to negligence. This will depend on whether the MUTCD is viewed as establishing mandatory minimum standards or are such that nonconformance amounts to negligence as a matter of law or whether the MUTCD is viewed as prescribing a desirable but noncompulsory standard.

CONCLUSIONS

The motorist opinion survey showed that the majority of the motorists correctly interpreted the MUTCD sanctioned marking and signing systems and preferred them to the MPM.

The null hypothesis tested was that there would be no difference in the safety and operational characteristics between the MPM and the standard MUTCD markings for passing and no-passing zones. The before and after analysis showed that this null hypothesis could be statistically acceptable, and that the differences caused by the replacement of the MPM with the MUTCD patterns would be minimal. Considering the motorists' familiarity with them and their use on the rest of the two-way highways in Virginia and those in other states, the MUTCD standard marking patterns should produce a better driving environment than the MPM on two-lane, two-way highways in mountainous areas.

The MUTCD requirements for the minimum length of passing zones and minimum passing sight distances should, however, be revised because they were found to be inadequate for motorists to complete passing maneuvers safely.

RECOMMENDATIONS

Based on the findings from the study, the following recommendations are offered.

1. The MPM should be replaced with the standard MUTCD marking patterns for passing and no-passing zones.

2. Upon adopting the MUTCD sanctioned marking patterns, the Virginia Department of Highways and Transportation's minimum passing sight distance requirements (see Table 3) should not be used as they have been shown to be too conservative.

3. Upon adopting the MUTCD sanctioned marking patterns, the MUTCD sanctioned minimum length of passing zone, 400 ft., should be increased to take into consideration the factors which affect this distance as determined in this study. (See Table 31.)

4. Upon adopting the MUTCD sanctioned marking patterns, the long-zone concept should be used for determining passing sight distances. The minimum passing sight distances established, in this study are thus recommended. (See Table 31.)

5. Until a marking system which delineates the buffer zone of the passing sight distances based on the long-zone concept is nationally accepted, the short-zone concept should be used for marking no-passing zones. In other words, the double solid yellow line is started at a location beyond which the minimum passing sight distance requirements developed by the long-zone concept will not be available.

6. For supplemental signs denoting passing and no-passing zones, the conventional signs such as the MUTCD W14-3, "NO PASSING ZONE," and the MUTCD R4-1, "DO NOT PASS," are recommended.

TABLE 31

SUGGESTED MINIMUM PASSING ZONE AND PASSING SIGHT DISTANCE REQUIREMENTS FOR TWO-LANE, TWO-WAY HIGHWAYS IN MOUNTAINOUS AREAS

85th Percentile Speed (MPH)	Min. Passing Zone Length		Min. Passing Sight Distance	
	Proposed (Ft.)	MUTCD (Ft.)	Proposed (Ft.)	MUTCD (Ft.)
30	560	400	645	550
35	610	400	735	550[a]
40	660	400	825	600
45	710	400	910	700[a]
50	750	400	1000	800
55	800	400	1115	900[a]

Note: When the speed difference on opposite lanes is equal to or greater than 5 mph, use the suggested sight distances in Table 20 .

[a] Interpolated.

REFERENCES

1. National Advisory Committee on Uniform Traffic Control Devices, Manual on Uniform Traffic Control Devices for Streets and Highways. U. S. DOT, FHWA, 1978.

2. Division of Motor Vehicles, Virginia Driver's Manual. Richmond, Virginia, June 1977.

3. Gordon, Donald A., Studies of the Road Marking Code. U. S. DOT, FHWA, FHWA-RD-76-59, April 1976.

4. Shelton, W. B., and J. C. Echols, Mountain Pavement Marking: Rural Primary System. Virginia Department of Highways, Richmond, Virginia, March 1962.

5. Garber, Nicholas J., and C. W. Lynn, "A Case Study of Experimental Passing Zones on Route 8 in Patrick County." Memorandum to State Traffic and Safety Engineer A. L. Thomas, Jr., March 31, 1982.

6. Leupold and Stevens, Inc., Traffic Performance Measures Reporting System. Beaverton, Oregon, May 1981.

7. National Highway Traffic Safety Administration. Acceleration and Passing Ability. Consumer Aid Series, U. S. DOT. Washington, D. C.: Government Printing Office, Annual Publication.

8. Institute of Transportation Engineers, Transportation and Traffic Engineering Handbook. Englewood Cliffs, N. J.: Prentice-Hall, 1976.

9. Virginia Department of Highways and Transportation, Summary of Accident Data: State Highway Systems. Richmond, Virginia, Annual Publication.

10. Kearney, Edward F., and Joanne Chusid, "State Laws on No-Passing Zones." National Committee on Uniform Traffic Laws and Ordinances, U. S. DOT, FHWA. Requisition No. 41-41-7137, 1977 (Unpublished).

11. Weaver, Graeme D., and John C. Glennon, Passing Performance Measurements Related to Sight Distance Design. Texas Transportation Institute, Research Report 134-6, July 1971.

12. Weaver, Graeme D., and Donald L. Woods, *Passing and No-Passing Zones: Signs, Markings, and Warrants*. U. S. DOT, FHWA, Final Report, FHWA-RD-79-5, September 1978.

13. Saito, Mitsuru, *Passing Zones and Sight Distance Requirements for Two-Lane, Two-Way Highways in Mountainous Areas*. Master's Thesis, University of Virginia, January 1983.

14. American Association of State Highway Officials, *A Policy on Geometric Design of Rural Highways* (Blue Book), Washington, D. C. 1965.

15. American Association of State Highway Officials, *A Policy on Criteria for Marking and Signing No-Passing Zone on Two-and Three-Lane Roads: Standards for Marking and Signing No-Passing Zones*, Washington, D. C., 1940.

16. American Association of State Highway Officials, *A Policy on Sight Distance for Highways*, Washington, D. C., 1940.

17. Weaver, Graeme D., and Donald L. Woods, *No-Passing Zone Treatments for Special Geometric and Traffic Operational Situations*, U. S. DOT, FHWA, Final Report, FHWA-RD-81-093, September 1981.

18. Prisk, C. W., "Passing Practices on Rural Highways." *Proceedings of Twenty-First Annual Meeting*, Highway Research Board, Washington, D. C., 1941, pp. 366-378.

19. Dixon, W. J., et al. *BMDP Biomedical Computer Program* P-Series, Los Angeles: University of California Press, 1979.

20. Lieberman, Edward B. "A Model of the Passing Maneuver on Two-Lane Rural Roads." KLD Associates, Huntington Station, N. Y., January 1982.

21. Wilson, Ernest E., "Deceleration Distances for High Speed Vehicles," *Proceedings of Twentieth Annual Meeting*. Highway Research Board, Washington, D. C., 1940, pp. 393-398.

22. Van Valkenburg, G. W., "No-Passing Zones: Criteria Legislation and Location," Final Report, Project No. C-36-17FF, Purdue University, June 1969.

APPENDIX A

SUMMARY OF THE QUESTIONNAIRE SURVEY OF MARKING PRACTICES IN OTHER STATES

QUESTIONNAIRE SURVEY OF STATES

Centerline Pavement Marking Practices For Two-Lane Highways

1. State 48 states*, D.C., Puerto Rico Date June 1978

2. Does your Department use the pavement marking standards outlined in the Manual on Uniform Traffic Control Devices (1971 FHWA MUTCD with subsequent revisions) for centerlining two-lane highways?

   37 Yes, adhere specifically to MUTCD
   12 Yes, in most cases
   0 No. Please outline your policy or enclose a copy of your standards.

3. With regard to each item listed below, please indicate the pavement marking practice used in your state for marking two-lane highways. Also, please note any exceptions to the practice.

Item	Practice	Exceptions
a. Centerline mark and gap lengths		
b. Width of centerline		
c. Width of edgeline		
d. Color of centerline	See Summary	Attached
e. Color of edgeline		
f. Minimum width of pavement centerlined		
g. Minimum width of pavement edgelined		
h. Minimum traffic volume warrant for centerlines		
i. Minimum traffic volume warrant for edgelines		
j. Other considerations. Please specify type.		

4. Please describe any non-MUTCD markings used by your Department on two-lane highways and outline traffic, geometrical, or environmental conditions that you feel justify the use of special marking.

   Exceptions in mountainous areas in Kentucky, Missouri New Hampshire, Virginia, Hawaii, and Washington

*No response was received from Nevada or Mississippi.

5. Does your Department use any non-MUTCD centerline marking patterns on two-lane highways where passing zones cannot be permitted for several miles or more due to restricted sight distances?

3 Yes. Please describe the pattern(s) used and indicate the guidelines you use to determine where nonstandard markings are applied.

46 No.

1- No Reply Mountain markings used in Arkansas, Virginia, Hawaii California, Massachusetts - Washington and Oregon only mark vertical curves.

6. Does your state have continuous sections of two-lane highways on which a double solid, yellow centerline is used to prohibit passing for several miles or more due to restricted sight distances?

37 Yes.
12 No.
1 No reply.

7. If either MUTCD or non-MUTCD patterns are used to mark continous sections of two-lane highways where restrictive sight distances limit passing opportunities, please indicate any problems that have been observed with regard to the following items.

Item	Observation
a. Passing accidents	Insufficient data - ~~Few~~ problem
b. Illegal passing maneuvers	Occasionally - No problem
c. Public complaints	none - Some
d. Slow-moving vehicles causing delay to normal traffic flow	No problem - on grades
e. Driver understanding of the marking code	good - excellent
f. Other problems or benefits. Please specify type.	

8. If you have observed operational or safety problems related to continuous no-passing zones on two-lane highways where sight distancesare restricted for several miles or more, what actions have been taken to improve conditions? Check one or more actions if applicable.

a. 4 None
b. 34 Construct climbing lanes
c. 10 Erect special signing. Indicate message ________
d. 7 Increase law enforcement to reduce illegal passing maneuvers
e. 23 Reconstruct highway to provide adequate sight distance for passing
f. 8 Other. Please specify action. Construct vehicle pullouts - improve sight distance
g. 8 No reply

9. If your state is using a non-MUTCD marking pattern on two-lane highways, on what percentage of the total two-lane highway mileage is the nonstandard marking used?

a. 4 Less than 5%
b. 2 5% to 10%
c. 1 10% to 15%
d. 0 Greater than 15%
e. 4 Unknown
f. 35 Not applicable
g. 8 No reply

10. Are no-passing zones marked in accordance with the minimum passing sight distances outlined in the MUTCD for the various prevailing off-peak 85th percentile speeds?

45 Yes
4 No
1 No reply

11. For the 85th percentile off-peak speeds listed below, please indicate the minimum length of a passing zone and the minimum length of a no-passing zone marked in your state.

85th Percentile Speed (MPH)	Minimum Length of a Passing Zone (Feet)	Minimum Length of a No-Passing Zone (Feet)
30		
40	See Summary Attached	
50		
55	(Appendix D-3)	

12. In addition to sight distance considerations, what other factors do you use to determine the minimum length of a passing zone?

a. 28 None
b. 10 Grades
c. 4 High percentage of slow-moving trucks
d. 8 Availability of other passing zones in the area
e. 11 Other. Please specify factor ______
f. 1 No reply

13. Is it legal in your state to begin a passing maneuver in a passing zone and end the pass in a no-passing zone, i.e., by crossing the solid line to complete the pass?

7 Yes
40 No
3 No reply

14. Based on your experience, do you feel traffic flow would be enhanced with little effect on highway safety if the driver was permitted to complete a pass in a no-passing zone? Please give a reason for your answer?

10 Yes. Reason *Been successful for years - Only way to pass in some areas*

34 No. Reason *Adverse effect on Safety*

6 No reply

15. In addition to pavement markings, are other traffic control devices used to emphasize the existence and extent of a passing or no-passing zone?

43 Yes. Please give the type of device used and message content. *No passing Zone Pennant,*

7 No.

16. When designing passing sight distances for two-lane highways, does your Department use the design standards outlined in the AASHO Policy on Geometric Design of Rural Highways (1965 Blue Book)?

44 Yes

4 No . Please describe your design practice or enclose a copy of your standards or guidelines.

2 No reply

17. Does your organization contemplate changing either the marking pattern or the standards used to mark passing and no-passing zones in the near future?

2 Yes. Please indicate the type of change anticipated. *Change gap ratio to mark*

45 No.

3 No reply

18. Please describe the method (manpower and equipment required and the criteria) your organization uses to determine location of passing and no-passing zones on two-lane highways. If possible, please enclose a copy of your field procedures.

Two car method, Range tracking device computerized surveys, Walking method, Chain gauge method with rope & targets.

19. Does your organization have any planned, ongoing, or completed studies involving the investigation of either the effects of the centerline marking pattern on traffic operations and safety or criteria for marking passing and no-passing zones?

5 Yes. Contact *Studies are continuing in Arizona, Idaho, Maryland, Massachusetts, and Mississippi*

Phone (Area Code) ( ) ________
or please include a copy of the report or indicate project status.

19. (Continued)

43 No
2 No reply

20. Additional comments or observations ______________________________
____
____
____

21. Would you like a copy of our final report on this project?

47 Yes
3 No

Your Name ______________________________
Title ______________________________
Mailing Address ______________________________
____
____

Phone Number (Area Code) ( ) ______________________________

Thank you for your cooperation and assistance. The information you have provided will be tabulated along with data from other jurisdictions and summarized in the final report. If you have any questions or would like more information concerning the study, please contact: Martin R. Parker, Jr., Virginia Highway and Transportation Research Council, Charlottesville, Virginia, Telephone (804) 293-1908.

State	A (Ft.)	B (Inch)	C (Inch)	D	E (Ft.)	F (Ft.)	G (Ft.)	H	I
Alabama	15-25 & 10-30	4	4	Yellow	White	None	None	None	None
Alaska	10-30 & 6-18	4	4	Yellow	White	17	20	None	None
Arizona	10-30	4	4	Yellow	White	16	22	None	None
Arkansas	10-30	4	4	Yellow	White	18	20	None	None
California	7-17[a]	4	4	Yellow	White	—[b]		None	None
Colorado	10-30	5	4	Yellow	White	20	20	None	None
Connecticut	15-25	4	4	Yellow	White	16	24	None	None
Delaware	10-30	4	4	Yellow	White	16	20[c]	250 AADT	250 AADT
Dist. of Columbia*		4		Yellow		22		N.A.	Freeway Only
Florida	10-30	4	4	Yellow	White	Non-Stand.	20	250 ADT	250 ADT
Georgia	10-30	4-6	4-5	Yellow	White	16	18	All Rds.	All Rds.
Hawaii	10-30	4	4	Yellow	White	16	None	None	None
Idaho	20-30[d]	4	4	Yellow	White	18	20	None	None
Illinois	10-30	4-5	4	Yellow	White	16	16	—[e]	1000 ADT
Indiana	10-30[f]	4[g]	4[h]	Yellow	White[i]	16	18	None	None
Iowa	10-30	4.5	4	Yellow	White		20	None	None
Kansas	12.5-37.5	5	4	Yellow	White	None	None	None	None
Kentucky	25-15[j]	4	4	Yellow	White	16	20	300 ADT	None
Louisiana	10-30	4	4	Yellow	White	None	24[k]	None	None
Maine	15-25	4	4	Yellow	White	15	20	250 ADT	
Maryland	10-30	4-6	4-6	Yellow	White/ Yellow	16	18	None	None
Massachusetts	10-30	4	4	Yellow	White	16	20	None	None
Michigan	12.5-37.5	4	4	Yellow	White	16	None	None	None
Minnesota	10-40	4	4	Yellow	White	None	None	None	None
Mississippi				Yellow	White				
Missouri	10-30	4	4	Yellow	White	18	—[l]	225 ADT	
Montana	10-30[h]	4	4	Yellow	White	None	24	None	None
Nebraska	10-30	4	4	Yellow	White				
Nevada				Yellow	White				
New Hampshire	10-30	4	4	Yellow	White	15	20	None	200 ADT
New Jersey	15-25[h]	4	4[i]	Yellow	White/ Yellow	16	20	None	None
New Mexico	10-30[f]	4	4	Yellow	White	16	18	250 ADT	250 ADT
New York	15-25[h]	4	4	Yellow	White	16	16	None	None
North Carolina	10-30	4	4	Yellow	White	16	16	100 ADT	100 ADT
North Dakota	10-30	4	4	Yellow	White	16	16	None	None
Ohio	10-30	4	4	Yellow	White/ Yellow	16	18	None None	None None
Oklahoma	12-33	4	4	Yellow	White	18	20	None	None
Oregon	15-25	4	4	Yellow	White	18	22	None	None
Pennsylvania	10-30	4	4	Yellow	White	16	20	250 ADT	250 ADT
Puerto Rico	15-25	4	4	Yellow	White	16	20	250 VPD	250 VPD
Rhode Island	Solid Dbl. Line	4	4	Yellow	White	22	24	None	None
South Carolina	10-30	4	4	Yellow	White	18	20[k,j]	—[k,j]	None
South Dakota	10-30	4	4	Yellow	White	16	24	None	None
Tennessee	10-30	4	4	Yellow	White	18			
Texas	10-30[f]	4	4	Yellow	White	16	22	300 VPD	1000 VPD
Utah	12-28	4	4	Yellow	White		26		
Vermont	10-30	4	4	Yellow	White	15	18	None	None
Virginia	10-30	4[i]	4[i]	Yellow	—[m]	16	20	500 VPD	None
Washington	10-30	4	4	Yellow	White	20	20	None	None
W. Virginia	10-30	4	4	Yellow	White	16	18	250 ADT	250 ADT
Wisconsin	15-35	4	4	Yellow	White	16	18	None	—[l]
Wyoming	15-25[h]	4	4	Yellow	White	18	20	300 ADT	300 ADT

* — See Questionnaire

a. 12' - 36' on high speed roads
b. Centerline is placed only where two vehicles can pass safely
c. With centerline; 15' without centerline
d. 15' - 35'
e. "Significant traffic volumes"
f. 15' - 25' as stated in Indiana
g. 5" on freeways
h. 10' - 30'
i. 3"
j. For equal or less than 1,000 ADT
k. 18' for less than 500 ADT
l. See questionnaire
m. Form T & 3 - 138

SUMMARY OF MINIMUM LENGTH OF PASSING ZONE IN FEET
(Question 11 of Questionnaire)

State	85th Percentile Speed (mph)		
	30	40	50
Alabama*	400	600	800
Alaska	441	588	735
Arizona	350	500	500
Arkansas	500	500	500
California	1,100	1,500	1,800
Colorado*	500	600	800
Connecticut	400	400	400
Delaware	300	400	499
Dist. of Columbia	-	-	-
Florida	500	500	500
Georgia	-	-	-
Hawaii	400	400	400
Idaho	600	600	600
Illinois	400	500	600
Indiana	400	500	600
Iowa	-	-	-
Kansas	400	400	400
Kentucky	400	400	400
Louisiana	-	-	-
Maine	400	400	400
Maryland	400	400	400
Massachusetts*	500	600	800
Michigan	500	500	500
Minnesota	500	500	500
Mississippi	-	-	-
Missouri	400	400	400
Montana	600	600	600
Nebraska*	500	600	800
Nevada	-	-	-
New Hampshire*	500	600	800
New Jersey*	500	600	800
New Mexico *	500	600	800
New York	400	400	400
North Carolina	400	400	400
North Dakota	1,100	1,500	1,800

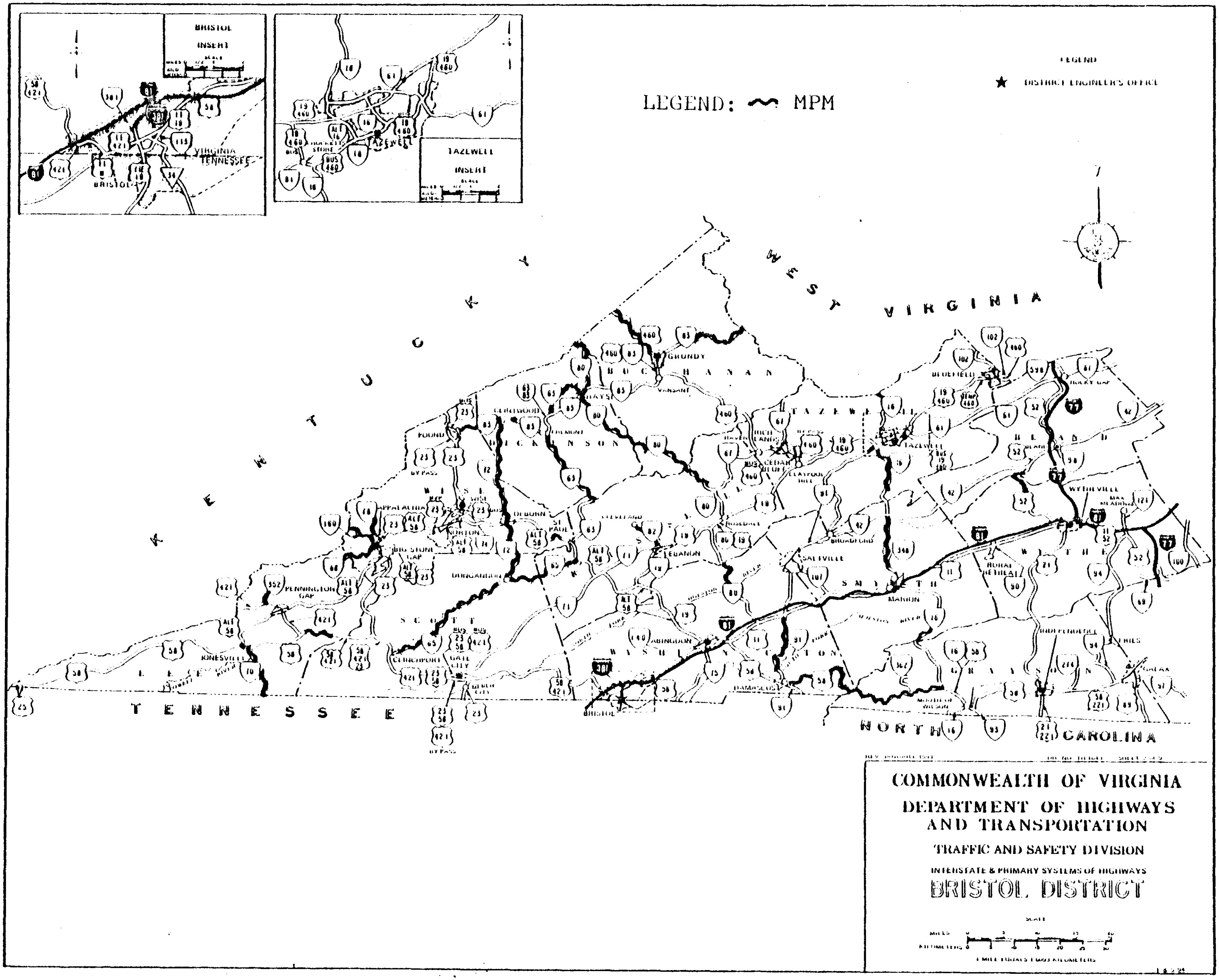
SUMMARY OF MINIMUM LENGTH OF PASSING ZONE IN FEET
(continued)

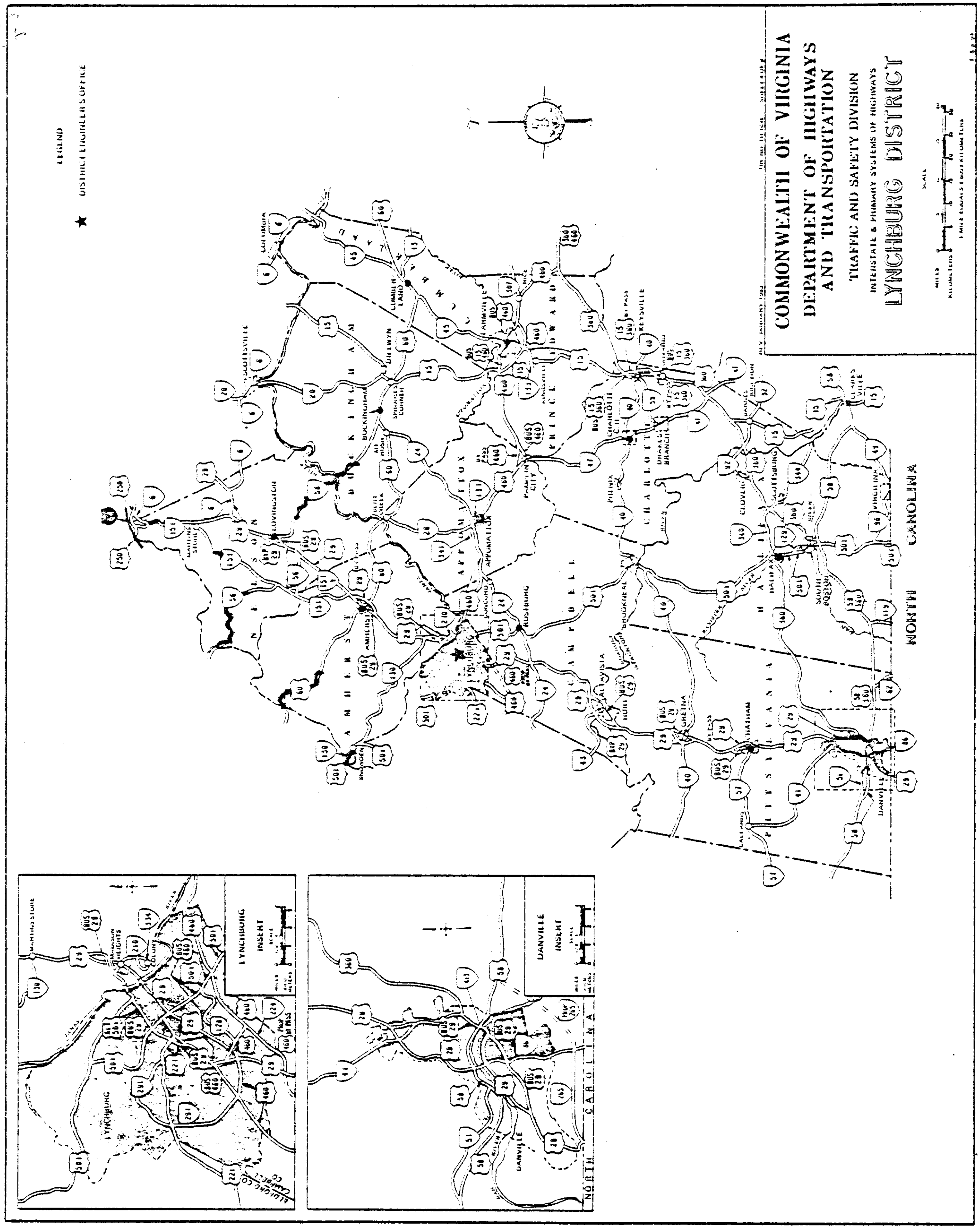
State	85th Percentile Speed (mph)		
	30	40	50
Ohio	400	400	600
Oklahoma	400	400	400
Oregon	400	400	600
Pennsylvania	400	400	600
Puerto Rico	-	-	-
Rhode Island*	500	600	800
South Carolina	400	500	400
South Dakota	400	400	400
Tennessee	MUTCD	MUTCD	MUTCD
Texas	400	400	400
Utah	MUTCD	MUTCD	MUTCD
Vermont	-	-	-
Virginia*	500	600	800
Washington	400	400	400
West Virginia	400	400	400
Wisconsin	528	528	660
Wyoming	400	450	480

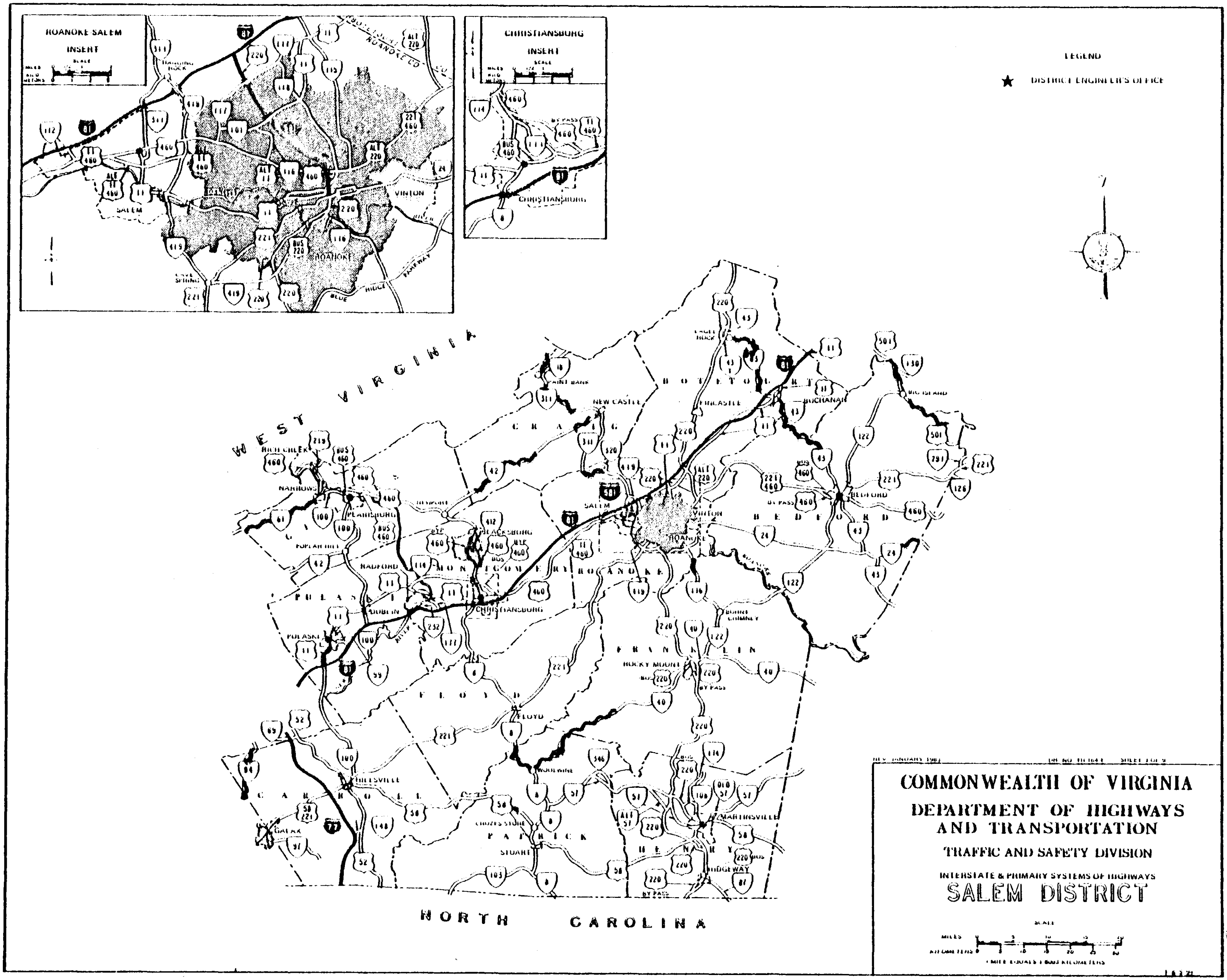
*These states may have given the minimum passing sight distance requirements instead of the minimum length of passing zone, which was the intent of this question.

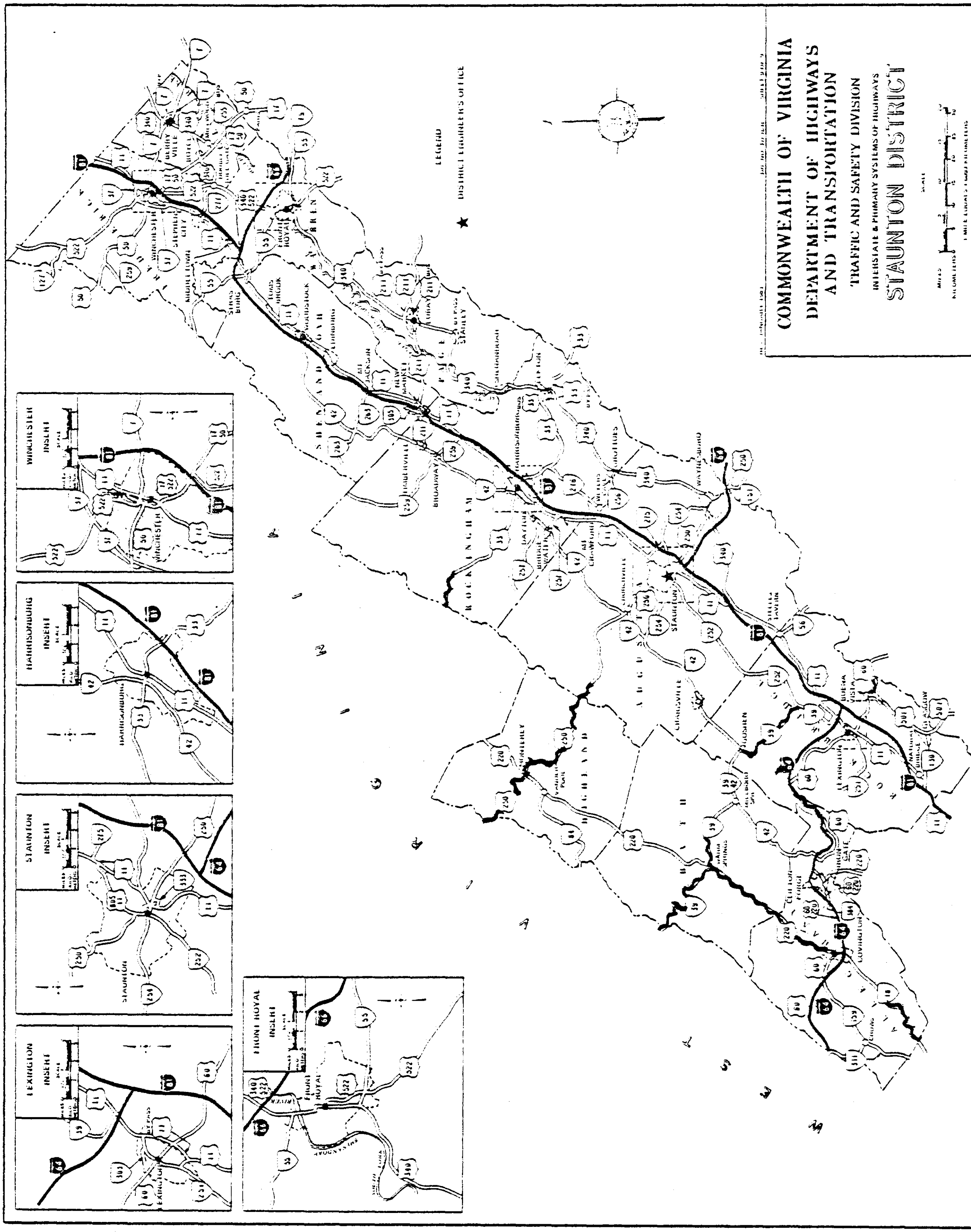
APPENDIX B

ROUTES WITH MPM




COMMONWEALTH OF VIRGINIA
DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
TRAFFIC AND SAFETY DIVISION
INTERSTATE & PRIMARY SYSTEMS OF HIGHWAYS
LYNCHBURG DISTRICT
LEGEND
DISTRICT ENGINEER'S OFFICE
LYNCHBURG INSENT
DANVILLE INSENT
NORTH CAROLINA


COMMONWEALTH OF VIRGINIA
DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
TRAFFIC AND SAFETY DIVISION
INTERSTATE & PRIMARY SYSTEMS OF HIGHWAYS
SALEM DISTRICT
SCALE
MILES
KILOMETERS
LEGEND
DISTRICT ENGINEER'S OFFICE
ROANOKE SALEM INSERT
CHRISTIANSBURG INSERT
WEST VIRGINIA
NORTH CAROLINA
BOTETOURT
CRAIG
BEDFORD
ROANOKE
MONTGOMERY
PULASKI
FLOYD
FRANKLIN
CARROLL
PATRICK
HENRY
SALEM
ROANOKE
VINTON
CHRISTIANSBURG
BLACKSBURG
RADFORD
PULASKI
DUBLIN
PEARISBURG
NARROWS
RICH CREEK
NEW CASTLE
PAINT BANK
FINCASTLE
BUCHANAN
EAGLE ROCK
BIG ISLAND
BEDFORD
ROCKY MOUNT
BOONES MILL
FLOYD
WOOLWINE
STUART
MARTINSVILLE
RIDGEWAY
HILLSVILLE
GALAX
POPLAR HILL


COMMONWEALTH OF VIRGINIA
DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
TRAFFIC AND SAFETY DIVISION
INTERSTATE & PRIMARY SYSTEMS OF HIGHWAYS
STAUNTON DISTRICT
LEGEND
DISTRICT ENGINEER'S OFFICE
WINCHESTER INSET
HARRISONBURG INSET
STAUNTON INSET
LEXINGTON INSET
FRONT ROYAL INSET

APPENDIX C

INVENTORY OF MOUNTAIN PAVEMENT MARKING
AS OF JULY 1982

Bristol District

Route	County	From	To	Mileage
598	Bland	W. Va. State Line	4.8 Mi. S. West Va. State Line	4.8
52	Bland	Wythe County Line	2.2 Mi. N. Wythe County Line	2.2
52	Bland	Rte. 615 (Bastian)	3.0 Mi. S. Rte. 615 (Bastian)	3.0
80	Buchanan	Russell County Line	Dickenson County Line	9.9
83	Buchanan	NCL Grundy	W. Va. State Line	14.3
83	Buchanan	Dickenson County Line	Int. Rte. 460	10.4
460	Buchanan	WCL Grundy	Kentucky State Line	11.2
609*	Buchanan	Int. Rte. 460	Int. Rte. 614	2.5
624*	Buchanan	Int. Rte. 460 (Oakwool)	Int. Rte. 632	3.0
652*	Dickenson	2.3 Mi. E. Wise County Line	Wise County Line	2.3
63	Dickenson	Russell County Line	Int. Rte. 83 (Fremont)	15.0
63	Dickenson	Int. Rte. 83 (Clinchco)	Haysi (Rte. 83)	9.3
72	Dickenson	Int. Rte. 83	Wise County Line	7.7
80	Dickenson	Buchanan County Line	Kentucky State Line	20.6
83	Dickenson	Haysi (Rte. 80)	Buchanan County Line	3.6
614 *	Dickenson	Route 63	John Flannagan Dam	2.0
607 *	Dickenson	Rte. 83 (Clintwood)	Route 689	1.5

* - secondary roads

Bristol District (Continued)

Route	County	From	To	Mileage
16	Grayson	Smyth County Line	1.0 Mi. S. Smyth County Line	1.0
58	Grayson	Int. Rte. 16 (Volney)	Washington County Line	17.3
58	Lee	Stickleyville	0.75 Mi. E. Rte. 421 (Dot)	3.5
70	Lee	Int. Rte. 58 (Jonesville)	Tennessee State Line	12.3
352	Lee	Int. Rte. 421	Int. Rte. 634	2.4
606*	Lee	Wise County Line	Keokee	3.2
63	Russell	Dickenson County Line	1.4 Mi. S. Dickenson C. L.	1.4
80	Russell	WCL Honaker	Buchanan County Line	5.3
82	Russell	WCL Lebanon	Int. Rte. 600 (Cleveland)	6.5
600*	Russell	Int. Rte. 82	Int. Rte. 664	0.4
615*	Russell	Int. Rte. 63 (Hamblin)	Int. Rte. 600	7.1
616*	Russell	Int. Rte. 777	Int. Rte. 615	2.1
664*	Russell	Int. Rte. 600	Int. Rte. 777	1.4
72	Scott	Wise County Line	3.2 Mi. S. Wise County Line	3.2
600*	Scott	Int. Rte. 23	Int. Rte. 638	2.8
614*	Scott	Int. Rte. 23	Int. Rte. 866	4.2
638*	Scott	Int. Rte. 604	Int. Rte. 58	1.1
619*	Scott	Int. Rte. 71	Dungannon	10.4
16	Smyth	Int. Rte. 348	E. Int. Rte. 42	10.0
16	Smyth	Int. Rte. 699	Int. Rte. 622	3.0
16	Smyth	Int. Rte. 676	Grayson C. L.	4.5

* - secondary roads

Bristol District (Continued)

Route	County	From	To	Mileage
91	Smyth	Int. Rte. 42	Tazewell County Line	0.5
16	Tazewell	Int. Rte. B-460	Int. Rte. 601	9.3
16	Tazewell	Int. Rte. 643	W. Va. State Line (Bishop)	4.0
91	Tazewell	Smyth County Line	Int. Rte. 601	1.6
644*	Tazewell	Int. Rte. 702	W. Va. State Line	13.0
58	Washington	Int. Rte. 91	Grayson County Line	15.4
80	Washington	Int. Rte. 700	Russell County Line	8.8
91	Washington	Int. Rte. 11 (Old Glade)	Int. Rte. 722	6.0
702*	Washington	Int. Rte. 11 (Abingdon)	Int. Rte. 699	1.2
68	Wise	Int. Rte. 23	Lee County Line	5.4
72	Wise	Scott County Line	3.5 Mi. N. Scott County Line	3.5
72	Wise	Dickenson County Line	Cranes Nest	7.3
160	Wise	Int. Rte. 23	Kentucky State Line	8.3
640*	Wise	ECL Wise	2.5 Mi. E. ECL Wise	2.5
646*	Wise	NCL Coeburn	Int. Rte. 648	2.7
813*	Wise	Rte. A-58 (Tacoma)	Rte. A-58 (Coeburn)	3.0
652*	Wise	Dickenson County Line	1.3 Mi. W. Dickenson C. L.	1.3
52	Wythe	Bland County Line	3.6 Mi. S. Bland C. L.	3.6
	Total			323.8

* - secondary roads

Lynchburg District

Route	County	From	To	Mileage
60	Amherst	0.4 Mi. W. of W. Int. Rte. 635	Rockbridge County Line	8.62
130 & 501	Amherst	1.2 Mi. N. of Rte. 130	Rockbridge County Line	2.60
56	Nelson	0.06 Mi. N. E. of Rte. 647	0.3 Mi. S. E. of Rte. 639	10.18
56	Nelson	0.75 Mi. E. of Rte. 687	Rockbridge County Line	9.38
151	Nelson	0.5 Mi. N. of Rte. 707	Route 628	2.11
151	Nelson	0.2 Mi. S. of Rte. 631	0.1 Mi. S. of Rte. 250	1.70
	Total			34.59

Salem District

Route	County	From	To	Mileage
43	Bedford	0.2 Mi. N. 641	Blue Ridge Parkway	2.10
501	Bedford	0.2 Mi. N. 657	1.6 Mi. N. Rte. 761	2.20
501	Bedfrod	0.2 Mi. N. Rte. 752	1.3 Mi. S. Rte. 612	2.40
501	Bedford	0.1 Mi. S, Amherst C. L.	2.5 Mi. N. Rte. 600	2.20
43	Botetourt	0.09 Mi. S. Rte. 625	Blue Ridge Parkway	3.90
43	Botetourt	2.0 Mi. N. Rte. 649	Route 688	7.10
94	Carroll	Route 605	0.56 Mi. S. Rte. 601	7.28
18	Craig	0.16 Mi. N. Rte. 311	Alleghany C. L.	5.02

Salem District (Continued)

Route	County	From	To	Mileage
42	Craig	0.16 Mi. W. Rte. 640	0.79 Mi. E. Rte. 622	2.62
42	Craig	0.27 Mi. W. Rte. 622	0.26 Mi. E. Rte. 658	11.05
311	Craig	0.07 Mi. N. of Rte. 18	West Va. State Line	3.33
311	Craig	0.21 Mi. S. Rte. 600	0.17 Mi. N. Rte. 658	10.72
40	Franklin	Route 789	Patrick C. L.	5.10
116	Franklin	Roanoke C. L.	0.63 Mi. N. Rte. 678	2.94
61	Giles	0.16 Mi. W. of WCL Narrows	0.18 Mi. E. of Bland C. L.	12.24
8	Patrick	0.12 Mi. N. Rte. 605	Floyd C. L.	3.19
40	Patrick	Franklin C. L.	0.16 Mi. E. of Rte. 8	9.87
58	Patrick	1.43 Mil W. Rte. 640	0.67 Mi. E. Rte. 610	3.27
11	Pulaski	0.24 Mi. S. of SCL Pulaski	0.87 Mi. S. of Rte. 766	1.80
116	Roanoke	Route 939	Franklin C. L.	.71
311	Roanoke	0.1 Mi. N. Rte. 911	0.28 Mi. S. Rte. 698	2.96
	Total			102.00

Staunton District

Route	County	From	To	Mileage
60	Alleghany	Rockbridge C. L.	3.9 Mi. West	3.9
220	Alleghany	Bath C. L.	0.1 Mi. N. Rte. 687	8.2
18	Alleghany	Craig C. L.	0.3 Mi. N. Rte. 610	6.1
687 *	Alleghany	0.9 Mi. W. Rte. 220	Route 686	3.9
606 *	Alleghany	Bath C. L.	Route 703	1.2
703 *	Alleghany	Route 606	Bath C. L.	1.3
250	Augusta	Highland C. L.	2.3 Mi. East	2.3
56	Augusta	Route 11	Rockbridge C. L.	0.2
250	Highland	Augusta C. L.	ECL Monterey	18.5
250	Highland	WCL Monterey	W. Va. Line	13.3
39	Bath	0.2 Mi. E. Rte. 220	2.8 Mi. E. Rte. 220	2.6
39	Bath	0.2 Mi. E. Jackson River Bridge	W. Va. Line	13.0
220	Bath	Alleghany C. L.	4.5 Mi. N. Alleghany C. L.	4.5
220	Bath	1.3 Mi. S. Rte. 658	0.3 Mi. S. Rte. 658	1.0
220	Bath	1.16 Mi. S. Rte. 642	0.04 Mi. N. Rte. 642	1.2
220	Bath	0.06 Mi. S. of S. Int. Rte. 39	1.16 Mi. S. of S. Int. Rte. 39	1.1
606 *	Bath	Route 220	Alleghany C. L.	1.4
703 *	Bath	Alleghany C. L.	End State Maint. at airport	5.0
601 *	Clarke	Route 50	Loudoun C. L.	9.9
56	Rockbridge	Augusta C. L.	Nelson C. L.	5.3

* - secondary roads

Staunton District (Continued)

Route	County	From	To	Mileage
39	Rockbridge	Int. Rte. 750 (0.7 Mi. W. Rte. 11)	0.2 Mi. E. Rte. 780	17.5
60	Rockbridge	ECL Buena Vista	Amherst C. L.	3.8
60	Rockbridge	4.9 Mi. E. Alleghany C. L.	Alleghany C. L.	4.9
33	Rockingham	4.2 Mi. W. Va. Line	W. Va. Line	4.2
263	Shenandoah	0.2 Mi. W. of W. Int. Rte. 42	Route 610 (Orkney Springs)	6.1
	Total			140.4

APPENDIX D

PERCENTAGE DISTRIBUTION OF MPM ROADS BY
COUNTY FOR EACH DISTRICT

Bristol District		Lynchburg District		Salem District		Staunton District	
County	MPM Roads in County as % of MPM Road the District	County	MPM Roads in County as % of MPM Road the District	County	MPM Roads in County as % of MPM Road the District	County	MPM Roads in County as % of MPM Road the District
Bland	3.90	Amherst	32.44	Bedford	8.73	Alleghany	15.46
Buchanan	17.88	Nelson	67.56	Botetourt	10.78	Augusta	2.12
Dickerson	21.94			Carroll	7.14	Highland	27.02
Grayson	7.14			Craig	31.10	Bath	19.88
Lee	7.11			Patrick	16.01	Rockbridge	35.52
Russell	5.15			Roanoke	3.60		
Scott	1.25			Pulaski	1.76		
Smyth	7.03			Franklin	7.88		
Tazewell	5.82			Giles	12.00		
Washington	11.80						
Wise	9.57						
Wythe	1.41						
Total	100.00	Total	100.00	Total	100.00	Total	100.00

Note: Percentage distribution as of July 1982.

APPENDIX E

SUMMARY OF MOTORIST OPINION SURVEY ON ROUTE 130, AMHERST COUNTY

MOTORISTS OPINION SURVEY Rte 130 Before

Questionnaire for Rural Two-Lane Highways Amherst Co.

1. Direction of Travel WB - 60.3% EB - 38.2% Not stated - 1.5%
2. Type Vehicle: Standard 33.8% Compact 10.8% Subcompact 7.8% Car W/Tr. 1.5% Motorcycle .5% Pickup 18.1% Van 5.4% Recreation Vehicle .5% Trailer (3/4 T & Over) 9.3% Bus 0% Tractor Trailer 8.3% Other .5% Not stated 2.9%
3. Age of Vehicle: 77 & 78 24.0% 73 thru 76 44.1% 68 thru 72 20.6% Prior to 68 5.3% Not stated 2.9%
4. Vehicle Licensed: Va. 75% N.C. 4.9% W. Va. 2.5% Tenn. 1.5% Other 3.3% Not stated 6.9%
5. No. of Occupants (Including Driver) See List 6. Driver Sex: M 85.3% F 10.8% Not stated 3.9%

   # of occupants
   1. 52.0%
   2. 24.5%
   3. 6.9%
   4. 6.4%
   5. 2.5%
   6. 2.0%
   7. 1.0%
   10. .5%
   Not stated - 3.9%
7. Driver Age: 16 to 21 3.9% 22 to 30 27.9% 31 to 60 59.8% Over 60 4.4% Not stated 3.9%
8. How often do you travel this road? (Suggest Response) Daily 29.9% 1-3 Times Week 19.6% 1-3 Times Month 17.2% Rarely 18.6% First Time 14.7% Not stated 1.5%
9. Purpose of Trip: (Suggest Response) Going to Work 8.8% Coming from Work 7.8% Business 53.9% Shopping 1.5% Recreation 24.5% Other 3.9%
10. Have you encountered anything within the last two miles on the way up the mountain that caused you any delay? Yes 17.2% No 82.4% Not Sure .5%
    - A. If yes, what was it? (Suggest Response) Slow Moving Vehicle: Car .5% Truck 9.8% Recreation Vehicle 0% Other Curves - 6.9% Not applicable 82.9%
    - B. Was the delay? (Suggest Response) Minor 2.5% Moderate 2.0% Major .5% Excessive .5% Not stated 11.6% Not Applicable 82.9%
11. Have you encountered anything within the last two miles up the mountain that you feel is a safety hazard? Yes 19.6% No 79.9% Not Sure 0% Not Stated .5%
    - A. If yes, what was it? (Suggest response) Narrow road with sharp curves 8.3% Improper centerline marking 1.5% Unsafe motorist action ____ (Please describe: ____) Other 9.3% Not applicable 80.4%
12. What is the meaning of the double solid yellow centerline marking? Passing is prohibited 96.1% Do not know 2.5% Other 1.0% Not stated .5%
13. What is the meaning of the single broken yellow centerline marking? Passing is permitted 88.7% Do not know 3.4% Other Divided Highway - 3.9% other - 3.9%
14. How often do you pass other vehicles going in the same direction on this mountain? Is it: (Suggest Response) Never 39.7% Rarely 47.1% Several times a week 9.3% Daily 1.5% Not stated 2.5%
15. Have you noticed any signs related to passing on this mountain? Yes 57.8% No 42.7% What was the message? PASS WITH CAUTION 42.2% HAZARDOUS PASSING ____ DO NOT PASS 4.4% Other 4.4% Not applicable 42.0% Not Sure 3.9% Not stated 4.4%
16. Is it legal to pass another vehicle traveling in the same direction anywhere on this mountain? Yes 56.9% No 33.3% If no, where is passing prohibited? Not Sure 7.8% Not stated 2.0% Not sure ____
17. Have you noticed any recent changes in the centerline marking patterns on this mountain? Yes 19.6% No 64.2% If yes, describe change New Paint - 3.3% Double lines 3.9% other 4.9% Not stated 2.5% Not Sure 4.9% Not Applicable 11.3% - (First time on this road) Not applicable 80.4%
18. Do you feel that passing and no-passing zones should be marked on this mountain road? Yes 77.9% zones should be marked. No 18.6% zones should not be marked. Not sure or no opinion 2.5% Other .5% Not stated .5%
19. Time of Day: ____ A.M. ____ P.M.

APPENDIX F

Tort Liability for Mountain Markings

This appendix briefly explores whether Virginia or its employees incur tort liability because of the Commonwealth's mountain marking policy. For purposes of this analysis, it is assumed that the plaintiff can show that the markings at the accident site were not in conformance with MUTCD standards, and that confusion created by the nonstandard markings was at least partially responsible for the damages. The examination has led to the following conclusions:

1. Virginia's policy does not create a tort claim under federal law. Thus, plaintiff would have to ground his suit in Virginia state law under the Virginia Torts Claims Act.

2. Because the Virginia Tort Claims Act has been in effect for a relatively short time, the Virginia courts have not had an opportunity to articulate how they will analyze specific acts of nonconformance to determine whether they amount to negligence under the standard for culpability contained in the Act. Virginia courts will choose between two alternatives: either the MUTCD will be viewed as establishing mandatory minimum standards that are such that nonconformance amounts to negligence as a matter of law, or the MUTCD will be viewed as prescribing a desirable but noncompulsory standard such that the jury may consider the MUTCD standards as a yardstick in determining whether the degree of nonconformance amounted to negligence. Although other states have split over these two approaches, pre-VTCA decisions indicate that Virginia will adopt the latter view.

3. In arguing before a jury as to the reasonableness of the mountain marking policy, the state's case is bolstered to the extent that the policy was motivated by empirically established gains in traffic efficiency and safety. This report will go a long way toward laying that empirical foundation. On the other hand, the state's case is hindered by the fact that Virginia did not follow MUTCD procedures for proposing and testing the new markings.

The remaining text of this memorandum has been prepared for direct transcription into the report on the study of MPM.

The Federal Aid Highway Act, [1] conditions the release of federal funds on the recipient state's use of safety devices that comply with standards fixed by the Secretary of Transportation. [2] Similarly, uniform federal standards for safety devices were necessary to review the highway safety plans states submit to receive funds under the Highway Safety Act. [3] Pursuant to these statutes, the Federal Highway Administration adopted the marking standards in the Manual on Uniform Traffic Control Devices (MUTCD). [4] While the MUTCD documents the nonconformity of Virginia's mountain markings,[5] at issue is whether the federal government's adoption of MUTCD standards as a basis for the release of federal funds implies that plaintiff motorists have a federal cause of action in tort against states for damages arising from noncompliance. A federal cause of action was denied in Daye vs. Pennsylvania. [6]

In Daye, the court focused on whether a state's acceptance of federal highway funds implied a waiver of immunity and authorized private tort actions arising from nonstandard highway design. The district court declared that in areas of traditional state sovereignty, an offer of federal funds must expressly contain or overwhelmingly imply a waiver for one to take effect. [7] The opinion not only concluded that the plaintiff failed to show that a waiver existed, it also stated that neither the Federal Aid Highway Act nor the Highway Safety Act expressly authorized private suits. [8] After concluding its discussion on the presence of a waiver, the Daye decision held that the only sanction for nonconformance under federal law was disqualification for funds, and that honoring a private sanction, tort liability, was an improper attempt to expand and redefine Congressional intent. [9] The circuit court upheld this conclusion, and added that only Congress had the authority to append new sanctions. [10]

Although the United States Supreme Court has recognized implied rights of private action in similar federal statutes, [11] it has done so only after considering the propriety of expansively interpreting federal law to the detriment of state sovereignty. This inhibition would be particularly strong in cases of highway regulation because of the Court's longstanding recognition of state authority in this area. [12]

Since _Daye_ precludes a federal cause of action, plaintiff would have to ground his suit in Virginia law. More specifically the suit would be brought against an individual employee under traditional common law doctrines, or against the Commonwealth itself under the Virginia Tort Claims Act.(VTCA). [13] Virginia adopted the MUTCD, including the sections relating to passing zone markings, pursuant to statutory authority granted to the State Highway and Transportation Commission over the location, form and character of traffic control devices used on Virginia's roadways. [14] The Commission is further required to adopt a uniform system of markings that correlates as closely as possible to the systems adopted in sister states. [15] In examining whether Virginia's willful divergence from a self-imposed standard amounts to culpable negligence, it is necessary to distinguish between the standards of liability that apply to state employees and those that would apply to the Commonwealth itself.

At common law, state employees have always been personally accountable for their acts; however, for an injured party to prevail the act must be "performed so negligently that it can be said that its negligent performance takes him who did it outside the protection of his employment." [16] The Virginia Supreme Court recently discussed this standard:

> Admittedly, no single all inclusive rule can be enunciated or applied in determining entitlement to sovereign immunity.... The difficulty in application comes when a state employee is charged with similar negligence... under such circumstances we examine the function this employee was performing and the extent of the state's interest and involvement in that function. Whether the act performed involves the use of judgement and discretion is a consideration, but it is not always determinative. Virtually every act performed by a person involves the exercise of some discretion. Of equal importance is the degree of control and direction exercised by the state over the employee whose negligence is involved. [17]

The above passage means that employees who exercise professional judgement (i.e., engineers, physicians, accountants, etc.) in performing their duties will be judged, as they always have, by the standards of their profession, without regard to any immunity that their employer (the State) may have. This standard will not be affected by the VTCA. Since traffic engineers adopt mountain markings on well-founded professional judgements regarding traffic efficiency and safety, it is hard to conceive of such judgements amounting to commow law negligence.

The Commonwealth stands on different ground. Under the VTCA, Virginia is exposed to tort liability for the "negligent or wrongful acts or omissions" of its employees.[18] Because the Act has been in effect only since July 1982, the courts have not had a sufficient opportunity to link specific acts to this standard. In making this linkage, Virginia courts will doubtlessly consider relevant precedents in other states.

Reference to other states' jurisprudence reveals two approaches of incorporating the MUTCD into standards of negligence. The first approach, adopted in Washington, holds that the MUTCD sets mandatory minimum standards for traffic control devices. Failure to conform to the MUTCD is thus conclusively deemed to be negligent as a matter of law.[19] The second approach adopted in Kansas and Montana, does not view the MUTCD as a mandatory standard with the force and effect of law; instead it views the manual's standards as directory, describing a professional consensus as to what devices are appropriate but not compulsory under standard conditions.[20] Under this approach, nonconformity is not negligent per se, but the manual will be admitted into evidence so that the jury may gauge the degree of nonconformity in determining whether the deviation is unreasonable and amounts to negligence. There are strong arguments for each approach. A per se treatment is justified by the motorist's need to be able to rely on the uniformity of the information conveyed by traffic control devices. A comparative approach is supported by the traffic engineer's need to tailor devices within reason to unusual needs.

Any attempt to predict which approach will be taken in Virginia involves an irreducible degree of speculation, but one can assume that in contemplating this choice the court will draw guidance from its common law perspective as well as any relevanat statutory language.

At common law (pre-VTCA), Virginia defined the scope of governmental immunity by distinguishing between government and proprietary functions. Governmental functions required the independent judgement of a policy maker, while proprietary functions involved maintenance and other nondiscretionary tasks. Sovereign immunity was frequently extended to the former but rarely to the latter.[21] In recent common law cases applying common law sovereign immunity to traffic regulation,[22] the Virginia Supreme Court held that this function was governmental and could not give rise to liability. Since adoption of a per se approach to nonconformance would amount to a complete departure from Virginia's historical perspective, one would predict that the court would adopt the more moderate approach of allowing the MUTCD to be referenced by the jury in its evaluation of the degree and negligence of a specific act of nonconformance.

This approach can also be rationalized by reference to the state statutes that motivated the adoption of the MUTCD. In requiring the State Highway and Transportation Commission to adopt a uniform marking standard, the code states that the marking system shall correlate with — and "so far as possible conform to the system adopted by other states". [23] From the phrase "so far as possible," one may argue that the legislature foresaw and permitted noncompliance where there was an adequate and reasonable engineering rationale for the deviation. If this argument is accepted, a per se approach would defeat the legislative intent. On the other hand, that phrase might also have been written to account for cases where budgetary conditions constrain the state from upgrading outdated devices to meet MUTCD standards. If this was the purpose behind the operating language, the legislative argument would be irrelevant to the instant case.

Assuming that the per se approach is rejected in Virginia, the state must argue that the nonconformance was reasonable, or at least not tantamount to a breach of its duty to motorists on its highways. On the other hand, the state's case is weakened by the fact that it knew of MUTCD-approved procedures for proposing and testing new devices yet it refused to adopt them.

Based on this analysis, the following conclusions are made:

1. Virginia's policy does not create a tort claim under federal law. Thus, plaintiff would have to ground his suit in Virginia state law under the Virginia Tort Claims Act.

2. Because the Virginia Tort Claims Act has been in effect for a relatively short time, the Virginia courts have not had an opportunity to articulate how they will analyse specific acts of nonconformance to determine whether they amount to negligence. Virginia courts will choose between two alternatives: either the MUTCD will be viewed as establishing mandatory minimum standards or are such that nonconformance amounts to negligence as a matter of law, or the MUTCD will be viewed as prescribing a desirable but noncompulsory standard such that the jury may consider the MUTCD standards as a yardstick in determining whether the degree of nonconformance amounted to negligence. Although other states have split over these two approaches, pre- VTCA decisions indicate that Virginia will adopt the latter view.

3. In arguing before a jury as to the reasonableness of the mountain marking policy, the state's case is bolstered to the extent that the policy was motivated by empirically established gains in traffic efficiency and safety. On the other hand, the state's case is hindered by the fact that Virginia did not follow MUTCD procedures for proposing and testing the new markings.

FOOTNOTES

1. 23 U.S.C. §§101 et seg. (1976).

2. Id., §109(e) (1976).

3. 23 U.S.C. §402(a) (1976).

4. Federal Highway Administration, United States Department of Transportation. Manual on Uniform Traffic Control Devices (1978).

5. Compare Federal Highway Administration, U. S. Department of Transportation, Manual of Uniform Traffic Control Devices for Streets and Highways pt. 3B, §§3B-3,-5 (1978) with the description of Virginia's practices found elsewhere in this report.

6. Daye v.Pennsylvania, 344 F. Supp. 1337 (E.D. Pa. 1972) aff'd 483 F.2d 294 (3 cir. 1973) cert. denied 461 U.S. 946 (1974).

7. Id. at 1343 (citations omitted).

8. Id. at 1347.

9. Id. at 1347-348.

10. Id., 483 F.2d at 299.

11. See Cort v. Ash, U. S. 66 (1975).

12. See generally South Carolina State Highway Department v. Barnwell Bros., 303 U. S. 177 (1938).

13. Va. Code §8.01-195.1 et seg. (Supp. 1982).

14. Va. Code §33.1-46 (Supp. 1982).

15. Va. Code §46.1-173 (Supp. 1982).

16. See generally, T. Heumbach, K. McLean & O. Shean, Sovereign Immunity in Virginia an Overview, 3-4 (June 1981) (Publichsed by the Virginia Highway and Transportation Research Council, Charlottesville, VA.) Hereinafter referred to as Sovereign Immunitu Overview.

17. James v. Jane, 221 Va. 43, 53, 267 S.E. 2d 108, 113, (19).

18. Va. Code §8.01-195.3 (Supp. 1982).

19. See Kitt v. Yakima County, 93' Wn. 2d 670, F. 2d 1234 (en banc) (1980).

20. See Schneck v. City of Shawnee, 651 P. 2d 585 (Kan. 1982); Runkle v, Burlington Northern, 613 P 2d 982 (Mont. 1980); and Workman v. McIntyre Construction Co., 617 P. 2d. 1231 (Mont. 1980).

21. Sovereign Immunity Overview, supra n. 16, at 3-4.

22. Freeman v. City of Norfolk, 221 Va. 57, 2665 S.E. 2d 885 June 6, (1980), and Transportation Inc. v. city of Falls Church, 219 Va. 1004, 254 S.E. 2d 62 (1979).

23. Va. Code §46.1-173 (Supp. 1982).