

20-7/21

NEED FOR CENTER MARKINGS ON
LOW-VOLUME RURAL ROADS

FINAL REPORT

Prepared for

National Cooperative Highway Research Program
Transportation Research Board
National Research Council

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March 15, 1984

TABLE OF CONTENTS

	Page
INTRODUCTION AND RESEARCH APPROACH	1
Problem Statement	1
Research Objectives	2
Research Approach	2
SUMMARY OF FINDINGS	4
Questionnaire Results	4
Analysis of Traffic Data	5
Analysis of Head-On Meetings	6
Analysis of Passing Conflicts	6
Accident Comparisons	8
CONCLUSIONS AND RECOMMENDATIONS	10
REFERENCES	12
APPENDIX A: QUESTIONNAIRE SURVEY	13
APPENDIX B: EXAMINATION OF TRAFFIC DATA	17
APPENDIX C: ANALYSIS OF HEAD-ON MEETINGS	23
APPENDIX D: ANALYSIS OF PASSING CONFLICTS	26
APPENDIX E: ACCIDENT COMPARISONS	33

INTRODUCTION AND RESEARCH APPROACH

Problem Statement

In designing and operating highways, the highway agency is interested in providing maximum traffic safety and efficiency. Maximum safety requires wide roadways and shoulders, gentle alinement, clear roadsides, and high quality traffic control devices.

When considering low-volume rural roads, however, the highway agency is faced with an apparent dilemma. On one hand, the agency would like to provide each individual motorist with the same degree of safety he experiences on the modern Interstate system. On the other hand, the cost of providing this degree of safety often conflicts with the agency's philosophy of economic expediency. The way to solve this apparent dilemma is to gain knowledge of the safety effects of each highway design and traffic control element so that the application of criteria can be established through the principals of cost-effectiveness.

The use of centerline and no-passing zone markings is one area where the cost-effectiveness is unclear. For example, the "Manual on Uniform Traffic Control Devices" (1) does not give a guideline on the minimum traffic volume level for the application of centerline markings. For no-passing zone markings, the manual mandates them on all highways where centerlines are used.

NCHRP Report 214 "Design and Traffic Control Guidelines for Low-Volume Rural Roads," (2) used probability analyses and assumptions about accident reduction to arrive at the conclusion that centerline markings are not cost-effective below 300 vpd. What is needed is a more definitive empirical study that either substantiates or modifies these findings.

Research Objectives

The objectives of this research were to evaluate practices used for centerline and no-passing markings on low-volume paved rural roads and to collect traffic and accident data for the purpose of verifying or modifying the warrants for centerline and no-passing zone markings suggested in NCHRP Report 214.

Research Approach

The research was divided into four tasks that aligned with the research objectives. In Task 1, a questionnaire survey was sent to all state departments of transportation with questions about existing road characteristics, warrants for center markings, opinions on needed warrants, and available accident, traffic, and marking cost data. A small effort was also devoted in this task to finding any literature on the safety effectiveness of center markings on low-volume rural roads.

Task 2 involved collecting 24-hour traffic volume data for low-volume rural roads to verify or modify assumptions made in NCHRP Report 214. The traffic volume characteristics of concern were:

1. Daily distribution
2. Hourly directional split
3. Percent of large vehicles

This data served to modify the conservative assumptions made in NCHRP Report 214 to predict the frequency of head-on meetings and passing conflicts for various ADT levels.

Task 3 involved collecting accident data on paved roads, stratified by ADT and type of center markings, for the purpose of determining the safety effectiveness relationships for center-line and no-passing zone markings. Where available, road width, terrain, and other highway characteristics were also desirable.

In Task 4, the traffic and accident data were analyzed for the purpose of evaluating the safety effectiveness of center markings and for developing practical warrants for their use.

SUMMARY OF FINDINGS

Questionnaire Results

Forty-four of the 50 questionnaires sent to the traffic departments of each state department of transportation were returned. The results, reflecting state DOT practice, are described in Appendix A, and briefly summarized as follows:

1. Of the states that responded to a question on road mileage distribution, 54% had over half of their road mileage with ADT's below 1,000 vpd.
2. Sixty-one percent of the states use center markings on all roads. The other states, have either or both minimum ADT and road width warrants. Minimum ADT warrants ranged from 100 to 1,000 vpd. Minimum road width warrants ranged from 16 to 20 feet, with the most predominant width being 16 feet.
3. Twenty percent of the states do not always mark no-passing zones where a centerline is present. The most common practice of these is to omit the no-passing marks in mountainous terrain and use general warning signs for stretches of highway.
4. One state has a minimum ADT warrant of 1,000 vpd for no-passing marks on non-numbered state routes. Below 1,000 vpd, only a dashed centerline is used.
5. Forty-eight percent of the states favor either

minimum ADT or road width warrants for center markings. Suggested minimum ADT warrants ranged from 100 to 750 vpd. Suggested minimum road width warrants ranged from 16 to 20 feet, with the most predominant width being 18 feet.

6. Striping installation costs range from about \$80 per mile for a dashed centerline only to \$400 per mile for a double solid-yellow centerline.
7. The average service lives for center markings ranged from 2.25 years to 1.00 years for roads carrying less than 100 vpd to roads carrying over 1,000 vpd, respectively.

Analysis of Traffic Data

Usable traffic count data were obtained for over 200 count stations in seven states. Station ADT counts ranged from 25 to 1,985 vehicles per day. These data were used to relate ADT to traffic proportions by time of day, directional distribution by time of day, and vehicle type proportions.

Analysis of the traffic distribution by 4-hour increments during the day for 153 count stations in five states indicated an almost identical distribution by time of day regardless of ADT in the range of 25 to 2,000 vpd. Nighttime traffic was found to be a small percentage of total daily traffic, with only 8.5% between 10 p.m. and 6 a.m. and 25% between 6 p.m. and 6 a.m.

One hundred and twenty-three count stations in 4 states

were used to analyze the directional split of traffic throughout the day. The average hourly directional distribution (by percentage in the highest direction) of traffic by 4-hour increments generally decreases as the traffic volume increases both for hourly traffic and daily traffic.

One hundred and sixty-four count stations in five states were used to analyze the composition of traffic by vehicle type. This analysis shows that: (1) pickup and panel trucks comprise 35-45% of the traffic on lower volume 2-lane rural highways; (2) for ADT's below 500 vpd, passenger cars represent less than half of the traffic; and (3) large trucks and buses represent about 15% of the traffic for ADT's below 1,000 vpd.

Analysis of Head-On Meetings

Using the traffic characteristics determined in Appendix B, a probability analysis of head-on meetings was developed in Appendix C. The number of head-on meetings per mile per day related to ADT gives some indication of the need for centerline stripes to separate opposing traffic. As seen from Table 1, the estimated number of head-on meetings increases exponentially from only one meeting per mile per day at 50 vpd to 1,784 meetings per mile per day at 2,000 vpd.

Analysis of Passing Conflicts

The traffic characteristics of Appendix B were also used to develop a probability analysis of 3-car passing conflicts in areas of limited sight distance, which is shown in Appendix D. As seen from Table 2, the estimated number of passing conflicts

TABLE 1

ESTIMATED NUMBER OF HEAD-ON MEETINGS
RELATED TO ADT

<u>ADT</u>	<u>Head-on Meetings</u> <u>Per Mile Per Day</u>	
	<u>All Vehicles</u>	<u>At Least One</u> <u>Large Vehicle</u>
50	1	0.3
100	4	1
250	25	7
500	108	31
1,000	444	118
2,000	1,784	458

TABLE 2

ESTIMATED NUMBER OF PASSING CONFLICTS
RELATED TO ADT

<u>ADT</u>	<u>Annual Passing Conflicts</u> <u>per Mile in Areas of</u> <u>Limited Sight Distance</u>
50	.02
100	.20
250	3
500	27
1,000	219
2,000	1,650

also increases exponentially from 0.02 conflicts per mile per year at 50 vpd to 1,650 conflicts per mile per year at 2,000 vpd.

Accident Comparisons

Several sources of data were gathered to analyze the potential safety effectiveness of the application of centerline and no-passing zone markings. Most of the data represented before and after comparisons made as a part of the Pavement Marking Demonstration Program that was established in the Federal Highway Safety Act of 1973. Table 3 shows a summary of the sources, accident reduction effectiveness, and statistical significance of comparisons. The results of Table 3 are somewhat conflicting but do indicate the following:

1. The widespread application of center pavement markings to all paved roads with no existing markings is not likely to produce accident reduction benefits.
2. Center markings applied to roads with 500 vpd day or less appear to produce increased accident rates.
3. Center markings applied to roads with less than 10 foot lane widths and less than 1,000 vpd appear to produce increased accident rates.
4. Accident reduction benefits may be generally associated with wider roads and higher ADT's.

TABLE 3
CHANGE IN ACCIDENT RATES ASSOCIATED WITH CENTER MARKINGS

		8 - 9 ft Lanes		10 - 11 ft Lanes		All Lane Widths	
0-500 vpd	FHWA Data Base 1	+3%	FHWA Data Base 1	+63% (\$)	FHWA Data Base 1	+15%	
	FHWA Data Base 2	+15%	FHWA Data Base 2	+55% (\$)	FHWA Data Base 2	+15% (S)	
	Missouri (Dashed Centerline Only Added)	+32%					
500- 1,000 vpd	FHWA Data Base 1	+40% (S)	FHWA Data Base 1	-11%	FHWA Data Base 1	+19%	
	FHWA Data Base 2	+47% (S)	FHWA Data Base 2	+7%	FHWA Data Base 2	+29% (S)	
			Missouri (No-Passing Stripe Added)	-25% (S)			
Greater than 1,000 vpd	FHWA Data Base 1	-14%	FHWA Data Base 1	-2%	FHWA Data Base 1	-10%	
	FHWA Data Base 2	-5%	FHWA Data Base 2	-16%	FHWA Data Base 2	-9%	
			Missouri (No-Passing Stripe Added)	-23% (S)			
All ADT's	FHWA Data Base 1	+4%	FHWA Data Base 1	+10%	1981 FHWA Stewardship Report (3)	+1%	
	FHWA Data Base 2	+15% (S)	FHWA Data Base 2	+1%	1982 FHWA Stewardship Report (4)	-1%	
					FHWA Data Base 1	+5%	
				FHWA Data Base 2	+13% (S)		
				Ohio Data Base	-35% (S)		

- Notes:
1. FHWA Data Base 1 includes 48 before-after site comparisons between no markings and combined centerline and no-passing zone markings (5 States).
 2. FHWA Data Base 2 includes 87 sites with no markings and 111 sites with both centerline and no-passing zone markings (5 States)
 3. (S) indicates statistically significant change at 90% confidence level.

CONCLUSIONS AND RECOMMENDATIONS

The nationwide application of center markings on previously unmarked two-lane rural roads under the federal Pavement Marking Demonstration Program does not appear to have produced any reduction in accident rates. In fact, the before-after results for hundreds of center marking projects in 15 states indicates a significant increase in injury accident rates (3,4).

Despite, this seemingly negative result, a more detailed analysis of available data indicates potential accident benefits for wider roads carrying higher traffic volumes. This result was evident both for adding centerline and no-passing zone markings to previously unmarked roads and for adding no-passing zone markings to roads previously marked with only a dashed centerline.

Although the data were not sufficient for determining specific road width and ADT warrants based on a precise break-point of cost-effectiveness, they do seem to indicate lower boundries for these warrants based on omitting center markings where they appear to produce significant increases in accident rates. Using this basis, the following tentative warrants seem reasonable for the application of both dashed centerline and no-passing zone markings:

<u>Road Width</u>	<u>Minimum ADT</u>
Less than 16 ft	N/A
16 - 18 ft	1,000 vpd
Greater than 20 ft	500 vpd

This concept of road width and minimum ADT warrants is generally consistent with current state department of transportation practice in those states that have high portions of low-volume road mileage. The practice of not marking low-volume rural roads is also prevalent among local rural jurisdictions. Perhaps the lack of markings on these roads, which tend to have lower design standards, provides the driver a greater ability to distinguish the need for a more cautious driving behavior than is required on higher-volume roads with better design standards.

REFERENCES

1. U.S. Department of Transportation, "Manual on Uniform Traffic Control Devices for Streets and Highways," 1978.
2. Glennon, John C., "Design and Traffic Control Guidelines for Low-Volume Rural Roads," NCHRP Report 214, October 1979.
3. U.S. Department of Transportation, "The 1981 Highway Safety Stewardship Report," April 1981.
4. U.S. Department of Transportation, "The 1982 Highway Safety Stewardship Report," April 1982.
5. Lee, Robert L., "Effectiveness Evaluation of Pavement Markings at Night," unpublished, September 1980.

APPENDIX A

QUESTIONNAIRE SURVEY

Early in the project a questionnaire survey was designed and sent out to the traffic departments of every State Department of Transportation. The questionnaire was designed to elicit information on the following: (1) traffic volume distribution on the state system; (2) striping practices and warrants; (3) opinions about striping warrants; (4) availability of traffic counts and accident studies; and (5) cost and service life of centerline markings.

Of the 50 questionnaires sent out, 44 were returned. A summary of the results is as follows:

Road Mileage Distributions

1. Only 50% of the states gave road mileage breakdowns by ADT.
2. Of the states responding, 28% had over 40% of their road mileage with ADT's below 500 vpd.
3. Of the states responding, 54% had over 50% of their mileage with ADT's below 1,000 vpd.

Striping Practices

1. 61% of the states use centerline markings on all roads.
2. 39% of the states have either or both minimum ADT and road width warrants for centerline striping.

Minimum ADT warrants range from 100 to 1,000 vpd with an average of about 500 vpd. Minimum road width warrants range from 16 to 20 ft., with the most predominant value being 16 ft. None of these states were in the category that had more than 50% of their mileage with over 1,000 vpd.

3. 20% of the states do not always mark no-passing zones when a centerline is present. The most common practice of these is to omit the no-passing marks in mountainous terrain and use a sign that says, "No Passing Next 'X' Miles". 55% of the states use other devices to either reinforce or replace no-passing markings.
4. One state has a minimum ADT warrant of 1,000 vpd for no-passing marks on non-numbered state routes. Below 1,000 vpd only a dashed centerline is used. This state has over 22,000 miles or 76% of its mileage with ADT's below 1,000 vpd.

Striping Warrant Opinions

1. 48% of the states favor either minimum ADT and/or road width warrants for centerline markings. Suggested minimum ADT warrants ranged from 100 to 750 vpd, with an average of about 325 vpd. Suggested minimum road width warrants ranged from 16 to 20 ft., with the most predominant value being 18 ft.
2. 23% of the states favored changing the MUTCD require-

ment for no-passing mark from a "shall" to a "should" condition.

3. 18% of the states favored a single solid yellow centerline in mountainous terrain.

Striping Costs

The responses on striping cost were highly variable. Some were apparently just paint costs, while others included labor and/or overhead costs. Then too, some responses were costs per lined foot of striping, while others were average costs per foot or mile of striped highway. In an attempt to rationalize these costs, it would appear that they average from about \$80 per painted mile of highway for a dashed centerline only to about \$400 per mile for a solid double yellow centerline. Combination centerline and no-passing stripes would range between these two values depending on the length and number of no-passing zones per mile, with an average cost of about \$200 per mile. In other than flat terrain, it appears that the no-passing markings are the more expense of the two, on a per mile basis.

Service Life of Striping

The following are the survey results on striping service lives. The variability in the results probably reflects striping practice more than actual service life.

ADT	<u>Service Life (yrs.)</u>	
	<u>Range</u>	<u>Average</u>
0 - 100	1 - 5	2.25
101 - 250	1 - 5	2.00
251 - 500	1 - 3	1.75
501 - 1,000	0.5 - 2	1.35
> 1,000	0.5 - 2	1.00

APPENDIX B

EXAMINATION OF TRAFFIC DATA

In NCHRP Report 214, probability analyses were performed to determine relationships between ADT and the number of head-on meetings and the number of passing conflicts per mile per day. These analyses employed certain safety-conservative assumptions about the daily distribution and hourly directional distribution of traffic. The purpose of the collection, compilation, and analysis of traffic data in this current project was to modify these previous analyses using real traffic characteristic inputs.

Usable traffic count data were obtained from Georgia, Illinois, Iowa, Nevada, Oregon, West Virginia, and Wyoming. Considerable effort was spent in compiling the raw count data into a form necessary for analysis. Station ADT counts ranged from 25 to 1985 vehicles per day.

Daily Distribution of Traffic

Table B-1 shows the average distribution of traffic by 4-hour segments during the day for various ADT levels. This table was compiled from seventy 24-hour count stations and eighty-three 16-hour count stations (6 am - 10 pm). The hourly proportions exhibited for the 24-hour stations were used to expand the 16-hour count data.

Although this table cannot be said to precisely represent

TABLE B-1

TRAFFIC DISTRIBUTION BY TIME OF DAY

ADT	% of Traffic by Time of Day*							
	10 pm - 2 am	2 am - 6 am	6 am - 10 am	10 am - 2 pm	2 pm - 6 pm	6 pm - 10 pm		
0 - 100	5.2	1.6	20.4	23.7	29.1	18.4		
101 - 250	5.3	3.6	21.4	24.4	30.1	15.4		
251 - 500	4.3	4.8	21.3	25.4	29.6	14.5		
501 - 1,000	4.5	3.3	20.8	24.8	29.6	16.5		
1,001 - 2,000	4.7	5.4	21.9	22.6	29.7	16.5		
Average	4.8	3.7	21.1	24.2	29.6	16.3		

* Percentages computed as the sum of vehicles in the time interval divided by the sum of ADT's for all sites in each cell.

all roads everywhere, it does give some general indications about lower volume 2-lane rural roadways. The table indicates that the daily distribution does not vary much over the range of ADT considered. It also indicates that nighttime traffic is a small percentage of total daily traffic, with only 8.5% between 10 pm and 6 am and 24.8% between 6 pm and 6 am.

Daily Distribution of Directional Traffic

Table B-2 shows the average hourly directional distribution (by percentage in the highest direction) of traffic by 4-hour segments during the day for various ADT levels. This table was compiled from thirty-two 24-hour count stations and eighty-nine 16 hour stations (6 am - 10 pm). This table indicates the percentage of traffic in the highest direction generally decreases as the traffic volume increases both for hourly traffic and daily traffic.

Table B-3 shows the average hourly directional distribution (by percentage in the highest direction) of traffic over a 24-hour period for the different ADT levels. These percentages were calculated as the product of Tables B-1 and B-2. As expected, the average hourly percentage of vehicles in the highest direction decreases with increasing ADT.

Vehicle Classification

Table B-4 shows the percentage of traffic associated with various vehicle types by ADT level. This table was compiled from ninety-one 24-hour count stations and seventy-three 16-hour count stations (6am - 10 pm). This table indicates that (1) panel and pickup trucks represent a large proportion of traffic

TABLE B-2

AVERAGE HOURLY DIRECTIONAL DISTRIBUTION BY TIME OF DAY

ADT	Average % of Hourly Traffic in Heavy Direction by Time of Day									
	10 pm - 2 am	2 am - 6 am	6 am - 10 am	10 am - 2 pm	2 pm - 6 pm	6 pm - 10 pm				
0 - 100	-	-	69	74	67	78				
101 - 250	82	74	68	65	64	74				
251 - 500	76	71	64	61	60	64				
501 - 1,000	71	72	62	57	58	61				
1,001 - 2,000	63	61	63	56	59	57				

TABLE B-3

AVERAGE HOURLY DIRECTION DISTRIBUTION BY ADT

ADT	Ave. % of Hourly Traffic in Heavy Direction
0 - 100	71.5
101 - 250	67.9
251 - 500	62.8
501 - 1,000	60.0
1,001 - 2,000	59.6

TABLE B-4

VEHICLE CLASSIFICATION BY ADT

<u>ADT</u>	<u># of Sites</u>	<u>Passenger Cars</u>	<u>Panel & Pick-Up Trucks</u>	<u>Large Trucks & Buses</u>
0 - 100	12	37.5	46.0	16.5
101 - 150	30	47.4	38.5	14.1
251 - 500	37	47.9	36.5	15.6
501 - 1,000	58	51.2	34.5	14.3
1,001 - 2,000	27	50.9	35.3	13.8

on lower volume 2-lane rural highways, (2) for ADT's below 500 vpd, passenger cars represent less than half of the traffic, and (3) large trucks represent about 15% of the total traffic for ADT's below 1,000 vpd.

APPENDIX C

ANALYSIS OF HEAD-ON MEETINGS

This analysis uses the traffic characteristics of Appendix B to refine a similar analysis presented in NCHRP Report 214, which assumed safety-conservative values for these characteristics. The number of head-on meetings per mile per day related to ADT gives some indication of the need for centerline stripes for the purpose of separating opposing traffic.

The number of head-on meetings per mile per day can be estimated using the following equation:

$$N_M = N_A \times N_{O/A}$$

$$\text{or } N_M = V(d_h) \times \frac{V(1-d_h)t}{86,400}$$

- where N_M = number of head-on meetings per mile per day;
 N_A = number of arrivals in one direction per day;
 $N_{O/A}$ = number of opposing arrivals per 1 mile travel of a one-direction arrival;
 V = average daily traffic, vehicles per day;
 d_h = average proportion of total traffic in the highest direction;
 t = exposure interval for head-on meetings within the one mile analysis interval, sec/mi.

Assuming an average speed of 45 mph, the exposure interval of a vehicle to head-on meetings per mile is calculated as

twice the time it takes a vehicle at 45 mph, to travel one mile. The factor of two accounts for both the opposing vehicles within the 1-mi. segment when the subject vehicle arrives and those opposing vehicles that arrive after that time but before the subject vehicle leaves the 1 mi. segment. This total exposure time is $5280 \times 2/45 \times 1.47 = 160$ sec. Using this time interval yields the following equation for head-on meetings:

$$N_M = \frac{V^2(d_h)(1-d_h)}{540}$$

From this equation and using the average hourly directional distributions (d_h) of Table B-3 and the percentages of large trucks from Table B-4, the following numbers of head-on meetings are calculated for various ADT's:

ADT	Estimated Number of Head-on Meetings Per Mile Per Day	
	All Vehicles	At Least One Large Truck
50	1	0.3
100	4	1
250	25	7
500	108	31
1,000	444	118
2,000	1,784	458

Because one of the reasons for centerline striping is to separate opposing vehicles and this separation is more critical for larger vehicles, its interesting to compute the percentage of head-on meeting which involve buses and large trucks. Table B-4

shows the percentage of buses and large trucks ranging from 13.8 to 16.5% of all traffic. This means that from about 24 to 28% of all head-on meetings involve at least one bus or large truck.

APPENDIX D

ANALYSIS OF PASSING CONFLICTS

This analysis uses the traffic characteristics of Appendix B to refine a similar analysis presented in NCHRP Report 214, which assumed safety-conservative values for these traffic characteristics.

For this analysis, passing maneuvers are initially assumed to occur without regard to oncoming vehicles in the zone of conflict. In other words, all passing maneuvers with an oncoming vehicle in the zone of conflict would result in a collision. This assumption is made to simplify the analysis and is, of course, very safety-conservative.

To analyze the three-car critical passing situation, the average speed differential between the passing vehicle and the passed vehicle is assumed as 10 mph. The assumed speeds for the three vehicles are 40 mph for the passed vehicle and 50 mph for both the passing vehicle and the oncoming vehicle.

A pass occurs when, without regard for passing sight distance, the passing driver pulls into the opposing lane to pass. If an oncoming vehicle enters the zone of hazard while the passing vehicle is in the opposing lane, a collision will result. The expected number of this kind of conflict is calculated from the following general equation:

$$E(C) = E(P)P(A/P)$$

where E(C) = expected number of conflicts per day;

E(P) = expected number of passes per day; and

P(A/P) = probability of an oncoming vehicle arrival that will conflict with the passing vehicle in the left lane.

Expected Number of Passes

The initiation of a pass (occupation of opposing lane) is assumed to occur when the passing vehicle arrives within 1 sec behind the passed car. Using the Poisson assumption, the probability of two or more arrivals within 1 sec is given by:

$$\begin{aligned} P(2 \text{ or more arrivals in } 1 \text{ sec or less}) &= 1 - P(0) - P(1) \\ &= 1 - e^{-v/3600} - \frac{v e^{-v/3600}}{3600} \end{aligned}$$

where v equals average one direction volume in vehicles per hour. This equation is not the assumed probability of a pass, however, because it does not distinguish between the vehicles or their position in a pass. If the highway is divided into segments defined by the initial 1-sec separation with the passing vehicle behind, there will be 71.84 segments of 73.5 ft per mi. Considering a pass initiated with the passing vehicle 1-sec behind the passed vehicle, the separation of the two vehicles would proceed as follows.

Increment	Distance Relationship of Passing Vehicle to Passed Vehicle at Beginning of Increment (ft)*	Arrival Time Separation (sec)
1	-73.5	1.00
2	-55.1	0.75
3	-36.8	0.50
4	-18.4	0.25
5	0	0
6	+14.7	0.25
7	+29.4	0.50
8	+44.1	0.75
9	+58.8	1.00

* 1 ft = 0.305 m.

Looking at the time separation shows that there are 9 passing increments that have one second or less separation, but only one in nine that defines a pass initiation. Recognizing that each 73.5-ft highway increment has equal probability of each of the nine passing increments, if passes are accounted by 73.5-ft highway increments, the probability of a pass per one second for that interval is the probability of 2 or more arrivals within 1 sec divided by 9 or:

$$P(P) = \frac{1 - e^{-v/3600} - \frac{v}{3600} e^{-v/3600}}{9}$$

To arrive at the expected number of passes per mile per day for each direction, the probability of a pass per increment is multiplied by the number of seconds in a day and by 71.84, the number of 1-sec passing increments.

$$E(P) = 6.9 \times 10^5 \left[1 - e^{-v/3600} \left(1 + \frac{v}{3600} \right) \right]$$

Using the average directional distribution values given in Table B-3, the following table gives expected number of passes per day for each direction of travel for various ADT's.

<u>ADT</u>	<u>Expected Number of Passes per Mile per Day, E(P)</u>	
	<u>Heavy Direction</u>	<u>Light Direction</u>
50	.059	.009
100	.236	.038
250	1.330	.311
500	4.518	1.581
1,000	16.564	7.371
2,000	65.060	29.987

Probability of an Oncoming Vehicle in Conflict

The probability of one or more arrivals of oncoming vehicles for any interval is given by the following Poisson relationship:

$$P(A) = 1 - P(0) = 1 - e^{-vt/3600}$$

where: v = average one direction volume, vph; and

t = arrival interval, sec.

Thus, the probability of an oncoming vehicle in conflict with the passing vehicle for any traffic volume depends on the conflict interval. Assuming the passing vehicle enters the opposing lane at the initiation of the pass and leaves the opposing lane 1 sec after it has achieved a 1-sec clearance ahead of the passed vehicle, the passing interval is 11 sec. Allowing for both the opposing vehicles within the conflict region when the pass is initiated and those that enter during the pass interval,

the conflict interval for oncoming vehicles at 50 mph (80.5 kph) is 22 sec. The probability of a conflict given a pass, therefore, is calculated by substituting the 22-sec arrival interval into the previous equation to yield:

$$P(A/P) = 1 - e^{-v/164}$$

By using this equation and the average directional distribution values given in Table B-3, the following table shows the probability of a conflict given a pass for various ADT's.

<u>ADT</u>	<u>Probability of a Conflict Given a Pass, P(A/P)</u>	
	<u>Heavy Direction</u>	<u>Light Direction</u>
50	.00361	.00904
100	.00721	.01800
250	.02018	.04221
500	.04616	.07668
1,000	.09663	.14139
2,000	.18558	.26129

Expected Number of Passing Conflicts

As previously stated, the expected number of passing conflicts is the product of the expected number of passes and the probability of an oncoming vehicle arrival during the pass. The following expected number of conflicts for various ADT's is obtained by using the previously calculated values.

<u>ADT</u>	<u>Unadjusted Rate for Expected Number of Passing Conflicts per Mile per Day</u>
50	.0003
100	.0024
250	.0400
500	.3298
1,000	2.6428
2,000	19.9091

Considering the assumptions of this development, these conflict rates are highly inflated. Recognizing that a driver will not pull out to pass when he sees an opposing vehicle within about 3 sec to collision (about 400 ft), and also when he does pull out he can easily abort within the first 3 sec, the foregoing conflict rates should be multiplied by 0.455. Also, one is interested in justifying no-passing stripes where sight distance is restricted. By using a safety-conservative assumption that 50 percent of the highway has passing sight distance restrictions, a more realistic conflict rate per mile would be $0.455 \times 0.50 = 0.227$ of the previous table values. Using this multiplier, and also multiplying by 365 to compute an annual conflict rate, yields the following values.

<u>ADT</u>	<u>Adjusted Rate for Annual Number of Passing Conflicts Per Mile Associated With Areas of Limited Sight Distance</u>
50	.02
100	.20
250	3.
500	27.
1,000	219.
2,000	1,650.

These final values for conflict rates are still probably inflated because: (1) they presume vehicles will make passes regardless of available sight distance; (2) they presume vehicles will initiate passes with oncoming vehicles as close as 6 seconds from impact; and (3) they ignore that a large percentage of vehicles (pick-ups, panels, buses, and large trucks) on rural two-lane highways have greater eye heights and vehicle heights than those of passenger vehicles. Using Table B-4, between 74 and 86% of all passing maneuvers on lower volume rural highways have greater passing sight distance than that represented by the passing conflict between two passenger cars. This suggests that the requirements for total length of no-passing zone markings may be considerably less than indicated by the "Manual on Uniform Traffic Control Devices" (1) for a large majority of passing maneuvers.

APPENDIX E

ACCIDENT COMPARISONS

Effectiveness of Adding Centerline and No-Passing Zone Markings

Of primary interest in this project was the determination of any accident benefits associated with the placement of centerline and no-passing zone markings on low volume rural roads. A review of published literature revealed the lack of any descriptive data. The 1981 (3) and 1982 (4) editions of the Federal Highway Administrations "Highway Safety Stewardship Report," did provide a general overview of the Pavement Marking Demonstration Program (PMDP) that was established in the Federal Highway Act of 1973. Table E-1 from these documents shows the net accident effect on the application of centerline and no-passing zone markings on previously unmarked highways. As seen from this table, the general accountability of the PMDP is a significant increase in injury accidents, a significant decrease in property-damage-only accidents (PDO), and no significant change in total accidents.

In attempting to find more descriptive data regarding the evaluation of pavement marking effectiveness, several unpublished documents were found. Most helpful was an unpublished Federal Highway Administration (FHWA) report by Lee (5), which contained an evaluation of 225 pavement marking projects in six

TABLE E-1

ACCIDENT REDUCTION EFFECTIVENESS FOR THE PMDP
APPLICATION OF CENTERLINE AND NO-PASSING ZONE MARKINGS (3,4)

Year	Number of States	Number of Miles	Total Cost (\$)	% Reduction in Accidents ^{1/}			
				Fatal	Injury	PDO	Total
1980	14	11,475	4,416,000	-8	-8*	2*	-1
1981	15	12,673	5,039,000	-3	-6*	4*	1

1/ - Minus sign denotes increase

* - Significant change at 95% level of confidence

states. A brief summary of this evaluation is given in Table E-2. Although the statistical significance of these evaluations were not given, all pavement marking categories showed an increase in accident rate.

On request to the FHWA, the original data base for the Lee report was obtained. In addition to before and after accident data for each project, the data base also included highway information on project length, before and after study periods, ADT, lane width, shoulder width, terrain, and speed limit.

Additional data was obtained from several states as a result of follow-up to the questionnaire responses. Some of these data sets were not descriptive enough for additional analysis and other data sets were from those states already included in FHWA data base. As a result, only data sets from Ohio and Missouri were used in additional analyses. The data from Missouri provides the only available analysis of the effectiveness of adding dashed centerlines only to unmarked highways and the effectiveness of adding no-passing zone markings to highways marked with either dashed centerlines only or with dashed centerlines and edgelines.

Table E-3 shows a general analysis of the effectiveness of adding centerline and no-passing zone markings to previously unmarked highways. This table includes the five states with this kind of project in the FHWA data base and Ohio. This table shows somewhat mixed results. Montana showed a significant increase in accidents and Ohio showed a significant decrease

TABLE E-2

SUMMARY OF PMDP EFFECTIVENESS
REPORT BY LEE (5)

<u>Improvement Type</u>	<u>No. of Sites</u>	<u>Length</u>	<u>Accident Rate</u>		
			<u>Before</u>	<u>After</u>	<u>% Change</u>
Centerline Striping	48	382	4.18	4.28	+2
Edgeline Striping Added	94	721	2.88	2.93	+2
C.L. & E.L.	83	943	1.97	2.55	+29
TOTAL	225	2,046	2.64	2.99	+13

TABLE E-3

SUMMARY OF BEFORE AND AFTER ACCIDENT STATISTICS
 FOR PROJECTS WHERE CENTERLINE AND NO-PASSING
 MARKINGS WERE ADDED TO PREVIOUSLY
 UNMARKED HIGHWAYS

State	No. of Sites	No. of Miles	Before Period			After Period			Significant Difference*
			MVM	Accid	Accid Rate	MVM	Accid	Accid Rate	
			<u>FHWA Data Base</u>						
MI	4	27.80	13.140	45	3.42	11.308	33	2.92	N.S.
MT	2	20.30	3.482	10	2.87	2.449	24	9.80	S(+)
NC	13	96.90	29.775	127	4.27	30.457	150	4.92	N.S.
VA	22	168.11	30.628	151	4.93	33.180	168	5.06	N.S.
WV	7	68.70	36.321	144	3.96	39.233	141	3.59	N.S.
TOTAL	48	381.81	113.346	477	4.21	116.627	516	4.42	N.S.
			<u>Ohio Data Base</u>						
OH	N/A	468.24	92.870	153	1.65	94.360	106	1.12	S(-)
GRAND TOTAL	N/A	850.05	206.216	630	3.06	210.987	622	2.95	N.S.

* Significance @ 90% confidence level using two-tailed t-test.

in accidents, while the other four states showed non-significant differences. Obviously these six states may have different reporting levels, ADT distribution, and road design characteristics in their samples of projects.

The significance test used in Table E-3 and all subsequent tables is a one-sample t-test using a normal approximation to a binomial distribution. In essence it tests whether the proportion of before or after accidents to total accidents is significantly different than the proportion of before or after vehicle-miles to total vehicle-miles. The statistic is as follows:

$$t = \frac{A_B M_A - A_A M_B}{\sqrt{(A_B + A_A) M_A M_B}}$$

where: A_B = number of accidents in before period

A_A = number of accidents in after period

M_B = number of vehicle-miles in before period

M_A = number of vehicle-miles in after period

Table E-4 uses the same data as Table E-3 to show before-after comparisons for fatal plus injury accidents. In this case, Ohio is the only state that shows a significant change, a decrease in severe accidents.

In an attempt to understand some of the variances shown in Tables E-1 through E-4, several analyses were conducted on the FHWA data base, where information was available on highway characteristics for each project. These analyses showed

TABLE E-4

SUMMARY OF BEFORE-AFTER INJURY PLUS FATAL
ACCIDENT STATISTICS FOR PROJECTS WHERE
CENTERLINE AND NO-PASSING
MARKINGS WERE ADDED

State	No. of Sites	No. of Miles	Before Period			After Period			Significant Difference*
			MVM	F & I Accid	F & I Rate	MVM	F & I Accid	F & I Rate	
<u>FHWA Data Base</u>									
MI	4	27.80	13.140	20	1.52	11.308	15	1.33	N.S.
MT	2	20.30	3.482	8	2.30	2.449	11	4.49	N.S.
NC	13	96.90	29.775	48	1.61	30.457	52	1.71	N.S.
VA	22	168.11	30.628	52	1.70	33.180	66	1.99	N.S.
WV	7	68.70	36.321	42	1.16	39.233	47	1.20	N.S.
TOTAL	48	381.81	113.346	170	1.50	116.627	191	1.65	N.S.
<u>Ohio Data Base</u>									
OH	N/A	468.24	92.870	59	0.64	94.360	42	0.45	S (-)
GRAND TOTAL	N/A	850.05	206.216	229	1.11	210.987	233	1.10	N.S.

* Significance @ 90% confidence level using two-tailed t-test.

state, ADT, and lane width to be the only interesting stratification variables. Also, total accident comparisons and fatal plus injury accident comparison showed similar results so only the total accident comparisons are shown.

Table E-5 shows a summary of the FHWA data base stratified by ADT. In this table, Montana shows a significant increase in accident rate for ADT's of 0-500 vpd, and North Carolina shows a significant increase in accident rate for ADT's of 501-1,000 vpd. The totals for each ADT category are non-significant but show a trend toward accident benefits with higher ADT's.

Table E-6 shows a summary of the FHWA data base stratified by lane width. In this table, Montana shows a significant increase in accident rate for lane widths of 10-11 ft. All other comparison show no significant differences.

In an attempt to find a more discerning relationship for the accident effectiveness of centerline and no-passing markings, the FHWA data were stratified by both ADT and lane width. For this purpose, two separate analyses were undertaken. The first analysis used the 48 before-after sites shown in previous tables. The second analysis, which is not entirely a before-after comparison, used portions of data from all 225 projects in the FHWA data base where either no markings were present or centerline and no-passing zone markings were present.

Tables E-7 and E-8 show the 48 before-after projects

TABLE E-5

SUMMARY OF BEFORE-AFTER ACCIDENT STATISTICS
 STRATIFIED BY ADT FOR 48 PROJECTS WHERE
 CENTERLINE AND NO-PASSING ZONE
 MARKINGS WERE ADDED
 (FHWA DATA BASE)

ADT	State	No. of Proj	Before Period			After Period			Significant Difference*
			MVM	Accid	Accid Rate	MVM	Accid	Accid Rate	
0 - 500	MI	1	1.205	9	7.47	1.009	3	2.97	N.S.
	MT	2	3.482	10	2.87	2.449	24	9.80	S(+)
	NC	9	13.347	53	3.97	13.661	50	3.66	N.S.
	VA	15	15.831	73	4.61	16.400	88	5.37	N.S.
	TOTAL	27	33.865	145	4.28	33.519	165	4.92	N.S.
501 - 1,000	MI	1	1.900	15	7.89	1.900	10	5.26	N.S.
	NC	4	16.428	74	4.50	16.796	100	5.95	S(+)
	VA	4	5.981	31	5.18	6.402	31	4.84	N.S.
	WV	3	4.031	14	3.47	4.059	23	5.67	N.S.
	TOTAL	12	28.340	134	4.73	29.157	164	5.62	N.S.
> 1,000	MI	2	10.035	21	2.09	8.399	20	2.38	N.S.
	VA	3	8.816	47	5.33	10.378	49	4.72	N.S.
	WV	4	32.290	130	4.03	35.174	118	3.35	N.S.
	TOTAL	9	51.141	198	3.87	53.951	187	3.47	N.S.

* Significance @ 90% confidence level using two-tail t-test.

TABLE E-6

SUMMARY OF BEFORE-AFTER ACCIDENT STATISTICS
 BY LANE WIDTH FOR 48 PROJECTS WHERE
 CENTERLINE AND NO-PASSING
 MARKINGS WERE ADDED
 (FHWA DATA BASE)

Width (ft)	State	No. of Proj	Before Period			After Period			Significant Difference*
			MVM	Accid	Accid Rate	MVM	Accid	Accid Rate	
8 - 9	NC	11	23.436	87	3.71	23.983	110	4.59	N.S.
	VA	19	24.776	114	4.60	26.360	128	4.86	N.S.
	WV	7	36.321	144	3.96	39.233	141	3.59	N.S.
	TOTAL	37	84.533	345	4.08	89.576	379	4.23	N.S.
10 - 11	MI	4	13.140	45	3.42	11.308	33	2.92	N.S.
	MT	2	3.482	10	2.87	2.449	24	9.80	S(+)
	NC	2	6.339	40	6.31	6.474	40	6.18	N.S.
	VA	3	5.852	37	6.32	6.820	40	5.87	N.S.
	TOTAL	11	28.813	132	4.58	27.051	137	5.06	N.S.

* Significance @ 90% confidence level using two-tail t-test.

stratified by ADT and lane width. These tables show significant increase in accident rate for highways with 0-500 vpd and 10-11 ft. lane width and for highways with 501-1,000 vpd and 8-9 ft. lane widths. Although all other categories are non-significant, there does appear to be a decided trend toward accident rate decrease with higher ADT's and wider lanes.

Tables E-9 and E-10 show a comparison from the FHWA data base of all sites with no markings in the before period to all sites with centerline and no-passing zone markings in either the before or after period. These tables also show significant increases in accident rate for highways with 0-500 vpd and 10-11 ft. lane width and for highways with 501-1,000 vpd and 8-9 ft. lane widths. These tables also show a trend toward rate reduction with higher ADT's.

Effectiveness of Adding Dashed Centerline Markings

Missouri was the only state found that makes extensive use of a dashed centerline without a non-passing stripe. Their practice is to use this treatment on non-numbered state highways with less than 1,000 vpd. These highways are basically local rural access roads. Table E-11 shows an evaluation of nine projects where dashed centerlines only were added to previously unmarked highways with 88-512 vpd and 10-11 ft. lane widths. This analysis shows a 22% non-significant increase in accident rates.

TABLE E-9

COMPARISON OF ACCIDENT RATES FOR SITES WITH NO MARKINGS TO SITES WITH CENTERLINE AND NO-PASSING ZONE MARKINGS
(FHWA TOTAL DATA BASE)

State	No Lines			C.L. & NPZ			Significant Difference*
	No. of Sites	MVM	Accid Rate	No. of Sites	MVM	Accid Rate	
				ADT = 0 - 500 vpd/Lane Width = 8 - 9 ft			
NC	21	32.758	117	59	82.133	344	4.19 N.S.
VA	13	13.775	56	13	14.220	66	4.64 N.S.
TOTAL	34	46.533	173	72	96.353	410	4.26 N.S.
				ADT = 501 - 1,000 vpd/Lane Width 8 - 9 ft			
NC	3	14.930	51	4	16.405	84	5.12 S(+)
VA	4	5.981	31	5	9.177	44	4.79 N.S.
WV	5	9.122	22	3	4.059	23	5.67 S(+)
TOTAL	12	30.033	104	12	29.641	151	5.09 S(+)
				ADT > 1,000 vpd/Lane Width 8 - 9 ft			
VA	2	5.020	27	2	5.738	31	5.40 N.S.
WV	6	42.175	154	4	35.174	118	3.35 N.S.
TOTAL	8	47.195	181	6	40.912	149	3.64 N.S.
GRAND TOTAL	54	123.761	458	90	166.906	710	4.25 S(+)

*Significance @ 90% confidence level using two-tailed t-test.

TABLE E-10

COMPARISON OF ACCIDENT RATES FOR SITES WITH NO MARKINGS TO SITES WITH CENTERLINE AND NO-PASSING ZONE MARKINGS
(FHWA Data Base)

State	No Lines			C.L. & NPZ			Significant Difference*
	No. of Sites	MVM	Accid Rate	No. of Sites	MVM	Accid Rate	
				ADT: 0 - 500 vpd/Lane Width 10 - 11 ft			
MI	8	11.304	46	2	4.186	13	N.S.
MT	3	4.963	16	2	2.449	24	S(+)
VA	2	2.056	17	2	2.180	22	N.S.
TOTAL	13	18.323	79	6	8.815	59	S(+)
				ADT: 501 - 1,000 vpd/Lane Width 10 - 11 ft			
MI	11	31.129	104	2	4.180	15	N.S.
NC	2	6.339	40	4	14.526	62	S(-)
TOTAL	13	37.468	144	6	18.706	77	N.S.
				ADT > 1,000 vpd/Lane Width 10 - 11 ft			
MI	6	43.703	116	2	8.399	20	N.S.
VA	1	3.796	20	7	27.751	67	S(-)
TOTAL	7	47.499	136	9	36.150	87	N.S.
GRAND TOTAL	33	103.290	359	21	63.671	223	N.S.

*Significance @ 90% confidence level using two-tailed t-test.

TABLE E-11

SUMMARY OF BEFORE-AFTER ACCIDENT STATISTICS
FOR PROJECTS IN MISSOURI WHERE DASHED
CENTERLINES ONLY WERE ADDED

No. of Projects: 9
 No. of Miles : 58.45
 ADT Range : 88-512 vpd
 Lane Widths : 10-11 ft

Accident Parameters	Before Period			After Period			Significant Difference*
	MVM	Accid	Accid Rate	MVM	Accid	Accid Rate	
Total Accidents	12.426	32	2.58	12.752	40	3.14	N.S.
Injury & Fatal Accidents	12.426	14	1.13	12.752	19	1.49	N.S.

* Significance @ 90% confidence level using two-tailed t-test.

Effectiveness of Adding No-Passing Stripes

Missouri also provided for evaluating the effectiveness of adding no-passing stripes to highways previously marked with dashed centerlines only. Table E-12 shows an evaluation of 20 projects where no-passing zone markings were added to highways with 10-11 ft. lanes previously marked with dashed centerline only. This evaluation shows significant decreases in accident rates for both ADT levels of 501-1,000 vpd and greater than 1,000 vpd.

Table E-13 shows an evaluation of 33 projects where no-passing zone markings were added to highways previously marked with dashed centerline only and edgelines. This evaluation shows no significant differences in accident rates for any ADT category.

TABLE E-12
SUMMARY OF BEFORE-AFTER STATISTICS BY ADT FOR 20 PROJECTS
IN MISSOURI WHERE NO-PASSING ZONE MARKINGS WERE ADDED
TO EXISTING CENTERLINE MARKINGS
(10-11 ft lanes)

ADT	No. of Projects	No. of Miles	Before Period			After Period			Significant Difference*
			MVM	Accid	Accid Rate	MVM	Accid	Accid Rate	
501 - 1,000	7	66.10	44.263	103	2.33	45.949	80	1.74	S(-)
> 1,000	13	130.59	139.011	281	2.02	141.279	220	1.56	S(-)
TOTAL	20	196.69	183.374	384	2.09	187.228	300	1.60	S(-)

* Significance @ 90% confidence level using two-tailed t-test.

TABLE E-13

SUMMARY OF BEFORE-AFTER STATISTICS BY ADT FOR 33 PROJECTS
IN MISSOURI WHERE NO-PASSING ZONE MARKINGS WERE ADDED
TO EXISTING CENTERLINE AND EDGE LINE MARKINGS

ADT	No. of Projects	No. of Miles	Before Period			After Period			Significant Difference*
			MVM	Accid	Accid Rate	MVM	Accid	Accid Rate	
0 - 500	4	35.59	11.740	36	3.07	14.364	36	2.51	N.S.
501 - 1,000	17	355.01	192.841	496	2.57	202.557	503	2.48	N.S.
> 1,000	12	241.61	244.649	689	2.82	240.415	708	2.94	N.S.
TOTAL	33	632.21	449.230	1221	2.72	457.336	1247	2.73	N.S.

* Significance @ 90% confidence level using two-tailed t-test.